

MASW Seismic Method in Brebu Landslide Area, Romania

Marinescu Mihai ¹, Cristea Paul ², Marunteanu Cristian ¹, Mezincescu Matei ¹

¹ University of Bucharest, 36-46, M. Kogalniceanu Blvd, Romania

² Geological Institute of Romania, 1 Caransebes St., Bucharest, Romania

mmar54@yahoo.com

Abstract. This paper is focused on assessing the possibility of enhancing the geotechnical information in perimeters with landslides, especially through applications of the Multichannel Analysis of Surface Waves (MASW) method. The technology enables the determination of the phase velocities of Rayleigh waves and, recursively, the evaluation of shear wave velocities (V_S) related to depth. Finally, using longitudinal wave velocities (V_P), derived from the seismic refraction measurements, in situ dynamic elastic properties in a shallow section can be obtained. The investigation was carried out in the Brebu landslide (3-5 m depth of bedrock), located on the southern flank of the Slanic Syncline (110 km North of Bucharest) and included a drilling program and geotechnical laboratory observations. The seismic refraction records (seismic sources placed at the centre, ends and outside of the geophone spread) have been undertaken on two lines, 23 m and 46 m long respectively) approximately perpendicular to the downslope direction of the landslide and on different local morpho-structures. A Geode Geometrics seismograph was set for 1 ms sampling rate and pulse summations in real-time for five blows. Twenty-four vertical Geometrics SpaceTech geophones (14 Hz resonance frequency) were disposed at 1 m spacing. The seismic source was represented by the impact of an 8kg weight sledge hammer on a metal plate. Regarding seismic data processing, the distinctive feature is related to performing more detailed analyses of MASW records. The proposed procedure consists of the spread split in groups with fewer receivers and several interval-geophones superposed. 2D Fourier analysis, f-k (frequency-wave number) spectrum, for each of these groups assures the information continuity and, all the more, accuracy to pick out the amplitude maximums of the f-k spectra. Finally, combining both values V_S (calculated from 2D spectral analyses of Rayleigh waves) and V_P (obtained from seismic refraction records) plots of mean geodynamic parameter evolution related to depth were constructed. Parameter value differentiations referring to slope stability are revealed. Lowest values of V_S and both shear and longitudinal elastic moduli are defined for the area with landslide rock-mass, in opposition with stable land for which the biggest values for same parameters are revealed. Intermediate values are signalized above the main plane of sliding, zone classified unstable.

1. Introduction

The purpose of our research was, mainly, to obtain additional information of perimeters with landslides by using MASW (Multichannel Analysis of Surface Waves) seismic method. This technology enables to determine the phase velocities of Rayleigh surface waves and, recursively, the shear wave velocities (V_S) related to depth are evaluated. Because the recording of Rayleigh waves involved data acquisition technology based on seismic refraction method, the complementary



information concerning longitudinal wave velocities (V_p) allowed the calculus of *in situ* rock properties in a shallow section.

The investigation, carried out in a landslide area near Brebu village (located about 110 km North of Bucharest, Romania), included also a summary drilling program and geotechnical laboratory observations. Field records were performed on two seismic refraction lines with approximate SW-NE orientation and length of 23 m and 46 m respectively. Lines were positioned quasi-transversely to the landslide direction (figure 1), satisfying the requirement of the smallest variation elevation along each alignment. The first profile (L1) was placed on the micro-relief above the main plane of detachment of shallow formations (figure 1). Downstream, at about 65 m, the profile L2 is partially located (along 0÷23 m panel) on rock-slide deposits and, continuously (up to 46 m), on stable formations.



Figure 1. Seismic refraction alignments (L1 and L2) designed over Brebu landslide photo:
g1, g24: the end-on receiver places of each spread

2. Geology of the Brebu area

The Brebu area is located on the southern flank of the Slanic Syncline with the basement composed of lower and middle Miocene deposits (figure 2) [1].

The Cornu Formation (m_1^{cn} on the geological map) starts with the Lower Gypsum Member, constituted of decametric gypsum beds with centimetric gypsum-bearing sandstones or clays inter-layerings. Above this member, a sequence consisting of middle-size conglomerates to micro-conglomerates, breccias, glauconitic sandstones, silty-clays and clays is developed. The overlying formation, Doftana Molasse (m_{1+2}) [2], Ottnangian - Karpatian (or Late Burdigalian Early Langhian) starts with the Brebu Conglomerates, a pile of polymictic weakly cemented conglomerates. The rest of the Doftana Molasse consists of micro-conglomerates and coarse to fine-grained sandstones alternating with grey or reddish clays or marls. At several levels, thin gypsum or cineritic beds and laminated dolomitic or calcareous shales are interbedded. The Slanic Tuff (composed of tuffs and tuffites, interbedded with Globigerina Marls), is covered directly by Sarmatian deposits (vh+bs) (regular alternations of sands in metric layers, or clays in decimetric to centimetric layers Volhynian - Bessarabian). The Quaternary deposits are represented by alluvial deposits - gravels and sands (Upper Pleistocene - Holocene to actual) and by deluvial and coluvial deposits - landslides (Holocene - actual).

The landslide is located approximately 2 Km NNE from Brebu village, extending approximately 300 m in NW-SE direction. The landslide crosses a fault separating a higher compartment (marls – Badenian) from a lower compartment (silty marls, sands – Sarmatian). The body of the landslide is

composed predominantly of grey marls, in which yellow sands, yellow-brown altered silty marls and rare fragments of sandstones are mixed.

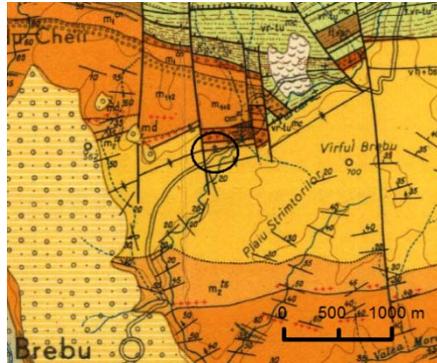


Figure 2. Geology of the Brebu area [1]. Explanations of the Legend in text.
Solid circle: location of the studied landslide

3. Seismic researches

3.1. Features of the methodology approaches

Determination of the shear wave velocities (V_s), based on spectral analysis of Rayleigh surface waves, is a relative recent approach in the practice of shallow section seismic investigation. From early laborious studies of seismic pulses on tandem channels and varying the frequencies by means of a vibrator standing on the ground surface [3], the methodology was developed gradually [4], finally enhancing the technology of multichannel spread records [5].

As follows, the present paper has two objectives: improving the accuracy of MASW data processing and identifying the possibility of using both shear wave and longitudinal wave velocities as a non-invasive assessment of the main geodynamic parameters of shallow ground. MASW developments consist in the geophone spread (24 receivers) splitting in groups with fewer receivers (five geophones were selected) and overlapping these sub-arrays (two geophone-intervals). The improvements provided not only continuity of Rayleigh waves f - k spectrum along the spread, but also more and accurate phase velocities, therefore more and exact V_s data [6]. The applications were facilitated by a personalized routine-soft to processing of the two-dimensional spectra of Rayleigh waves to both whole spread and optional group-geophones. As MASW method approaches involve records based on seismic refraction method, the possibility of using the information regarding V_p not only for building cross-section has been inferred. By means of specific mathematical relationships [7] based on V_p and V_s data, the evolution plots of the Poisson ratio (μ_{dyn}) and both shear (G_{dyn}) and longitudinal (E_{dyn}) elastic moduli in the shallow section were built. Geological interpretation of the seismic survey results was completed by both geotechnical drilling and laboratory data.

Seismic measurements were performed with the *Geode Geometrics equipment* (24 seismic channels) using: 1.0 ms sampling rate, the signal amplification to 24 dB and 36 dB (depending on the offset location to the seismic source) and the pulse summations in real-time for five successive blows. The seismic source was represented by the impact of an 8kg sledge hammer weight on a metal plate. Vertical component geophones, characterized by 14 Hz resonance frequency (*Geometrics SpaceTech* receivers), were at 1 m spacing. The seismic recordings have been carried out in forward and reversed mode using impact-points placed at the centre and at the ends of the spread and with additional seismic sources located at the half spread long offset beyond the ends.

3.2. Results of the measurements

The presenting of the results follows the main sequences of the processing data in seismic refraction applications. First-arrival waves (direct and refracted P-waves) are treated, then Rayleigh pulses are analysed by developments in MASW technology, and, finally, key geodynamic parameters are calculated by analysing and combining the data obtained through these methods. Processing of the seismic refraction travel time curves permitted the construction of the shallow sections using velocity analyses and, subsequently, the half-intercept times and time-section (delay-time-function) procedures [8], and Hagerdoon's plus-minus method [9]. These methods are adequate when refracting horizon is shallow and has a large velocity contrast reporting to the overlying deposits [10], conditions revealed to Brebu landslide.

Seismic line L1. Travel time curves (figure 3 top) reveal two seismic waves: t_{direct} , that propagates within less compact deposits from the surface (*silty clay*), and t_{bedrock} , the refracted wave at the surface of the underlying formations, more compact (*marl*). The interface constitutes the sliding surface of the ground. The t_{direct} -travel time curves, by their discrete curvature with the distance, indicate a vertical gradient of velocities due to diminishing in depth of the influence of exogenous factors on superficial formations. The apparent velocities increase from about 150 m.s^{-1} , in the near-surface, up to 400 m.s^{-1} (IP 0 m) and 500 m.s^{-1} (IP 23 m) respectively, close to the bedrock. At the top of *marl formation*, the velocity analysis applied to t_{bedrock} -travel time curves reveals the boundary velocity of 1600 m.s^{-1} .

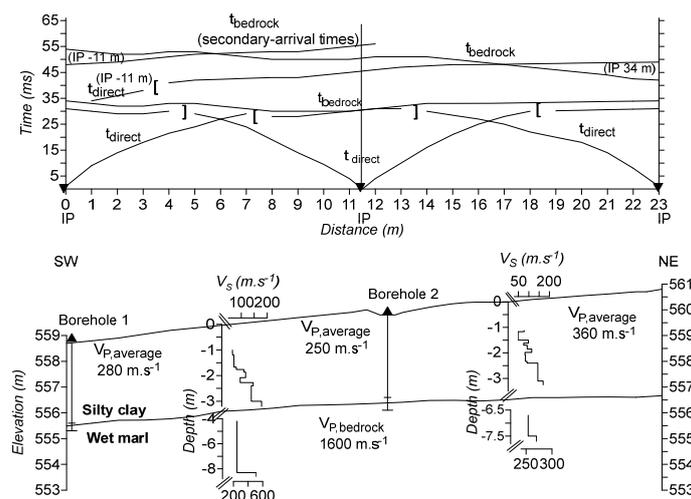


Figure 3. Seismic line L1. Travel time curves (top) and resulting seismic section (bottom).

IP acronym, together with vertical down arrow peak, marked impact-source location. On the cross-section are depicted V_s - depth graphs for both IP 0 m and 23 m, obtained by MASW applications.

The next stage was focused on analysing two-dimensional spectra (f-k spectra) for Rayleigh waves. In the figure 4, the series of charts synthesizes the stages and the attributes of the MASW data processing technique. One can remark (figure 4b) the increasing of the data amount concerning the spread splitting maximum f-k values (highlighted by cross dashed lines) comparative with the 2D Fourier analysis of the whole spread (figure 4a). The last chart (figure 4c) emphasizes the capability of the 2D analysis on receiver groups to build the accurate dispersion curve (the solid and dashed lines). Dashed line interval, marked out by low values of phase velocity-frequency pairs, signaled dispersion curve anomalous compartment, caused by heterogeneities in landslide environments. It must be noted that to avoid the lateral influences, the maximum-spots on the recordings closer than half the wave-length from source have been discarded [11], [12].

V_S -shear wave velocity values together with V_P - longitudinal wave velocity values enable to construct the main geodynamic parameters (μ_{dyn} , G_{dyn} , and E_{dyn}) evolutions related to depth (figure 5). To silty clay and marl formations are used mass density of 1.8 g.cm^{-3} and 2 g.cm^{-3} respectively, values based on laboratory measurements.

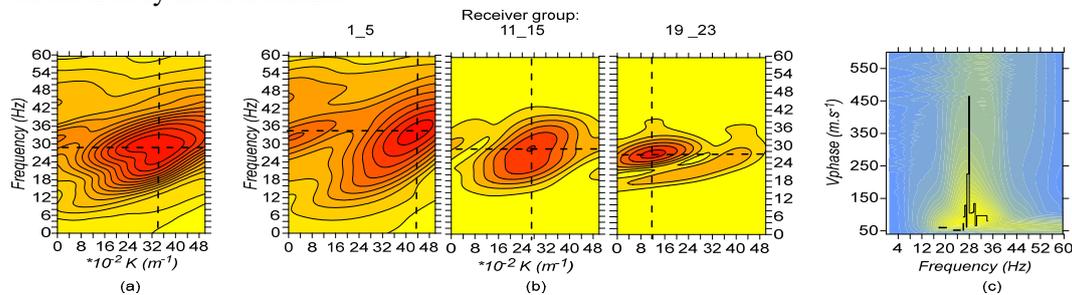


Figure 4. Line L1. Spectral analyses of Rayleigh waves (seismogram recorded with source placed at distance-picket 0 m). 2D Fourier spectra for: (a) whole spread (24 receivers); (b) several receiver groups (5 receivers); (c) dispersion curve (synthesized from all f-k analysis groups) superposed on the integral dispersion spectrum (derived from wholespread f-k spectrum).

The V_S -graphs, derived from spectral analyses for both above-mentioned and revers impact points (IP 0 m and IP 23 m) are depicted on the seismic section (figure 3 bottom). In the first depth interval, on which core laboratory observations have shown the presence of *silty clay* deposits, the natural tendency of increasing the V_S with depth from about 60 m.s^{-1} to about 150 m.s^{-1} is revealed (table 1). On the surface of bedrock, consisting of *wet compact marl*, there can be noted a leap of V_S values at about 250 m.s^{-1} (table 2, first two lines), with the rising trend in depth to about 500 m.s^{-1} for the depth difference of about 4 m (table 2, first line).

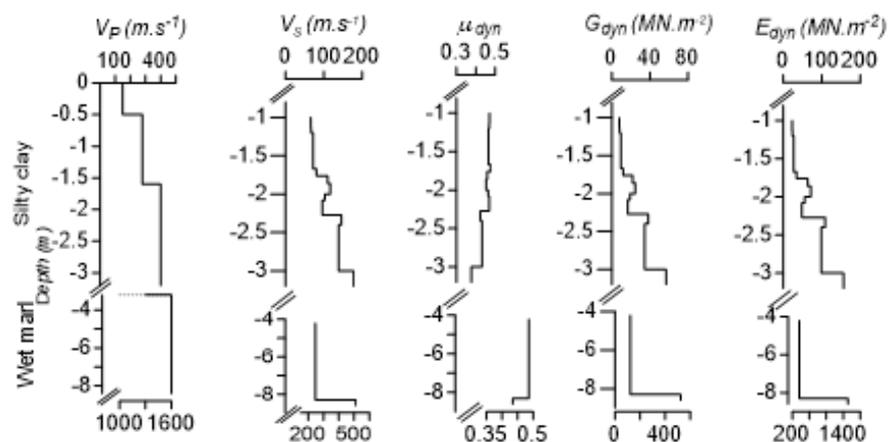


Figure 5. Line L1. Geodynamic parameter evolutions related to depth resulted by applications of both methods: seismic refraction and MASW (Rayleigh waves were selected from file recorded to IP 0m).

Table 1. *Silty clays*. Extreme values, in relation to the depth, of both shear wave velocities (results of MASW method applications) and derived geodynamic parameters.

Diagram identification	V_S (m.s^{-1})	G_{dyn} (MN.m^{-2})	E_{dyn} (MN.m^{-2})	Depth (m) up to:	Stability features
Line L1, IP 0 m - F*	66÷178	7.8÷57	23.0÷157.0	3.2	Unstable area
Line L1, IP 23 m - R*	89.7÷170.5	14.5÷52.3	42.5÷150.1	3.2	
Line L2, IP 0 m - F*	74.2÷120	9.9÷25.9	29.3÷74.9	3.5	Slide deposits
Line L2, IP 23 m - R*	67.0÷108	8.1÷21.0	23.9÷61.7	3.7	
Line L2, IP 23 m - F*	81 ÷287	11.8÷148.3	33.1÷422.9	4.4	Stable area

Line L2, IP 46 m - R*	83÷245	12.4÷108	36.6÷309.0	4.5
-----------------------	--------	----------	------------	-----

F*- forward profile impact, R*-reversed profile impact

Table 2. *Marl formations.* Extreme values, in relation to the depth, for shear wave velocities (results of MASW method applications) and derived geodynamic parameters.

Diagram identification	V _s (m.s ⁻¹)	G _{dyn} (MN.m ⁻²)	E _{dyn} (MN.m ⁻²)	Depth interval (m)	Stability features
Profile L1, IP 0 m - F*	247÷512	122÷525	365÷1504	4.2÷8.35	Unstable area
Profile L1, IP 23 m - R*	254÷270	129÷146	384÷434	6.7÷7.8	
Profile L2, IP 46 m - R*	271÷433	132÷337	394÷999	5.2÷6.25	Stable area

F*- forward profile impact, R*-reversed profile impact

Seismic line L2. Information is distinguished by emphasizing peculiar velocity ranges, related to waves which travel through the upper formations (both direct and intermediary refracted waves), as well as for refracted wave from the bedrock (figure 6 top). On the 0÷23 m panel, *silty clay formations* are characterized by relatively constant V_P-velocity of 380 m.s⁻¹, on the 0÷14 m interval, and then, up to 23 m distance, velocity gradual increases with a depth up to 550 m.s⁻¹. A shallower, intermediary refractor (t_{shallow}) is highlighted along the adjacent panel, 23÷46 m (figure 6 bottom). The boundary separates *intense weathered deposit* and *soil deposit* (V_P up to 200 m.s⁻¹) from underlying *fine sand* and *silty clay deposits*, a complex characterized by larger V_P values, relatively constant, 800 m/s, on the first half-spread, and 700 m/s, continuous up to line end.

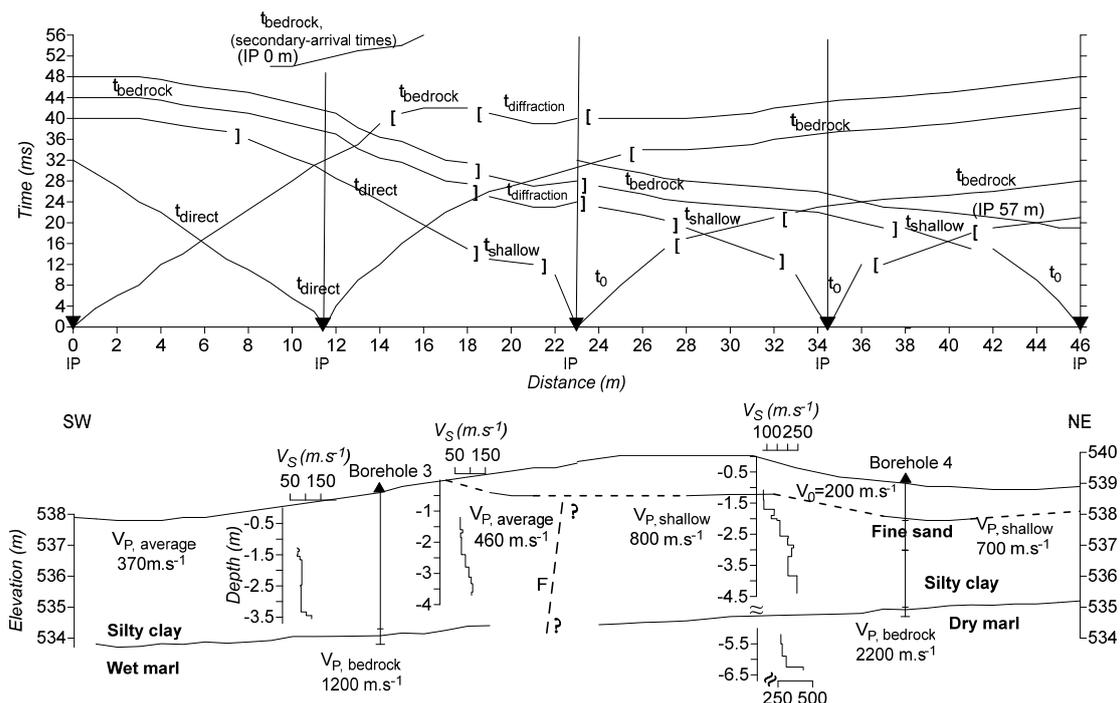


Figure 6. Seismic line L2. Travel time curves (top) and resulting seismic section (bottom).

IP acronym, together with vertical down arrow peak, marked impact-source location. On the cross-section are depicted successively V_s – depth graphs, obtained by MASW applications to both forward (IP 0 m) and reversed (both IP 23 m and 46 m) impact profiles on each spread.

Regarding *the bedrock*, on the two receiver spreads great different boundary velocities are revealed (figure 6 bottom). Lower value, 1200 m/s, limited on the western part of the profile (panel 0÷23m) can be sourced in status of *wet marls*, feature identified by laboratory analyses. The greatest velocity, 2200 m/s, was located on the next panel (23÷46 m) for *consolidated, dry marl*, identified as well by rock

sample analyses. F-fault was traced (dashed line in figure 6 bottom) on base of diffraction travel time events (figure 6 top) and consequence of different velocity characteristics for both *silty clay* and *marl formations* related to western and eastern compartments of the profile.

As in the preceding case, the most important theme of shallow seismic research was focused on 2D spectral analyses of Rayleigh waves. Slides with f-k spectra referring to 0÷23 m spread (IP 23 m) once again show (figure 7) the more detailed spectral data obtained by splitting initial spread (figure 7a) in subsequent receiver groups (figure 7b). In consequence, dispersion curve allows a much more precise interpretation comparing with the global dispersion spectrum (figure 7c). On the adjacent panel (23÷46 m), located in an *area mapped as geotechnically stable*, the "habitus" of f-k spectra is more complicated (figure 8), highlighting two maximum-spots amplitudes, sometimes with the near frequency values, on the same f-k spectrum slide. This "behaviour" can be interpreted as the peculiar effect of both local mechanical stress and lithological conditions.

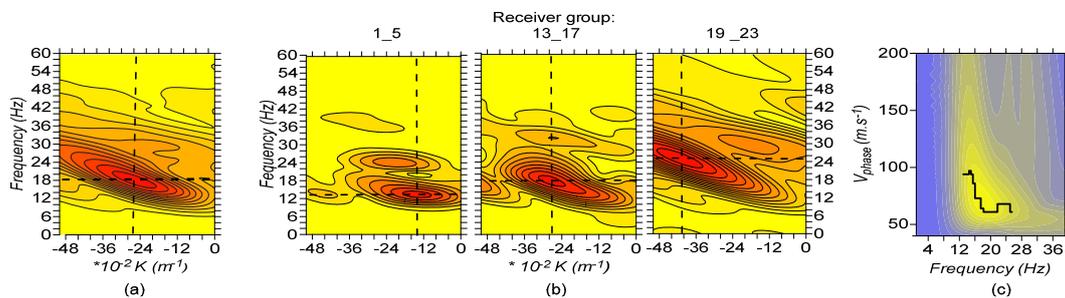


Figure 7. Line L2 (0÷23 m spread). Spectral analyses of Rayleigh waves (seismogram recorded with source placed at distance-picket 23 m). 2D Fourier spectra for: (a) whole spread (24 receivers); (b) several receiver groups (5 receivers); (c) dispersion curve (synthetized from all f-k analysis groups) superposed on the integral dispersion spectrum (derived from whole spread f-k spectrum).

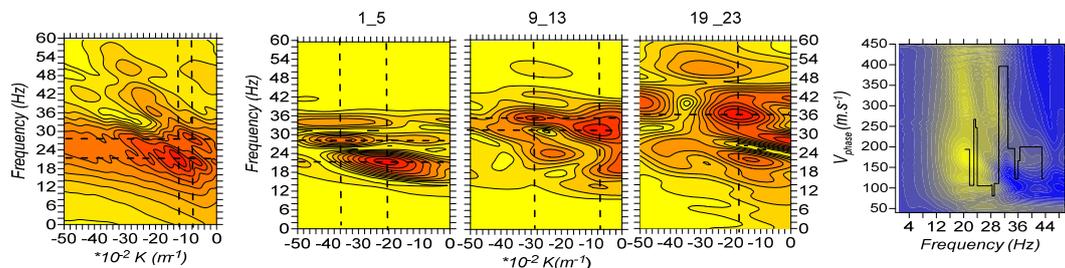


Figure 8. Line L2 (23÷46 m spread). Spectral analyses of Rayleigh waves (seismogram recorded with source placed at distance-picket 46 m). 2D Fourier spectra for: (a) whole spread (24 receivers); (b) several receiver groups (5 receivers); (c) dispersion curve (synthetized from all f-k analysis groups) superposed on the integral dispersion spectrum (derived from whole spread f-k spectrum).

The distributions of all data regarding the V_p parameter (from evaluations of direct and refracted longitudinal waves) and V_s (based on the f-k spectrum analyses) allowed the calculation of the main geodynamic parameter values related to depth. The representative values are notified in both table 1 and 2. For 0÷23 m panel, located on the *rock-slide chart* (figure 1), V_s graphs regarding the *covering deposits* on the bedrock, also depicted on the cross-section (figure 6 bottom), are distinguished by the lowest values.

4. Geotechnical assessments

Seismic survey data was supplemented by geological mapping (including observations on cores extracted from shallow boreholes), lithological analyses, and laboratory measurements on both mass density and static longitudinal elastic modulus on some cores. Thus some correlations between seismic

results and geotechnical factors were evidenced. The data analysis tried to address two distinct objectives: significances of *share wave velocity values* (V_S) and veracity of *geodynamic parameters in situ*, especially E_{dyn} - *dynamic longitudinal elastic modulus*.

Graphs of V_S - depth reveal the frequent data for the formations above the bedrock (*silty clay deposits*), as opposed to sporadic information on underlying *marls*. The larger V_S values for *marls*, the lack of data related to the strict bedrock surface, as well as the scale changes led to the splitting of the graphs near the interface between the above-mentioned formations. F-k spectra images on groups of seismic channels, whether they contain generally a spot of maximum amplitude of 2D Fourier spectrum (e.g. profile L2, panel 0÷23 m, figure 7) or two closed apex-values (profile L2, panel 23÷46 m, figure 8) persuasively illustrate the accurate results by focusing f-k maximum values. Subsequently, precise V_S values were calculated.

The substantial particularity of V_S graphs, ranging from *silty clay formations*, lies in the different regimes of V_S evolution reported to the degree of slope stability. On the profile L1, located *upstream of the landslide* (evaluated as unstable land), V_S discrete values (figure 9-intermediary curves) are larger than in *the downstream area with slide deposits*-profile L2, panel 0 m÷23 m (figure 9 - left side curves). The above statements are completed by the largest values for S-wave velocities in the area *classified as stable*-profile L2, panel 23÷46 m (figure 9 - right side curves).

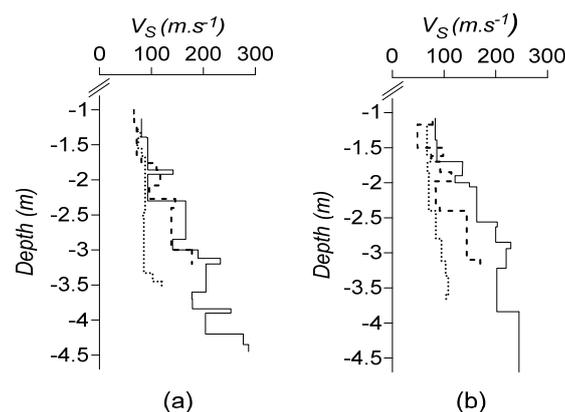


Figure 9. V_S comparable graphs for *silty clay formations* referring to: slide rock-mass (dotted line), unstable area (dashed line) and stable zone (solid line). Data are collected from seismograms obtained for: (a) forward impact profile; (b) reversed impact profile.

Concerning the *marl formation*, the local bedrock, the information is rare (Lines L1 and L2, panel 23÷46 m) or absent (e.g. line L2, panel 0÷23m). One explanation could be local unfavorable physical-geological conditions, related to frequent non-homogeneities in landslide areas.

On the line L1, V_S -depth graph obtained by data addition resulted from f-k spectra based on forward and reversed profile, sources placed in distance-pickets IP 0 m and IP 23 m respectively (fig.10a), is presented. The small velocity slowly variation (between 247÷270 $m.s^{-1}$) over the relative big depth interval (between -4.2÷-8.3 m) signalized an accentuated state of weathering. In the base (-8.3 m relative level), the V_S value of 512 $m.s^{-1}$ can represent the mark from which the alteration state diminish with increasing depth. The small velocities in the wet marl upper part (figure 10a) and the anomalous comportment of the dispersion spectrum (figure 4c) can be interpreted as precursor marks of the new land displacement, produced six months after the seismic measurements, in the western part of the line L1.

Relevant V_S data were obtained also on the line L2 (panel 23÷46 m, to IP 46 m). The graph (figure 10b) reveals a weathering zone, characterized by quasi-gradual increasing of V_S values (from 271

$\text{m}\cdot\text{s}^{-1}$ to $433 \text{ m}\cdot\text{s}^{-1}$) over a relative small depth interval (between $-5.3 \div -6.25 \text{ m}$). Considering the ratio $V_P/V_S \approx 1.74$, equivalent with the expression $\mu \approx 0.25$ (characteristic generic value of non-altered rock), for V_P of $2200 \text{ m}\cdot\text{s}^{-1}$ (figure 6 bottom) the resulted $V_S \approx 1264 \text{ m}\cdot\text{s}^{-1}$. Subsequently, by means of linear tendency function ($V_h = 219.4 + 146.5 \cdot h$), weathered zone thickness of 7.1 m was obtained. Based on the above example, one can conclude that in landslide areas, the V_P values, produced by seismic refraction measurements, need to be complemented by V_S values, derived from spectral analyses of Rayleigh waves, to provide more details concerning both intensity and depth extension of weathering zones.

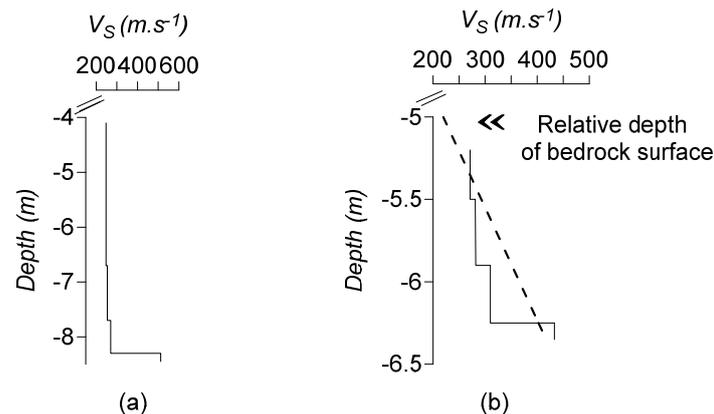


Figure 10. V_S -depth evolution related to the upper part of *marl formation*: (a) weathered formation (line L1); (b) more compact, dry formation (line L2, panel 23÷46 m, IP 46 m, picket 31 m).

The other important objective of the seismic research plane consisted in evaluations of the *information reliability by comparing E-Young modulus values, resulted for both measurements, in field, dynamic, and, in laboratory, static*. Measurements on two samples of *silty clays*, taken from 2 m relative depth of boreholes 1 and 2 (located on Line 1), indicated the same value of $13.5 \text{ MN}\cdot\text{m}^{-2}$. At the same depths on the line L1, seismic results showed E_{dyn} value of $56.6 \text{ MN}\cdot\text{m}^{-2}$ and $36.6 \text{ MN}\cdot\text{m}^{-2}$ for files recorded of impact source placed in distance-pickets 0m (figure 5, column 5) and 23 m respectively. Average value on the profile, for 2 m depth, leads to $E_{\text{dyn}}/E_{\text{static}}$ ratio of 3.45. The expression of polynomial trend, inferred from set of micro-conglomerate sandstone samples analysed in the framework of a hydroelectric dam project [13], showed values of the $E_{\text{dyn}}/E_{\text{static}}$ ratio that tended asymptotically to 3.38 for dynamic moduli below $100 \text{ MN}\cdot\text{m}^{-2}$. Good correspondence of results regarding elastic longitudinal modulus, such as results from the two groups of ratings (dynamic and static), increases the confidence in the seismic information for deeper levels, as well as other *in situ* dynamic parameters (Poisson ratio and shear elastic modulus).

5. Conclusions

The approached subject attests, mainly, the MASW method capability to provide non-invasive *in situ* data on the evolution of shear wave velocities in landslide areas. Subsequently, in connexion with information provided by seismic refraction, the values of the main geo-elastic parameters could be calculated.

The methodologic survey was focused on developments of the MASW method data processing, elements described in the context of applications in a shallow landslide zone. The processing improving essence consists in dividing the geophone spread into groups with the number of geophones optionally selectable and some overlapped receiver-intervals. In the framework of the research, the configuration consisting of five geophones with two receiver-intervals superposed was selected. This configuration allowed both to acquire more and better defined data by maximum-spots of the series of f-k spectra. Practically, the proposed procedure offers an advanced version, comparing with the

routine rule of sampling median line, drawn subjectively along the maximum value area of integral spread dispersion spectrum, actually used in topical works.

MASW method applications in the context of seismic refraction records reveal in the first step the evolutions of the longitudinal and shear wave velocities in shallow sections. Then, using lithologic data of some geotechnical drillings and measurements of physical properties (mass density and static elastic modulus) on cores, the dynamic values of the Poisson ratio (μ_{dyn}) and both elastic moduli: shear (G_{dyn}) and longitudinal (E_{dyn}) were calculated and geologically interpreted. Values about 3.4 of the $E_{\text{dyn}}/E_{\text{static}}$ ratio are consensual with the literature data [13]. Following the physical-mathematical relationships, the μ_{dyn} and G_{dyn} values gain confidence, which validates the seismic results related to the geological engineering meanings in the Brebu landslide area.

The other conclusion of the application MASW method is the differentiation tendency of evolution with depth of the physical parameters above mentioned, namely the shear wave velocities, in relation to the degree of stability of the explored slope sector. The lowest values are located on the rock-slide deposit zone (western segment of the profile L2), unlike the eastern part of the same profile, the stable area, is characterized by the greatest V_s values. Intermediate values of the analysed physical parameters were evidenced for the deposits located immediately upstream to the main slope detachment area (seismic line L1). As follows, we can conclude that the applicative feature of the survey consists in enlarging criteria for the landslide characterization with new parameters, starting with the shear wave velocities and continuing with both shear and longitudinal elastic moduli.

Acknowledgments

This paper was realized in the frame of *Parteneriate in domenii prioritare-PN II program*, with support of MEN-UEFISCDI, Romanian project nr. 83/2014. The authors thank to this Romanian national financing unit. Thanks also to Virgil Bardan, *Honorary Member of the EAGE*, for the essential support to build the Fourier analysis soft-routine.

References

- [1] M. Stefanescu, S. Radan, M. Micu, M. Marunteanu, and M. Stefanescu, "Geological Map of Romania", Sc. 1: 50,000, sheet Slanic (Prahova), *Inst. Geol. Geofiz.*, Bucharest, 1978.
- [2] M. Stefanescu, and M. Marunteanu, "The age of the Doftana Molasse". *D. S. Inst. Geol. Geofiz.*, LXV/4, pp. 169-182, 1980.
- [3] K. O. Addo, and P. K. Robertson, "Shear wave velocity measurement of soil using Rayleigh Waves", *Can. Geotech. J.*, vol.29, pp. 558-568, 1992.
- [4] C. B. Park, R. D. Miller, and J. Xia, "Multichannel Analysis of Surface Waves", *Geophysics*, V. 64, No. 3, pp. 800-808, 1999.
- [5] M. Cercato, F. Cara, E. Cardarelli, G. Di Filippo, G. Di Giulio, and G. Milana, "Shear wave velocity profiling at sites with high stiffness contrasts: a comparison between invasive and non-invasive methods", *Near Surface Geophysics*, vol.8, No. 1, Febr., pp. 75-94, 2010.
- [6] D. Enescu, "Surface waves", in *Geophysical Prospecting* (in Romanian), vol.II, Ed. Tehnica, Bucuresti, pp. 250-255, 1965.
- [7] C. P. Abbiss, "Shear wave measurements of the elasticity of the ground", *Géotechnique* 31, No.1, pp. 91-104, 1981.
- [8] P. J. Hatherly, and M. J. Neville, "Experience with the generalized reciprocal method of seismic refraction interpretation for shallow engineering site investigation", *Geophys.*, Vol. 51. No. 2, pp. 255-265, 1986
- [9] R. A. Overmeeren, "Hagerdoon's plus-minus method the beauty of simplicity", *Geophys. Prospecting*, 49 (6), pp. 687-696, 2001, 255-265, 1986.
- [10] K. T. Kilty, A. R. Norris, R. W. McLamore, P. H. Hennon, and K. Euge, "Seismic refraction Horse Dam. An application of the generalized reciprocal method", *Geophys.*, Vol. 51, No. 2,

- pp. 266-275, 1986.
- [11] C. Strobbia, and S. Foti, “Multi-offset phase analysis of surface wave data (MOPA)”, *Journal of Applied Geophysics*, 59, pp. 300-313, 2006.
- [12] G. Grandjean, J. C. Gourry, O. Sanchez, A. Bitri, and S. Garambois, “Structural study of the Ballandaz landslide (French Alps) using geophysical imagery”, *Journal of Applied Geophysics*, 75, pp. 531-542, 2011.
- [13] D. Enescu, D. Danchiv, and A. Danchiv, “Determination of rock elastic parameters in the Paltinul dam area. Contributions on relationship between dynamic and static moduli” (in Romanian), *St. Cercet. Geol., Geofiz., Geogr., Geofiz.*, 2/8, pp. 169-189, Bucuresti, 1970.