Estonian Journal of Earth Sciences, 2017, **66**, 2, 109–117 https://doi.org/10.3176/earth.2017.06

Seismic properties of soil in the Eastern Baltic Sea Region based on the horizontal to vertical spectral ratio method

Valerijs Nikulins

University of Latvia, 19 Raina Blvd., Riga LV-1586, Latvia; valerijs.nikulins@lu.lv
Latvian Environment, Geology and Meteorology Center, Maskavas iela 165, Riga LV-1019, Latvia; valerijs.nikulins@lvgmc.lv

Received 24 October 2016, accepted 28 February 2017

Abstract. The purpose of this study was to estimate and compare seismic properties of soil under different geological conditions of the southern part of the Baltic Shield and the northwestern part of the East European Platform. Horizontal to vertical spectral ratios (HVSRs) were estimated with respect to seismic stations of the Baltic Virtual Seismic Network (BAVSEN). The HVSRs were made based on the analysis of ambient seismic noise and regional seismic events. Distinct peak amplitudes of HVSRs for the stations located on the Baltic Shield, the southern slope of the Baltic Shield and the sedimentary cover of the northwestern part of East European Platform were revealed. The stability of amplitudes and frequencies of HVSR peaks, soil vulnerability index and interrelation between frequency and unconsolidated sediment thickness were estimated. The results can be of practical importance for the solution of problems of engineering seismology and for the assessment of dynamic properties of soil and vulnerability of buildings.

Key words: horizontal to vertical spectral ratio, HVSR, Baltic Virtual Seismic Network, BAVSEN, ambient seismic noise, ellipticity.

Abbreviations

ADC – analogue-to-digital converters
BAVSEN – Baltic Virtual Seismic Network
BSD – Bornholm Skovbrynet, Denmark
GEOFON – GEOFOrschungsNetz
GFZ – GeoForschungsZentrum Potsdam
H/V – horizontal to vertical
HVSR – horizontal to vertical spectral ratio
LTA – long time average
MEF – Metsähovi, Finland
MTSE – Matsalu, Estonia
PABE – Paberze, Lithuania
PBUR – Paburge, Lithuania
PUL – Pulkovo, Russia
QTS – quasi-transfer spectra
RAF – Laitila, Finland
SESAME – Site EffectS assessment using AMbient Excitations
SLIT – Slitere, Latvia
STA – short time average
SUW – Suwalki, Poland
VSU – Vasula, Estonia

INTRODUCTION

The method of horizontal to vertical spectral ratio (HVSR), as an analogue of the quasi-transfer function (quasi-transfer spectra – QTS), has become widely known and is widely used in seismological practice. The method was proposed by Nogoshi & Igarashi (1971) and has been extended thanks to the research by Y. Nakamura (Nakamura 1989) and his followers. The method can be applied to solving problems of engineering seismology, such as the assessment of dynamic properties of soil under railway embankments (Nakamura 1997) or the estimation of the vulnerability of buildings and constructions including historical monuments (Gallipoli et al. 2004; Nakamura 2008). Moreover, the method is used in seismic micro-zoning for the assessment of prevailing frequencies and resonant amplification of soil (Zaharia et al. 2008). The main advantage of the HVSR method lies in its efficiency and economic expediency. An important benefit of this method is its applicability in both seismic and aseismic areas (Nakamura 2008). As a basis of input data, not only earthquakes but also an ambient seismic noise can be used, which consists of seismic noise proper (microseisms) and human-induced noise (microtremor). In a number of methodological studies – in particular, those carried out within the framework of the Site EffectS assessment using AMbient Excitations (SESAME) project (Bard et al. 2004), the influence of many factors upon HVSRs was estimated. Nevertheless, insufficient research of some man-caused impacts (such as train or sea vessels), some structures, proximity of the sea, level of the water table for HVSRs and also of the stability of HVSRs over time was noted (Bard et al. 2004). Methodological problems of HVSRs are relevant to ancient platform territories, including the East European Platform. Methodical research can promote the achievement of more correct practical results when using the HVSR method in the solution of applied problems of engineering seismology.

Stationary stations of seismic monitoring of the Baltic Virtual Seismic Network (BAVSEN) (Nikulins 2009; Nikulin 2011), as a part of the GEOFON network of the *GFZ Potsdam Helmholtz-Zentrum*, give a good chance for the analysis of the stability of peak values and other parameters of spectral relations. The stations are located in different geological conditions. This feature enables one to reveal both the common patterns, and individual features of HVSRs, to estimate the resolving power of separate stations for a low-level detection and qualitative location of seismic events and to estimate the efficiency of the use of seismic noise and seismic events for the assessment of dynamic properties of soil. Dynamic properties of soil are important for finding solutions for applied tasks of engineering seismology and for high-quality records of seismic events at seismic stations.

MATERIALS AND METHODS

The HVSRs were defined for eight seismic stations of the BAVSEN virtual network. The stations are located in the East Baltic Sea region (Fig. 1), in different geological conditions. The Metsähovi (MEF) and Laitila (RAF) stations are located on the Baltic Shield, the Matsalu (MTSE) and Vasula (VSU) stations on the southern slope of the Baltic Shield, the Slitere (SLIT), Paberze (PABE) and Paburge (PBUR) stations on the East European Platform, within the Baltic Syneclise and the Suwalki (SUW) station lies at the border between the Baltic Syneclise and the Mazuro-Belorussian Anteclise. Geological conditions change markedly from north to south and the thickness of the sedimentary cover increases along the coastal profile from 150 to about 2600 m (Paškevičius 1997). The thickness of Quaternary deposits changes from 10 to 130 m for the seismic stations within the Baltic Syneclise (SLIT, PABE, PBUR).

Seismic sensors are located at different depths from the earth surface (from 0 to 6.5 m) to diminish the impact of Quaternary loose deposits and to reduce the high-frequency microtremor a little. The standardization of seismic sensors and analogue-to-digital converters (ADC) are important advantages of the stations of the BAVSEN network. Streckeisen STS-2 broadband sensors and PS6-SC – ADC are mainly used. The HHZ, HHN and HHE channels with the sampling rate of 100 Hz were used for HVSR analysis. The BSD and PUL stations do not record such channels and therefore, data from these stations were not used in this study.

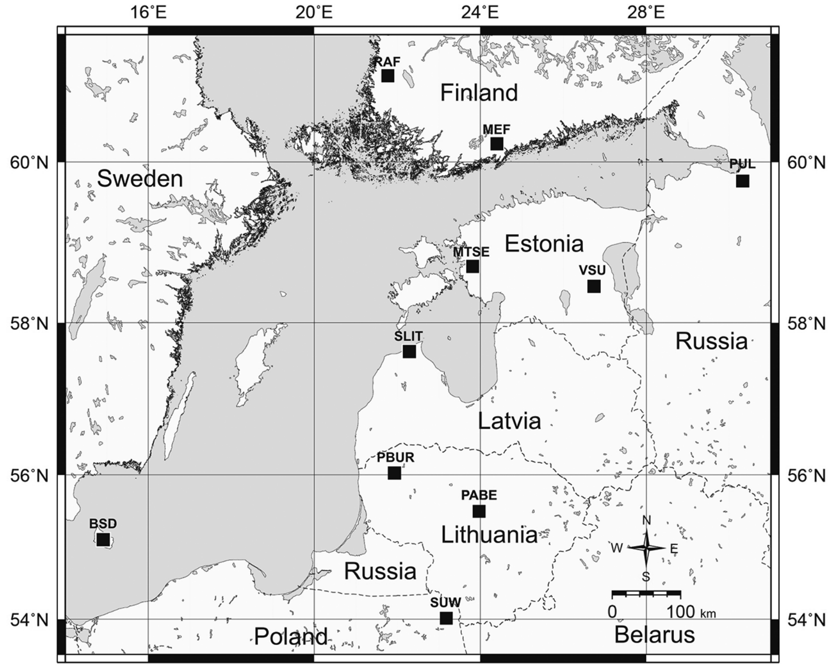

Fig. 1. Stations of the Baltic Virtual Seismic Network BAVSEN.

The Geopsy program was applied for calculations of the HVSR. This program is based on the original method by Nogoshi & Igarashi (1971) that spread widely due to Nakamura (1989). The method was based on the interpretation developed in the project SESAME (Bard et al. 2004).

An automatic choice of windows was used for analysis. The time window length was 25 s. To calculate the average, 71 windows were used. Casual, transient processes were excluded from the noise analysis. Frequency sampling output was 0.2–15.0 Hz. The smoothing type by the Konno–Ohmachi method was used (Konno & Ohmachi 1998).

In each window, the horizontal spectrum is computed by merging the horizontal components (N–S and E–W), by using the method of the quadratic mean and the formula:

$$H = \sqrt{\left(H_{\mathrm{EW}}^{2} + H_{\mathrm{NS}}^{2}\right)/2}\,. \tag{1}$$

Only background seismic noise records produced during night-time were used for the analysis of HVSR in August 2015, with the duration of 30 min. Following this choice, the influence of man-caused noise, i.e. microtremor, was minimized. Because of technical problems, the number of records of seismic noise for different stations varied from 23 to 27. The analysis of HVSRs for engineering seismology (within the frequency band from 0.2 to 10 Hz) was highly interesting since it is associated with self-resonant frequencies of buildings and industrial structures. Recommendations of the SESAME project (Bard et al. 2004) were used as a methodical basis.

Nakamura (1997) has introduced the concept of vulnerability index K_g. This parameter characterizes the weakest sites of soil or buildings. Average shear strain deformation γ of the surface ground can be presented in the form

$$\gamma = A_g \cdot {}^{d_b}\!/_{h}\,, \tag{2}$$

where A_g is the amplification factor, h is the thickness of the surface layer and d_b is the seismic displacement of the basement ground.

The surface ground in the East Baltic region is usually represented by unconsolidated, Quaternary deposits of sand, clays, sandy loams and loams. Quaternary deposits lie on more dense deposits mainly of Devonian origin, and to a lesser degree – on deposits of Silurian, Ordovician, Jurassic, Triassic, Cretaceous, Palaeogene and Permian origin, in decreasing order of presentability.

The peak frequency of the surface ground F_g can be expressed as

$$F_g = v_{ss} / 4h = v_{sb} / 4h \cdot A_g\,, \tag{3}$$

where v_{ss} is S-wave velocity (m/s) in the top Quaternary sedimentary layer; v_{sb} is S-wave velocity (m/s) in the basement ground.

The left part of formula (3) reflects the fundamental property of the peak frequency. The right part of formula (3) is valid only on condition that the densities of the basement and surface ground have similar values.

Taking into account that the acceleration α_b of the basement ground has the expression

$$a_b = (2\pi F_g)^2 d_b\,, \tag{4}$$

where d_b is the seismic displacement of the basement ground, the shear strain deformation γ can be expressed as

$$\gamma = \frac{A_g \cdot \alpha_b}{(2\pi F_g)^2} \cdot 4A_g \cdot \frac{F_g}{v_{sb}} = \frac{A_g^2}{F_g} \cdot \frac{\alpha_b}{\pi^2 v_{sb}} = r \cdot K_g \cdot \alpha_b\,, \tag{5}$$

where $r = 1/\pi^2 v_b$, $K_g = A_g^2 / F_g$. The parameter r is practically constant for various sites which are located in similar geological conditions.

The parameter $K_g = A_g^2 / F_g$ is vulnerability index, which characterizes a specific site and can be useful when assessing the weak points of soil discovered. The weak points of soil are soil sites typically characterized by big peak amplitude square/resonance frequency ratios. If the efficiency e of the applied seismic force can be expressed in per cent through static force, it is possible as average to accept e = 60%.

RESULTS AND DISCUSSION

The HVSRs vary for different geological conditions. For the stations located on the Baltic Shield (MEF and RAF), the HVSR curve has almost flat characteristics, with a step-by-step increase towards high frequencies (Fig. 2). The HVSRs for the stations MEF and RAF do not exceed 1.52–1.75 for frequencies 10 Hz and higher. Thus, clear spectral peaks are absent for the stations MEF and RAF (Fig. 2).

The station SUW participated little in locating seismic events and, therefore, there is lack of sufficient data to describe them. At the SLIT station, although peak values are pointed, they are still lower than level 2. For other stations, the maximum amplitudes of HVSRs of ambient seismic noise change from 1.66 to 10.52 (Table 1).

According to methodical recommendations of the SESAME project (Bard et al. 2004), the frequency above 0.4 Hz (f_0 >10/windows length) corresponds to the

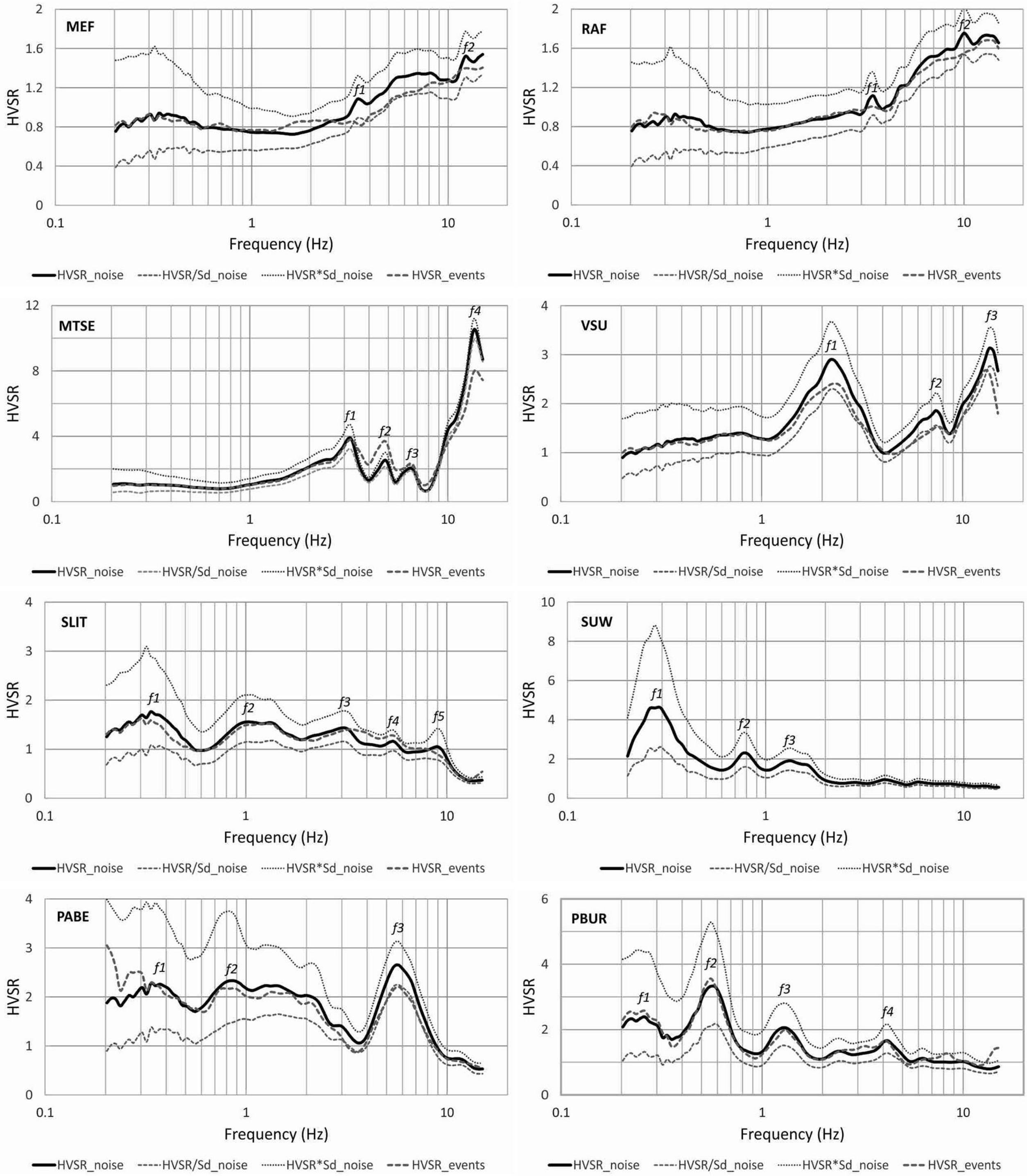

Fig. 2. Horizontal to vertical spectral ratios (HVSRs) for stations of the BAVSEN network.
HVSR_noise – the generalized curve of the HVSR for ambient seismic noise; HVSR/Sd_noise and HVSR*Sd noise – the HVSR curve divided and multiplied by the standard deviation Sd; HVSR_events – the generalized curve of the HVSR for seismic events (earthquakes, explosions and other man-made events); f_1 ... f_5 – frequencies of HVSR peaks pointed in Table 1 for relevant seismic stations.

Table 1. Parameters of HVSRs of ambient seismic noise for stations of the BAVSEN network

Station	Parameter	f_1	f_2	f_3	f_4	f_5	Station	Parameter	f_1	f_2	f_3	f_4	f_5
Metsähovi	f, Hz	3.46	12.25	–	–	–	Slitere	f, Hz	0.34	1.03	3.12	5.45	9.04
	σ_f	0.14	0.79					σ_f	0.03	0.10	0.36	0.18	0.56
	A_{HVSR}	1.08	1.52	–	–	–		A_{HVSR}	1.77	1.56	1.43	1.16	1.05
	$\sigma_A(f)$	1.22	1.52					$\sigma_A(f)$	1.63	1.35	1.24	1.20	1.36
Laitila	f, Hz	3.46	10.01	–	–	–	Suwalki	f, Hz	0.29	0.76	1.35	–	–
	σ_f	0.10	0.65					σ_f	0.02	0.02	0.07		
	A_{HVSR}	1.11	1.75	–	–	–		A_{HVSR}	4.62	2.28	1.90	–	–
	$\sigma_A(f)$	1.21	1.15					$\sigma_A(f)$	1.77	1.46	1.34		
Matsalu	f, Hz	3.24	4.87	6.61	13.54	–	Paberze	f, Hz	0.34	0.84	5.73	–	–
	σ_f	0.00	0.00	0.32	0.65			σ_f	0.04	0.17	0.18		
	A_{HVSR}	3.87	2.52	2.00	10.52	–		A_{HVSR}	2.28	2.33	2.65	–	–
	$\sigma_A(f)$	1.21	1.19	1.08	1.06			$\sigma_A(f)$	1.66	1.60	1.18		
Vasula	f, Hz	2.19	7.38	13.56	–	–	Paburge	f, Hz	0.26	0.56	1.26	4.23	–
	σ_f	0.07	0.12	0.33				σ_f	0.02	0.02	0.06	0.11	
	A_{HVSR}	2.89	1.86	3.13	–	–		A_{HVSR}	2.39	3.33	2.05	1.66	–
	$\sigma_A(f)$	1.27	1.20	1.13				$\sigma_A(f)$	1.82	1.59	1.36	1.30	

f_i – frequency of an HVSR peak, A_{HVSR} – amplitude of a peak at frequency f, $\sigma_A(f)$ – standard deviation for the amplification factor A_{HVSR}, σ_f – standard deviation of the frequency of an HVSR peak, the dash '–' means there are no peaks.

criterion of reliable spectral peaks. Thus, the frequencies 0.34 Hz (SLIT), 0.29 Hz (SUW), 0.34 Hz (PABE) and 0.26 Hz (PBUR) do not meet these requirements. Thus, only 22 frequencies satisfy the actual peak's criterion. Nevertheless, none of these remaining peak frequencies satisfies the criterion for a clear peak. In the range of engineering seismology (0.2–10 Hz) covered by this study, only three peak frequencies have significant level extremum and are of interest from the practical point of view. These are the frequencies 2.19 Hz (VSU), 5.73 Hz (PABE) and 0.56 Hz (PBUR).

The amplitude of the HVSR for ambient seismic noise is in general higher than the one for seismic events. The difference between HVSRs for ambient seismic noise and seismic events is insignificant at the stations SLIT and PBUR. The standard deviation for the HVSR for ambient seismic noise is mainly less than that for seismic events (Table 1). The same applies to frequency peaks.

The frequency stability and minimum standard deviation σ_f correspond to low values (up to 1.35 Hz) for the stations SLIT, SUW, PABE and PBUR. There is also an exception for average frequencies 2.19 Hz (VSU), 3.24 (MTSE) and 4.87 Hz (MTSE). The maximal stability of the HVSR corresponds to frequencies 6.61 and 13.54 Hz for the station MTSE.

However, the estimates of HVSRs and frequency peaks of seismic events are made for insufficient statistical representativeness. For the stations RAF, MTSE and VSU 23 records of seismic events, for the station MEF 16 records, for the station SLIT 13 records and for the PABE and PBUR stations 6 records have been used. All the seismic events were localized with the aid of the BAVSEN network. These events took place between 2 and 22 July 2016. Most of these events occurred in the northeast of Estonia. Moreover, seismic events that occurred in Lake Pskov and the northwest of Russia, in the coastal area in Sweden and Finland have been used. All of these events are very likely man-made explosions. Only two events are of uncertain origin. These seismic events took place on the border of Moldova and Ukraine and down to the Black Sea. The HVSRs are more reliable with respect to ambient seismic noise.

The interrelation between Rayleigh waves and the HVSR can be shown on the basis of comparison between the HVSR and an ellipticity curve. The criterion of ellipticity has been applied in many studies (Nogoshi & Igarashi 1971; Lachet & Bard 1994; Malischewsky et al. 2010). Theoretical ellipticity has been estimated for Rayleigh waves. Ellipticity is the ratio of amplitudes of horizontal and vertical motions of a particle in a plane of a Rayleigh wave. The station VSU was selected for ellipticity assessment because there is a rather obvious spectral peak of 2.19 Hz on the HVSR curve. A three-layer model has been used for the assessment of ellipticity (Fig. 3). The peak amplitude of curve ellipticity (dashed line in Fig. 3) of the fundamental mode of Rayleigh wave is practically coincident with the frequency f_1 of the HVSR. In addition, a transfer function was estimated for a model of three layers and the vertical component.

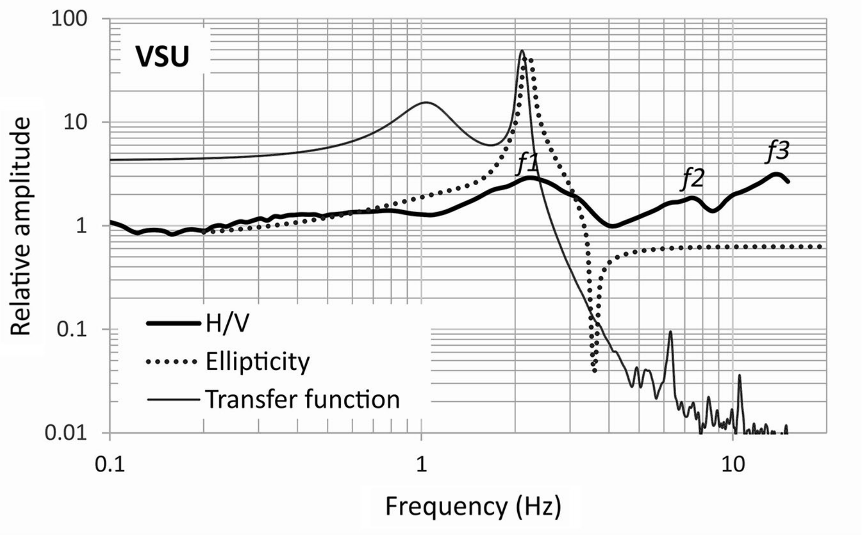

Fig. 3. Curves of HVSR, ellipticity and transfer function for the Vasula (VSU) station. f_1 ... f_3 – frequencies of HVSR peaks pointed in Table 1 for the VSU station.

The Berlage impulse was used as the input signal to excite the layer's model. According to several authors (Korchinsky 1971), surface motion is more exactly described by the function of the Berlage impulse.

There is quite a good consistency between the main extremum (f_1) of the experimental curve of the HVSR, the transfer function and Rayleigh wave ellipticity for the fundamental mode.

The assessment of the vulnerability index K_g is of practical interest. As a boundary value of the vulnerability index, Nakamura (2008) considers $K_g = 20$, having shown it by an example from the effects of the Loma Prieta earthquake in 1989. The Loma Prieta earthquake occurred in Northern California. The moment magnitude reached 6.9, the bet focal depth 19 km. The seaside area was damaged to a greater extent. From the side of the opposite hill area there was no damage.

There are only two BAVSEN stations (SUW, PBUR) and three frequencies (0.29, 0.26, 0.56 Hz) for which K_g is close to or higher than 20 (73.6, 22.0 and 20.0). It is also known that in the case of deformation $\gamma = 10^{-3}$, the ground surface begins to show nonlinear characteristics, and in the case of $\gamma = 10^{-1}$ a serious deformation and damage to buildings may occur (Nakamura 2008). Provided an earthquake with the magnitude 5.2 occurs at a depth of 16 km (Gregersen et al. 2007) under a station, acceleration can reach about 0.96 m/s^2 in the epicentral zone on the surface. These parameters are taken for the Kaliningrad earthquake with the biggest magnitude in the Eastern Baltic region.

In this case, estimates of γ deformation on the surface for specified stations and frequencies yield values 0.001–0.003, assuming that the effective shear strain is accepted as $e = 60\%$. Thus, there are threshold, critical values for the beginning of non-linear effects. The specified frequencies are typical for buildings with concrete moment frames and height from 55 to 115 m. Such estimates are valid for those places where the seismic stations are located. At the same time, it should be noted that seismo-geological conditions of the surface ground elsewhere in the East Baltic region can be much worse.

The correlation between frequencies of spectral peaks and thickness of unconsolidated, Quaternary deposits has been widely used (Ibs-von Seht & Wohlenberg 1999; Parolai et al. 2002; Mokhberi et al. 2013) in studies of HVSRs. The correlation is usually presented in the form of a power function:

$$h = a \cdot f^{b}, \qquad (6)$$

where a, b are correlation coefficients.

Limited data were used in research for the assessment of correlation dependence between the HVSR peak frequency and the thickness of the sedimentary layer of unconsolidated deposits. Limited data are based only on the six measurement points which are on the stations of BAVSEN network. Nevertheless, it is important to estimate such a relationship, because the HVSR method can be applied to the solution of application-oriented tasks of engineering seismology under conditions of low seismicity in the East Baltic region.

Estimates of the relationship are made for four (VSU, SLIT, PABE, PBUR) and six (VSU, SLIT, PABE, PBUR, SUW, MTSE) stations (Fig. 4) on the basis of ambient seismic noises. The data describing the thickness of sedimentary deposits for the SUW and MTSE stations are less reliable.

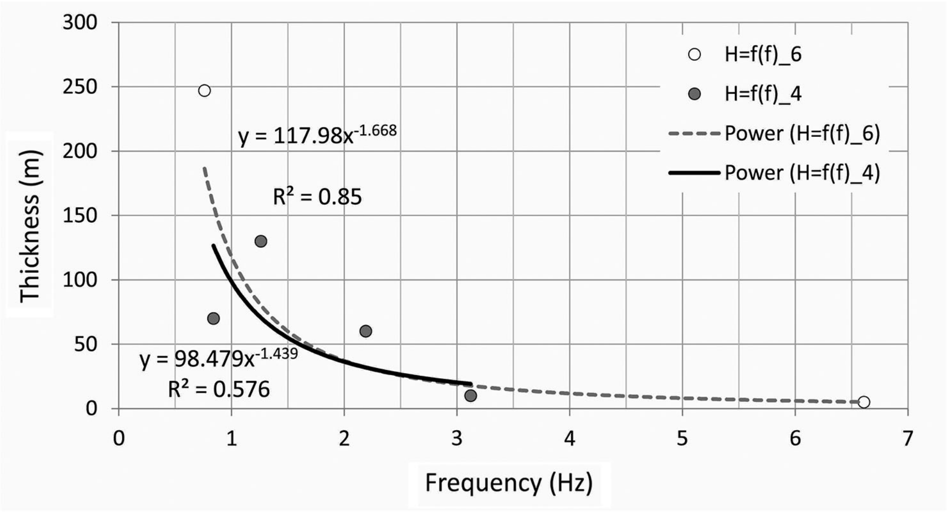

Fig. 4. Interrelation between frequencies of HVSR peaks on the basis of ambient seismic noises and thickness of Quaternary deposits. H = f(f)_6 and H = f(f)_4 – the values for estimating the dependence of the thickness of Quaternary deposits from frequency, respectively for 6 and 4 observational points; Power (H = f(f)_6 and Power (H = f(f)_4 – trend line on power law averaging, respectively for 6 and 4 observational points.

Two options of power regression have been identified for six observational points (formula 7) and for four observational points (formula 8):

$$h = 118.0 \cdot f_0^{-1.67}, \tag{7}$$

$$h = 98.5 \cdot f_0^{-1.44}. \tag{8}$$

In both cases, correlation coefficients are rather high, 0.92 and 0.76, respectively. The comparison with similar parameters of relationship for Germany and Iran (Ibs-von Seht & Wohlenberg 1999; Parolai et al. 2002; Mokhberi et al. 2013) shows that parameters *a* and *b* in expression 6 are higher in the Baltic region. For example, with regard to Germany (Ibs-von Seht & Wohlenberg 1999; Parolai et al. 2002), $a = 96$ (Aachen) and 108 (Cologne), $b = -1.388$ (Aachen) and -1.551 (Cologne). For Iran, the deviation of parameters is even greater. Parameter *a* is changing from 29.86 (Bushehr) up to 128 (South Pars), and parameter *b* is changing from -0.63 (Bushehr) up to -1.15 (Mokhberi et al. 2013).

Preliminary analysis of the origin of H/V spectral peaks has shown that, to understand the genesis of spectral peaks, it is necessary to carry out comprehensive analysis. Even for the most expressive frequency ($f_1 = 13.54$ Hz) at the MTSE station, the comprehensive analysis of wave field's different parameters is required. There are some factors pointing that this peak frequency can be due to man-made genesis (low damping of wave amplitudes, narrower H/V spectral peak with the increasing smoothing parameter of Konno–Ohmachi (Konno & Ohmachi 1998), as well as some factors pointing to its natural origin (the unchanging state throughout the day and weeks, practically with invariable amplitudes).

CONCLUSIONS

The HVSRs received based on ambient seismic noises and seismic events allow one to evaluate frequencies of spectral peaks, amplification factors and standard deviations for stationary seismic stations of the BAVSEN network in the East Baltic region. It is shown that estimates of HVSRs are more reliable with respect to seismic noise than with respect to seismic events (earthquakes, man-made events and explosions).

The actual peak's criterion is carried out for the most of analysed frequencies (22 frequencies), but none of these peak frequencies meet the criterion of detection for the clear peak. Nevertheless, from the practical point of view, three spectral peaks are important, corresponding to frequencies 2.19 Hz (VSU), 5.73 Hz (PABE) and 0.56 Hz (PBUR).

Seismic stations are located under different geological conditions. It is shown that, with regard to seismic stations on the Baltic Shield, H/V spectral peaks (with the amplitude ≥2) are missing. There are no significant peaks for the stations SLIT and SUW either. Detailed analysis and comparison between HVSR, ellipticity and transfer function is made for the station VSU. Good agreement between these parameters suggests that $f_1 = 2.19$ Hz corresponds to the Rayleigh wave fundamental mode.

The assessment of the vulnerability index has shown that, with respect to two stations (SUW and PABE) and three frequencies, K_g is higher than 20. This is higher than the critical level of this value. Assuming the vibration levels are similar to the Kaliningrad earthquake of 2004 (Gregersen et al. 2007), there is a probability of manifestation of nonlinear effects in soil under high structures and buildings. High buildings on such a soil can have frequencies close to frequencies of H/V spectral peaks.

Interrelations between frequencies of H/V spectral peaks and thickness of unconsolidated deposits, usually associated with Quaternary deposits, were estimated. These estimates need additional confirmation because the number of observational points was not sufficient.

To identify the origin of the H/V spectral peaks, additional detailed analysis of the wave field parameters has to be made.

Acknowledgements. The author is grateful to the reviewer H. Soosalu and the anonymous referee for useful comments on the manuscript. The publication costs of this article were covered by the Estonian Academy of Sciences.

REFERENCES

Bard, P.-Y. et al. 2004. *Guidelines for the Implementation of the H/V Spectral Ratio Technique on Ambient Vibrations. Measurements, Processing and Interpretation*. Grenoble, 62 pp. Available at: http://sesame.geopsy.org/Papers/HV_User_Guidelines.pdf [accessed 20 February 2017].

Gallipoli, M. R., Mucciarelli, M., Castro, R. R., Monachesi, G. & Contri, P. 2004. Structure, soil-structure response and effects of damage based on observations of horizontal-to-vertical spectral ratios of microtremors. *Soil Dynamics and Earthquake Engineering*, **24**, 487–495.

Gregersen, S., Wiejacz, P., Dębski, W., Domanski, B., Assinovskaya, B., Guterh, B., Mäntyniemi, P., Nikulin, V. G., Pacesa, A., Puura, V., Aronov, A. G., Aronova, T. I., Grünthal, G., Husebye, E. S. & Sliaupa, S. 2007. The exceptional earthquakes in Kaliningrad district, Russia on September 21, 2004. *Physics of the Earth and Planetary Interiors*, **164**, 63–74.

Ibs-von Seht, M. & Wohlenberg, J. 1999. Microtremor measurements used to map thickness of soft sediments. *Bulletin of the Seismological Society of America*, **89**, 250–259.

Konno, K. & Ohmachi, T. 1998. Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor. *Bulletin of the Seismological Society of America*, **88**, 228–241.

Korchinsky, N. P. 1971. *Seismostojkoe stroitel′stvo zdanij* [*The Earthquake-Proof Construction of Buildings*]. Higher school, Moscow, 320 pp. [in Russian].

Lachet, C. & Bard, P. Y. 1994. Numerical and theoretical investigations on the possibilities and limitations on Nakamura's technique. Journal of Physics of the Earth, **42**, 377–397.

Malischewsky, P. G., Zaslavsky, Y., Gorstein, M., Pinsky, V., Tran, T. T., Scherbaum, F. & Estrella, H. F. 2010. Some new theoretical considerations about the ellipticity of Rayleigh waves in the light of site-effect studies in Israel and Mexico. *Geofisica Internacional*, **49**, 141–152.

Mokhberi, M., Davoodi, M., Haghshenas, E. & Jafari, K. 2013. Experimental evaluation of the H/V spectral ratio capabilities in estimating the subsurface layer characteristics. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, **37**(N C+), 457–468.

Nakamura, Y. 1989. A method for dynamic characteristic estimation of subsurface using microtremor on the ground surface. *Quarterly Report of Railway Technical Research Institute*, **30**, 25–33.

Nakamura, Y. 1997. Seismic vulnerability indices for ground and structures using microtremor. In *World Congress on Railway* Research, Florence, pp. 1–7.

Nakamura, Y. 2008. On the H/V spectrum. In *The 14th World Conference on Earthquake Engineering, Beijing, China*, pp. 1–10.

Nogoshi, M. & Igarashi, T. 1971. On the amplitude characteristics of microtremor – Part 2. *Journal of the Seismological Society of Japan*, **24**, 26–40 [in Japanese, with English abstract].

Nikulin, V. G. 2011. Sejsmicheskij monitoring v Baltijskom regione s ispol′zovaniem virtual′noj seti BAVSEN [Seismic monitoring in the Baltic region with the use of the virtual BAVSEN network]. In *Topical Issues of Monitoring of the Geological Environment and Safety of the Urbanized Territories. Theses of Reports of the 1st International Conference*, pp. 129–131. Baltic Federal University, Kaliningrad [in Russian].

Nikulins, V. 2009. Baltijas virtualais seismiskais tikls un ta aprobesanas iepriekšejie rezultati [Baltic virtual seismic network and the preliminary results of its testing]. In *Latvijas Universitates 67. zinatniska konference* [*The 67th Scientific Conference of the University of Latvia*]. University of Latvia, Riga, pp. 222–223 [in Latvian].

Paškevičius, J. 1997. *The Geology of the Baltic Republics*. Vilnius University, Geological Survey of Lithuania, 387 pp.

Parolai, S., Bormann, P. & Milkereit, C. 2002. New relationship between Vs, thickness of sediments, and resonance frequency calculated by the H/V ratio of seismic noise for the Cologne area (Germany). *Bulletin of the Seismological Society of America*, **92**, 2521–2527.

Zaharia, B., Radulian, M., Popa, M., Grecu, B., Bala, A. & Tataru, D. 2008. Estimation of the local response using the Nakamura method for the Bucharest area. *Romanian Report in Physics*, **60**, 131–144.

Pinnase seismilised omadused Läänemere idapoolsetel aladel, tuginedes H/V spektrisuhete meetodile

Valerijs Nikulins

On hinnatud ja võrreldud pinnase seismilisi omadusi erinevates geoloogilistes tingimustes Balti kilbi lõunaosas ning Ida-Euroopa platvormi loodeosas. Seismogrammide horisontaalsete ja vertikaalsete komponentide H/V spektrisuhteid (HVSR) on hinnatud Baltikumi virtuaalse seismojaamade võrgu (BAVSEN) andmetel. HVSR-diagrammid on koostatud seismilise taustfooni ja regionaalsete seismiliste sündmuste analüüsi põhjal. Selged maksimumid tulid välja jaamades, mis asuvad Balti kilbil, Balti kilbi lõunanõlval ja Ida-Euroopa settelise platvormi peal. On hinnatud HVSR-i maksimumide amplituudide ja sageduste stabiilsust, pinnase kahjustatavuse indeksit ja suhet maksimumide sageduste ning pudedate setete paksuse vahel. Tulemustel võib olla praktiline tähtsus, kui lahendatakse inseneriseismoloogia probleeme ja hinnatakse pinnase dünaamilisi omadusi ning hoonete kahjustatavust.