16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 1632

Registration Code: S-R1464699894

APPLICATION OF H/V METHOD IN A SAMLL-SCALED BASIN

Yushi Wang[(1)], Xiaomei Yang[(2)], Xiaojun Li[(3)]

[(1)] *Associate Researcher, Institute of Geophysics, China Earthquake Administration, wangyushi1982@126.com*
[(2)] *Associate Professor, Guangdong University of Technology, xmyang_86@aliyun.com*
[(3)] *Researcher, Institute of Geophysics, China Earthquake Administration, beerli@vip.sina.com*

Abstract

Nakamura method, i.e. H/V method of ambient tremor, is applied in a small-scaled lacustrine sedimentary basin in Northeast China, which is suspected to be a meteorite impact crater covered by soft and deep lacustrine deposit layers. The ambient tremor was observed for hours at 50 points in the basin, and then horizontal Fourier amplitudes to vertical Fourier amplitudes ratios, i.e. H/V spectral ratios, were calculated. The results showed that in the whole basin the predominant periods of H/V spectral ratios of all observation points were identical, but with different amplitudes. The in situ geological drillings showed that the peak values of H/V spectral ratio amplitudes at the predominant period (corresponding to 0.72Hz) depended on the depths of soft deposit soil and the distances to the basin center. The fact that H/V spectral ratios on the ground surface in the whole basin had only one predominant period but with different amplitudes indicated that the ambient tremor propagating through the deep and soft soil layers was affected by the three dimensional structure of lacustrine sediments, rather than the local soil depth right under the observation point . Our observations in several other sites showed that the H/V spectral ratios were not sufficient reliable when there were strong vibration sources on the ground surface nearby, meanwhile the H/V spectral ratios in this basin gave a satisfied result. We thought that no obvious vibration sources in this basin guaranteed the reliability of Nakamura method. In addition, amplitudes of H/V spectral ratios at the predominant period should be used in soil velocity inversion when the soil layers vary violently in horizontal plan, which could not be treated as one dimension layered medium any more.

Keywords: ambient tremor, Nakamura method, H/V spectral ratio, seismic basin effect, seismic site effect

1. Introduction

Ground motions induced by earthquakes are significantly influenced by dynamic characteristics of covering soil layers near ground surface, as thick and soft soil layers would obviously change the strength and frequency contents of ground motions. The conventional research methods of seismic site effect are Standard Spectral Ratio (SSR), Generalized Inversion Technique (GIT), Wave Propagation Simulation, and Nakamura method or horizontal to vertical spectral ratio (H/V spectral ratio) method.

H/V spectral ratios of seismograms were first used in inverson of crustal and uppermantle velocity structures[1,2]. One decade later, H/V spectral ratios of ambient tremor were used to evaluated seismic site effect[3], and then H/V spectral ratios of strong-motion accelerograms were applied to study the same problem[4]. The current consensus amongst the world's scientists is that the site predomainant periods determined by H/V spectral ratios of ambient tremor are satisfied, but the amplification ratios of strong motions from the bedrock to ground surface determined by H/V spectral ratios are not sufficent reliable[5,6,7]. Meanwhile, the H/V spectral ratios of accelerograms under weak to medium ground motions are considered to be more reliable, as they are unique within the error range at the same observation point in different earthquakes[8], and they have strong relationship with site geological conditions[9,10] and the spectral ratios obtained by SSR[5,11]. A more reliable spectral ratio, ground surface spectra to down hole spectra, is also introduced to evaluate the motion amplifications of soil layers[12]. This method is much more reliable than other spectral ratios in site effect evaluation and soil velocity structure inversion at the observation point, but it is not a realistic method for all engineering sites in need of site effect evaluation for the lack of down hole observations. Ambient tremor arrays are also used to help inverse the soil velocity structures, but it still needs verifications when engineering sites could not be treated as horizontal layered medium.

The horizontal to vertical spectrum ratios (Nakamura method) of ground microtremors developed by Nakamura and his followers, was thought to be an efficient and economic method to estimate the overburden layer depths of alluvial sites, the shear wave velocity structures of soil layers, and the site amplification of strong ground motions. Meanwhile, there are still some doubts about its instability of theoretical foundations.

Our research team endeavors tentatively to develop a method of three dimensional modeling of actual site using H/V spectral ratio distribution and limited geological drillings. Three dimensional modeling is fundamental and essential in site seismic numerical simulation. The dense geological drillings can give the most reliable soil layer structures, but it can not to be applied to every site because of its high capitalized cost. If H/V spectral ratio distribution of ambient tremor could be found dependent on the soil layer structures or the soil velocity structures, the site modeling of seismic numerical simulation can be carried on at an affordable cost. This article focused on the verification of the efficiency and reliability of Nakamura method in a small-scaled lacustrine sedimentary basin, Xiuyan meteorite crater, in Northeast China.

2. Xiuyan meteorite crater

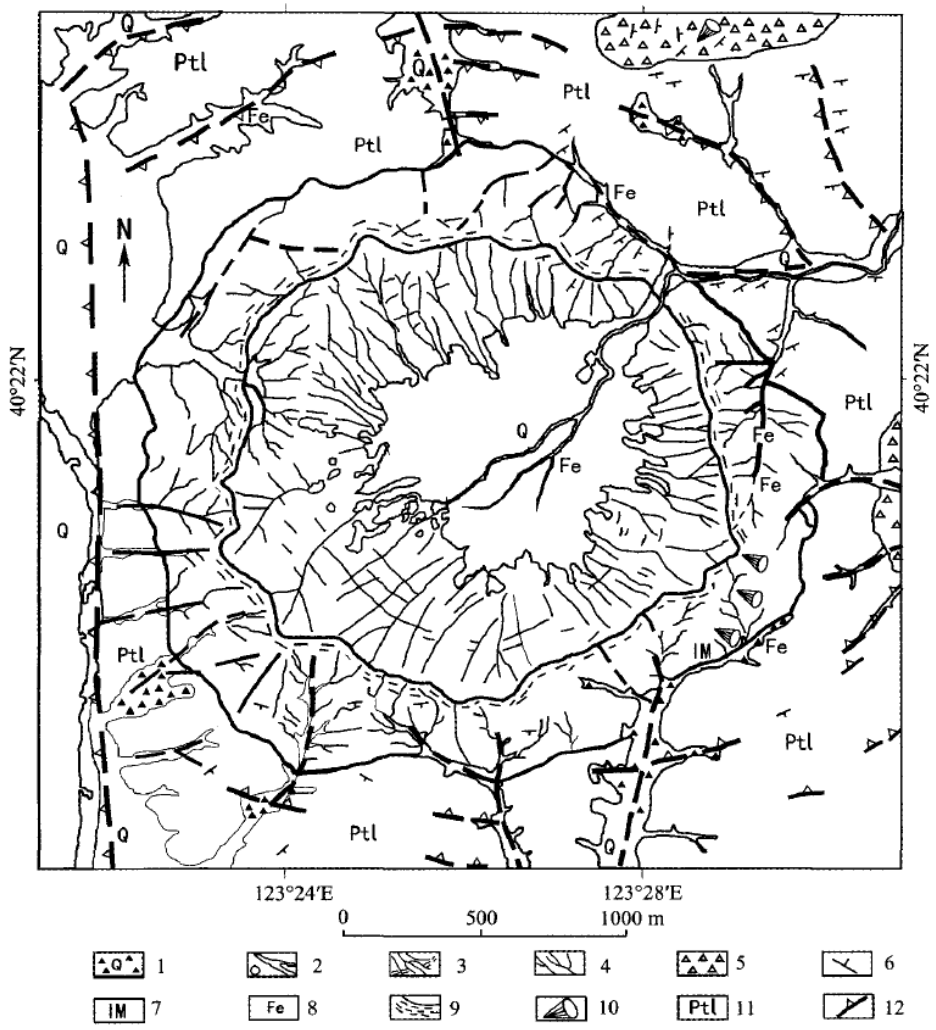
Xiuyan meteorite crater(Fig. 1), centered at 123.462°E, 40.366°N, is located at low mountain and hilly area of Liaotung peninsula, Northeast China. The shape of the crater is a closed circular funnel, whose crater ridge diameter is 1800 meters, and basin bottom diameter is 800 meters. The altitudes of the crater ridges are 250-344 meters, and the altitudes of the basin bottom surfaces are 130-150 meters. The slope angles of the inner crater edge are 35-40° while the slope angles of the outer crater edge are much smaller.

The bedrock of the crater is leptite of Lower Proterozoic, which also exposes sporadically on the crater ridges. The hillsides are mostly covered by completely weathered, saprolite, and diluvium layers with a depth of 0.5-6 meters. The surface of the basin bottom is covered by alluvial-diluvial gravel soil, but a narrow talat from the basin center to the crater outside in the northeast direction reveals that there are lacustrine sediments under the overburden shallow gravel soil.

This small-scaled basin is considered to be the first acknowledged site showing significant seismic basin effect inferred from earthquake damages in China. In Haicheng *M*7.3 earthquake on 4 February, 1975 which

happened about 60 kilometers far away, 39 sets of rural buildings near the center of the basin bottom collapsed and caused casualties, 23 buildings a little further from the basin center were severely or moderate damaged, and the other more than 60 buildings at the edge of the basin were slightly or not damaged. It was also reported that sand boiled along fissures around the basin center, which is regarded as typical liquefaction phenomena that appear under strong ground motions. Meanwhile, no severe or moderate damages were reported from the nearby villages outside of this crater comparatively.

The ambient tremor level in Xiuyan meteorite crater at midnight is extraordinary low as it is located in a secluded and quiet place far away from vibrative industrial facilities or heavy-duty traffic systems. So we chose it as a satisfactory in situ experiment site to verify the efficiency and reliability of Nakamura method in estimating the overburden soil layer structures of deep and soft alluvial sites.



1. 第四纪冲击物 Quaternary Period alluvium; 2. 河流水塘 River and pond; 3 放射状裂隙 Fractures; 4. 坑外裂隙 Fractures beyond crater; 5. 角砾岩块 Breccia block; 6. 地层产状 Stratum occurrence; 7. 撞击熔岩 Impact magma; 8. 铁陨石 Iron meteorite; 9. 坑边及震裂片理 Schistosity; 10. 震裂锥 Shatter cones; 11. 下元古界辽河群 Lower Proterozoic; 12 片理产状 Schistosity occurrence.

Fig. 1 – Geological map of Xiuyan meteorite crater [13] (adapted form Qin, *et al*., 2001)

3. Ambient tremor observations

Ambient tremor in Xiuyan meteorite crater was observed at midnight with Basalt, an accelerograph with a built-in triaxial force balance accelerometer produced by Kinemetrics. The observation points were shown in Fig. 2, and the H/V spectral ratios at some points along a profile line across the basin were shown in Fig. 3.

The H/V spectral ratios showed that in the whole basin, the predominant periods of H/V spectral ratios of all observation points were approximately identical to a unique value 0.72 Hz, but with different amplitudes. From the local areas centered at points 19, 20, and 44 to the foot of the crater, the peak values of H/V spectral ratios near 0.72 Hz attenuated from 4.63 to 1.0 gradually.

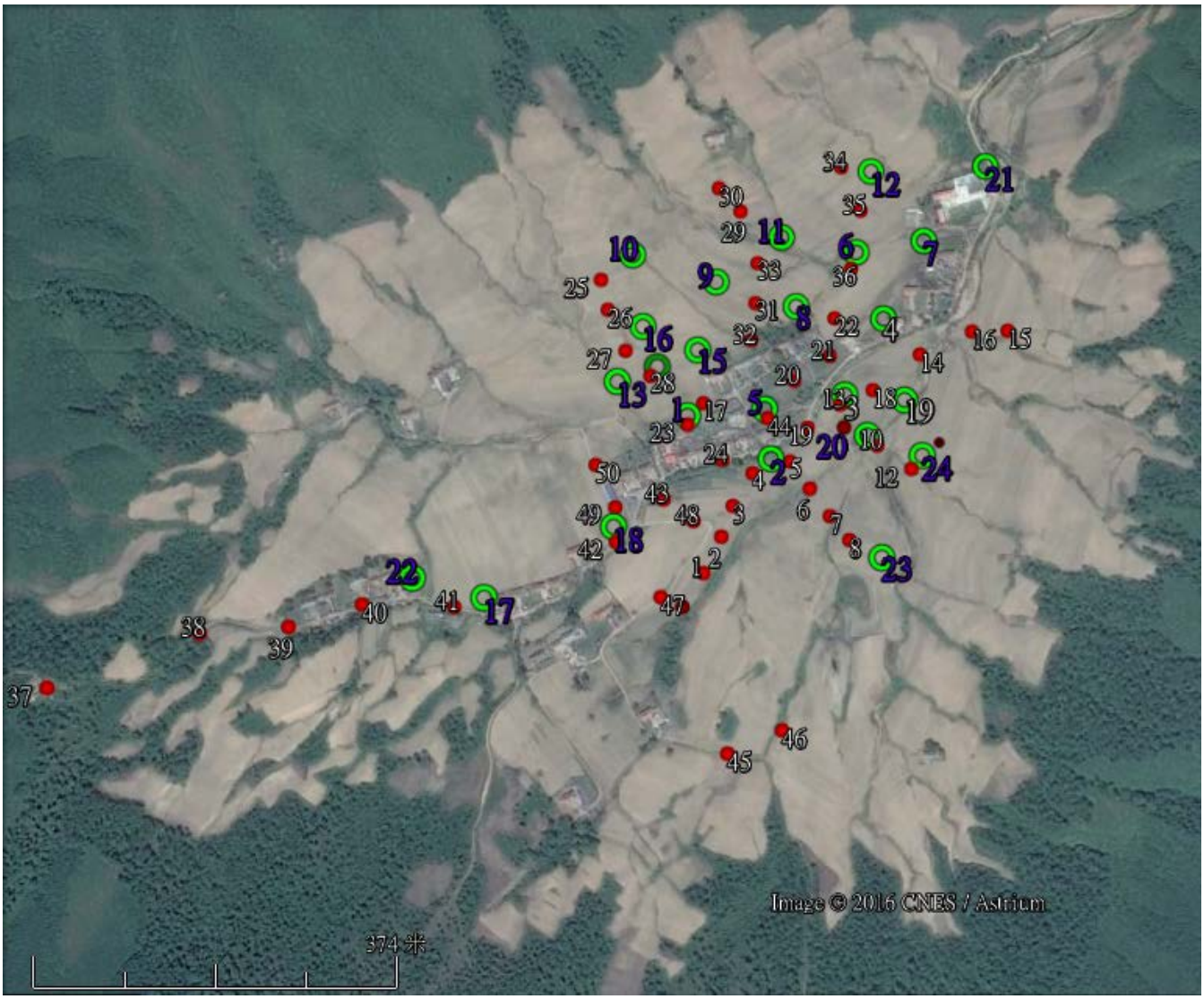


Fig. 2 – Distribution of ambient tremor observation showed in solid points (The hollow circles denote the geological drilling positions)

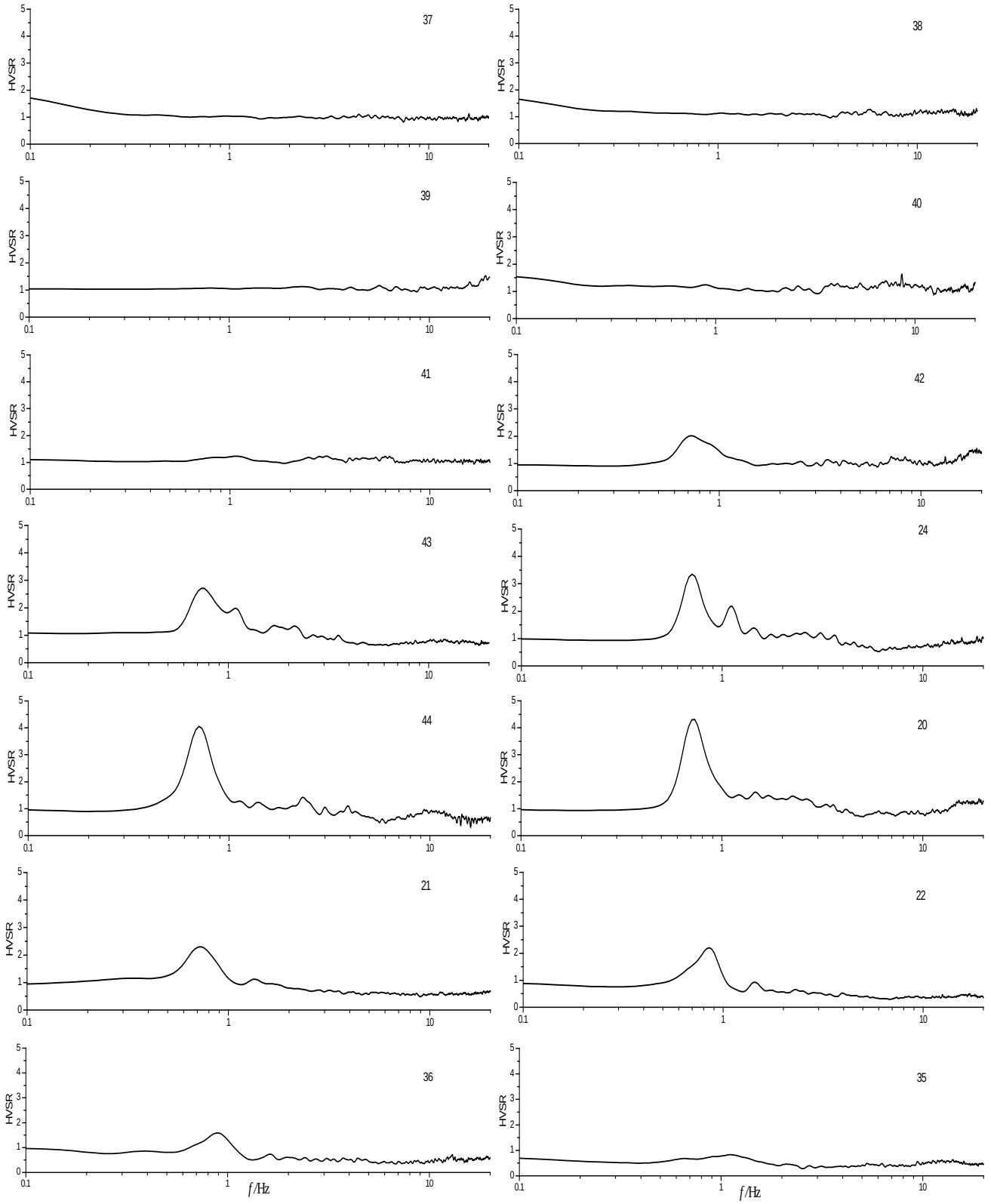


Fig. 3 – The H/V spectral ratios at points along a profile line across the basin

4. Geological drillings

In order to reveal the soil layer structures, 24 engineering geological holes (showed in hollow circles in Fig. 3) were drilled. The drilling results (Fig. 4) revealed that the ground surface is covered with alluvial-diluvial gravel layers constituted with a thin cultivated soil layer and a pebble layer of varied thickness. Beneath the alluvial-diluvial layers there are thick lacustrine sediment layers constituted with black, soft and clastic lacustrine deposits up to 100 meters deep. The gravel strata with a thickness of up to 50 meters were found between the lacustrine sediment layers and the bedrock, which were probably formed by landslides occurring soon after the meteorite impact. Gravel intercalary strata of small thickness were also found among the sediment layers at inconstant depths.

The shear velocity of the soil layers were also tested in two drilling holes, and the results showed that the shear velocity of lacustrine sediment increased with depth linearly from 120 m/s to 410 m/s.

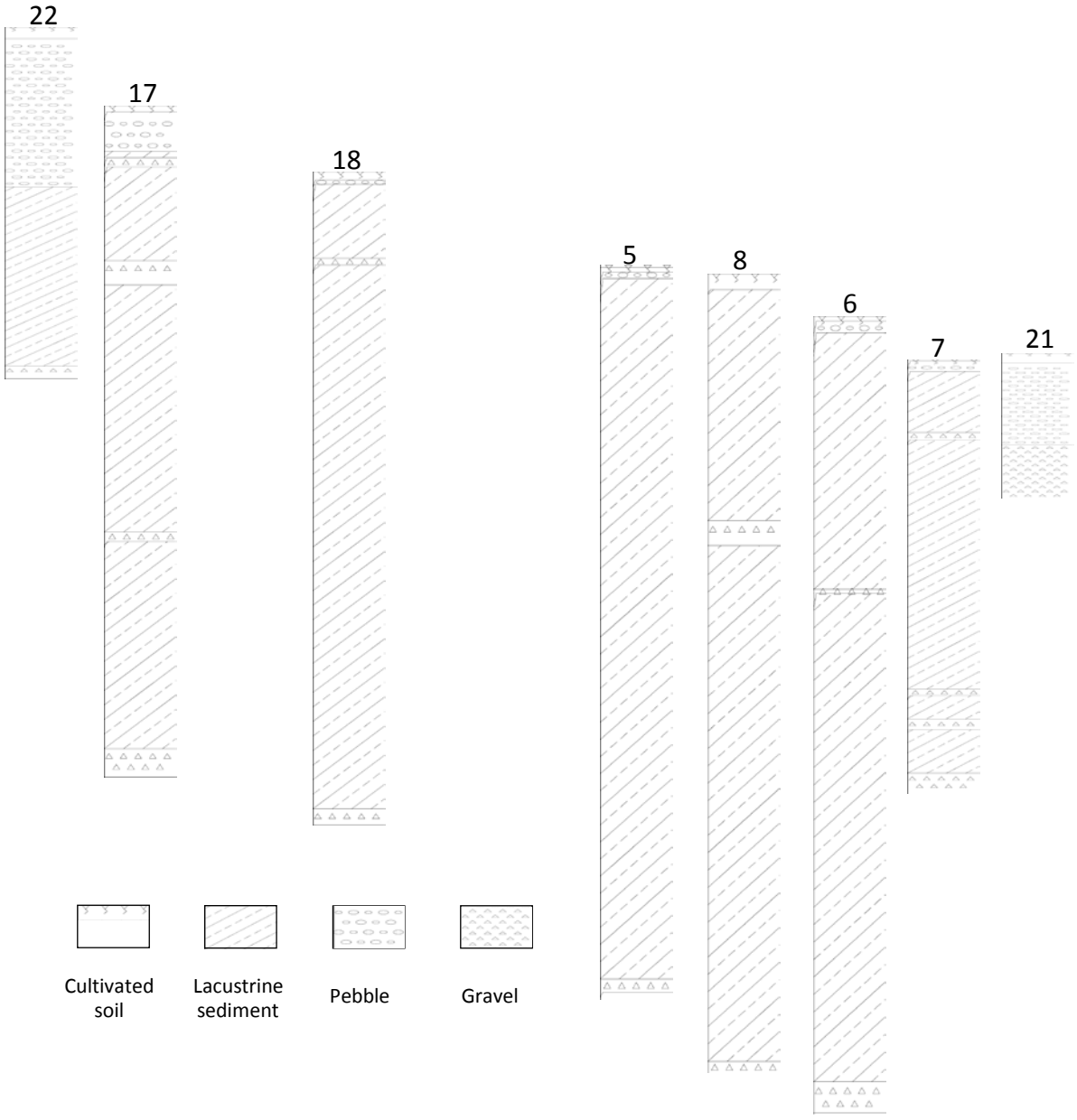


Fig. 4 – Drillhole columns along a profile line across the basin

5. Factors affecting H/V spectral ratios

The depth of the soft and deep lacustrine deposits at the observation point was always thought to be the greatest factor affecting the ambient tremor, as shown in Fig. 5. As the H/V spectral ratios attenuated with the distance from the observation point to the basin center, it was considered to be the other important factor affecting the ambient tremor, as shown in Fig. 6. The correlation coefficient between H/V spectral ratios at f=0.72Hz and the depth of lacustrine deposits was 0.446, and the correlation coefficient between H/V spectral ratios at f=0.72Hz and the distance to the basin center was 0.663, which indicated that the H/V spectral ratios depended on the distance to the basin center much more significantly than the depth of lacustrine deposits. The binary linear regression result with the least square method also indicated that H/V spectral ratios at f=0.72Hz were less dependant on the lacustrine deposit depth than the distance to the basin center, as in Eq. (1),

$$Ratio_{f=0.72} = 3.59 + 2.228D/C - 3.680R/C \pm 0.69 \quad (1)$$

where D denotes the depth of lacustrine deposits, and R denotes the distance from the observation point to the basin center, and C denotes the basin bottom radius and C =800 meters.

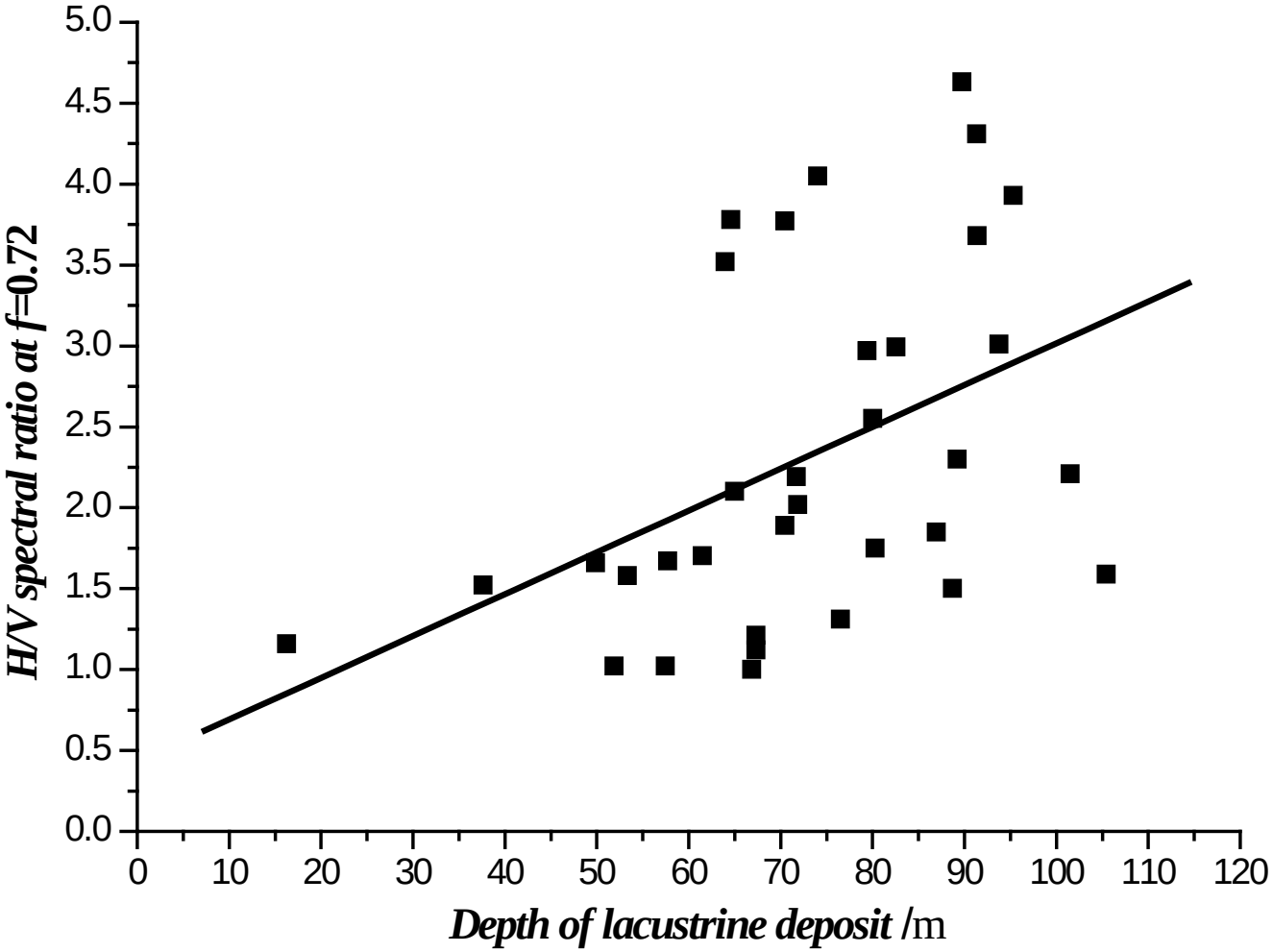


Fig. 5 – Ralationship between H/V spectral ratios at f=0.72Hz and the depth of lacustrine deposits at the observation point

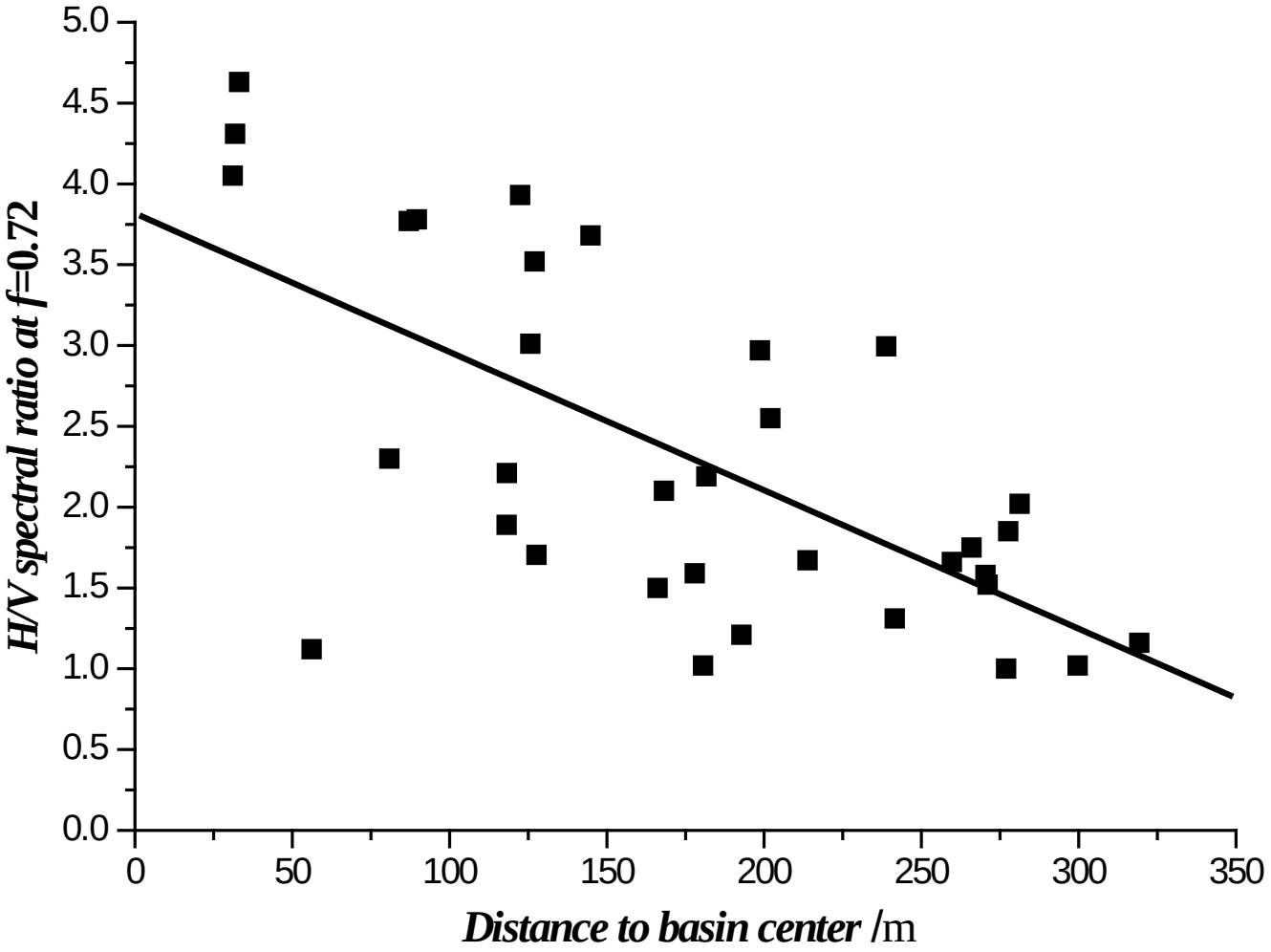


Fig. 6 – Ralationship between H/V spectral ratios at f=0.72Hz and the distance from the observation point to basin center

6. Summaries and Discussions

Focused on the Xiuyan meteorite crater in North-east China, the analysis of high density ambient tremor observations indicated that in the whole basin the predominant periods of H/V spectral ratios of all observation points were approximately identical to a unique value 0.72Hz, but the peak values of H/V spectral ratios at 0.72Hz attenuated from 4.63 in the basin center to 1.0 at the basin edge gradually. The correlation between H/V spectral ratios at 0.72Hz and distance from observation point to basin center was much stronger than the correlation between H/V spectral ratios at 0.72Hz and the overburden lacustrine deposit depth, which indicated that the three dimensional basin structures affected the wave propagation severely and this basin could not be treated as one dimension layered medium.

As the near-source environmental vibration caused by ground surface sources was sufficiently weak in Xiuyan meteorite crater, the observed ambient tremor was probably scattered from the overlying badrock propagating through the soft and deep lacustrine deposits, and this guaranteed a stable H/V spectral ratios dependant on the basin structure. Our observations in several other sites including Tonghai lacustrine sedimentary basin in Southwest China showed that the H/V spectral ratios were not sufficient reliable as there were strong vibration sources on the ground surface in sufficiently close distance.

Three dimensional model of the Xiuyan meteorite crater would be built based on the geological drilling data in the following days, and the frequency-dependent ratios of seismic amplification could be calculated by

numerical simulation. Comparisons between the simulated frequency-dependent amplification ratios and H/V spectral ratios of ambient tremor would verify the Nakamura method further more.

7. Acknowledgements

This research work was supported by Special Research Fund for Seismic Industry of China (201408020), National Program on Key Basic Research Project (973 Program 2011CB013601), and National Natural Science Foundation of China (51578514, 51208475). We owed lots of thanks to the anonymous reviewers for their elaborative and constructive comments on the submitted abstract.

8. Copyrights

9. References

[1] Langston, C.A. (1977) Corvallis, Oregon, Crustal and Uppermantle Receiver Structure from Teleseismic P and S waves. *Bulletin of the Seismological Society of America* **67**(3), 713–724.

[2] Langston, C.A. (1979) Structure under Mount Rainier, Washington, Inferred from Teleseismic Body Waves. *Journal of Geophysical Research* **84**(B9), 4749–4762.

[3] Nakamura, Y. (1989) A Method for Dynamic Characteristics Estimation of Subsurface Using Microtremor on the Ground Surface. *Quarterly Report of Railway Technical Institute (RTRI)* **30**, 25–33

[4] Lermo, J. and Chávez-García, F.J. (1993) Site Effects Evaluation Using Spectral Ratios with Only One Station. *Bulletin of the Seismological Society of America* **83**(5), 1574–1594.

[5] Parolai, S. and Richwalski, S.M. (2004) The Importance of Converted Waves in Comparing H/V and RSM Site Response Estimates. *Bulletin of the Seismological Society of America* **94**(1), 304–313.

[6] Castro, R.R., Pacor, F., Bindi, D., Franceschina, G. and Luzi, L. (2004) Site Response of Strong Motion Stations in the Umbria, Central Italy, Region. *Bulletin of the Seismological Society of America* **94**(2), 576–590.

[7] Barnaba, C. and Vuan, A. (2012) Local Site Response in an Alpine Valley from Recorded Earthquakes and Ambient Noise Analysis. *Bulletin of the Seismological Society of America* **102**(5), 2225–2231.

[8] Zandieh, A and Pezeshk, S. (2011) A Study of Horizontal-to-Vertical Component Spectral Ratio in the New Madrid Seismic Zone. *Bulletin of the Seismological Society of America* **101**(1), 287–296.

[9] Zhao, J.X., Irikura, K., Zhang, J., Fukushima, Y., Somerville, P.G., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T. and Ogawa, H. (2006) An Empirical Site-Classification Method For Strong-Motion Stations in Japan Using H/V Response Spectral Ratio. *Bulletin of the Seismological Society of America*, **96**(3), 914–925.

[10] Gallipoli, M.R. and Mucciarelli, M. (2009) Comparison of Site Classification from VS30, VS10, and HVSR in Italy. *Bulletin of the Seismological Society of America* **99**(1), 340–351.

[11] Pratt, T.L. and Brocher, T.M. (2006) Site Response and Attenuation in the Puget Lowland, Washington State. *Bulletin of the Seismological Society of America* **96**(2), 536–552.

[12] Oth, A., Bindi, D., Parolai, S. and Giacomo, D.D. (2011) Spectral Analysis of K-NET and KiK-net Data in Japan, Part II: On Attenuation Characteristics, Source Spectra, and Site Response of Borehole and Surface Stations. *Bulletin of the Seismological Society of America* **101**(2), 667–687.

[13] Qin, G.J., Lu, D.R., Ou, Q., Chu, X.L. (2001) The Discovery of PGE Anomaly and Platina from Luoquanli Impact Crater, China. *Earth Science Frontiers* **8**(2), 333-338. (In Chinese with English abstract)