MICROTREMOR EXPLORARIONS FOR SHALLOW S-WAVE VELOCITY PROFILES AT STRONG MOTION STATIONS IN TURKEY

H. Yamanaka(1), K. Chimoto(2), O. Ozel(3), O. Ozmen(4), S. Arslan(5), E. Yalcinkaya(6), M. Tun(7), E. Pekkan(8), S. Tsuno(9), O. Kaplan(10), H. Miyake(11), G. Tanircan(12), N. Takai(13), E. Ates(14), K. Tekin(15), A. Sezen(16), T. Ozturk(17), M. Alkan(18), M. Nurlu(19), S. Citak(20), O. Karagoz(21), K. Hatayama(22), M. Ohori(23), M. Mirzaoglu(24), O. Sipahi(25), M. Morita(26), S. Sasano(27), and Y. Fujita(28)

(1) Professor, Tokyo Institute of Technology,. yamanaka.h.aa@m.titech.ac.jp
(2) Assistant Professor, Tokyo Institute of Technology, chimoto.k.aa@m.titech.ac.jp
(3) Professor, Istanbul University, oguzozel@istanbul.edu.tr
(4) Geophysics Engineer, Ministry of Interior Disaster and Emergency Management Presidency, Turkey, otuna.ozmen@afad.gov.tr
(5) Research Assistant, Istanbul University, safaarslan@istanbul.edu.tr
(6) Professor, Istanbul University, eyalcin@istanbul.edu.tr
(7) Associate Professor, Eskişehir Technical University, mtun@eskisehir.edu.tr
(8) Assistant Professor, Eskişehir Technical University, epekkan@eskisehir.edu.tr
(9) Assistant Senior Researcher, Railway Technical Research Institute, tsuno.seiji.75@rtri.or.jp
(10) Researcher, Eskişehir Technical University, onur_kaplan@eskisehir.edu.tr
(11) Associate Professor, The University of Tokyo, hiroe@eri.u-tokyo.ac.jp
(12) Associate Professor, Kandilli Observatory and Earthquake Research Institute, Boğaziçi University, birgore@boun.edu.tr
(13) Associate Professor, Hokkaido University, tki@eng.hokudai.ac.jp
(14) Geophysics Engineer, Ministry of Interior Disaster and Emergency Management Presidency, Turkey, erkan.ates@afad.gov.tr
(15) Geophysis Engineer, Ministry of Interior Disaster and Emergency Management Presidency, Turkey, kudret.tekin@afad.gov.tr
(16) Geological Engineer, Ministry of Interior Disaster and Emergency Management Presidency, Turkey, ahmet.sezen@afad.gov.tr
(17) Geological Engineer, Ministry of Interior Disaster and Emergency Management Presidency, Turkey, taylan.ozturk@afad.gov.tr
(18) Geophysis Engineer, Ministry of Interior Disaster and Emergency Management Presidency, Turkey, akif.alkan@afad.gov.tr
(19) Head of Earthq. Depart.,Ministry of Interior Disaster and Emergency Management Presidency,Turkey murat.nurlu@afad.gov.tr
(20) Former Researcher of Japan Agency for Marine-Earth Science and Technology, seckincitak@gmail.com
(21) Research and Teaching Assistant, Canakkale Onsekiz Mart University, ozlemkaragoz@comu.edu.tr
(22) Senior Researcher, National Research Institute of Fire and Disaster, hatayama@fri.go.jp
(23) Associate Professor, University of Fukui, ohorim@u-fukui.ac.jp
(24) Engineer, Ministry of Interior Disaster and Emergency Management Presidency, Turkey, mete.mirzaoglu@afad.gov.tr
(25) Engineer, Ministry of Interior Disaster and Emergency Management Presidency, Turkey, ozcan.sipahi@afad.gov.tr
(26) Associate Professor, Yokohama National University, morita-masashi-rc@ynu.ac.jp
(27) Professor Emeritus, Tokyo Institute of Technology, ssasano532@icloud.com
(28) Associate Professor, Tokyo Institute of Technology, fujita.y.ab@m.titech.ac.jp

Abstract

We have conducted microtremor array explorations at strong motion stations in several regions of Turkey for an estimation of shallow S-wave profiles. In this study we selected strong motion stations in areas where previous surveys have not been done yet. Strong motion stations in Marmara Sea region, and provinces of Eskishehir, Hatay, Kahramanmaraş, Denizli, Aydin and Van were explored in this study. Some of the results of these explorations have already published in papers. We compiled all the results of our surveys for characterizing site conditions of the strong motion stations. Two temporary small-size arrays with seven sensors were deployed at each strong motion station to measure vertical microtremor records to retrieve Rayleigh-wave phase velocities in a frequency range of 1 to 30 Hz mainly with the SPAC method. The phase velocity at each station was inverted to a sallow 1D S-wave velocity profile whose bottom layer corresponds to an engineering bedrock with an S-wave velocity more than 500m/s. We applied a hybrid heuristic inversion method to find optimal thicknesses and S-wave velocities for a three-layer model at most of the stations. We then used the derived S-wave velocity models to identify the site classifications at the strong motion stations. 1D amplification factors were calculated using the S-wave velocity profiles to know site characteristics of the strong motion stations. We finally discussed the site conditions of the strong motion stations in Turkey by using our results and S-wave profiles obtained in the previous studies.

Keywords: S-wave velocity exploration, Microtremors, Site effects, Strong motion station, Turkey

1. Introduction

Turkey is located in one of the highest seismicity regions in the world. In particular seismicity along the two major fault zones, North Anatolian and East Anatolian fault zones are so high in the country. It is also known that the seismicity in the Aegean Sea region is also high with many small faults. Accordingly many strong ground motion observations have been conducted with national–wide network of strong motion instruments in turkey by Ministry of Interior Disaster and Emergency Management Presidency (AFAD). Strong motion data have provided important data to understand relation between strong shaking and building damage observed in past earthquakes (e.g., [1, 2]);. These strong motion data have been also used in estimation of effects of sources, sites and propagation paths (e.g., [3]). Since earthquake ground motion records are affected by local geological condition, an S-wave profile must be known at individual strong motion stations. Accordingly Akkar et al. [4] and Sandıkkaya et al. [5] have conducted surface-wave explorations for shallow S-wave profiles at strong motion stations in Turkey. Although these studies provided important information on shallow S-wave profiles at the stations, S-wave data at some of the strong motion stations are still unknown.

In this study we report the results of series of the microtremor explorations at strong motion stations in several provinces in Turkey in several projects to know shallow S-wave velocity profiles. The shallow S-wave profiles from the microtremor explorations are used to compare their average S-wave velocity with empirical amplification factors estimated by Yamanaka et al.[6].

2. Microtremor exploration

Microtremor exploration has conducted in eight provinces by some of the authors, and their results have already published in papers ([7, 8, 9]). We used these results in this paper to integrate them with the other explorations. They are located in Marmara region including Istanbul province, Central Anatolia, Aegean, Mediterranean, East Anatolia regions as shown in Fig.1. The total numbers of the exploration stations is 111 as shown in Table 1. The details of the location can be seen in Fig.2. The Marmara sea region (A in Fig.1) includes strong motion stations in Tekirdag, Kocaeli, Bursa and Canakkale provinces. We have conducted many explorations at the stations in Tekirdag and Kocaeli provinces. The results of the surveys has been published in [7, 8]. In the region B in Eskishehir, most of the surveyed stations are located in Eskishehir city area, and some of the results have been reported in [10]. The region C near the Aegean sea includes two provinces of Aydin and Denizli. Many strong motion stations are located in a narrow valley from the coast to the mountains in Denizli as shown in Fig.2. The region D has two provinces of Hatay and Kahramanmaras. Stations in Hatay province shows significant variation of surface geological condition from the coast of Mediterranean sea to eastern hills. On the other hand, most of the surveyed stations re located in a basin surrounded by mountains. The region E covers the major part of the Van province with a station in Bitlis province. It is noted that no explorations of an S-wave velocity profile have been done at many of the stations surveyed in this study.

We selected open space near a strong motion station for the surveys position to install seismometers as shown in Fig.2. It is noted that distances between a strong motion station and centers of the surveyed positions are less than 50meters. Array observations of vertical microtremors have been conducted at each strong motion station with two temporary arrays. Each array consists of 6 vertical sensors at edges of two triangles with a sensor at their center as show in Fig.4. The side-lengths of the triangle-shaped arrays are 1 to 20 meters at most of the stations. Records of vertical microtremors at each array were recorded in 10 to 30 minutes.

We analyzed the records using SPAC method [11] for Rayleigh wave phase velocity in a frequency range from 1 to 30 Hz at most of the stations. Dispersive part of the phase velocity was inverted to a 1D shallow S-wave profile from the surface down to the top of engineering bedrock with an S-wave velocity more than 400m/s using a hybrid heuristic method [12, 13].

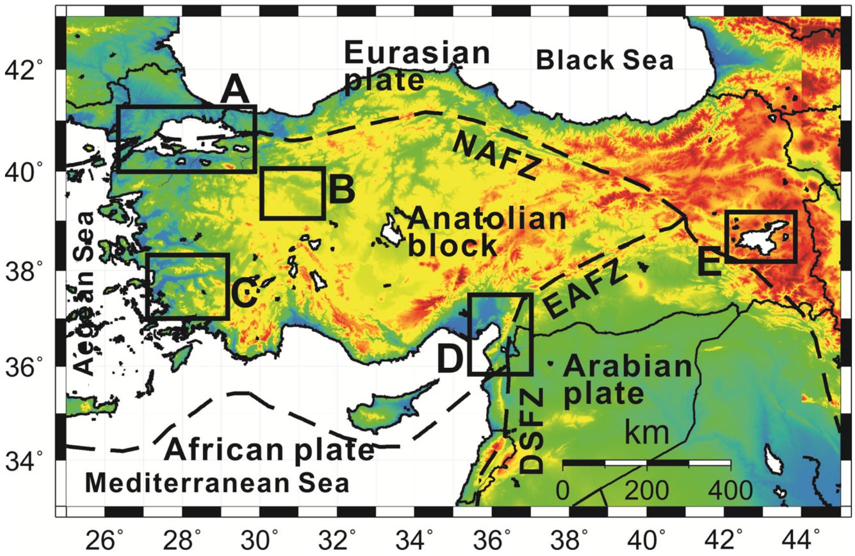

Fig.1 – Location of study areas. A:Marmara Sea, B:Central Anatolia, C: Aegean sea region, D: Mediterranean Sea, E: East Anatolia.

Table 1. List of microtremor array explorations.

Region	Provinces	Number of stations	Station codes
Marmara Sea	Terkidag	8	5901, 5902, 5903, 5904, 5906, 5907, 5908, 5910
	Kocaeli	14	4108, 4114, 4115, 4116, 4117, 4118, 4119, 4120, 4121, 4122, 4123, 4126, 4127, 4128
	Yalova	3	7704, 7706, 7707
	Bursa	6	1601, 1604, 1609, 1614, 1618, 1621
	Canakkale	6	1701, 1703, 1710, 1711, 1712, 1714
	Edirne	1	2201
	Balikedsir	1	1014
Central Anatolia	Eskishehir	11	2601, 2602, 2604, 2606, 2610, 2611, 2612, 2613, 2614, 2615, 2616
Aegean Sea	Denizli	15	2002, 2005, 2008, 2009, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020
	Aydin	12	905, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920
Mediterranean Sea	Kahramanmaraş	12	4612, 4616, 4617, 4618, 4619, 4620, 4621, 4622, 4623, 4624, 4625, 4626
	Hatay	16	3112, 3113, 3114, 3115, 3116, 3117, 3118, 3119, 3120, 3121, 3123, 3127, 3129, 3134, 3135, 3140
East Anatolia	Van	5	6501, 6506, 6509, 6510, 6512
	Bitlis	1	1302
Total	14	111	

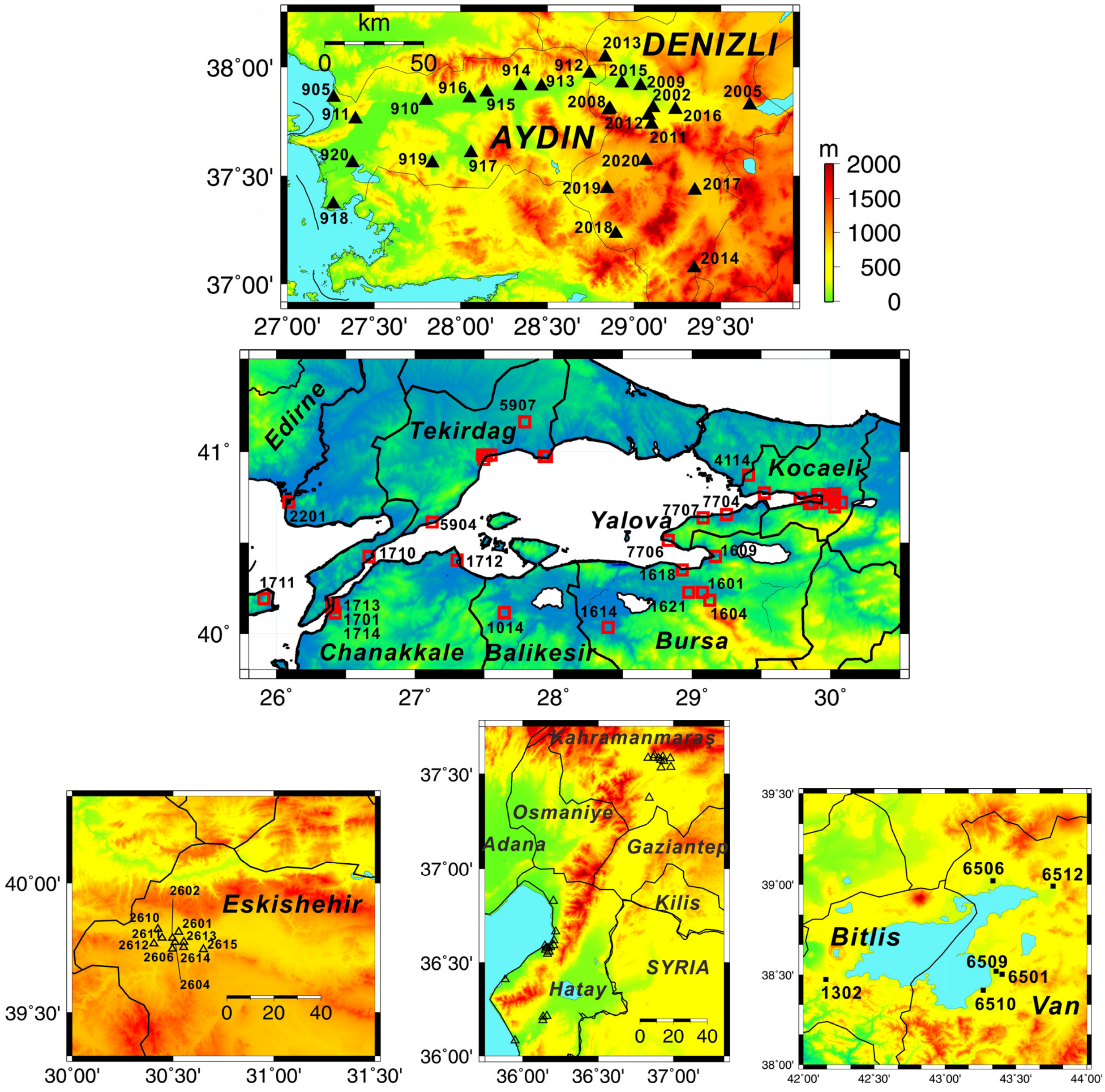

Fig. 2 – Map of study areas in Turkey with locations of strong motion stations and microtremor exploration.

Fig. 3 – Photos of microtremor exploration

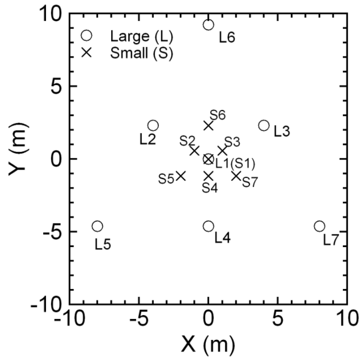

Fig. 4 – Example of array configuration in microtremor exploration

3. Results

The observed microtremors in a small array at station of 914 in Aydin province are shown in Fig.5. Coherent waves can be easily seen in the seven records. The spectra in the figure indicate large amplitudes at frequencies from 2 to 20 Hz. The SPAC coefficients derived from these records in arrays with different sizes are shown in Fig.5, too. As expected from the spectral amplitudes, the SPAC coefficients reduce their amplitudes at frequencies lower than 2Hz.

We estimated Rayleigh wave phase velocity from these SPAC coefficients at each station. Examples of the observed phase velocities are shown in Fig.6. The phase velocity at 1609 in Gemlik shows low values at frequencies higher than 4Hz. Similar low phase velocity can be found at 1601 in the city center of Bursa. The phase velocities at 1621 and 1604 are different from that of 1601 in spite of close distances from 1601 suggesting significant variation of local geological condition in the city. The phase velocities at three stations of 1713, 1701, and 1714 in central part of Canakkale city exhibit very different features with low values at 1701. Most of the stations in Aydin have similar phase velocities except for 914 with low values and 912 with high values. The phase velocities at 6501 and 6509 in the center of Van city are almost same at frequencies higher than 5 Hz. At 6510 located in the south of the city center are much higher than those of the city center.

S-wave velocity profiles derived from the inversions of some of the phase velocities shown in Fig.6 are displayed in Fig.7. The S-wave profile at 1601 has thick and low-velocity soil layers over the engineering bedrock of 500 m/s. The thickness is thin at the other two stations of 1604 and 1621. The S-wave profile at 1701 has deep depth to the engineering bedrock, while the other two stations have thin layers with thicknesses less than 10 meters over the engineering bedrock. Three stations in Aydin province are similar except for the bottom velocity at 912, because of the high phase velocity. The two stations of 6501 and 6509 in Canakkale have similar S-wave profiles as expected with the phase velocities.

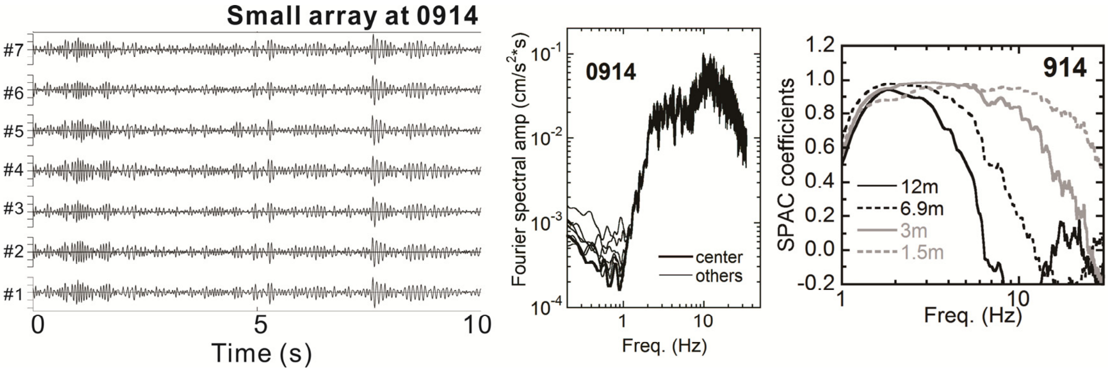

Fig. 5 – Examples of results of SPAC analysis of microtremor array data.

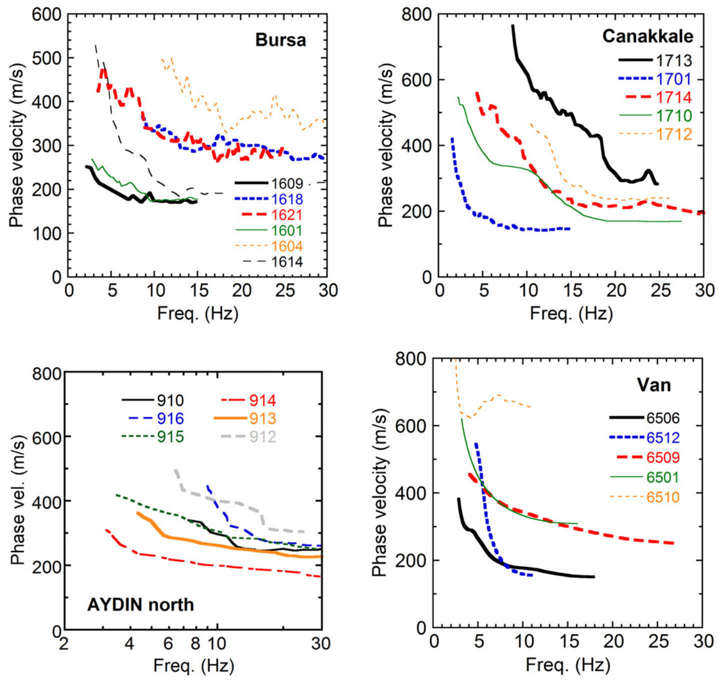

Fig.6 – Phase velocities observed at sites in Bursa, Canakkale, Aydin and Van provinces.

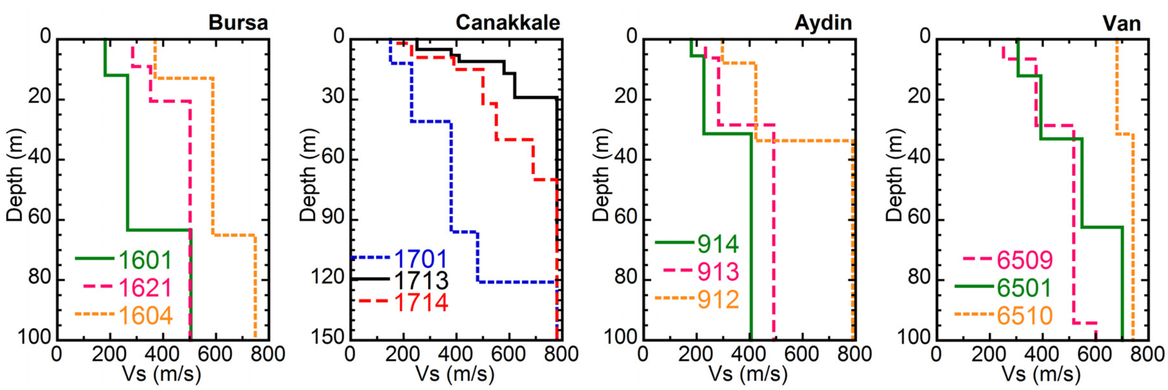

Fig. 7 – Shear-wave velocity profiles derived from phase velocities in Fig.6.

4. Discussion

We selected our strong motion stations where no explorations have been conducted yet. However, S-wave velocity profiles are available at some of the stations in the previous researches ([4, 5]) as explained above. S-wave profiles were estimated from surface-wave explorations along a surveying line of 100 meters in the previous studies. We compared our S-wave profiles with those from the previous researches. Fig.8 compares S-wave profiles at some of the stations. The S-wave velocity distributions in the top 20 meters are similar to each other as can be seen in the figure. Since average S-wave velocity in the top 30 meters from the surface (Vs30 in the following) is often used as a proxy to evaluate sit amplification, we compare Vs30s from this study and the previous studies. Fig.9 shows the comparison between the Vs30s. They are similar to each other except for a few data.

Yamanaka et al. [6] estimated site amplification factors at the strong motion stations from weak ground motion records using a spectral separation analysis. Their estimated amplification was interpreted as the effects of the shallow and deep soil layers over the basement with an S-wave velocity of 2.2 km/s as similar to [14]. Their amplification factors are compared with the Vs30s from our study as shown in Fig.10 at 4 different frequency ranges. The amplification factors at frequencies of 0.5 to 1.3 Hz and 1.3 to 3.2 Hz are correlated with the Vs30s derived in this study, while the amplification factors at frequencies higher than 3.2 Hz are not well related with the Vs30s. These figures also contain similar plots using the Vs30s from the previous surface-wave explorations by red triangles. They have almost the similar relationships with those from our explorations.

5. Conclusions

We have conducted microtremor array explorations at 111 strong motion stations in Marmara Sea region, and provinces of Eskishehir, Hatay, Kahramanmaraş, Denizli, Aydin and Van in Turkey for shallow S-wave profiles. Rayleigh-wave phase velocities at frequency range from 2 to 30 Hz were derived from array records of vertical microtremors. An S-wave velocity profile down to the engineering bedrock with S-wave velocities more than 500 m/s was estimated from the phase velocity at each station. The S-wave profiles were compared with results of previous surface-wave explorations. They are similar to each other to the depths of 20 meters. However we found similarity between the Vs30s from our study and the surface-wave exploration, because top 20 meters are responsible for the average velocity. We also examined relationships between Vs30s and site amplification factors from earthquake records. It was found that the amplification factors at frequencies less than 3Hz are well correlated with the Vs30s.

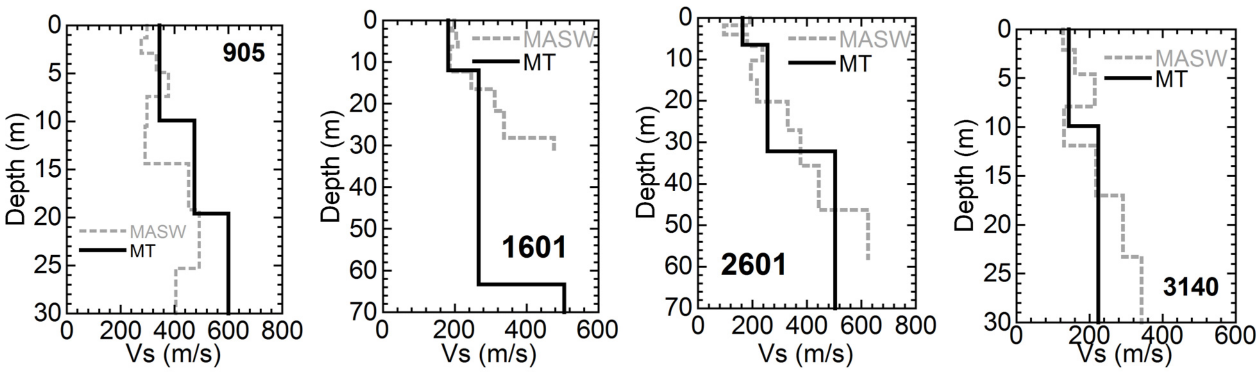

Fig. 8 – Comparison of Vs profiles between this study and MASW.

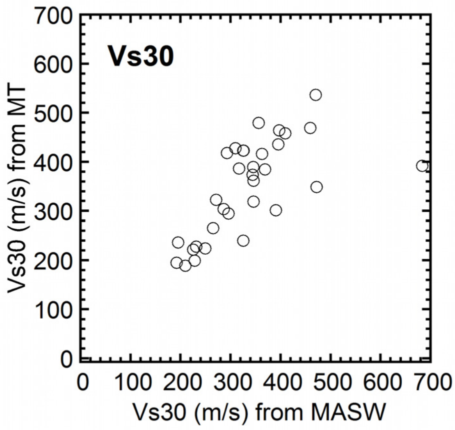

Fig. 9 – Comparison of Vs30s from microtremor explorations in this study (MT) and surface wave explorations compiled by AFAD (MASW).

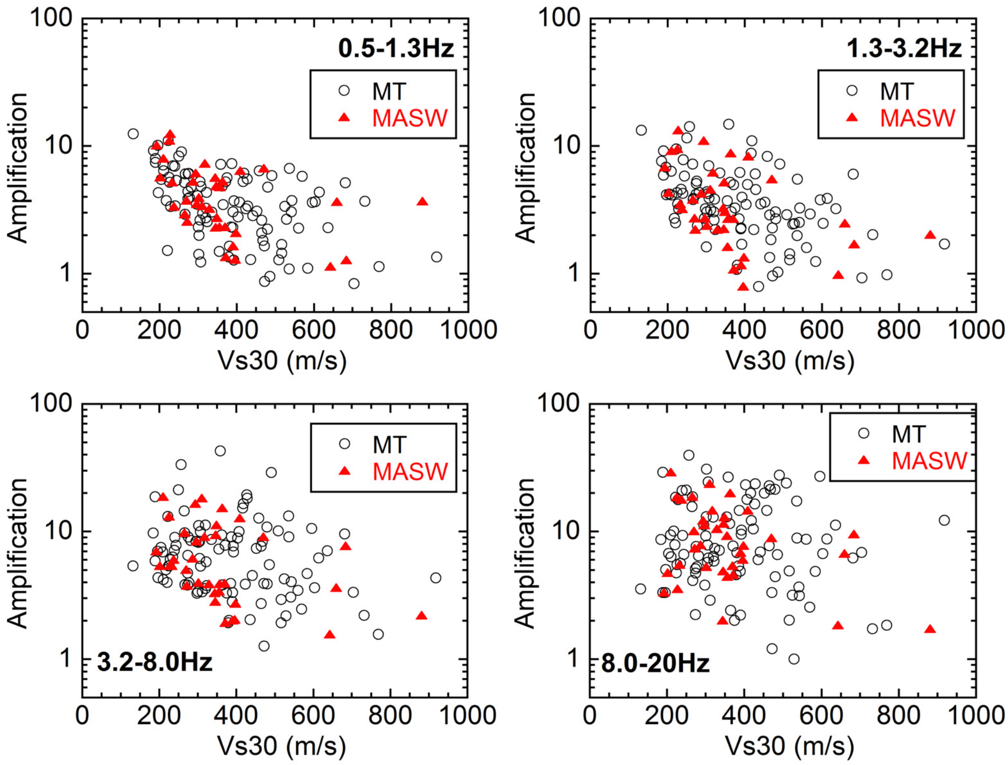

Fig. 10 – Comparison between Vs30s in this study and amplification factors in previous study [6].

References

[1] Bakir, S. B., H. Sucuoğlu, T. Yilmaz (2002): An Overview of Local Site Effects and the Associated Building Damage in Adapazari during the 17 August 1999 Izmit Earthquake, *Bull. Seism. Soc. Am.*, **92**(1), 509-526.

[2] Durukal, E., M. Erdik, J. Avci, Ö. Yüzügüllü, Y. Alpay, B. Avar, C. Zülfikar, T. Biro, A. Mert (1998): Analysis of the strong motion data of the 1995 Dinar, Turkey earthquake, *Soil Dynamics and Earthquake Engineering*, **17**, 557-578.

[3] Özel, N.M., T. Sasatani, O. Özel (2004): Strong ground motion during the largest aftershock (Mw=5.8) of the 1999 Izmit earthquake, Turkey, *Tectonophysics*, **391**, 347-355.

[4] Akkar, S., Çağnan Z., Yenier E., Erdoğan Ö., Sandıkkaya A., and Gülkan P. (2010). The recently compiled Turkish strong-motion database: preliminary investigation for seismological parameters: *J. Seismology*, **14**, 457–479.

[5] Sandıkkaya M.A., Yılmaz M.T., Bakır B.S., and Yılmaz Ö. (2010): Site classification of Turkish national strong-motion stations, *J. Seismology*, **14**, 543–563.

[6] Yamanaka, H., Ö. T. Özmen, U. Çeken, M. A. Alkan (2017): Estimation of site amplification using ground motion records at strong motion stations in Turkey, Joint Scientific Assembly of the International Association of Geodesy (IAG) and International Association of Seismology and Physics of the Earth's Interior (IASPEI), S07-1-03.

[7] Karagöz O., Chimoto K. , Citak S., Özel A.O., Yamanaka H., and Hatayama K. (2015): Estimation of shallow S-wave velocity structure and site response characteristicsby microtrmor array measurements in Tekirdag Region, *Earth, Planets and Space*, **67**(1), 176.

[8] Özmen, Ö. T., Yamanaka, H., Zanieh, H. E., and Alkan, M. A. (2017): Estimation of site effects using strong motion data of BYTNet array in Turkey, *J. Seismology*, **21**(1), 137-154

[9] Ö.T.Özmen, H. Yamanaka, M. A. Alkan, U. Çeken, T. Öztürk, A. Sezen (2016): Microtremor array measurements for shallow S-wave profiles at strong-motion stations in Hatay and Kahramanmaras provinces, southern Turkey, *Bull. Seim Soc. Am.*, **107**, 445-455.

[10] Yamanaka, H., Ö.T. Özmen, K. Chimoto, M.A. Alkan, M. Tün, E. Pekkan, O. Özel (2018):Exploration of S-wave velocity profiles at strong motion stations in Eskisehir, Turkey, using microtremor phase velocity and S-wave amplification, *J. Seismology*, **22**, 1127-1137.

[11] Okada, H. (2003): The microtremor survey method, Geophysical Monograph Series No. 12, Society of Exploration Geophysicists.

[12] Yamanaka, H. (2007): Inversion of surface-wave phase velocity using hybrid heuristic search method, *Butsuri Tansa (Geophysical exploration)*, **60**, 265–275, (In Japanese with English abstract).

[13] Takekoshi, M. and H. Yamanaka (2009): Waveform inversion of shallow seismic refraction data using hybrid heuristic search method, *Exploration Geophysics*, **40**, 99–104.

[14] Özmen, Ö. T., H. Yamanaka, K. Chimoto, U. Çeken, M. A. Alkan, K. Tekin, and E. Ateş, (2016): Microtremor exploration for shallow S-wave velocity profiles at stations in local strong motion network in Bursa, Yalova, and Kocaeli in northwestern Turkey, *Exploration Geophysics*, **48**, 255-263.

