Determination of the Site Characterization Properties in Eastern Segment of the North Anatolian Fault Zone in Turkey based on the MMSPAC Method

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SUMMARY

Erzincan (a small city in Eastern Turkey) is located in the conjunction of three active faults: North Anatolian, North East Anatolian and East Anatolian Fault Zones. Erzincan city centre is in a pull-apart basin underlain by soft sediments which significantly amplify the ground motions. Combination of the tectonic and geological settings of the region have led to destructive earthquakes such as the 27 December 1939 (Ms=8.0) and the 13 March 1992 (Mw=6.6) events resulting in extensive losses. In this study, in order to perform site characterization in the region, we employ the microtremor survey technique at different sites near the Erzincan city centre. The use of the microtremor method is a well-known passive seismic tool to estimate the properties of sedimentary overburden. A total of 9 sites were selected to be aligned in the north-south and east-west directions. At each site, we performed surface wave dispersion curve analysis using the Multi-Mode Spatial Autocorrelation (MMSPAC) technique on either single or nested arrays. The MMSPAC method uses primarily the fundamental modes for estimating S-wave velocity profile up to bedrock levels, and can also identify higher modes of the seismic energy if present. We present our results in the form of one dimensional velocity structure as well as fundamental frequencies obtained from the microtremor HVSR spectra computed at selected sites.

Keywords: MMSPAC, Erzincan-Turkey, Site Characterization,

INTRODUCTION

It is well-known that structural damage caused by the earthquakes depends not only on the magnitude and wave propagation properties but also on the soil properties. Soft soil layers on top of hard bedrock can greatly amplify the ground motions yielding severe structural damage. This is in particular the case when the resonance frequency of the soil and building are close to each other. As a result, site characterization is critical for purposes of disaster mitigation.

Erzincan is one of the most hazardous regions in the entire world located at a triple junction of the North Anatolian Fault, Northeast Anatolian Fault and Ovacik Faults (Barka, 1993). In addition to the several reported destructive earthquakes in the historic era (Ambraseys, 1995), two major earthquakes occurred in the instrumental period: the 1939 Ms=8.0 and 1992 Mw=6.6 Erzincan events (**Figure 1**). The Erzincan basin is one of the many basins on the NAFZ generated due to splay faults. It is a typical pull-apart basin where the soft soil deposits in addition to basin effects is believed to be responsible for the high-amplitudes recorded during the earthquakes. Thus, it is essential to investigate the velocity structure in the region. In this study, we present the initial results of a microtremor survey study performed at three of the nine surveyed sites in Erzincan (**Figure 1**2).

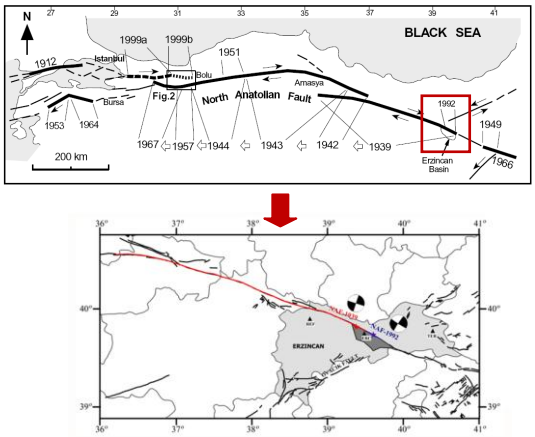

Figure 1: Location of Erzincan Basin on North Anatolian Fault Zone. (Top Panel: Major earthquakes along the NAFZ in the last century, the red rectangle indicate the Erzincan Basin. Bottom Panel: Major events that occurred in the Erzincan Basin) (Top figure is adapted from Akyuz et. al., 2002, bottom panel is adapted from Askan et al., 2013)

The microtremor survey method we use here employs Rayleigh-wave velocity dispersion in order to obtain a shear-wave velocity profile (SWVP) of the soil. We perform the multimode spatial auto-correlation method (MMSPAC) described by Asten (2006a) as an improvement of the SPAC method originally used in Aki (1957). In addition to MMSPAC analyses, microtremor Horizontal to Vertical Spectral Ratio (HVSR) is computed at the sites.

In this study, we present our results at a number of selected sites for which array geometries are shown in Figure 3. At these sites, multiple triangle array measurements are implemented in order to perform multiple (nested) SPAC

analyses, which facilitate use of wider bands of frequencies and hence provide more accurate SWVP's. Site 1, Site 2 and Site 3 are all located on a northern trend as shown in Figure 2. At Site 1, three nested four-station triangular arrays with side-lengths 30m, 100m and 300m were employed where at Site 2 and Site 3, two nested four-station triangular arrays with side-lengths 30m and 100m were used. In this paper, results from large arrays are shown for Site 1(300m), Site 2(100m) and Site 3(100m).

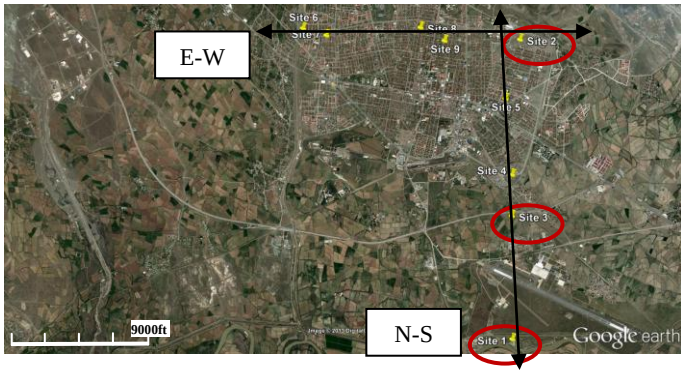

Figure 2: Location of the 9 selected sites used in this study (Red circles indicate the sites that results represent in this extended abstract)

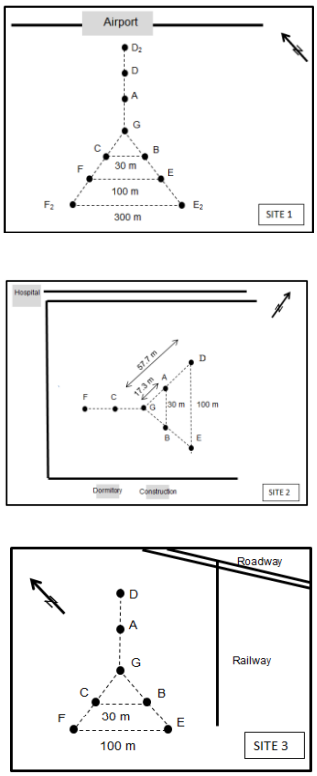

Figure 3: Array geometries for Site 1, Site 2 and Site 3, respectively

METHOD AND RESULTS

The MMSPAC method as outlined in Asten (2006a) is followed in this implementation for Erzincan sites. The method is based on fitting the measured SPAC spectra directly to model SPAC spectra via:

$$C_m(f) = J_0[2\pi fr / C_p(f)]$$

where $C_m(f)$ is the spatially averaged coherency, f is frequency, r is the station separation and $C_p(f)$ is the modelled phase velocity for layered earth structure.

These implementations are termed the multimode SPAC method because while the fitting is performed using the modeled fundamental Rayleigh mode (R0), the simultaneous plotting of modeled SPAC spectra for the first and second higher modes (R1, R2) allows identification of frequency bands where higher-mode energy is present (Asten 2006b).

In the field, we use a minimum of 1 hour records for arrays. The sampling rate was 100 Hz. In most of the sites, we used a centered equilateral triangular array of four stations that allowed measurement of SPAC at two station separations, being the radius *r1* and the side length *r2*, and where from geometry $r2 = r1 \cdot \sqrt{3}$. Recording instruments were Guralp CMG6TD seismometers containing internal data recorders, GPS sensors and a crystal clock synchronizable with a GPS signal.

Figures 4,7,10 display the observed and modelled coherency spectra at the sites whereas Figures 5,8,11 show the observed HVSR and modelled ellipticity curves at the same sites. For coherency curves (Figures 4,7 and 10), the black curve indicates the real part of MMSPAC field data whereas thin red curve is an imaginary part of the SPAC field data. In addition, modelled SPAC curves for modes fundamental, first and second (R0, R1, R2) are shown with thick red, yellow and green curves in the coherency curve figures, respectively.

For ellipticity curves (Figures 5, 8 and 11), the black curve indicates the observed HVSR whereas red, yellow and green curves demonstrate the modelled HVSR for fundamental, first and second modes, respectively.

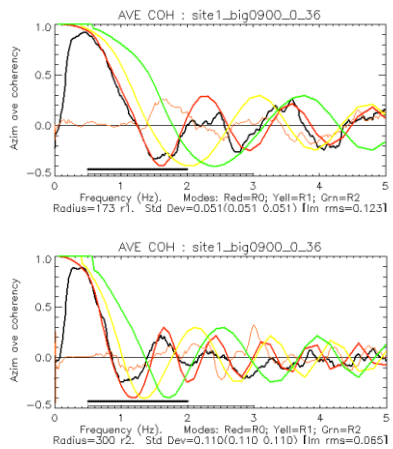

Figure 4: SPAC Spectra at Site 1 (Top Panel: SPAC Spectra for r1, Bottom Panel: SPAC Spectra for r1)

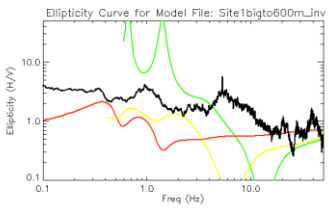

Figure 5: Ellipticity curve at Site 1

The standard deviation of the fit of observed and modelled coherency curves is 0.051 for r1 and 0.110 for r2. The useful low-frequency limit of the SPAC data at Site 1 is approximately 0.5 Hz whereas the useful high-frequency limit is 5 Hz (Figure 4) although only frequencies below 2 Hz are used here.

In Figure 5, there are clear peaks at 1 and 8 Hz. The HVSR peak at 1 Hz identifies Vs contrast at depth 108m and peak at 8 Hz identifies a Vs contrast at depth 10m.

After interpretation of the microtremor data, depth of the shear-wave velocity (Vs) profile at Site 1 is estimated to be about 480 m from spatial autocorrelation (SPAC) data alone. When considering both MMSPAC and HVSR methods, Vs30 is 264m/s, Vs100 is 331 m/s and Vs300 is 493m/s (Figure 6).

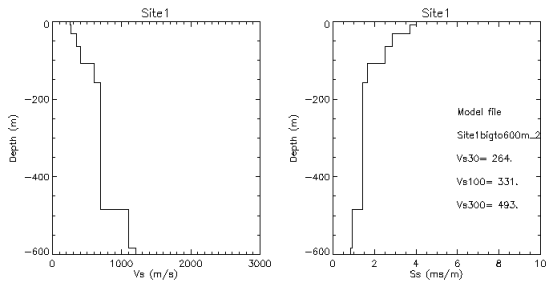

Figure 6: S wave velocity and slowness profile at Site 1

The coherency curve, ellipticity curve and S-wave velocity profile of the Site 2 is demonstrated in Figures 7, 8 and 9, respectively. At Site 2, there is a close fit between observed coherency curve and model coherency curve where the standard deviation is 0.72 for r1 and 0.69 for r2.The useful low-frequency limit of the SPAC data at Site 2 is approximately 0.1 Hz whereas the useful high-frequency limit is 10 Hz (Figure 7). Where the seismometers are buried, useful SPAC data is typically obtained down to frequencies of order 0.1 Hz (see for example Asten, 2005; Stephenson et al 2009, and Schramm et al, 2012).
In Figure 8, there is a clear peak at 1 Hz, which is shown on both observed and model HVSR curves. The HVSR peak at 1 Hz identifies Vs contrast at depth 145m.
At Site2, Vs30 is 569 m/s, Vs100 is 712 m/s and Vs300 is 1006 m/s (Figure 9).

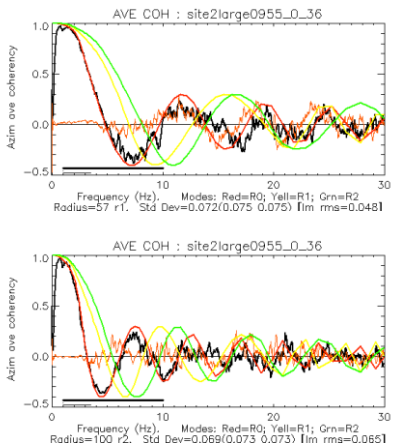

Figure 7: SPAC Spectra at Site 2 (Top Panel: SPAC Spectra for r1, Bottom Panel: SPAC Spectra for r1)

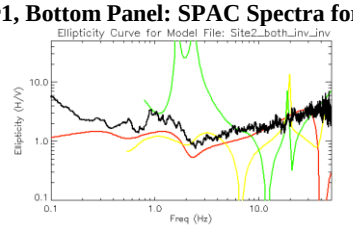

Figure 8: Ellipticity curve at Site 2

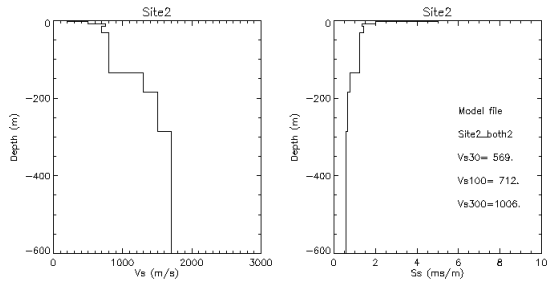

Figure 9: S wave velocity and slowness profile at Site 2

For the third selected case, Site 3, the standard deviation is 0.205 for r1 and 0.111 for r2. The useful low-frequency limit of the SPAC data at Site 1 is approximately 0.1 Hz whereas the useful high-frequency limit is 10 Hz (Figure 10).

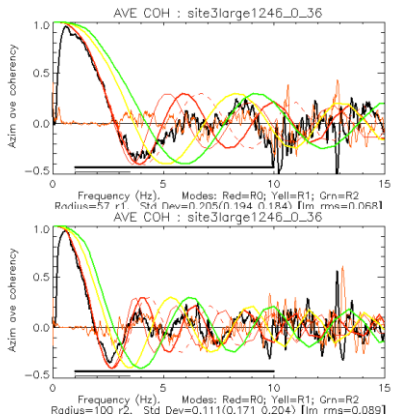

Figure 10: SPAC Spectra at Site 3 (Top Panel: SPAC Spectra for r1, Bottom Panel: SPAC Spectra for r1)

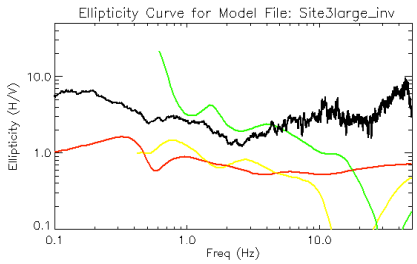

Figure 11: Ellipticity curve at Site 3

The result from HVSR analysis indicates that there is a weak peak at 0.9 Hz which appears to be associated with a Vs contrast at depth 160m (Figure 11).

Depth of the shear-wave velocity (Vs) profile at Site 3 is about 470 m from spatial autocorrelation (SPAC) data alone. In addition, Vs30 is 298m/s, Vs100 is 400 m/s and Vs300 is 543m/s (Figure 12).

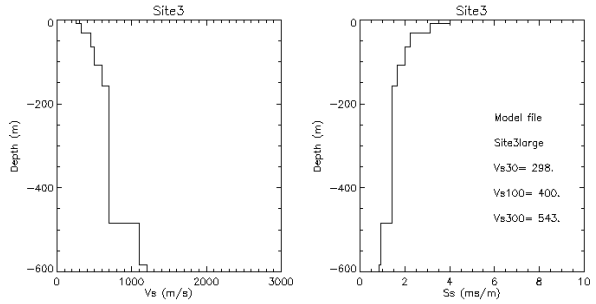

Figure 12: S wave velocity and slowness profile at Site 3

CONCLUSIONS

In this study, for site characterization purposes, we employed multi-mode spatial autocorrelation method in Erzincan basin (Turkey) at nine different sites of which three are reported here. The basin shows varying properties in the NS direction with the softest and thickest sediments in the south, as summarized in Table 1.

Table 1. Average velocities for upper 30, 100 and inferred from MMSPAC and HVSR interpretation 300 m, at three sites shown in Figure 2.

SITE	Vs30	Vs100	Vs300
	(m/s)	(m/s)	(m/s)
(north - mountains)			
2	569	712	1006
3	298	400	543
1	264	331	493
(south - river)			

Use of MMSPAC method allows the S-wave velocity profiles to include the high-frequency energy which otherwise would be missed. Use of a small array with even 4 stations is helpful to obtain a reliable velocity model at each site of interest. MMSPAC has the advantage of simultaneously resolving the shallow, middle and deeper parts of the soil structure. Use of MMSPAC method together with HVSR makes it possible to obtain velocity profiles down to deeper structure. This is important in particular in the urban areas where the invasive methods cannot be easily utilized.

In the longer run, the results from such non-invasive techniques conducted in seismically active urban regions can also be used in the estimation of site-specific seismic hazard maps; identification of structural damage patterns due to local soil conditions; microzonation and ground motion simulations. Most importantly, for regions without well-resolved wave velocity models, these studies constitute important initial basic steps to form two or three-dimensional velocity models.

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REFERENCES

Aki, K. ,1957, Space and time spectra of stationary stochastic waves, with special reference to microtremors. Bull, Earthq. Res. Inst, Vol 35, pp 415-456.

Akyüz, H. S., Hartleb, R., Barka, A., Altunel, E., Sunal, G., Meyer, B., and Armijo., R., 2002, Surface rupture and slip distribution of the 12 November 1999 Düzce earthquake (M 7.1), North Anatolian fault, Bolu, Turkey, Bull. Seismol. Soc. Am. 92, 61–66.

Ambraseys, N.N. and Finkel, C.F.,1995, The Seismicity of Turkey and Adjacent Areas: A Historical Review, 1500–1800. Muhittin Salih Eren, İstanbul, Turkey.

Askan, A., Sisman F.N., Ugurhan, B., 2013, Stochastic Strong Ground Motion Simulations in Sparsely-Monitored Regions: A Validation and Sensitivity Analysis on Eastern North Anatolian Fault Zone. submitted to Soil Dynamic Earthquake Engineering.

Asten, M.W., W.R. Stephenson and P. Davenport, 2005, Shear-wave velocity profile for Holocene sediments measured from microtremor array studies, SCPT, and seismic refraction, J. Environ. Eng. Geophys. 10, 235-242.

Asten, M.W., 2006a, On bias and noise in passive seismic data from finite circular array data processed using SPAC methods, Geophysics,71 (6), V153-V162.

Asten, M.W., 2006b, Site shear velocity profile interpretation from microtremor array data by direct fitting of SPAC curves: in P-Y Bard, E. Chaljub, C. Cornou, F. Cotton and P. Gueguen, eds, Proceedings of the Third International Symposium on the Effects of Surface Geology on Seismic Motion (ESG2006), Grenoble, France, 30 August - 1 September 2006, vol. 2, LCPC, Paris, 1069-82.

Barka, A. A. and Eyidoğan, H.,1993, The Erzincan earthquake of 13 March 1992 in eastern Turkey, Terra Nova, 5, 190-194.

Stephenson, W., Hartzell S., Frankel, A. Asten, M.W., Carver, D and Kim, W., 2009, Site characterization for urban seismic hazards in lower Manhattan, New York City, from microtremor array analysis, Geophys. Res. Lett. 36, L03301, doi 10.1029/2008GL036444.

Schramm, K., Patton, H., Abbott, R., Bilek, S., Pancha, A., Asten., M.W.,2012, Broadband Rayleigh-Wave Dispersion Curve and Shear Wave Velocity Structure for Yucca Flat, Nevada, Bull. Seism. Soc. Am. 102, 1361-1372, doi: 10.1785/0120110296