Preliminary Seismic Micro-Zoning Study for Damascus City by Using Microtremors

Hussam Eldein Zaineh
Tokyo Institute of Technology (TITech), Tokyo, Japan

Ahlam Khalil, Dania Nkshbndy, Mohamad Daoud, Nashaat Semman, Momena Dakkak, Rawaa Yasmeneh, Reem Deeb, Dareen Elsafady & Fatemah Mahmood
National Earthquake Center (NEC), Damascus, Syria

ABSTRACT:
The influence of local geology and soil conditions on the intensity of ground shaking and earthquake damage has been known for many years. Therefore, a significant part of damage observed in destructive earthquakes around the world is associated with seismic wave amplification due to local site effects. The main objective of this study is to evaluate the local site effects in Damascus city for the aim of building seismic design. As a first step in this study, single site Microtremor measurements were carried out for 300 sites in Damascus city. Horizontal to Vertical (H/V) spectral ratios were calculated and preliminary results show big variations in dynamic site characteristics (fundamental period and amplification factor) from area to area in Damascus city. Generally, the values of predominant period are increased from west to east of Damascus along the Quaternary deposits and the longest values were mainly observed in Eastern Ghouta Region. A high level of peak amplitude of H/V was observed in the locations of Quaternary regions. While flat H/V spectra as well as short values of peak period were mainly observed in the locations of Paleogene and Cretaceous regions. This good agreement between H/V spectra and surface geology distribution confirms the validity of microtremors in microzoning study in the case of Damascus city.

In addition, more than 200 soil profiles have been collected in Damascus area. Y. OHTA's empirical shear wave velocity equations in terms of characteristic soil indexes were used to estimate shear wave velocity for our borehole data. By following one-dimensional shear wave propagation law, theoretical site transfer functions (T.F.) were calculated and compared with Microtremor H/V Spectral Ratios. Not so good agreement between results was obtained for many sites which can be attributed to the usage of empirical shear wave velocity equations which derived from Tokyo soil profiles as well as the absence of deep soil layers in our soil profiles.

Keywords: Seismic Micro-zoning, Microtremors' H/V spectral ratio, Local Site Effect and Site Response.

1. INTRODUCTION

A significant part of damage observed in destructive earthquakes around the world is associated with seismic wave amplification due to local site effects. Local site effect is generally summarized as the amplification factors of strong ground motions resulting from responses of local soils relative to incident seismic wave in the bedrock. Site transfer function, which has been extensively used to evaluate the local site effects (Borcherdt 1970), is defined as the ratios of Fourier amplitude spectra of earthquake recorded on soft soil to Fourier amplitude spectra of incident earthquake waves in the bedrock. Since deep borehole records (input motions at bed rock) are not so easy to be obtained, a reference stiff site which is supposed to be free of site effects or with minimum site effects is used as an alternative of input motion at bed rock. Using earthquake data to calculate site transfer function gives very reliable results, but earthquake data are not often available. Site transfer function also can be estimated by boring exploration method that gives very accurate results. But, boring exploration method demands considerable manpower and substantial time as well as very high cost. On the other hand, using Microtremors to evaluate the seismic site response becomes very popular in seismic microzonation studies due to its easiness and inexpensive application of Microtremors.

Damascus city is bounded by Qasioun Mountain from the South West to North East where Paleogene (Middle Eocene) and Cretaceous (Turonian) are appeared and from the south it is bounded by El-kalb, Tamouriyeh and Abou Attiz Mountains where Basalt rocks are appeared while, main part of the city is located on sedimentary basin along Barada river (Geological Map of Syria, Ministry of Industry, 1963). The city of Damascus is surrounded by many active tectonic features such as Qasioun Fault, Surghaya Fault and near to the major Dead Sea Fault System (Tectonic Map of Syria by Cornell University, 2001). Historical seismicity of this area refers to an intensive damage in Damascus city and its vicinity from many destructive earthquakes in the past. The historical records suggest that Dead Sea Fault Zone, which is quiescent at present, is capable of producing relatively large earthquakes (Ambraseys 2009). No research has been carried out to evaluate the local site effects in Damascus city, and no regulations related to local site effects have been included in the Syrian building code.

2. BACKGROUND THEORY

Microtremors are the background vibration of the earth from artificial sources such as traffic, industrial machines and so on. The period of Microtremors ranges from 0.05 sec to 2 sec and their amplitude is less than several microns (Kanai 1961). While, other researchers considered that microtremors or microseisms are the background vibration of the earth from non-seismic sources, natural and artificial sources (Okada 2003). Whatever? Both natural and artificial sources vary with time. Consequently, microtremor activities vary with time. But, when microtremors are observed simultaneously at several places, it is noted that these tremors are not completely random. And some coherent waves exist in the records. In other words, microtremors are an assemblage of wave traveling in various directions. Toksöz and Lacoss (1968) clearly demonstrated that microtremors are an assemblage of body waves and surface waves.

Kanai and Tanaka (1961), who first proposed engineering application of Microtremors less that 1 sec, found out that the period distribution curve of Microtremors shows a definite form for respective kinds of sub-soils, and they established a proposal for ground classification by microtremor measurements. Also, they compared the predominant periods of small earthquakes with the period distribution curve of microtremors and they showed that the peak period of microtremors will be the most expected predominant period of earthquakes. Kanai et al. (1966), investigated the relation between the damage ratio of wooden houses and site characteristics obtained from microtremor observations conducted in damaged areas during the 1944 Tonankai earthquake, 1948 Fukui earthquake and 1964 Niigata earthquake, all in Japan. Also, it was found from long period microtremors observations that the amplitude of microtremors in long period range increases systematically with the increase of deposit depth to basement (KAGAMI et. al. 1982). Nakamura (1989) popularized the method of recording microtremors with a three-component seismometer and producing an estimation of site geological conditions from horizontal-over-vertical spectral ratio. He assumed that H-over-V spectral ratio is similar to transfer function for horizontal motion of surface layer with no need for any time restriction on microtremor measurements.

Recently, microtremors have been used worldwide for seismic microzonation purpose, for sedimentary basin analysis as a geophysical prospect tool, and for building response studies. The world wide usage of microtremors in microzonation is due to its easiness and inexpensive application of this method.

3. DATA GATHERING AND OBSERVATIONS

3.1. Microtremor Measurements:

Microtremor measurements were carried out by using very high sensitive seismometers with servo system. The triaxial sensor, CMG 40T-1 (GURALP), can observe ground motion for the period ranging from 0.1 Hz to 50 Hz. More than 300 Microtremor measurements were conducted in Damascus city, with a length of 300 sec for each record and with a spacing about 1 km between measurement sites. We have conduct 2 to 3 records in each site for verifying the stability of microtremors. Figure 1 shows the locations of Microtremor measurements represented on surface geology map of Damascus city.

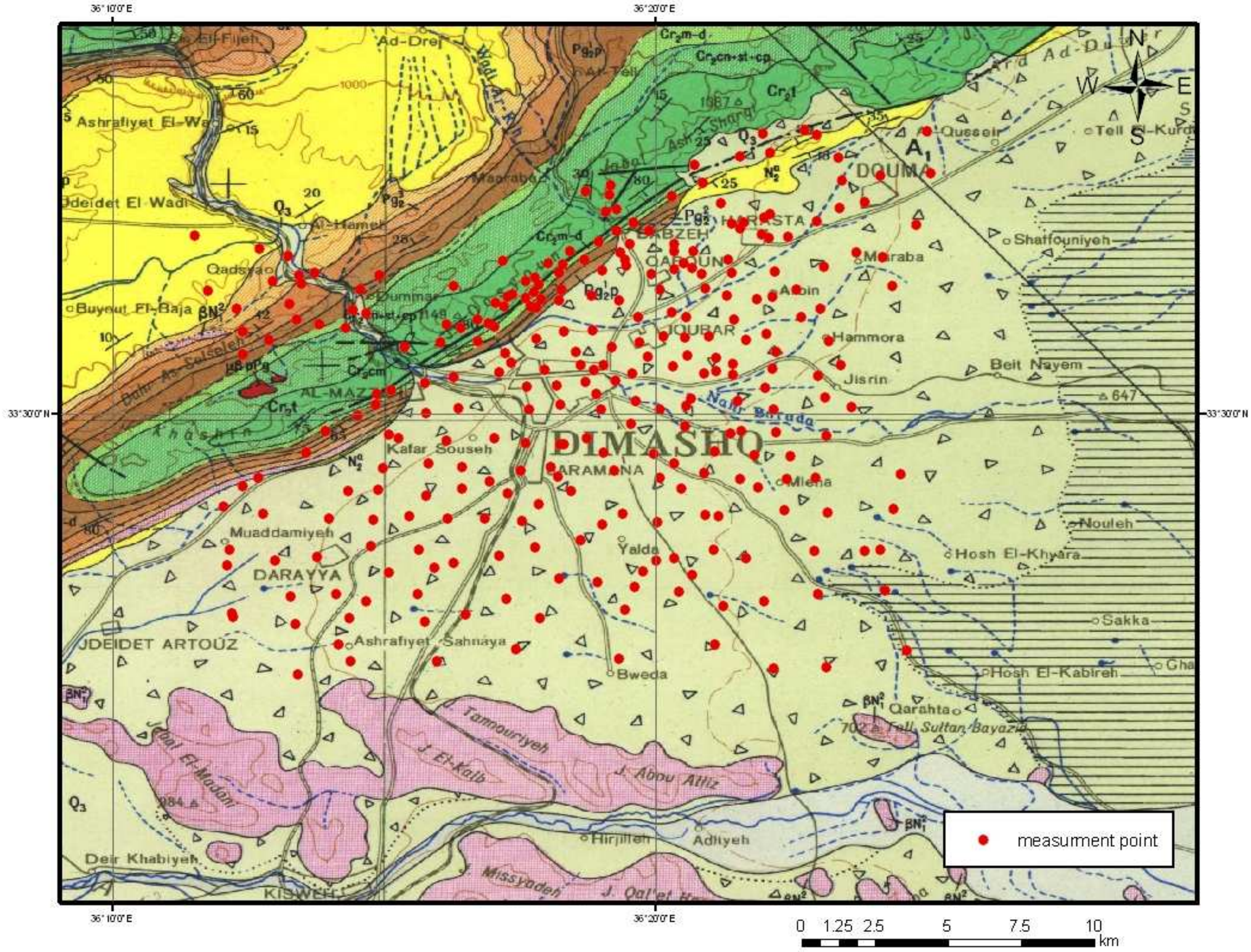

Figure 1. Locations of Microtremor measurements in Damascus city represented on surface geology map. Pink color region refers to Basalt rock, Yellow regions refer to Neogene, brown regions refer to Paleogene and green regions refer to Cretaceous. While grey regions refer to Quaternary deposits areas (Geological Map of Syria, Ministry of Industry, 1963)

3.2. Gathering of Geological and Geophysical data:

More than 200 soil profiles have been collected in Damascus area. The Depth of these profiles ranged from 10 meters (for geotechnical boreholes) up to 200 meters (for some geological boreholes). Borehole data contain soil description for each soil layer with depth and some other information while shear wave velocity is not mentioned in all these profiles. Since local empirical shear wave velocity in terms of soil characteristics are not available, Y. OHTA's empirical equations (which were derived from Japanese dataset) have been used to estimate shear wave velocity for our borehole data (Y. OHTA and N. GOTO, 1978). Also some Vs profiles estimated by microtremors array exploration method (Zaineh et al. 2010) have been used for site response estimation.

4. SITE RESPONSE ESTIMATION:

4.1. Microtremor Site Response:

Each Microtremor record has a length of 300 sec. The transit noise signals with amplitude higher than 5 times of average amplitude of this record were omitted from Fourier analysis. Then the remaining signals were divided into small segments with a length of 10.24 sec. Fourier spectra have been calculated for each segment and the mean value has been obtained and considered as the Fourier spectrum of this record. Horizontal to vertical spectral ratios were calculated for all Microtremor measurement points. Figure 3 shows the procedure of data analyzing.

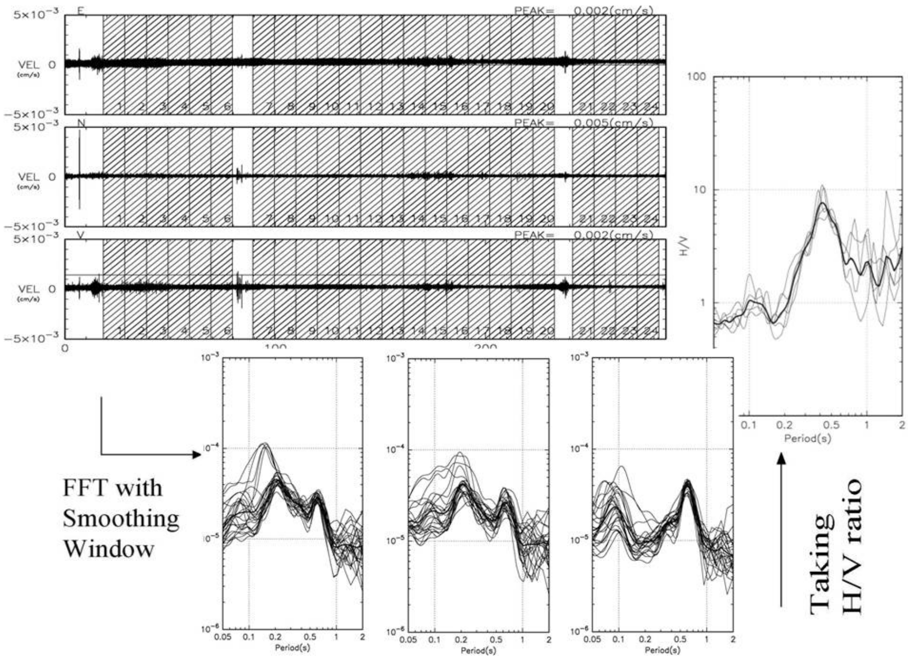

Figure 3. Steps of data analyzing procedure for one Microtremor record

Most researchers agree that Microtremor H/V spectral ratios give a good estimation for predominant period of soft soil layers. But still there is a big discussion about using H/V spectral ratios for estimating the level of amplification since there are two different theoretical definitions of H/V technique. Nakamura (1989, 2000) who first developed this technique gives theoretical definition of H/V with multiple reflection of SH waves. While other researchers suggest that the peak of H/V ratio can be explained with the fundamental characteristics of Rayleigh waves. That means H/V is basically related to the ellipticity of Rayleigh waves which exhibits a sharp peak around the fundamental frequency for sites having a high impedance contrast between surface and basement materials while the amplitude of H/V ratios is quite different from site amplification factor (Bard 1999). However, the peak amplitude of H/V ratios increased when the site effect appeared very clearly, which means the peak amplitude of H/V ratios gives a good indicator to identify significant site effects. Regarding Nakamura's method, H/V spectral ratios were calculated for all Microtremor measurement points. Figure 4 (a) shows the H/V spectral ratios for different sites in Damascus city. Although all these sites are located in the Q3 zone, which refer to recent Quaternary deposit layer, H/V spectral ratios are quite different among these sites. While (b) shows the H/V spectral ratios for other different sites in Damascus city which located on Cretaceous and Paleogene. These spectra are almost flat and they are quite far different from those spectra observed on Quaternary deposit layers.

4.2. Theoretical Site Response:

After estimating of shear wave velocity for collected soil profiles according to Y. OHTA's empirical equations (1978), theoretical sites transfer functions (sites response) were calculated for multi-layered strata based on one-dimensional shear wave propagation theory then theoretical site response had been compared with microtremors site response as it will be shown later.

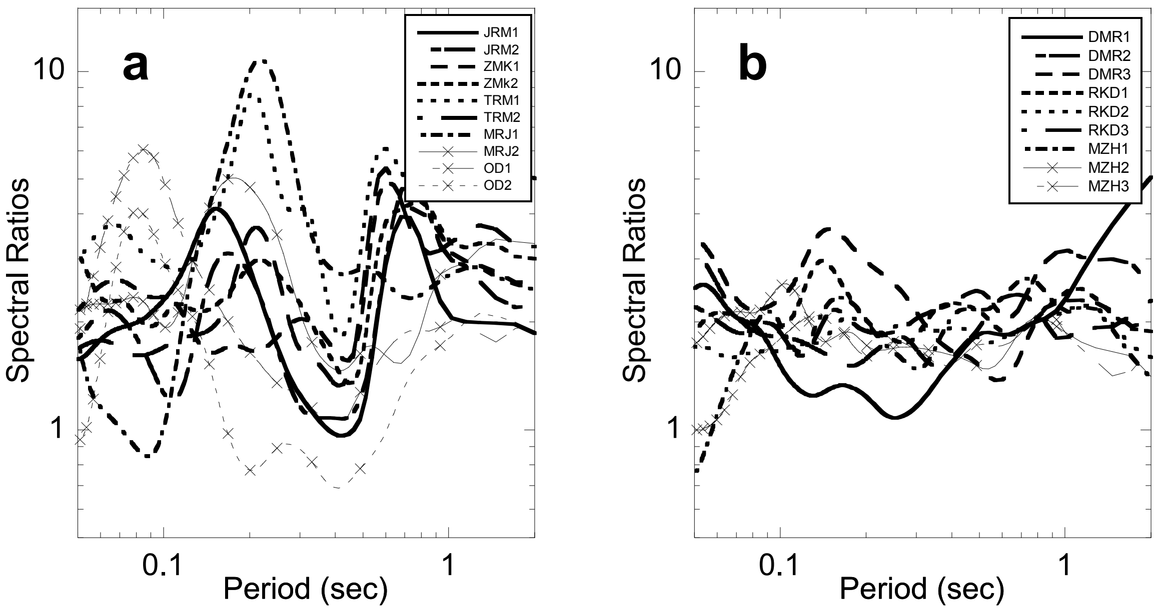

Figure 4. (a) H/V spectral ratios for some sites located on Quaternary deposits in Damascus city and (b) H/V spectral ratios for some sites located on Cretaceous and Paleogene.

4.3. Comparison and Discussion:

4.3.1. Microtremor H/V spectral ratios and geological index:

Peak period of Microtremor H/V spectral ratios have been defined as site predominant period and represented on surface geology map of Damascus city as it shown in Figure 5. Generally, the values of predominant period are increased from west to east of Damascus and the longest values were mainly observed in Eastern Ghouta region. It was remarkable that for sites located in Paleogene and Cretaceous regions, mainly flat H/V spectra and short to medium peak periods were observed in these sites with peak amplitude less than 3 except for few sites which need to be reconfirmed. While, for Quaternary deposit regions, short, medium and long values of peak periods with peak amplitude up to 10 were observed. The variety in site response among sites which located on Quaternary deposit could be interpreted due to the variety in sub soil structure of soil deposits. These results will be confirmed throughout Array measurement of Microtremors in different locations in Damascus city.

4.3.2. Microtremor H/V spectral ratios and Theoretical Site Transfer Functions:

As it mentioned above, by following one-dimensional shear wave propagation theory, theoretical transfer functions have been calculated and compared with Microtremor H/V Spectral Ratios. Figure 6 shows a comparison of calculated site transfer function with Microtremor H/V spectral ratios for some different sites in Damascus city.

A good agreement between theoretical site Transfer Function and Microtremor H/V spectral ratio has been observed for many sites. While the lack of agreement between both kinds of result for some other locations, can be attributed to the following:

- The usage of empirical shear wave velocity equations which derived from Tokyo soil profiles since we don't have our own empirical equations.
- Deep soil layers are not included in our numerical models for many sites since most of our borehole data are shallow one and deep borehole data are not available for many sites in

Damascus.
- The difference in the location between microtremor measurement and borehole location (this will be reflected in the upper most soil layers).

These above mentioned points have been confirmed by comparing Microtremors H/V spectral ratios with Theoretical transfer function of inverted Vs profiles from microtremor array exploration method (Zaineh et.al. 2010) as it shown in figure 7.

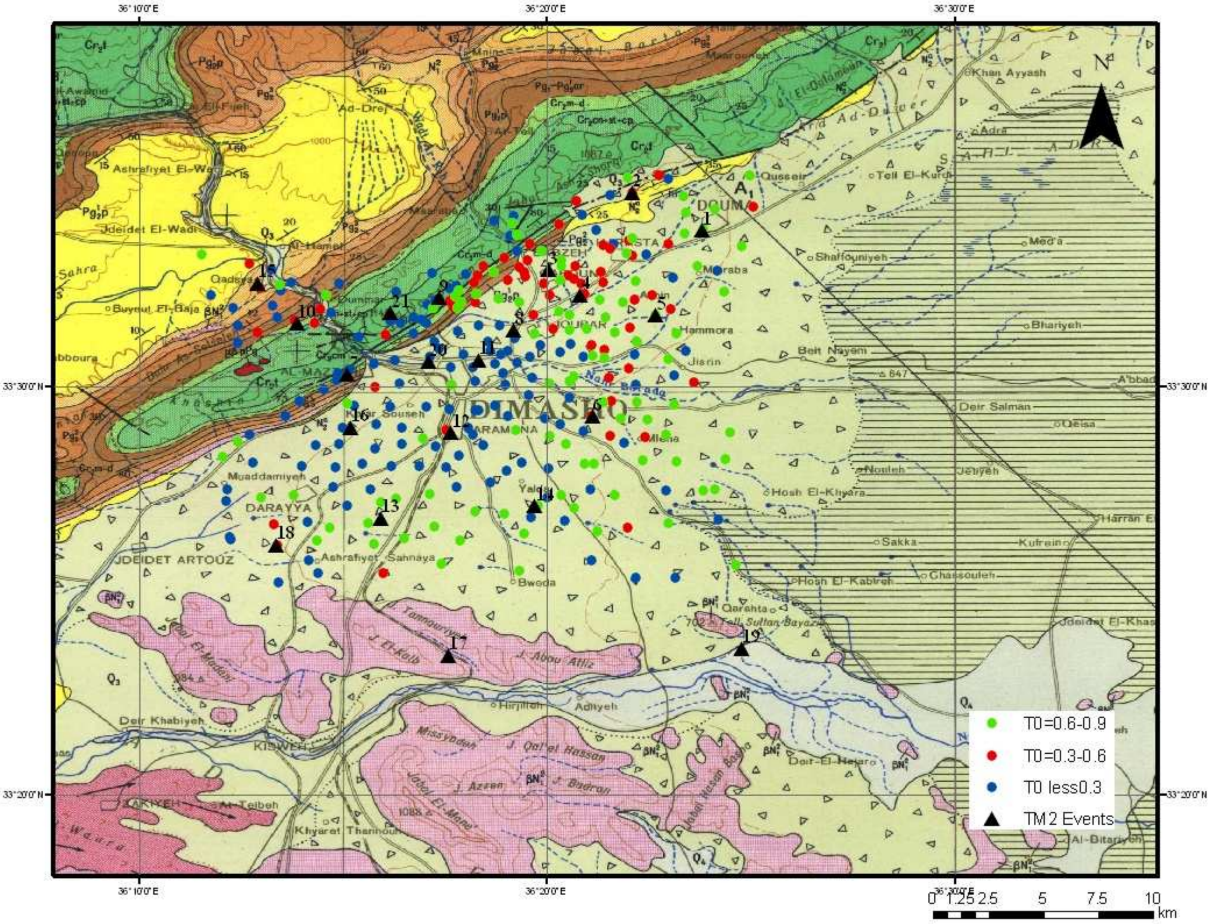

Figure 5. Peak Period of Microtremor H/V spectral ratios for all sites represented on surface geology map of Damascus city. Blue, red and green circles refer to short, medium and long peak periods respectively. Triangular refers to the location of Microtremor Array measurements.

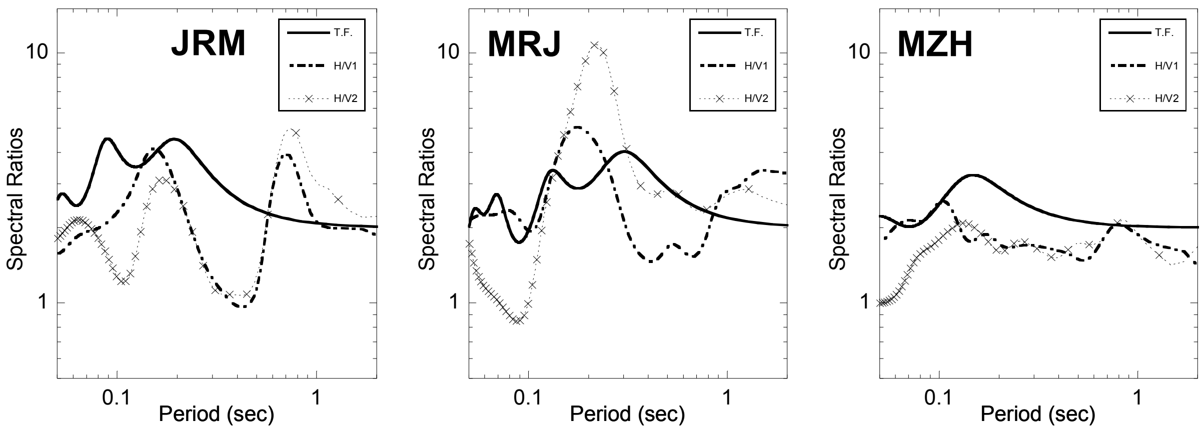

Figure 6. Microtremor H/V spectral ratios and Site Transfer Function (Vs velocity was calculated according to Y. OHTA's empirical equations, 1978) for different sites in Damascus city

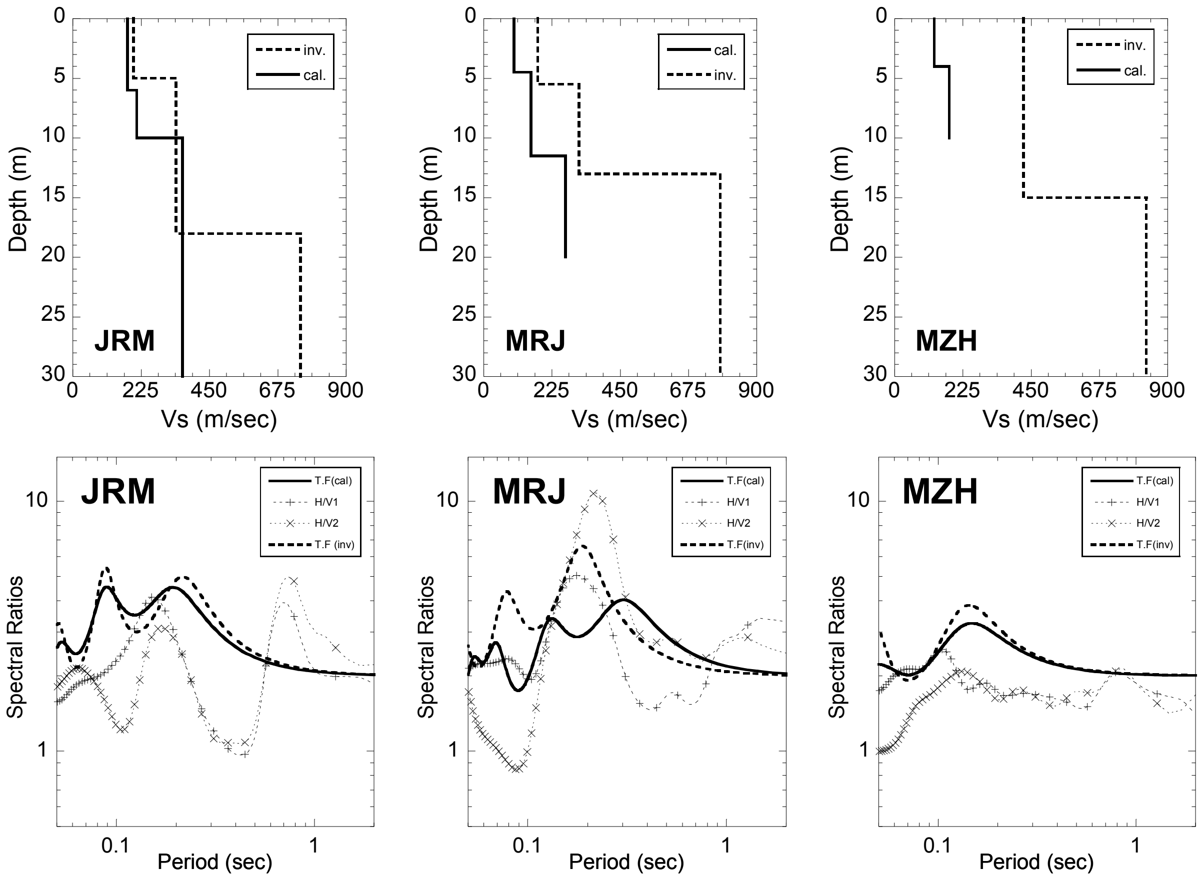

Figure 7. Upper part shows soil profiles (inverted and calculated Vs profile), while lower part shows Microtremor H/V spectral ratios with calculated site transfer function (Y. Ohta and N. Goto, 1978) and inverted one (Zaineh et al., 2010) for different sites in Damascus city

5. CONCLUSIONS AND RECOMMENDATIONS:

Microtremor measurements have been conducted in the city of Damascus and Microtremors H/V spectral ratios have been compared with Site Transfer Functions. As the results of processing the data, the following conclusions have been drawn:

The longest peak periods of H/V were observed in the locations of Quaternary deposits with peak amplitude up to 10. While short periods were observed in the locations of Paleogene and Cretaceous regions where, flat H/V spectra were mainly observed with peak amplitude less than 3. This good agreement between H/V peak periods and surface geology distributions confirm the validity of microtremors in microzonation study in the case of Damascus city.

Although most of our measurement sites are located on Quaternary layers (Q3 zone), a big variation in dynamic site characteristics (fundamental period and amplification factor) were observed among these sites. That illustrates the importance of this detailed study for Damascus city.

Developing of local empirical equations for estimating shear wave velocity in terms of soil indexes is so important for earthquake and civil engineering studies.

For more reliable estimation of site effects, earthquake observations in Damascus city are required. The obtained ground motions will provide more accurate information about site response.

More than one technique is recommended to estimate site response in order to obtain more reliable results. Comparison and complementation of different techniques are more probable to provide more accurate and adequate results.

ACKNOWLEDGMENT

This research was supported by National Earthquake Center, Ministry of Petroleum and Mineral Resources in Syria. We would like to express our deepest gratitude to Dr. Motoki -Tokyo Institute of Technology- for providing us with suitable software. Also, we are very thankful for Prof. Yamanaka and Prof. Seo –Tokyo Institute of Technology- for their valuable comments and their help.

REFERENCES

Bard, P. Y., (1998). Microtremor measurements: A tool for site effect estimation. *Proceedings of the second international symposium on the effects of surface geology on seismic motion:* ***1251-1279***.

Borcherdt, RD., (1970). Effects of local geology on ground motion near San Francisco Bay. *Bulletin of Seismological Society of America.* ***Vol 60****: 29-61.*

Field, E. H. and Jacob, K. H., (1995). A Comparison and Test of Various Site-Response Estimation Techniques Including Three That Are Not Reference-Site Dependent. *Bulletin of Seismological Society of America.* ***Vol 85****: 1127-1143.*

Horike, M., Zhao, B., and Kawase, H., (2001). Comparison of site response characteristics inferred from microtremors and earthquake shear waves. *Bulletin of the Seismological Society of America.* ***Vol 91****: 1526-1536.*

Kagami, H., Duke, C. M., Liang, C. and Ohta, Y., (1982). Observation of 1-To-5 second microtremors and their application to earthquake engineering. Part II. Evaluation of site effect upon seismic wave amplification due to extremely deep soil deposits. *Bulletin of Seismological Society of America.* ***Vol 72****, 3: 987-998.*

Kanai, K. and Tanaka, T., (1961). On Microtremors VIII, *Bulletin of the Earthquake Research Institute, University of Tokyo.* ***Vol 39****: 97-114.*

Kanai, K., Tanaka, T., Osada, K., Suzuki, T., Morishita, T., and Yoshizawa, S., (1966). On microtremors (Earthquake damage to wooden houses). *Bulletin of the Earthquake Research Institute.* ***Vol 44****: 645-696.*

Lachet, C. and Bard, P., (1994). Numerical and Theoretical Investigations on the Possibilities and Limitations of Nakamura's Technique. *Journal of Physics of Earth.* ***Vol 42****: 377-397.*

Nakamura, Y., (1989). A Method of Dynamic Characteristics Estimations of Subsurface Using Microtremors on the Ground Surface. *Quarterly Report of Railway Technical Research Institute (RTRI).* ***Vol 30****: 25-33.*

Nakamura, Y., (2000). Clear identification of fundamental idea of Nakamura's technique and its applications. *The 12th World Conference on Earthquake Engineering*

Okada, H. (2003). The Microtremor survey method. Soc. of Expl. Geophys. of Japan, translated by K. Suto, Geophys. Monograph Series No. 12, Soc. of Expl. Geophys., Tusla.

Seo, K., Haile, M., Moriuchi, M., Mori, K., Sueoka, H., Mualchin, L., Sheng, L. H. and Enomoto, T., (1994). Microtremor measurement in Los Angeles area –A Preliminary Study of Seismic Microzonation-. *Technical Report, Tokyo Institute of Technology.*

Toksöz, M. N. and Lacoss, R. T., (1968). Microseisms –mode structure and sources: Science. ***Vol 159****: 872-873.*

Zaineh, H. E., (2007). Seismic Microzonation Study by Comparing Measured Microtremors with Observed Earthquake Motions -A Case Study in the Damaged Area during the 2007 Noto Hanto Earthquake, Japan-. *Master Thesis, GRIPS university, Japan.*

Zaineh H. E., Yamanaka H., Daoud M., Ibrahim R., and Dakkak R., (2010). Estimation of S-Wave Velocity Structure Using Array of Microtremors in Damascus City (SYRIA). *Submitted to Japan Geoscience Union Meeting, 2010, May 23-28, Chiba, Japan.*