

# DETERMINATION OF CHARACTERISTIC SITE PERIOD AND PRELIMINARY GROUND RESPONSE ANALYSIS ACCORDING TO RESONANCE BY USING GIS

M. Tün<sup>a</sup>, U. Avdan<sup>a</sup>, M. Altan<sup>a</sup>, C. Ayday<sup>a\*</sup>

<sup>a</sup> Anadolu University, Satellite and Space Sciences Research Institute, Iki Eylül Campus, 26470 Eskisehir, Turkey - (mtun, uavdan, maltan, cayday)@anadolu.edu.tr

Commission VII, WG VII/5

**KEY WORDS:** Analysis, Building, Earthquakes, GIS, Hazards, Soil

## ABSTRACT:

Ground response analyses are mostly used for the development of design response spectra in the modern earthquake engineering. After 1999 Marmara Earthquake, the damages were mostly related with unavailable soil conditions and this unavailability were analysed according to liquefaction analysis. The other analyses which cover the dynamic soil properties were not studied in detail.

In this study, granular soil which the Eskisehir urban area is located has been studied according to vibration period. Eskisehir is the city, which would be influenced negatively by the earthquake due to unavailable soil conditions and uncontrolled constructions. Five different districts of the Eskisehir municipality were included in this studied area.

Seismic conic penetration test (SCPT) which is known seismic down hole test results have been used for obtaining low-strain dynamic soil properties in the study. The geophone in the seismic penetrometer detects the travel time, depth and shear wave velocity ( $V_s$ ) of the tested horizon have been obtained. The soil thickness of the studied area has been calculated from the seismic resistivity results of the State Hydraulic Works of Eskisehir. The raw 60 m seismic resistivity records have been evaluated by using 3 dimensional GIS and 3 dimensional alluvial thickness model have been created. Average shear wave velocity ( $V_{sav}$ ) of each 32 SCPT test points have been calculated by taking average of each SCPT drill log.

Characteristic site period ( $T_s$ ), which is defined as the period of vibration corresponding to the fundamental frequency has been obtained for each 32 test points. GIS which is a powerful tool and technique for especially earth science, has been used for the preparation of characteristic site period map ( $T_f$ ) of the studied area. After that, the number of story of each building has been determined by in-situ studies in the studied districts. Fundamental vibration period ( $T_f$ ) of each building has been calculated with respect to number of story according to building codes. GIS overlapping analyse technique, has been used with characteristic site period ( $T_s$ ) map layer and fundamental vibration period map layer of each building. Soil and structure relationship has been searched in this situation and close  $T_s$  and  $T_f$  values have been defined as critical values according to high resonance risk. It has been seen that, the number of critical buildings which are under the high resonance risk in the studied area are 63 and this covers approximately 5.4% of the total studied area. At the end, ground response of the soil according to resonance risk map has been prepared by GIS technique.

## 1. INTRODUCTION

Studies into the earthquake conducted within the applications of ground studies emphasize that an interaction between the features of the earthquake and local ground conditions is of great importance (Ansal, A., 1999; Keçeli, A., 2000). Just as the ground has an impact upon the features of the seismic waves that it gets exposed to, so the seismic waves have an impact upon the physical features of the ground as they pass through the ground layers in such a way that they affect the loss and softness of the ground. Some of the factors likely to influence the seismic features over the surface would be stratification of the ground, type of the ground, the main depth of the rock, geological structure, level of underground water, thickness, flexibility and plasticity of the ground layers (Ansal, A., 1999). Making use of shear wave velocity measured in the upper layers of the ground has brought a new dimension to earthquake risk analyses. Through analysing the data obtained from these studies, it is possible to determine seismic features of the regions susceptible to earthquakes and their effects upon

various geologic and ground features. Measuring the speed rapidity of the seismic waves, which occur as a result of seismic ground movements, passing through the ground is an essential variance in determination of a deformation likely to occur in the ground (Ansal A., 1999; Ersin, A., 1998; Ercan, A., 2000). Different methods are used for measuring shear wave velocity in the literature (Luna, R. and Jadi H., 2000). In this study, shear wave velocity ( $V_s$ ) was measured in determining the reactive characteristics of the grounds regarding ground movements in the regions susceptible to earthquakes.

The aim of this study was to determine the possibility percentages of structural damage due to earthquakes likely to occur in the region. A Seismic Conic Penetration Tests (SCPT) was made at 32 different points situated on new alluvium within a vicinity of 25 km<sup>2</sup> area of the city of Eskişehir. Shear wave velocity ( $V_{sav}$ ) was determined by using SCPT. This value was taken as one of the variables used in the process of calculating the fundamental vibration period. Another variable is the thickness of alluvium was obtained as a consequence of geophysical resistivity measurements carried out by Eskişehir

---

\* Can Ayday is with the Anadolu University Satellite and Space Sciences Research Institute, Iki Eylül Campus 26470, Eskisehir, Turkey (corresponding author to provide phone: 222-321-3550; fax: 222-323-9129; e-mail: cayday@anadolu.edu.tr).

DSİ in a depth of 60 m at 112 locations. The results were interpreted using the three-dimensional Geographical Information System (GIS) method.

Micro-zoning maps are used in determination of earthquake hazards in urban areas and industrial regions. Scenarios of earthquake hazards are drawn up and studies of micro-zoning are carried out based upon the technology of GIS. Analyses of satellite images acquired in September 1987 and in September 1999 revealed that the construction work focuses on unstable grounds in Eskişehir (Nefeslioğlu A. H. et al., 2003).

A pilot region including 5 districts was selected in attempt to form a basis for micro-zoning studies. The number of the storeys was determined for the buildings in this region and their characteristic site periods were calculated in consideration of the number of storeys in accordance with the standards followed in the literature. Maps showing the characteristic site periods of the superstructure and the ground were compared numerically in order to form a basis for analyses and modelling studies using GIS techniques. A structure-ground relationship was investigated through interpreting the fundamental vibration period of the ground in addition to conducting a risk analyses with respect to resonance.

## 2. FEATURES OF THE GROUND STUDIED

The ground investigated in our study is inclusive of a certain part of Eskişehir, which is 25 km<sup>2</sup>. The elevation of this city varies from 779 m to 800 m from the sea level. The Porsuk River is located to the south of the study area, cuts the area in half in the direction of E-W.

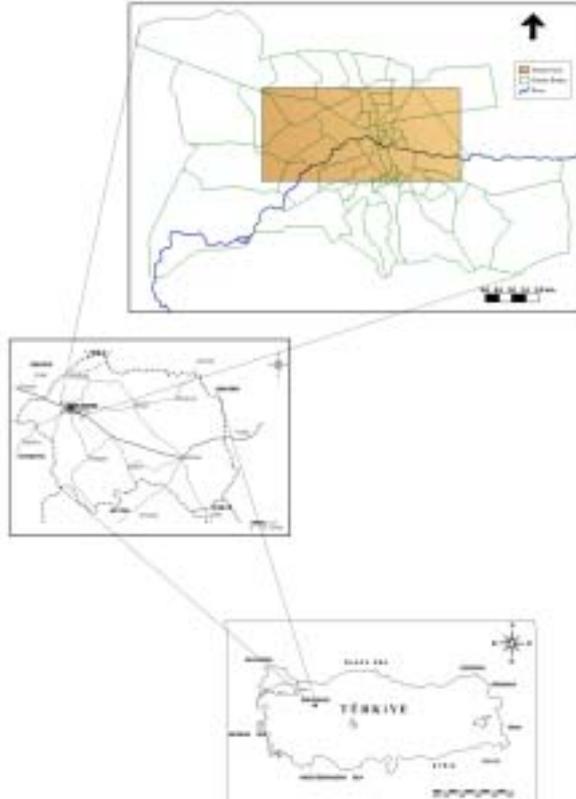


Figure 1. Location map of the studied area

## 2.1 Geology of the study area

It is known that the new alluvium, over which SCPT applications have been carried out, has been determined to be made up of loose soil seen in the plain of Eskişehir, among the particles of which no cementation occurred (Ayday C. et al., 2001). Generally, sand containing a high amount of silt is present below this level. In some parts, there is a thick layer of silt below the same level. As for the lower levels, there is sand and sand containing silt layers can be found. The percentage of sand increases towards the lower levels and gravelly sand start at the lowest level. The study area is also composed of old alluvium in North-West and rocks in South-East part of the city (Figure 2) (Ayday C. et al., 2001).

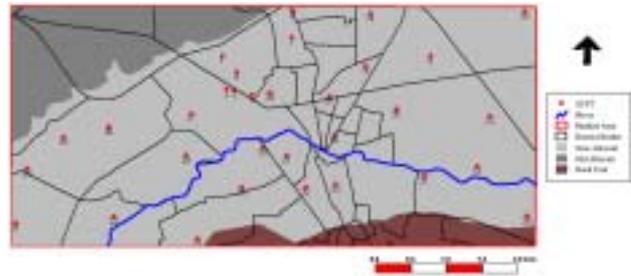


Figure 2. Geology of the study area and the location of SCPT applications

## 3. FIELD STUDIES

### 3.1 SCPT Studies

The Seismic Conic Penetration Test (SCPT) method is employed in analysing dynamic behaviours of the ground and in solving engineering problems (Campanella, R. G. et al., 1986; Robertson P. K. and Campanella, R. G., 1984). The application of SCPT is made using the SCPT probe formed through addition of a seismic receptor to the tip of the cone according to the standard Conic Penetration Test (CPT). Recording numerical data of the seismic measurements is carried out in such a way that, the seismic signal received by the seismometer is converted into numerical values by means of a seismic cable that is penetrated through the drilling stem in the depths where the application made (Campanella, R. G. et al., 1989).

The seismic energy is created by horizontally striking the sledgehammer upon the surface of the horizontally placed metal sign over the surface. By repeating this process with intervals of 1 m, interval speeds are calculated. Thus, the average speed is obtained using the first and last signals the reference levels. In an effort to measure the shear wave velocity ( $V_s$ ), 32 applications of SCPT were made in certain parts of the study area (Figure 2).

### 3.2 Determination of the Number of Storeys of the Buildings in the Study Area

A pilot region consisting of 5 districts was designated for as the study area. The number of the storeys of 1159 buildings in the pilot region, consisting of the districts of İhsaniye, Cumhuriye, Hayriye, Hacalibey and Haciseyit, was determined (Figure 3).



Figure 3. The number of stories of the buildings in the studied area

#### 4. GIS STUDIES

##### 4.1 Processing of Seismic Data

Data of the seismic trace obtained at intervals of 1 m were filtered using the 30-100 Hz band pass filter. Digital filtration is the most optimum approach to analysing seismic data (Campanella, R. G. and Stewart, W. P., 1991; Campanella R. G. et al., 1989). The average shear wave velocity ( $V_{sav}$ ) was determined using the first and the last reference signals.

##### 4.2 Determination of Fundamental Vibration Period Using GIS

Various techniques have been used in applications of determination of earthquake risks and micro-zoning based on GIS in accordance with the variation of the shear wave velocity (Hunter, J. A. et al., 2002). Map of fundamental vibration period of the ground ( $T_f$ ) is one of the maps used for determining regional earthquake risk that makes use of the shear wave velocity.

Fundamental vibration period of the ground ( $T_f$ ) is determined using the following equation.

$$T_f = \sum \frac{4 \times H_i}{V_{s_i}} \quad (1)$$

where  $H$  = the thickness of the alluvial ground focal length  
 $V_s$  = the average shear wave velocity

Determination of the fundamental vibration period of the ground depends on two variables.

1. ( $V_{sav}$ ): A map of the average shear wave velocity was obtained by using the SCPT technique. The average shear wave velocity was determined to vary between 100-340 m/s for all the seismic record depth in each of the 32 different points (Figure 4).

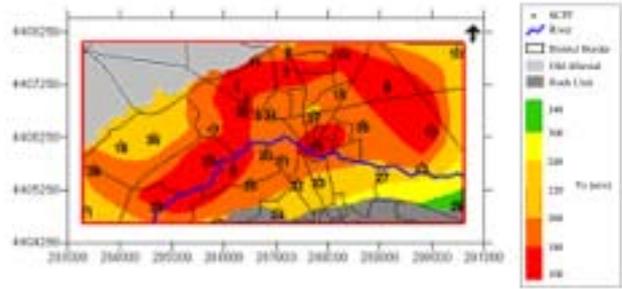


Figure 4. Shear wave velocity map of the studied area

2. Thickness of the alluvium ( $H$ ): A large part of the studied area is located over a ground composed of the new alluvium, containing loose gravel, sand, silt and clay, carried away by the Porsuk River. Electric resistivity method has been applied in 112 locations by DSI with a depth of nearly 60 m. (Azdiken S. and Çatalyürekli E., 2001; Azdiken S. and Çatalyürekli E., 2001) (Figure 5).

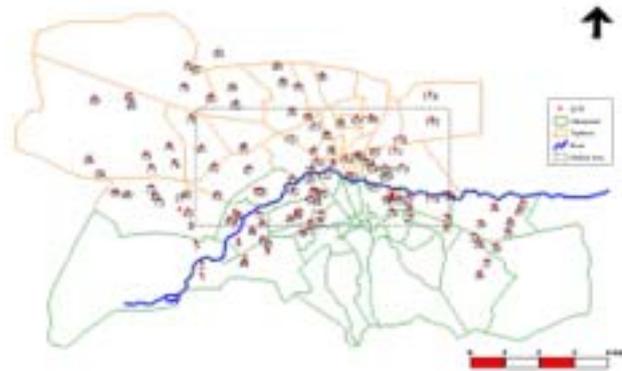


Figure 5. Locations of geophysical resistivity measurements

The geophysical measurements obtained revealed that, the thickness of the alluvium in the studied area varied between 10-25 m, and that the northern east part reached a thickness varying between 10-15 and 15-25 due to the over-storage of materials carried away by the Porsuk River (Azdiken S. and Çatalyürekli E., 2001; Azdiken S. and Çatalyürekli E., 2001). A three-dimensional model of thickness of alluvium was obtained by using geophysical resistivity data. Values of the thickness of the alluvium scattered across the study area have been presented in this model (Figure 6).

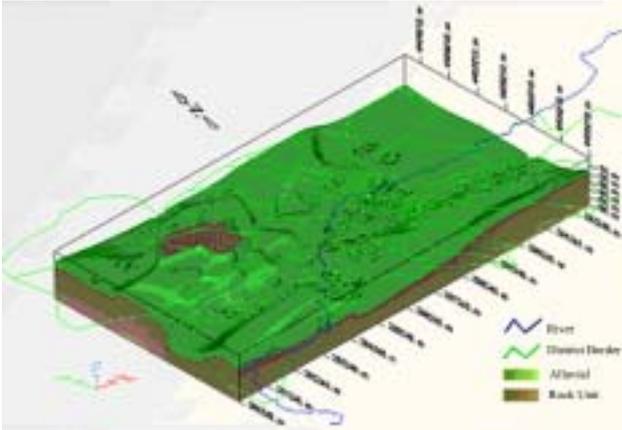


Figure 6. A three-dimensional model of the alluvium thickness of the studied area

Using this theoretical information,  $V_{sav}$  obtained from the locations undergoing SCPT applications and values of the thickness of the alluvium, the fundamental vibration period of the ground of the study area was determined and mapped accordingly (Figure 7).

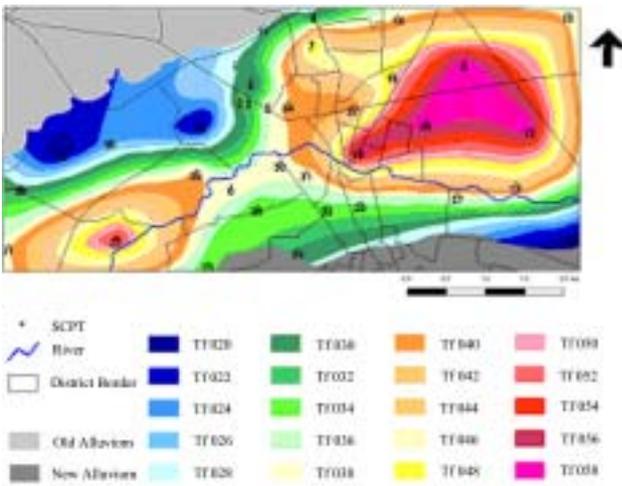


Figure 7. Fundamental vibration period map of the ground of the studied area ( $T_f$ )

The minimum value of the fundamental period of the ground was 0.18 and the maximum value was 0.61 for the 32 different locations in the studied area. All the data were determined to agree with the normal distribution function and the mean level was 0.39, which was in agreement with the characteristics of an alluvial ground (Figure 8).

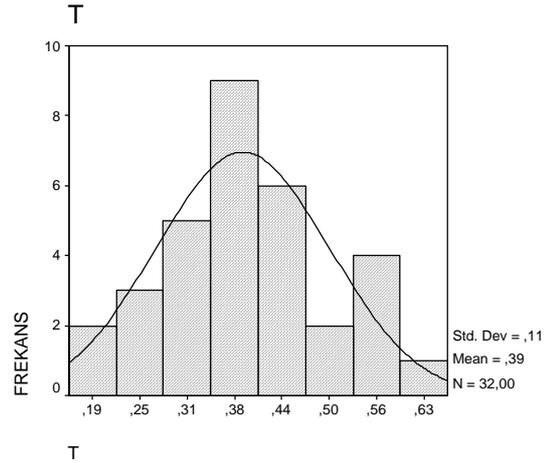


Figure 8. Frequency histogram of  $T_f$  values determined for the studied area

## 5. ANALYSIS OF EARTHQUAKE RISKS ACCORDING TO SITE PERIOD FOR THE STUDIED AREA

When the fundamental vibration period of the ground is equal to that of peculiar vibration period of the building, which is called resonance, seismic burdens that have an impact on the structure pose high risks and thus increase the possibility of damage to and vulnerability of the structure (Akkargan, Ş. and Özçep, F., 2000). Each structure and building on the earth has its own type of contraction materials for construction and different numbers of storeys and a peculiar characteristic site period frequency depending on many parameters (Sağlam, H., 2003).

Concrete buildings were determined to form the highest number of the structures in the study area. Characteristic site periods for different storeys of the structures to be constructed in the disaster areas according to the "Equal Earthquake Method" issued on 1998 in Building Code are determined using the following equation ;

$$T_1 \cong T_A = 0.05.(H_N)^{3/4} \quad (2)$$

where  $H_N$  = Building Story  $\times$  3

Regarding the structure-ground relationship, the peculiar characteristic site period of the superstructure was calculated with the equation of (2) so that a risk analysis could be made in terms of resonance.

Based on the fundamental vibration period of the ground in the study area, four possibilities were determined for the structures in the study area to experience resonance (Table 1).

T [s]	High Resonance [1]		Normal Resonance [2]		Low Resonance [3]		No Resonance				
	Story	Story	Story	Story	Story	Story	Story	Story	Story	Story	
0.58	9	8	10	7	6		5	4	3	2	1
0.56	8	9	7	10	6		5	4	3	2	1
0.54	8		9	7	10	6	5	4	3	2	1
0.52	7	8	9	6	10	5		4	3	2	1
0.50	7	8	9	6	10	5		4	3	2	1
0.48	6	7	8	5	9		10	4	3	2	1
0.46	6	7	8	5	9	4	10		3	2	1
0.44	6		7	5	8	4	10	9	3	2	1
0.42	5	6	8	7	4		10	9	3	2	1
0.40	5	6	7	4	8	3	10	9		2	1

Table 1. Possibilities of the structures to experience resonance depending on the number of their storeys

## 6. CONCLUSION

Analysing the map of  $T_B$  which was drawn up using  $T_f$  values determined for the study area with the applications of SCPT, revealed that the fundamental vibration period of the ground varied between 0.18 and 0.61. The most striking feature of the study area was that the fundamental vibration period of the ground decreased towards the northern east and southern east parts of the study area through which the Porsuk River flows with an east west oriented course. In parts with high elevations, the values of  $T_f$  in the study area varied due to such geological features as rock and presence of old alluvium. The fact that the  $T_0$  value was as low as 0.20 as a result of 18<sup>th</sup> and 28<sup>th</sup> applications seems to indicate that the ground is hard in this part.

It is known that, there is an alluvial ground in the SCPT application points numbered 6,13,16,22,25,27,30 and 32 (Ayday, C. et al., 2001). There was an agreement between the high values of  $T_f$ , varying between 0.40-0.61, and the profile of the ground.

Map of fundamental vibration period suggests that, buildings with 5 and 6 storeys constructed on alluvial grounds in the study area are likely to experience resonance. Using Chart 1, resonance-risk values were determined and mapped in consideration of the number of storeys of the buildings and the fundamental vibration period of the ground in the study area (Figure 9).



Figure 9. Map of resonance-risk values in terms of structure-risk of the studied area

When the distribution of resonance-risk values according to the districts in the study area was analysed, the number of the buildings likely to experience resonance was 63, which accounts for the 5.4 % of all the buildings investigated. The number of the buildings with little risk of resonance was 849, which accounts for 73 % of the buildings in the study area (Table 2).

	Risk1	Risk2	Risk3	Risk4	Toplam
Hacıseyit	18	14	9	208	249
Hayriye	1	5	27	122	155
İhsaniye	9	9	6	144	138
Hacıalibey	15	23	10	150	198
Cumhuriye	20	55	89	255	419
Toplam	63	106	141	849	1159
(%)	5.4	9.1	12.2	73.3	100

Table 2. Distribution of resonance-risk values in the study area according to districts

Buildings with 1,2 and 3 storeys were categorized as the fourth group as they were the ones with the least risk. They account for 73.3 % of all the buildings in the study area, but they accommodate only 25.5 % of the inhabitants residing there. On the other hand, buildings with 7, 8 and 9 storeys were categorized as the 1 group as they were the ones with the highest risk. They account for only 5.4 % of all the buildings in the study area, but they accommodate 51.9 % of the inhabitants of the study area. Therefore, we suggest that the risk should not be determined according to the number of the buildings. On the contrary, it should be determined according to the number of the storeys of the buildings and the number of the inhabitants occupying these buildings (Figure 10).

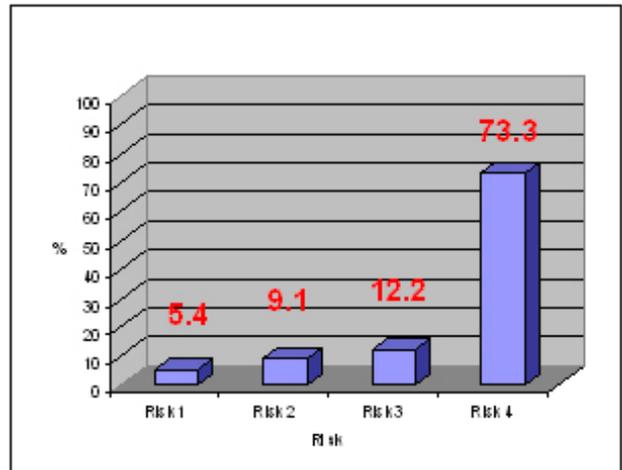


Figure 10. Percentage values of resonance-risk in the studied area

The following suggestions were made based on the study results:

- Determination of resonance risk should first be performed in the study area, and then be performed in the sites to be designated for constructions for the first time.
- Resonance risk should be taken into considered for the already existing residential areas as well as for the new sites to be opened to construction with respect to decreasing possible damages and collapses in case of an earthquake.

## 7. REFERENCES

- Ayday, C., vd., *Eskişehir Yerleşim Yerinin Yerleşim Amaçlı Jeoloji ve Jeoteknik Etüt Raporu*, Anadolu Üniversitesi, Uyu ve Uzay Bilimleri Araştırma Enstitüsü, Eskişehir, (2001)
- Akkargan, Ş., Özçep, F., *Rezonans Olayı ve Depremlerle İlişkisi*, Jeofizik Bülteni, 38, 95-96, (2000)
- Anasl, A., *Depremlerde Yerel Zemin Davranışları*, Bilim ve Teknik, 384, 64-68, (1999)
- Azdiken, S., Çatalyürekli E., *Eskişehir Odunpazarı Belediyesi Jeofizik Rezistivite etüt Raporu*, DSİ III. Bölge Müdürlüğü, Eskişehir, (2001)
- Azdiken, S., Çatalyürekli E., *Eskişehir Tepebaşı Belediyesi Jeofizik Rezistivite etüt Raporu*, DSİ III. Bölge Müdürlüğü, Eskişehir, (2001)
- Campanella, R.g., Robertson, P.K., Gillespie, D., *Seismic Cone Penetration Test*, Proceedings of In Situ 86', a Specialty Conference on Use Of In Situ Tests in Geotechnical Engineering, Blacksburg, Virginia. ASCE, New York, (1986)
- Campanella, R.G. and Stewart, W.P., "Downhole Seismic Cone Analysis Using Digital Signal Processing", 2nd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, No. 1.32, Vol. 1, pp. 77-83, (1991)
- Campanella, R.G., E.J. Baziw and J.P. Sully, *Interpretation of Seismic Cone Data Using Digital Filtering Techniques*, Department of Civil Engineering, University of British Columbia, Vancouver, Canada, (1989)
- Ercan, A., *Yermühendislik Özelliklerinin; Jeofizik Ölçümler, Jeolojik Gözlemler ve Jeoteknik Deneylerle Belirlenmesi*, Yerel Yöntemlerde Jeotermal Enerji ve Jeoteknik Uygulamalar Sempozyumu, Ankara, 297-331., (2000)
- Erdik, M., Swift, J., Onur, T., *Kentlerde Deprem Tehlikesinin Belirlenmesi: Mikrobölgelendirme*, Tübitak Deprem Sempozyumu, Ankara, (1996)
- Ersin, A., *Sismik Yöntemler ve Yorumlamaya Giriş*, TMMOB Jeofizik Mühendisleri Odası Yayını, İstanbul, Türkiye (1998)
- Huntera, J.A., et al., *Surface and Downhole Shear Wave Seismic Methods for Thick Soil Site Investigations*, Soil Dynamics and Earthquake Engineering, 22, 931-941, (2002)
- Keçeli, A., *Deprem-Zemin*, Jeofizik Bülteni, 36, 6-11, (2000)
- SAĞLAM, H., *Demetevler (Ankara) Bölgesinin Zeminlerinin Hakim Titreşim Periyodu ve Büyütmelerinin Belirlenmesi*, Yük. Müh. Tezi, H.Ü. Fen Bil. Enst., Ankara, (2003)
- Luna, R. and Jadi, H., *Determination of Dynamic Soil Properties Using Geophysical Methods*, Proceedings of the First International Conference on the Application of Geophysical and NDT Methodologies to Transportation Facilities and Infrastructure, St. Louis, MO, December (2000.)
- Nefeslioğlu, A. H., Tün, M., Ayday, C., Gökten, M., "Change Detection of Structures in the Earthquake Hazard Zoning Map of Eskişehir City, Turkey, by Using Satellite Images" 2<sup>nd</sup> Joint Workshop on Remote Sensing and Data Fusion over Urban Areas, URBAN 2003, P 177-181, Berlin, Germany, (2003)
- Robertson P. K. and Campanella. R. G., *Guidelines for Use and Interpretation of the Electronic Cone Penetration Test*, Soil Mechanics, Series No. 69. Vancouver, Canada: University of British Columbia, Department of Civil Engineering, (1984.)