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AN INTEGRATED APPROACH FOR ESTIMATION OF MODULUS DEGRADATION IN SOFT ROCKS

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ABSTRACT

Recently many high-rise tower structures are being constructed in Istanbul, Turkey. The subsoil is mainly greywacke formation of claystone - siltstone - sandstone alterations locally known as Trace Formation. The geotechnical and geodynamic subsoil modeling is necessary in order to use them in foundation engineering assessments and to obtain site specific response spectra for future earthquakes to be used in design of structures.

Due to the nature of the greywacke formations; in seismic modeling, in addition to refraction technique surface Ragleigh wave measurements together with inversion technique are being utilized to obtain shear wave velocity profile with depth. These results are used to obtain shear modulus G_0 value corresponding to very low strain levels.

Menard pressuremeter tests are also performed at certain depths within various boreholes and the resulting pressuremeter modulus values are obtained. The shear modulus corresponding to higher level of strains are deduced from these results. Consequently the modulus degradation with strain is obtained for the soft and firm rock formation of greywacke.

Keywords: Seismic survey, Integrated approach, Pressuremeter test, Modulus degradation, Soft rock

INTRODUCTION

The city of Istanbul due to its recent growth in economy caused a great attraction for the construction of high-rise residential and office buildings. In order to obtain parking space, deep excavations are employed to allow great number of basements below these tower structures. The depths of the excavations commonly reach to 25-40 meters below the ground surface. Although, heights of these towers are quite variable, the highest one planned to be constructed presently, will be in approximately 160 meters. Most of these tower structures are constructed along the newly developed longitudinal axis of the city along Buyukdere Street having similar subsoil conditions and seismicity.

As a result, it became compulsory for the geotechnical engineers to obtain the geotechnical modeling of subsoils, both to a depth of excavation to employ in the design of retaining structures and well below the foundation levels, to be utilized in foundation design and seismic analysis of these structures. Often, soil investigations were required to be performed to a depth of as great as 50^{+} meters below the ground surface.

In this paper, the results of soil investigations employing various techniques at three of these tower structures are utilized, to demonstrate the high degree of modulus degradation due to strain level for the encountered soft rock greywacke formation(locally known as Trace Formation) which is

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lithologically alternating sandstone, siltstone and claystones with various degree of weathering and fracturing. Obviously, the extend of weathering and fracturing controls the mechanical properties and in fact geological observations do well agree with the results of measurements reflecting mechanical properties of the formation.

An integrated seismic survey employed at these sites as described later together with Menard pressuremeters performed within boreholes at various locations and depths, gave unique opportunity to obtain;

- geotechnical and geodynamical modeling of subsoil to great depths,
- the weathered zones and extend of fracturing by means of velocity contrasts,
- shear modulus G_0, both for very low strain levels(10^{-4}%) i.e. seismic surveys and G_m for very high strain levels(1-10%) i.e. pressuremeter testing and consequently to develop the ratio of G_0 to G_m indicating the modulus degradation for so called rock formations.

SEISMICITY

The city of Istanbul is potentially under the influence area of the Marmara Fault System, located at the south, in the Marmara Sea, which is the western end of the North Anatolian Fault-NAF of Turkey. After the 1999 Kocaeli and Düzce earthquakes occurred on NAF within the Marmara Region in approximately 100-150 kilometers from the city of Istanbul, the structure of NAF system in Marmara Sea attracted worldwide scientific attention.

Recent studies conducted after the 1999 Kocaeli (M_w=7.4) and Düzce (M_w=7.2) earthquakes indicated that about 65% probability for the occurrence of a $M_w \geq 7.0$ effecting Istanbul within the next 30 years due to the existence of potential seismic gaps(Parsons et al., 2000).

Based on the probabilistic earthquake hazard analysis using a function relationship of Boore et.al.(1997), Peak Ground Acceleration for 10% Probability of Exceedance in 50 years is found to be 0.24g for the encountered soft and firm rock conditions.

The faulting system of the main Marmara fault indicates the worst case scenario earthquake is an event which would involve the two segments immediately south of Istanbul. The length of rupture is 110 kilometers producing an event of M_w=7.5. The distance to the fault from the tower sites is about 25 kilometers, and the focal depth is 12 kilometers. The attenuation relationship of Campell(1997) and Boore et.al.(1997) was used to evaluate the deterministic earthquake hazard yielding to 0.21g and 0.18g respectively.

INTEGRATED SEISMIC SURVEY

An integrated shallow seismic survey was conducted over the sites of investigations to derive a ‘geodynamical –seismic’ model below the ground surface. The seismic model is defined by three sets of parameters, i.e., geometry of the various subsurface layers, soil-bedrock interface, and the P- and S-wave velocities (v_p and v_s) of the layers themselves such as proposed by Yılmaz et al.(2006).

Multi-channel seismic data were recorded along numbers of traverses depending on the dimension of the specific site using a 48-channel recording system with 4.5 Hz vertical geophones at 2m intervals. For this purpose an explosive source that uses a pipe-gun (buffalogun) is used. Specifically, the receiver stations were kept the same for all shots, while the shots themselves were moved starting from one end of the line to the other.

Analysis of Refracted Waves

The first-arrival times picked from the shots gather by nonlinear travel time tomography to estimate a P-wave velocity-depth model along the receiver spread were analyzed as proposed by Zhang and Toksoz (1997). Starting with an initial model based on the observed (picked) firs-arrival times, the process involves iterative perturbation of the velocity-depth model and modeling of the first arrival times. The iteration is continued to derive a final, grid-based velocity-depth model until the discrepancy between the modeled and the picked times are minimized as shown in Figure 1. In all the sites, there were no ground water elevation, the perched waters and seeping waters were confined within the fractures of the foundation.

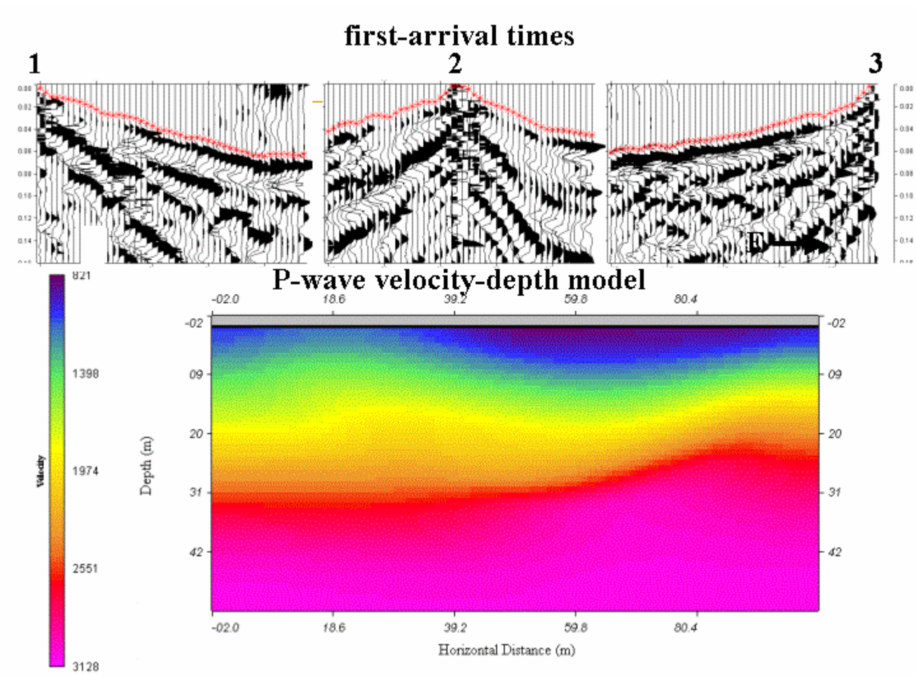

Figure 1. Analysis of refracted waves on shot records from the Levent-Soyak Tower site Top: First-arrival times picked from the shot gathers; bottom: the P-wave velocity-depth model

Analysis of Surface Waves

The off-end shot record with the most pronounced dispersive surface-wave pattern was identified as shown in Figure 2, left. A plane-wave decomposition is performed to transform the data from offset-time to phase-velocity versus frequency domain as shown in Figure 3. A dispersion curve associated with the fundamental mode of Rayleigh-type surface waves was then picked in the transform domain based on the maximum energy criterion as shown in Figure 3 and inverted to estimate the S-wave velocity as a function of depth as shown in Figure 2, right for the Soyak Tower Site as proposed by Xia et al.(1999). The velocity estimation from surface seismic data represents a lateral average over the receiver spread length in contrast with the velocity estimation from borehole seismic measurements usually performed which are influenced by localized lithological anomalies and borehole conditions. Figure 2 also shows the correlation between P- and S- waves for this specific measurement.

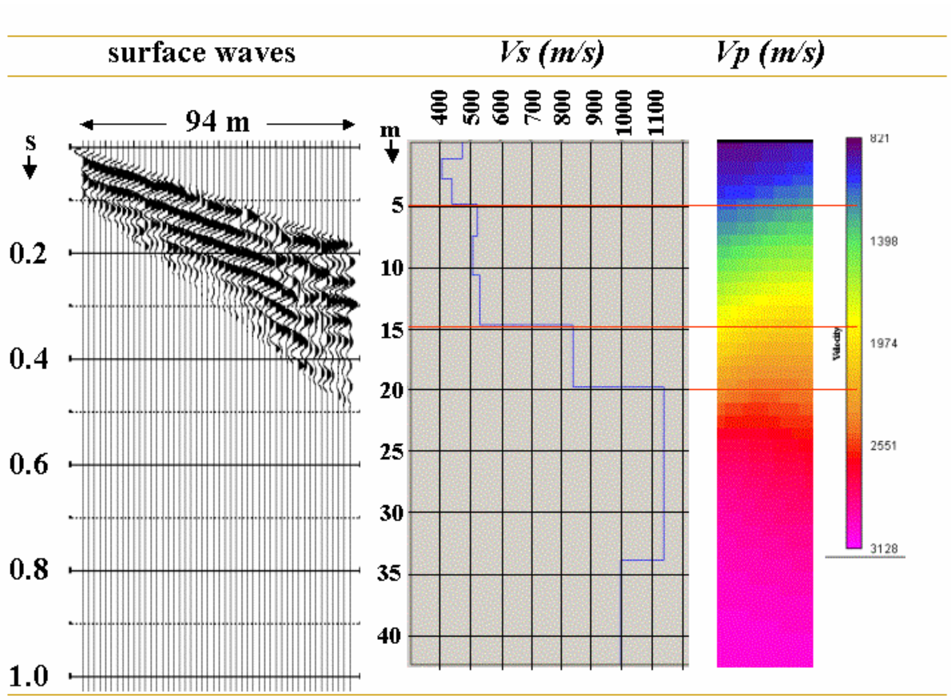

Figure 2. Analysis of surface waves on a shot record from the Levent-Soyak Tower site. Left: surface-wave package isolated from one of the off-end shot records; center: S-wave velocity-depth profile; right: a portion of the P-wave velocity-depth model in Figure 1.

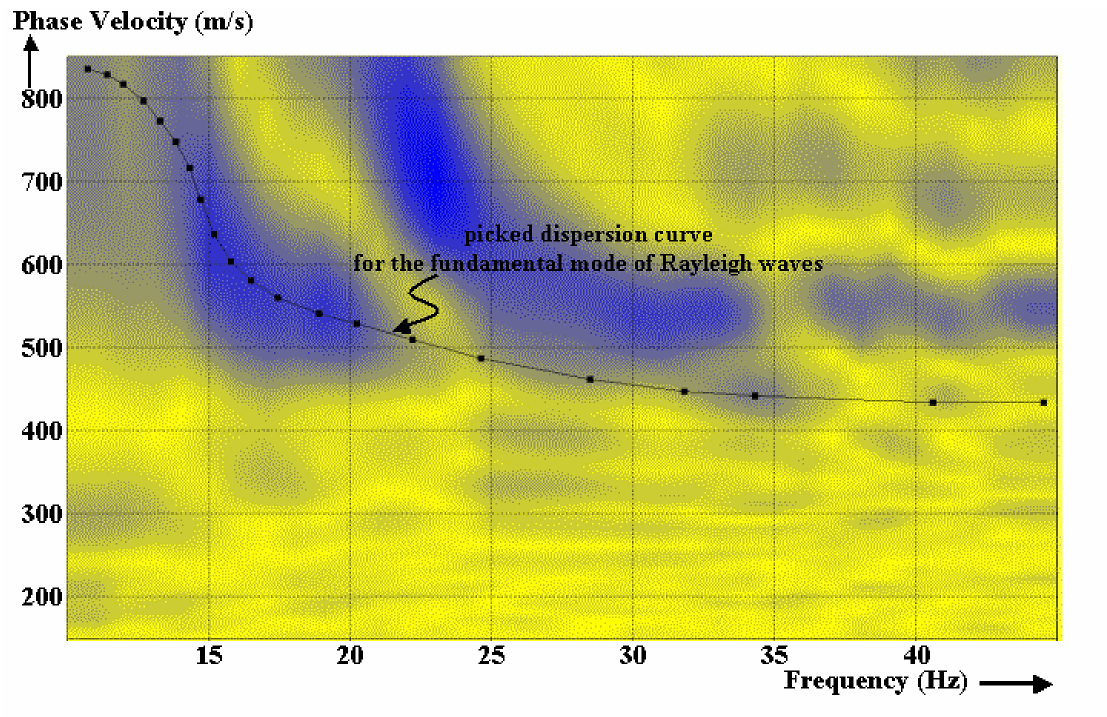

Figure 3. Plane-wave decomposition of the surface-wave package shown in Figure 2 from the Levent-Soyak Tower site.

PRESSUREMETER TESTS

The subsoil conditions at various sites were also determined by means of classical foundation engineering soil investigation program involving borings, sampling, in-situ measurements utilizing Menard type pressuremeter and laboratory testing.

Pressuremeter tests were conducted using up to cavity pressure of 5 MPa at various depths within pre-drilled boreholes. The volume change of the existing cavity as a function of applied pressure within the cavity is measured. As a result, it was possible to obtain, the pressuremeter modulus of the subsurface formation at that elevation together with the cavity strain(Baguelin F., 1978).

The modulus measured in pressuremeter test closely represents the modulus of elasticity at a certain strain level and the shear modulus, G_m could easily be determined. As a result, G_m vs. depth model could be obtained at various locations within the site. That data is often utilized in prediction of vertical displacements of foundations of the tower structure and under static dead and live loads. The magnitude of cavity strains were in the order of 10 percent in the pressuremeter testings.

On the other hand, the integrated approach for modulus measurements employing seismic (refraction + surface waves) and static (pressuremeter) tests offered an unique opportunity for the estimation of modulus degradation due to high level of strains that is known to occur as a result of static and strong earthquake loadings for the encountered soft rock formation, such an example for the Soyak Tower site given in Figure 4.

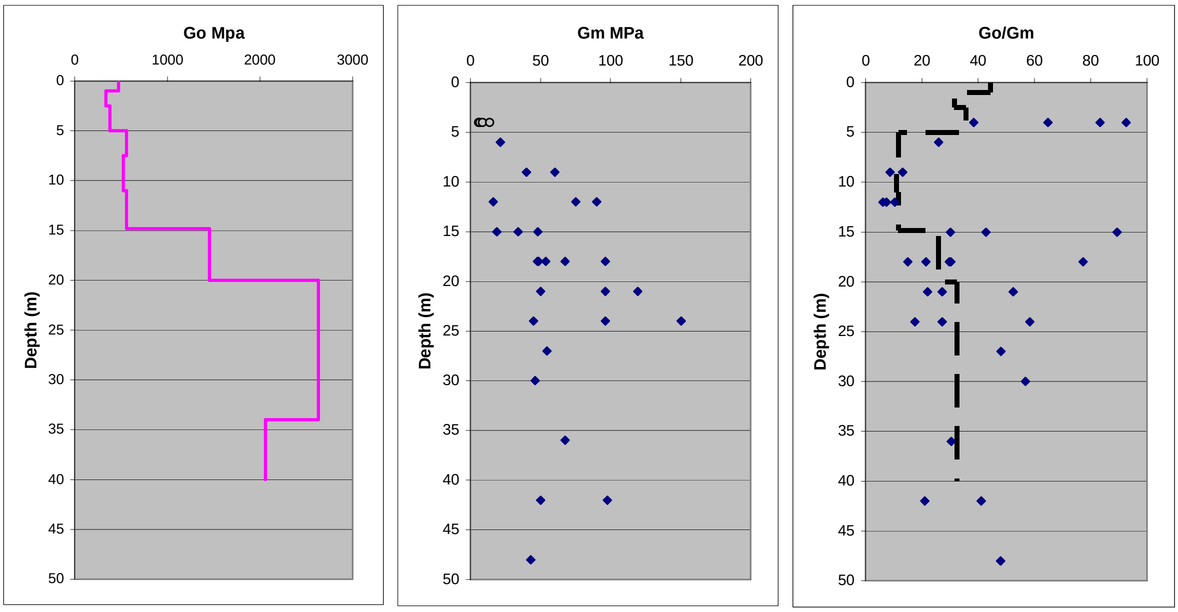

Figure 4. An example of The Shear Modulus Degradation Ratio vs. Depth for Soyak Tower Site

TOWER SITES

Maslak-Hattat Tower

The seismic survey and the additional soil investigations employing borings and pressuremeters are conducted after excavation reaching to a depth of approximately 25.0 meters below the ground surface.

Figure 5 shows the S-wave velocity-depth profile estimated from the analysis of surface waves and a portion of the P-wave velocity-depth model that may be considered an average in the lateral direction estimated from the analysis of refracted waves for seismic line Kl. Similarly, the S-wave velocity-depth profile and a portion of the P-wave velocity-depth model that may be considered an average in the lateral direction for seismic line K2 is also shown. The P-wave velocity-depth model for seismic line Kl exhibits a more moderate lateral variation in velocities compared to the model for seismic line K2. Thus, the normal-mode behavior of the surface waves along Line Kl would not be as complex as the surface waves along Line K2.

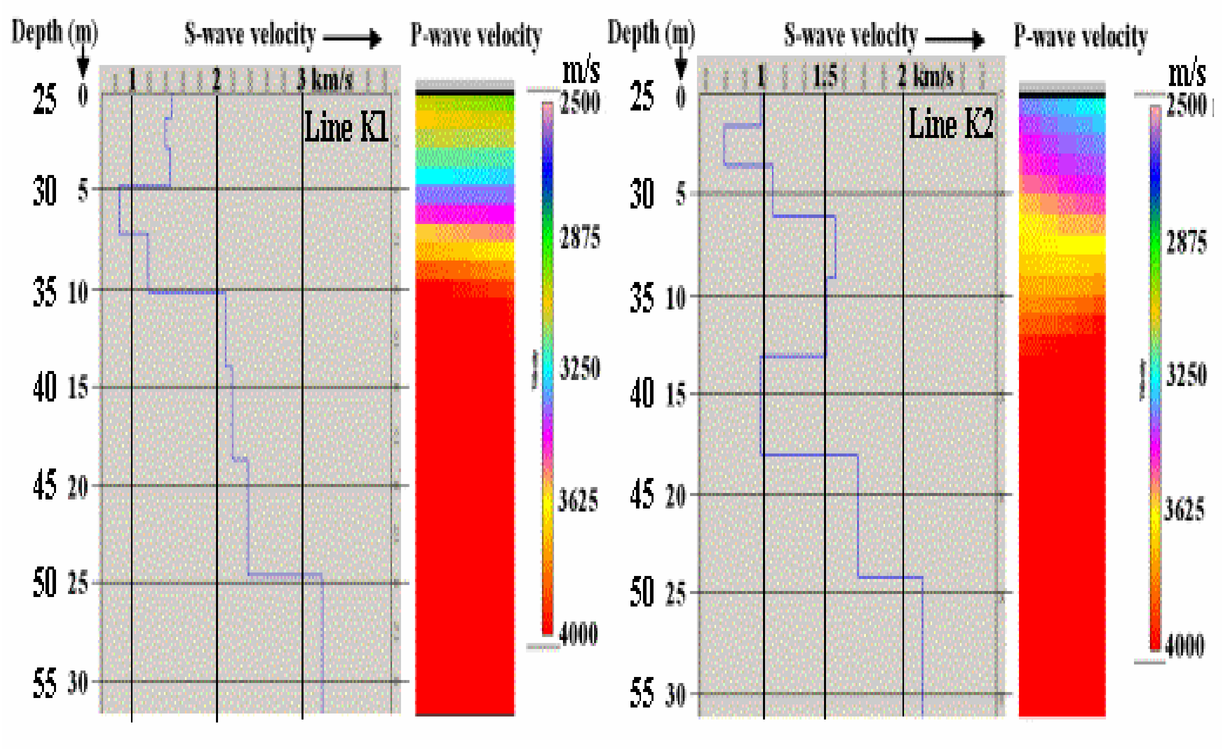

Figure 5. The combined interpretation of the P- and S-wave velocity-depth profiles along Lines K1 and K2 from the Maslak-Hattat Tower site.

From the velocity-depth profiles in Figure 5, note the presence of low-velocity zones within the depth interval 0-10 m. Specifically, along Line Kl, the S-wave velocity within the depth interval 5-10 m is much lower than that within the interval 0-5 m. Such velocity variations could be caused by secondary fracturing associated with tectonism or changes in lithology.

Another important observation in Figure 5 is that, within the depth interval 0-5 m, the average S-wave velocity (1,400 m/s) along Line Kl is significantly higher than the velocity (900 m/s) for the same interval along Line K2. During the field work, it was observed from an undisturbed outcrop that the rock layer within the depth interval 0-5 m has been subjected to severe fracturing. The fracture surfaces are parallel to the direction of Line Kl. The velocities in the direction (approximately coincident with the direction of Line K2) perpendicular to the direction associated with the fracture surfaces are less than the velocities in the latter direction indicating the presence of seismic anisotropy.

Zincirlikuyu-Çiftçiler Tower Site

The depth of excavation will be in excess of 40.0m at this site. It should be noticed that contrary to previous one both surveys are conducted at the present ground surface. The seismic model along P2 through stations S_4, S_5, S_2 and S_6 is presented in Figure 6.

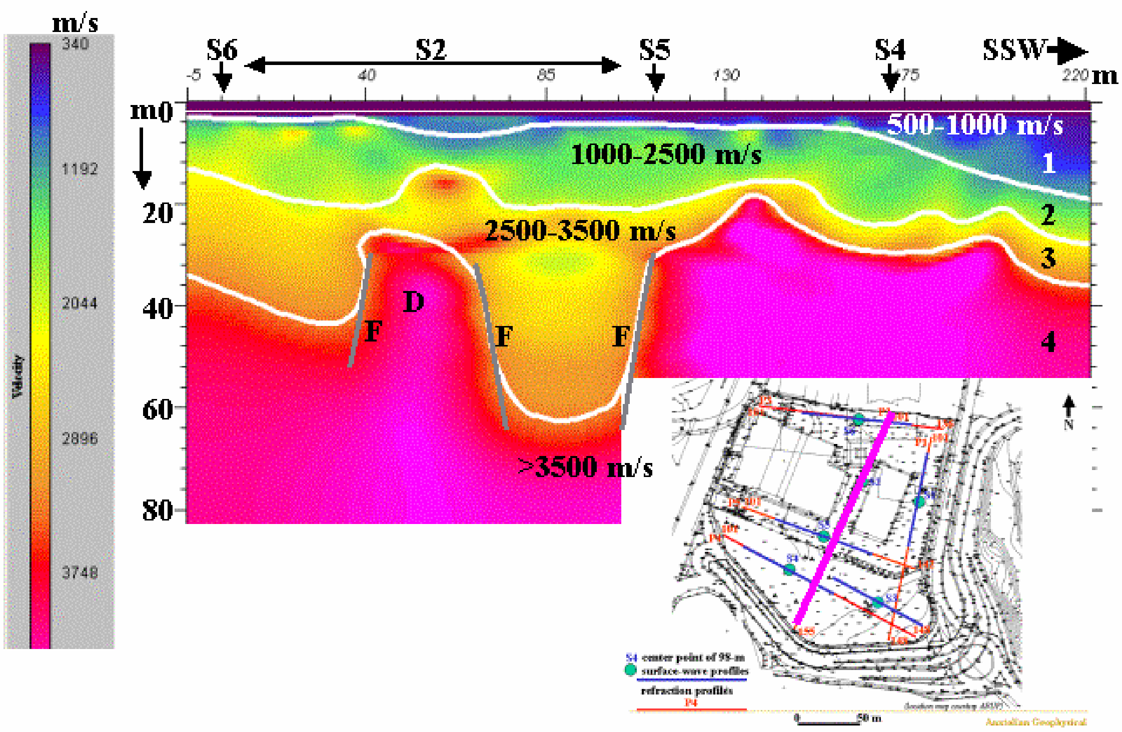

Figure 6. Structural interpretation of the P-wave velocity-depth model for a seismic line from the Zincirlikuyu-Çiftçiler Tower site with velocity-based layer identification. D is probably a dike and gray lines denoted by F are probably faults.

The near-surface at the comprises three main units starting from the ground level: (1) top soil and/or fill with v_p velocities varying between 500-1,000 m/s and thickness varying between 3-18m; v_s=200-600m/s (2) heterogeneous layer with velocities varying between 1,000-2,500m/s in most parts of the site and thickness varying between 10-35m; v_s=600-1200m/s (3) homogeneous layer with velocities varying between 2,500-3,500m/s, mostly in the vertical direction, and thickness varying between 10-20m. Below the near-surface layers is the geological bedrock with velocities exceeding 3,500m/s. P-wave velocities generally are 10-20% higher in the NS direction than the velocities in the EW direction, particularly within the third layer and bedrock. Such directional difference in velocities may be attributed to seismic anisotropy caused by fracture surfaces in the EW direction that may be present in the third layer and bedrock. The depth of the near-surface-bedrock interface varies between 20-45m. The interfaces between the near-surface units and the near-surface-bedrock interface have a prominent three-dimensional character. Some dikes and faults can also be inferred from the structural interpretation of the P-wave velocity-depth models based on velocity contrast. The variation of v_s with depth obtained at four stations, i.e. S_4, S_3, S_2, S_6 is shown in Figure 7.

Soyak Tower Site

Seismic modeling of this site is given in Figure 2 previously. it is seen that Vs velocities as low as 400 m/s are measured in surficial layers close to the ground surface. The average shearwave velocity to a depth of 15m is about 500 m/s and the Vs is as high as 1100m/s within the bedrock.

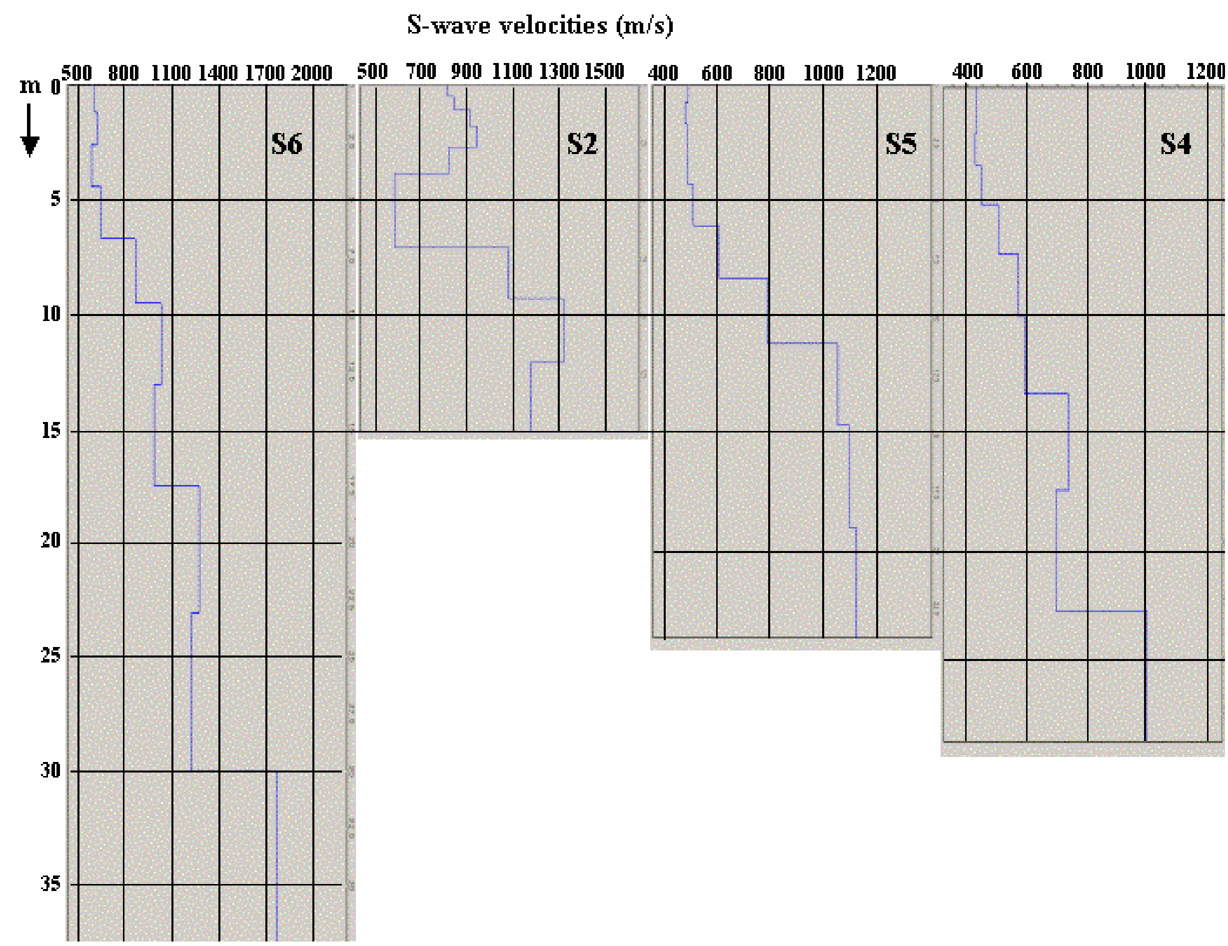

Figure 7. The S-wave velocity-depth profiles from the Zincirlikuyu-Çiftçiler Tower site along the seismic line associated with the P-wave velocity-depth model in Figure 6.

DEFINITION OF ROCK BASED ON V_S VALUES

The V_s^* values for many strong-motion recording sites used in various ground-shaking regression attenuation relationships is poorly established. Usually, the mean shear wave velocity in the upper 30 meters V_s^* m/s is used. However, appropriate V_s^* m/s values for various subjective site descriptions currently are being debated as shown at the Table 1.

Table 1. Definition of Soil Formation Based on V_s^* Values

Reference	Vs^* (m/s)				
	Weak Soil	Firm Soil	Soft Rock	Firm Rock	Hard Rock
Borcherdt, 1994	150	290	540	1050	1620
Boore et al., 1997	<180	180-360	360-750	>750	-
BSSC, 1998	<180	180-360	360-760	760-1500	>1500
Willes and et al., 2000	-	289	372	724	-
Frankelet et al., 2000	-	-	-	760	-
Campbell and Bozovgnia, 2003	163	301	372	718	-

Based on the table given modeled greywacke formation in three different tower sites could be described as soft rock/firm rock, considering that average V_s^* value were 820 m/s for the three sites considered.

MODULUS DEGRADATION

The modulus degradation values have been determined for the soils in the past by various authors. However, almost no data exists for the rock conditions. However, present study gave the opportunity to determine such ratio for the soft/firm rock conditions. The modulus ratios for the subject three sites are presented in Figure 8. It may be seen that closer to ground surface 0-30m for pertinent soft rock conditions the ratio is about 30 to 50, on the other hand, for deeper layers, 30^+ m, pertinent firm rock conditions the ratio is about 50-200. Based on the previous studies and this study, table 2 is recommended to be used for shear modulus degradation ratios for various soil/rock conditions.

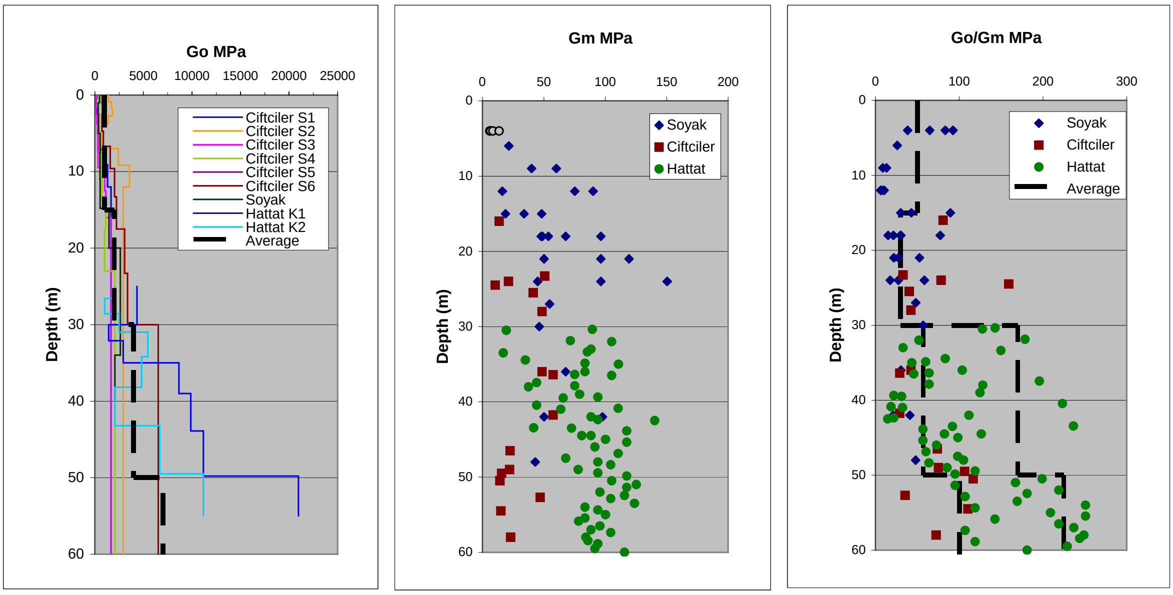

Figure 8. The Shear Modulus Ratios For Subject Three Site for Soft/Firm Rocks

Table 2. Recommended Shear Modulus Degradation Ratios

	Modulus Ratio, G_o/G_m	References
Loose-Medium Sand(Dr=30-75%)	10-20	Seed and Idriss, 1970
Dense Sand(Dr=75-100%)	20-25	
Cemented sands	30-50	Wang, 1986
Soft Rocks	30-50	Present Study
Firm Rocks	50-200	

SUMMARY AND CONCLUSIONS

- The integrated seismic survey described in this paper utilizing both refraction and surface wave measurement techniques gave a good opportunity to obtain the seismic modelling in the soft/firm rocks.
- The integrated approach involving both seismic survey for very low strain levels and pressuremeter tests for very high strain levels permit the determination of shear modulus degradation ratio for the encountered soft and firm rocks.
- Based on the results of this study together with previous studies, it is seen that the shear modulus degradation increases with the material brittleness. In other words, the ratio is as low as 10-25 for loose to dense sands and as high as 30-50 for soft rocks and 50-200 for firm rocks. These results suggest that, during strong earthquakes, comparatively there will be a great reduction even much higher in the stiffness (modulus) of the bedrock as well as in case of soil formations.

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REFERENCES

Baguelin F. et al., *The Pressuremeter and Foundation Engineering*, Trans Tech Publications, 1978

Boore D.M. et al., "Equations for Estimating Horizontal Response Spectra and Peak Acceleration from Western North America Earthquakes: A summary of Recent Work," *Seismological Research Letters*, Vol.68, No.1, pp.128-163, 1997

Borcherdt R.D., "Estimates of Site-Dependent Response Spectra for Design (Methodology and Justification)," Eartquake Spectra, Vol. 10, p. 617-653

BSSC(1998),"Edition NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, Parts I and II," *FEMA 302/303*, Washington D.C., 1977

Campell K.W., "Emprical New Source Attenuation Relationships for Horizontal and Vertical Components of Peak Ground Acceleration, Peak Ground Velocity, and Pseudo-Absolute Accelerations Response Spectra, Seismeological Research Letters, Vol. 68, No. 1, 1997

Campell K.W. and Bozovgnia Y. "Updated Near-Source Ground Motion Attenuation Relations for The Horizontal and Vertical Components of Peak Ground Acceleration and Acceleration Response Spectra," *Bulletin of the Seismological Society of America*, Vol. 93, 2003

Dobry R. and Vucetic M., "State of the Art Report: Dynamic Properties and Response of Soft Clay Deposits," *Proc. Int. Symp. On Geotechnical Engineering of Soft Soils*, Vol.2, p.51-87, 1987

Frankelet A. et al. "USGS National Seismic Hazard Maps," *Earthquake Spectra*, Vol.16, No.1, p.1-19, 2000

Parsons T.S. et al., « Heightened Odds of Large Earthquake Near Istanbul: An Interaction Based Probability Calculation," Science, 288, p. 661-665, 2000

Seed H.B. and Idriss I.M., "Soil Moduli and Damping Factors for Dynamic Response Analysis," ReportNo.EERC 70-10, University of California, Berkeley, 1970

Wang V.D., "Investigation of Constitute Relations for Weakly Cemented Sands," Ph.D. Thesis, University of California, Berkeley, p.293, 1986

Willis,C.J. et al., "A site-Conditions Map for California Based on Geology and Shear-Wave Velocity," *Bulletin of The Seismological Society of America*, Vol.90, p.187-208, 2000

Xia, J. et al., “Estimation of Near-Surface Shear-wave Velocity by Inversion of Rayleigh Waves” *Geophysics*, 64, 691-700, 1999.

Yilmaz, O. et al., “Seismic, Geotechnical, and Earthquake Engineering Site Characterization,” *Expanded Abstracts*, *76th Annual International Meeting of the Society of Exploration Geophysicists*, New Orleans, 2006.

Zhang J. and Toksoz M. N., “Nonlinear refraction traveltime tomography,” *Geophysics*, 63, 1726-1737, 1997.