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**STRONG GROUND MOTION ATTENUATION
RELATIONSHIP MODEL BY USING NEURAL
NETWORK METHODOLOGY**

**M.Sc. Thesis by
Mustafa Birkan BAYRAK, B.Sc.**

501021252

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Supervisor (Chairman): Assoc. Prof. Dr. Derin N. URAL

Members of the Examining Committee: Prof.Dr. Ahmet SAĞLAMER

Prof.Dr. Kutay ÖZAYDIN (Y.T.Ü.)

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**YAPAY SİNİR AĞLARI KULLANILARAK ELDE
EDİLEN KUVVETLİ YER HAREKETİ AZALIM
İLİŞKİLERİ MODELİ**

YÜKSEK LİSANS TEZİ

İnş. Müh. Mustafa Birkan BAYRAK

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Tez Danışmanı : Doç.Dr. Derin N. URAL

Diğer Jüri Üyeleri: Prof.Dr. Ahmet SAĞLAMER

Prof.Dr. Kutay ÖZAYDIN (Y.T.Ü.)

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PREFACE

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ÖNSÖZ

İstanbul Teknik Üniversitesi İnşaat Mühendisliği Bölümü Zemin Mekaniği ve Geoteknik Anabilim Dalı'nın bana yüksek lisans yapma olanağı tanıyan saygıdeğer öğretim üyelerine minnet dolu teşekkürlerimi bildirmek isterim. Özellikle danışmanım Doç. Dr. Derin URAL'a çalışmalarım boyunca gösterdiği rehberliği ve anlayıştan dolayı ve Geoteknik Anabilim Dalı Başkanımız Prof. Dr. Ahmet SAĞLAMER'e değerli desteklerinden dolayı en içten teşekkürlerimi sunmak istiyorum. Ayrıca bu tezi hazırlamam sırasında göstermiş olduğu yardımlardan dolayı da Nergis Anı ANIL'a teşekkürü borç biliyorum.

Son olarak, aileme de vermiş oldukları sonsuz destekten ötürü minnettarım. Bu tezin hazırlanması aylar süren uzun çalışma saatleri sonunda bitmiştir; onların anlayışı ve cesaretlendirmeleri olmadan bunu gerçekleştiremezdim.

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Mustafa Birkan BAYRAK

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ABBREVIATIONS

ANN	: Artificial Neural Network
BP	: Back-Propagation
COSMOS	: Consortium of Organizations for Strong-Motion Observation Systems
ENA	: Eastern North America
EPRI	: Electric Power Research Institute
ERD	: Earthquake Research Department of General Directorate of Disaster Affairs
GDDA	: General Directorate of Disaster Affairs
GMDH	: Group Method of Data Handling
GRNN	: General Regression Neural Network
HW	: Hanging Wall
IM	: Intensity Measure
ITU	: Istanbul Technical University
KOERI	: Kandilli Observatory and Earthquake Research Institute
LD	: Columbia University Lamont-Doherty Group
NAF	: North Anatolian Fault
NN	: Neural Network
PEER	: Pacific Earthquake Engineering Research
PGA	: Peak Ground Acceleration
PGV	: Peak Ground Velocity
PHA	: Peak Horizontal Acceleration
PHV	: Peak Horizontal Velocity
PNN	: Probabilistic Neural Network
PVA	: Peak Vertical Acceleration
RE	: Random Effects
SA	: Spectral Acceleration
UBC	: Uniform Building Code
USGS	: United States Geological Survey
WLS	: Weighted Least Squares

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LIST OF SYMBOLS

a	: Acceleration
a₁,a₂,a₃...	: Attenuation relationship coefficients
c₁,c₂,c₃...	: Attenuation relationship coefficients
D_b	: Depth to basement rock
ε	: Random error term
ε_e	: Epistemic uncertainty
ε_a	: Aleatory uncertainty
F	: Style of faulting factor
h	: Focal depth
m	: Magnitude
r	: Site-source distance
r_{cen}	: Center of energy release distance
r_{hypo}	: Hypocenter distance
r_{jb}	: Surface projection distance
r_{sels}	: Seismogenic depth distance
S_a	: Spectral acceleration
S_{HR}	: Hard rock site factor
S_{SR}	: Soft rock site factor
S_{sr}, S_{hr}	: Soft rock, hard rock factors
σ	: Standard deviation
X_i	: Input vector of the i th training data set
u	: Displacement
v	: Velocity
y	: The actual value
ŷ	: The predicted value
ȳ	: The mean of the y values
y	: The actual value
y	: The actual value
Y_i	: The output related to X _i
Z_t	: Subduction zone source factor

YAPAY SİNİR AĞLARI KULLANILARAK ELDE EDİLEN KUVVETLİ YER HAREKETİ AZALIM İLİŞKİLERİ MODELİ

ÖZET

Kuvvetli yer hareketi parametreleri için azalım ilişkilerinin tahmini deprem mühendisliği alanında ilginç bir araştırma sahası oluşturmaktadır ve sismik tehlike analizleri, depreme dayanıklı yapı tasarımı, sismik güvenlik değerlendirmesi, sismik bölgeleme gibi konularda çok önemli bir role sahiptir.

Bu çalışmada, Türkiye'nin kuzeybatısındaki değişik istasyonlarda alınmış gerçek kuvvetli yer hareketi kayıtları kullanılarak ölçülmüş maksimum yatay ve düşey ivmelerin azalımını tahmin etmek için yapay sinir ağları modeli kullanılmıştır. Çalışmadaki amaç, deprem parametreleri, zemin etkileri ve yer hareketindeki azalımın arasındaki kompleks ilişkinin yapay sinir ağları da kullanılarak modellenmesidir. Bu amaçla General Regression Neural Network (GRNN) yapısı kullanılmıştır. Temel olarak, dört deprem ve zemin parametresi programa girdi olarak verilmiş ve en iyi sonuçlara ulaşabilmek için değişik modeller ve yapılar denenmiştir.

Detayları çalışmada ayrıntılı olarak sunulmuş olan önerilen modeller, Türkiye'nin kuzeybatı bölgesinde, büyüklüğü 5.0 ile 7.4 arasında olan depremler için maksimum yatay yer ivmesi bileşenlerinin geometrik ortalamasının ve maksimum düşey yer ivmesinin tahmini için düşünülmüştür. Türkiye'nin kuzeybatısındaki yakın geçmişteki depremlere ait alınmış kuvvetli yer hareketi kayıtlarına ulaşılabilindiğinden bahsedilen azalım ilişkisi modelleri geliştirilebilmiştir.

Çalışmanın ilk bölümünde, toplam 202 kuvvetli yer hareketi kaydı maksimum yatay yer ivmesinin geometrik ortalamasının tahmini için kullanılmıştır. Herbir girdi parametresinin sonuca olan hassasiyeti incelendiğinde, maksimum yatay ivmeyi veren ilk modeldeki en önemli parametreler sırası ile, 1) Deprem büyüklüğü, 2) Deprem kaynağı ve istasyon arası uzaklık, 3) İstasyon altındaki zemin sınıfı, 4) Deprem derinliği olarak bulunmuştur.

Çalışmanın ikinci bölümünde, toplam 202 kuvvetli yer hareketi kaydı maksimum düşey yer ivmesinin tahmini için kullanılmıştır. Herbir girdi parametresinin sonuca olan hassasiyeti incelendiğinde, maksimum düşey ivmeyi veren ikinci modeldeki en önemli parametreler sırası ile, 1) Deprem kaynağı ve istasyon arası uzaklık, 2)

İstasyon altındaki zemin sınıfı, 3) Depremi büyüklüğü, 4) Depremi derinliği olarak bulunmuştur.

Kabul edilen hata sınırları çerçevesinde, maksimum yatay ivmeyi veren modelde %98, maksimum düşey ivmeyi veren modelde ise %99'luk bir başarı oranına ulaşılmıştır. Bu sonuçlar, yapay sinir ağlarının, zemin ve sismik parametreler ile kuvvetli yer hareketindeki azalılar arasındaki ilişkinin incelenmesinde güvenilir olduğunu göstermektedir.

Bu çalışmayı kendisinden önceki çalışmalardan ayıran bir özellik de, önerilen azalılar ilişkisi modellerinin yapay sinir ağları ile elde edilmiş ilk modeller olmalarıdır.

Belirtilmesi gereken bir diğer konu da, bu çalışmada sadece Türkiye'nin kuzeybatısında gerçekleşen depremlerin verilerinin kullanıldığı, dolayısıyla da modelin yine bu bölgedeki yatay ve düşey ivme değerlerinin tahmini için kullanılması gerektiğidir.



STRONG GROUND MOTION ATTENUATION RELATOIONSHIP MODEL BY USING NEURAL NETWORK METHODOLOGY

SUMMARY

Estimation of an attenuation relationship for strong ground motion parameters has been an interesting research subject in the field of earthquake engineering and has played a very important role in seismic hazard analysis, earthquake resistant design, seismic safety evaluation, seismic zoning, etc. The first important work is to choose a proper parameter to establish the attenuation relationship.

In this study, an investigation on the application of neural computing methods in prediction of attenuation of the peak horizontal and vertical accelerations recorded in different stations has been performed using actual strong-motion records. The emphasis is on obtaining optimized neural network architecture to model the complex relationship between the earthquake source parameters, site effects, and the attenuation of ground motions. For this purpose, programs written in GRNN algorithm is used. Basically, four earthquake and site parameters are selected as input, and different models are constructed to reach the best results.

The proposed attenuation relationship model presented in detail in this study is considered to estimate geometric mean of the horizontal peak ground acceleration and vertical peak ground acceleration for earthquakes with magnitude in the range M_w 5 to 7.4 in northwestern part of the Turkey. The attenuation models developed here have been proposed due to the availability of numerous strong ground motion records from recent earthquakes in Northwestern Turkey.

In the first part of the study, a total of 202 strong ground motion records are used to estimate the geometric mean of horizontal peak ground acceleration. As the input smoothing factor of each input parameter of the PHA model is considered, it is observed that the most important parameters on attenuation are 1) magnitude, 2) hypocentral distance, 3) site classification, and 4) the depth of the earthquake, respectively.

In the second part of the study, a total of 202 strong ground motion records are used to estimate the vertical peak ground acceleration. As the input smoothing factor of each input parameter of the PVA model is considered, it is observed that the most important parameters on attenuation are 1) hypocentral distance, 2) site classification, 3) magnitude, and 4) the depth of the earthquake, respectively.

The results, with an overall success rate of 98% in PHA and 99% in PVA (by the assumed error limits), indicates the reliability of neural networks to examine relationships between the soil and the seismic parameters on attenuation of the strong ground motions.

One of the most important advantages of this study is that the proposed attenuation relationship models are the first models developed by using neural network methodology.

This study is region-specific as only recordings from earthquakes that have occurred in Northwestern Turkey were used in the analyses. The models developed are, therefore, only recommended for prediction of ground motions in Northwestern Turkey.



1. INTRODUCTION

1.1 General

The earth is far from quiet, it vibrates almost continuously at periods ranging from milliseconds to days and amplitudes ranging from nanometers to meters. The great majority of these vibrations are so weak that they cannot be felt or even detected without specialized measurement equipment. Such microseismic activity is of greater importance of seismologists than engineers. Earthquake engineers are interested primarily in strong ground motion (i.e., motion of sufficient strength to affect people and their environment). Evaluation of the effects of earthquakes at a particular site requires objective, quantitative ways of describing strong ground motion.

The ground motions produced by earthquakes can be quite complicated. At a given point, they can be completely described by three components of translation, and three components of rotation. In practice, the rotational components are usually neglected; three ground motion records contain a tremendous amount of information. To express all of this information precisely, every twist and turn in each plot must be described.

Fortunately, it is not necessary to reproduce each time history exactly to describe the ground motion adequately for engineering purposes. It is necessary, however, to be able to describe the characteristics of ground motion that are of engineering significance and to identify a number of ground motion parameters that reflect those characteristics. For engineering purposes, three characteristics of earthquake motion are of primary significance: (1) the amplitude, (2) frequency content, and (3) duration of the motion. A number of different ground motion parameters have been proposed, each of which provides information about one or more of these characteristics.

The most common way of describing a ground motion is with a time history. The motion parameter may be acceleration, velocity or displacement, or all three may be displayed. Typically, one of these quantities is measured directly with the others computed from it by integration and/or differentiations (Kramer, 1996).

1.2 Literature Survey

Neural Network applications in geotechnical engineering are a new successful methodology when compared to conventional computational methods. In this study, the use of these tools in attenuation relations is presented. Predictive relationships for parameters that decrease with increasing distance (such as peak acceleration and peak velocity) are often referred to as attenuation relationships. A few of a large number of attenuation relationships for different geographic and tectonic environments are described in the literature.

Researchers involved in the development of attenuation relationships have developed a wide range of procedures for data analysis, each attempting to properly address data sampling issues so that the overall aleatory variability (i.e., sum of inter- and intra-event variability) in attenuation relations is properly quantified. Some of the common means by which these data weighing issues are treated are discussed below:

Joyner and Boore (1981) proposed a two-step regression procedure in which all data points are weighed equally to derive the shape of the function describing the variation of spectral acceleration with distance (i.e., the change of S_a with changes in r), and all events are weighed equally to derive the magnitude dependence of spectral quantities (i.e., the change of S_a with changes in m). Joyner and Boore (1993, 1994) have also proposed a one-step regression procedure that is similar in concept to the Brillinger and Preisler (1984, 1985) method discussed below, and produces regression results similar to the two-step procedure.

Campbell (1981) uses a weighed least squares regression that is performed as follows: The ground motion inventory is first “binned” according to m and r (i.e., all data within a limited range of m and r is placed into a “bin”), each bin of data is given equal weight in the regression, and within a bin, the collective data from each event are weighed equally.

Brillinger and Priesler (1984, 1985) developed a random effects model that is typically applied as described by Abrahamson and Youngs (1992). As part of the regression procedure, estimates of inter- and intra-event error are produced, as are “event terms” that represent the event-specific mean residuals in the data. Regression coefficients are estimated from a data set in which ground motion parameters are modified by subtraction of event terms. With the data set “corrected” in this manner, all data points are weighed equally. The standard error is the sum of the inter- and

intra-event error. For earthquakes with large data residuals, the random effects method evaluates how much of the event term is likely due to random sampling of the intra-event distribution, and how much is due to true inter-event variability. For example, the event terms for a well-recorded event are taken essentially as the mean residuals (since the median of the data is well established from the large sample), whereas event terms for poorly sampled events are less than the mean residual (since some of the residual may be due to intra-event variability).

Idriss (1991, 1994) does not perform formal regression analysis, but has developed relations that are judgment based. The relations are formed by postulating a model, studying the residuals, and revising the model as necessary.

There are different ground motion attenuation relationships for the different regions and zones. The attenuation relationships which are widely used for the active tectonic regions developed by the some researchers are given below.

N. A. Abrahamson and W. Silva, (1997), derive empirical response spectral attenuation relationships for both the horizontal and vertical components of ground motion. They explicitly include a factor to account for the systematic increase in ground motions recorded at sites over the hanging wall of dipping faults. They also explicitly allow non-linear soil response as a function of the expected peak ground acceleration on rock. David M. Boore, William B. Joyner, and Thomas E. Fumal, (1997), present updates of their earlier model. They now differentiate the responses for strike-slip, reverse-slip, and unspecified faulting, and more restrictive ranges of M and r_{jb} for use in their equations. Unlike the other models, they use a quantitative measure for the site classification based on the average shear wave velocity in the upper 30 m. Kenneth W. Campbell (1997), summarizes the results of several years work developing empirical relationships for horizontal and vertical PGA, PGV, and SA in active tectonic regions. These latest versions were developed using a much larger data set than earlier versions. Campbell's suite of attenuation relationships are designed to be used to estimate ground motion from earthquakes of $M > 5$ at sites within 60 km. K. Sadigh, C.-Y. Chang, J.A. Egan, F. Makdisi, and R.R. Youngs, (1997), present attenuation relationships for shallow crustal earthquakes determined from strong ground motion data recorded primarily in California. Their relationships for horizontal and vertical PGA and SA are applicable to earthquakes of M 4 to 8+ at distances of up to 100 km. P. Spudich, J.B. Fletcher, M. Hellweg, J. Boatwright, C. Sullivan, W.B. Joyner, T.C. Hanks, D.M. Boore, A. McGarr, L.M. Baker, and A.G., (1997) derived a new predictive relationship for PGA and SA using a global data set of earthquake ground motions recorded in extensional tectonic regimes. In

general, their values for PGA and SA are smaller than those derived by other researchers for active tectonic regions.

The strong ground motion attenuation relationships developed for the stable continental regions are given below.

Gail M. Atkinson and David M. Boore (1997) use empirical recordings from small to moderate size earthquakes recorded by the Eastern Canadian Telemetered Network and isoseismals from historic earthquakes to constrain some of the parameters in the stochastic point source model. Toro, G.R., Abrahamson, N.A., and Schneider, J.F.(1997) divide eastern North America into Mid-continent and Gulf Coast subregions, each with its own attenuation relationship.

The attenuation relationships developed for the subduction zones are given below.

R.R. Youngs, S.-J. Chiou, W.L. Silva, and J.R. Humphrey (1997) develop attenuation relationships for subduction zone interface and intraslab earthquakes using data from Alaska, Chile, Cascadia, Japan, Mexico, Peru, and the Solomon Islands. Gail M. Atkinson and David M. Boore (1997) develop preliminary ground motions for the Cascadia region. John G. Anderson (1997) presents a nonparametric model for peak ground acceleration for subduction zone events developed using only data from the Geurrero, Mexico, accelerograph network.

1.3 Objective

Estimation of an attenuation relationship for strong ground motion parameters has been an interesting research subject in the field of earthquake engineering and has played a very important role in seismic hazard analysis, earthquake resistant design, seismic safety evaluation, seismic zoning, etc. The first important work is to choose a proper parameter to establish the attenuation relationship.

In this study, an investigation on the application of neural computing methods in prediction of attenuation of the peak horizontal and vertical accelerations recorded in different stations has been performed using actual strong-motion records. The emphasis is on obtaining optimized neural network architecture to model the complex relationship between the earthquake source parameters, site effects, and the attenuation of ground motions. For this purpose, programs written in GRNN algorithm is used. Basically, four earthquake and site parameters are selected as input, and different models are constructed to reach the best results.

We have been faced with many hazardous earthquakes in our country and, in the end; we see not only the impact on the economical and social life but also the essential precautions. Among the nations all over the world, only a few, have a good understanding about the information of damage caused by earthquakes, so as we a civil engineer we should be well aware of the fact that all communities should work together and share information to minimize the significant hazards caused by earthquakes. For that reason, we would like to mention that we are completely ready to make partnerships with other researchers to obtain the efficient methodologies in order to reduce the damage caused by an earthquake.

As we are racing towards the 21st century, population density of a certain community on a certain place is getting larger and larger day by day, and the impact of potential earthquake has become complex. Our purpose to become a civil engineer is that we are eager to engage in the steps taken against earthquakes since we grew up in a community that has suffered a lot from the hazards caused by previous earthquakes. The importance of civil engineering in the development of modern society cannot be ignored, and our aim is to develop positive movements immediately to reduce the impact of earthquakes to social, economical, political, and environmental life.

2. STRONG GROUND MOTION EVALUATION PROCEDURES FOR PERFORMANCE BASED DESIGN

2.1 Introduction

Strong-motion seismology is the science concerned with the measurement, interpretation and estimation of strong shaking generated by potentially damaging earthquakes. Measurements of strong shaking generated by large earthquakes provides a principal tool, first, to understand the high-frequency nature of crustal seismogenic failure processes, the nature of seismic radiation from the source, and the nature of crustal wave-propagation phenomena near the source, all of which have a first order effect on the seismic loads applied to the physical environment. Second, these measurements are a principal tool used to develop empirical descriptions of the character of strong shaking. Principal goals of strong motion seismology are to improve the scientific understanding of the physical processes that control strong shaking and to develop reliable estimates of seismic hazards for the reduction of loss of life and property during future earthquakes through improved earthquake resistant design and retrofit.

The strongest earthquake motions that have been recorded to date have peak accelerations between 1 g and 3 g, where 1 g ($= 980 \text{ cm/s}^2$) is the acceleration of the earth's gravity field, although records with such large peak values are rare. It is less clear what threshold of ground motion needs to be exceeded to be considered "strong motion." Probably a logical level to choose would be about 10 cm/s^2 , as the older strong-motion instruments (accelerographs) that traditionally defined the field are not able to resolve ground accelerations with amplitudes smaller than this. Modern digital accelerographs are much more sensitive, able to resolve peak accelerations to 0.1 cm/s^2 or smaller. People at rest are able to feel motions as small as 1 cm/s^2 . The lower limit of acceleration perceptible to people is set by observation and experiment at approximately $0.001g$ or 1 cm/sec^2 at between $0.1g$ and $0.2g$ most people will have difficulty keeping their footing and ill symptoms may be induced. In moderate magnitude earthquakes, damage to structures that are not designed for earthquake resistance appears at accelerations of about 100 cm/s^2 .

Earthquakes with magnitude less than 5 are of minor concern for strong motion seismology. They are not known to damage structures of modern construction. Only a small fraction of such small events has caused deaths, and the number of deaths is minimal except in extraordinary circumstances of extremely poor construction and

faulting directly under a population center. As the magnitude grows, both the destructive capability and average number of deaths per event also grows. Events with magnitudes between 6 and 7.5 are the most commonly responsible for significant losses. Events with magnitude over 8, of course, have immense destructive potential, but fortunately they occur at an average rate of only about once per year, and some are located in remote oceanic locations.

Observation of strong motion is more difficult than the observations in other fields of seismology due to the infrequency of large earthquakes and the difficulty of anticipating areas of strong shaking for instrumentation. An earthquake with magnitude greater than 6 can be recorded worldwide. Thus a seismologist who studies teleseisms can record on the order of 100 earthquakes per year, for interpretations of earth structure or tectonics. Similarly, local networks are generally set to the most sensitive level possible to detect and locate the smallest earthquakes, which are much more abundant. The sensitive instruments used for these two branches of earthquake studies are driven off scale by strong shaking, and thus their records cannot be used. A specialized instrument, the strong motion accelerograph, was developed in the 1930's to record strong motion. A network of these specialized instruments must furthermore have the good fortune to be located close to the earthquake, and must be maintained, often for decades, in a state of readiness to record the rare strong shaking. In the 1990's, the situation changed somewhat with improvements in digital recording technology. A strong motion accelerograph manufactured in the second half of the 1990's has an analog-to-digital converter with resolution of at least 16, and typically 19, bits, allowing it to record nearby earthquakes with magnitude of 2 to 3 with a useful signal-to-noise ratio. With that capability, it can make a meaningful contribution to network seismology, and consequently is worth including as part of the real-time networks in seismic areas. This overlap in instrumental capabilities promises a significant increase in the amount and quality of data that is useful for the objectives of strong motion seismology.

2.2 The Measurement of Ground Motion

Ground motion is recorded by a seismograph, an instrument only in existence since the late nineteenth century. The Chinese seismoscope showed only the principal direction of the earthquake, and did not record its history. The seismograph records the movement over time of a freely supported pendulum within a frame that is attached to the ground.

In modern seismographs, pendulum movement is converted into electronic signals on tape. Strong-motion seismographs, called accelerographs, are designed to record nearby rather than distant ground movement directly, and produce a record called an accelerogram (or seismogram). Instruments are normally placed so as to measure movements along the two horizontal axes and the one vertical. Three measures are of major interest: acceleration, velocity, and displacement. Acceleration is the rate of change of velocity: when multiplied by mass it results in the inertial force which the building must resist. Acceleration is commonly measured in g, the acceleration of a free falling body due to earth's gravity (approx. 32 ft/sec/sec., or 980 cm/sec/sec., or 980 gals, or 1.0g). Velocity, measured in inches or centimeters per second, refers to the rate of ground motion. Displacement, measured in inches or centimeters, refers to the distance a particle is removed from its at rest position.

The accelerogram provides a picture of the ground shaking; accurate interpretation of this picture requires skill and experience. In the accelerogram the arrival of the P wave begins the motion. This is followed by the S wave: the time interval between the two enables the distance from the instrument to the earthquake focus to be calculated. The duration of strong motion shows clearly, and the maximum wave amplitude can be measured directly. The ground acceleration can be calculated by relating amplitude to time. Velocity and displacement are obtained mathematically by integrating the acceleration record once and twice respectively.

2.3 Ground Motion Parameters

Ground motion parameters are essential for describing the important characteristics of strong ground motion in compact, quantitative form. Many parameters have been proposed to characterize the amplitude, frequency content, and duration of strong ground motions; some describe only one of these characteristics, while others may reflect two or three. Due to the complexity of earthquake ground motions, identification of a single parameter that accurately describes all important ground motion characteristics is regarded as impossible (Jennings, 1985; Joyner and Boore, 1988; Kramer, 1996)

2.3.1 Amplitude Parameters

The most common way of describing a ground motion is with a time history. The motion parameter may be acceleration, velocity, or displacement, or all three may be displayed. Typically, only one of these quantities is measured directly with the others computed from it by integration and/or differentiation. The different predominant

frequencies in the acceleration, velocity, and displacement time histories can be noted clearly. The acceleration time history shows a significant proportion of relatively high frequencies. Integration produces a smoothing or filtering effect [in the frequency domain, $\tilde{v}(\omega) = \tilde{a}(\omega)/\omega$ and $\tilde{u}(\omega) = \tilde{v}(\omega)/\omega$, where $\tilde{u}$, $\tilde{v}$, and $\tilde{a}$ are the transformed displacement, velocity, and acceleration, respectively]. Therefore, the velocity time history shows substantially less high-frequency motion than the acceleration time history. The displacement time history, obtained by another round of integration, is dominated by relatively low frequency motion.

2.3.1.1 Peak Acceleration

The most commonly used measure of the amplitude of a particular ground motion is the peak horizontal acceleration (PHA). The PHA for a given component of motion is simply the largest (absolute) value of horizontal acceleration obtained from the accelerogram of that component. By taking the vector sum of two orthogonal components, the maximum resultant PHA (the direction of which will usually not coincide with either of the measured components) can be obtained.

Horizontal acceleration have commonly been used to describe ground motions because of their natural relationship to inertial forces; indeed, the largest dynamic forces induced in certain types of structures (i.e., very stiff structures) are closely related to the PHA. The PHA can also be correlated to earthquake intensity (e.g., Trifunac and Brady, 1975a; Murphy and O'Brien, 1977; Krinitzsky and Chang, 1987). Although this correlation is far from precise, it can be very useful for estimation of PHA when only intensity information is available, as in the cases of earthquakes that occurred before strong motion instruments were available (preinstrumental earthquakes). The use of intensity-attenuation relationships also allows estimation of the spatial variability of peak acceleration from the isoseismal maps of historical earthquakes.

Vertical acceleration have received less attention in earthquake engineering than horizontal accelerations, primarily because the margins of safety against gravity-induced static vertical forces in constructed works usually provide adequate resistance to dynamic forces induced by vertical accelerations during earthquakes. For engineering purposes, the peak vertical acceleration (PVA) is often assumed to be two-thirds of the PHA (Newmark and Hall, 1982). The ratio of PVA to PHA, however, has more recently been observed to be quite earthquakes and less than two-thirds at large distances (Campbell, 1985; Abrahamson and Litehiser, 1989). Peak vertical accelerations can be quite large; a PVA of 1.74g was measured between the Imperial and Brawley faults in the 1979 Imperial Valley earthquake.

Ground motions with high peak accelerations are usually, but not always, more destructive than motions with lower peak accelerations. Very high peak accelerations that last for only a very short period of time may cause little damage to many types of structures. A number of earthquakes have produced peak accelerations in excess of 0.5g but caused no significant damage to structures because the peak accelerations occurred at very high frequencies and the duration of the earthquake was not long. Although peak acceleration is a very useful parameter, it provides no information on the frequency content or duration of the motion; consequently, it must be supplemented by additional information to characterize a ground motion accurately (Kramer, 1996).

2.3.1.2 Peak Velocity

The peak horizontal velocity (PHV) is another useful parameter for characterization of ground motion amplitude. Since the velocity is less sensitive to the higher-frequency components of the ground motion, the PHV is more likely than the PHA to characterize ground motion amplitude accurately at intermediate frequencies. (e.g., tall or flexible buildings, bridges, etc.), the PHV may provide a much more accurate indication of the potential for damage than the PHA. PHV has also been correlated to earthquake intensity (e.g., Trifunac and Brady, 1975a; Krinitzsky and Chang, 1987).

2.3.1.3 Peak Displacement

Peak displacements are generally associated with the lower-frequency components of an earthquake motion. They are, however, often difficult to determine accurately (Campbell, 1985; Joyner and Boore, 1988), due to signal processing errors in the filtering and integration of accelerograms and due to long-period noise. As a result, peak displacement is less commonly used as a measure of ground motion than is peak acceleration or peak velocity (Kramer, 1996).

2.3.1.4 Other Amplitude Parameters

Although the parameters discussed previously are easily determined, they describe only the peak amplitudes of single cycles within the ground motion time history. In some cases, damage may be closely related to the peak amplitude, but in others it may require several repeated cycles of high amplitude to develop. Newmark and Hall (1982) described the concept of an effective acceleration as “that acceleration which is most closely related to structural response and to damage potential of an earthquake. It differs from and is less than the peak free-field ground acceleration. It is a function of the size of the loaded area, the frequency content of the excitation,

which in turn depends on the closeness to the source of the earthquake, and to the weight, embedment, damping characteristic, and stiffness of the structure and its foundation” (Kramer, 1996).

2.4 Strong Ground Motion Stations In Marmara Region

Strong-motion records included in this study are obtained from the stations operated by Earthquake Engineering Department of Bogazici University, Kandilli Observatory and Earthquake Research Institute (KOERI), Istanbul Technical University (ITU), Earthquake Research Department of General Directorate of Disaster Affairs (ERD), and the Columbia University Lamont-Doherty group (LD).

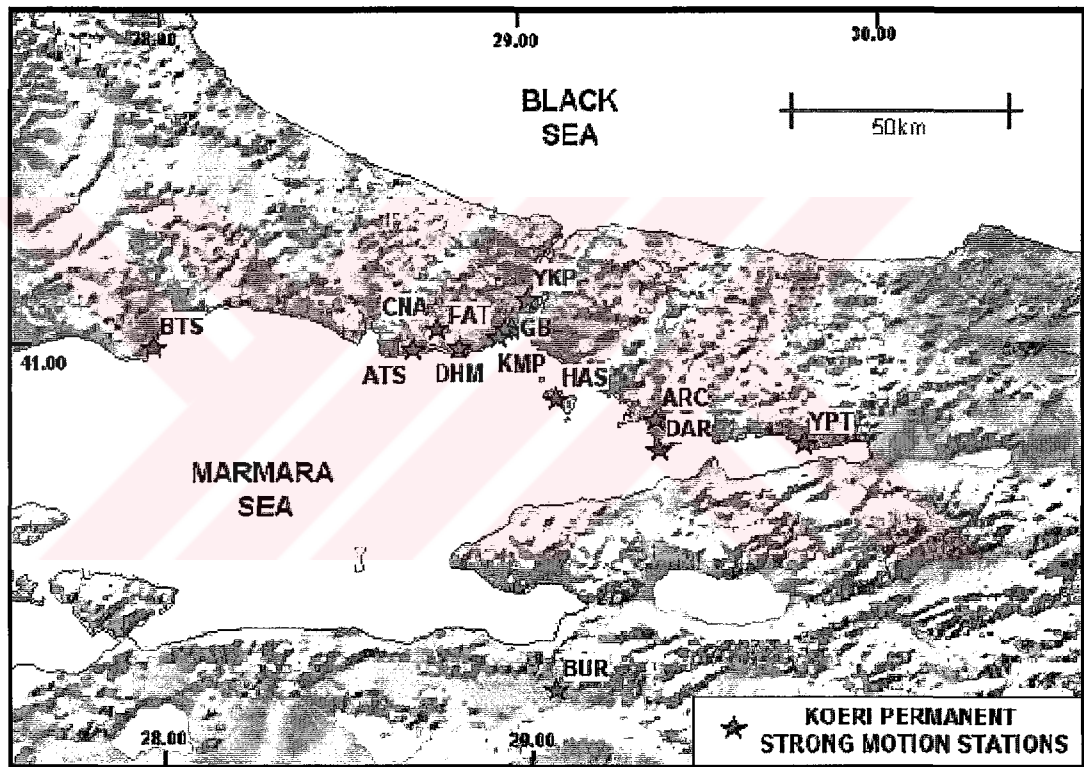


Figure 2.1. KOERI permanent strong motion stations (Özbay, 2003).

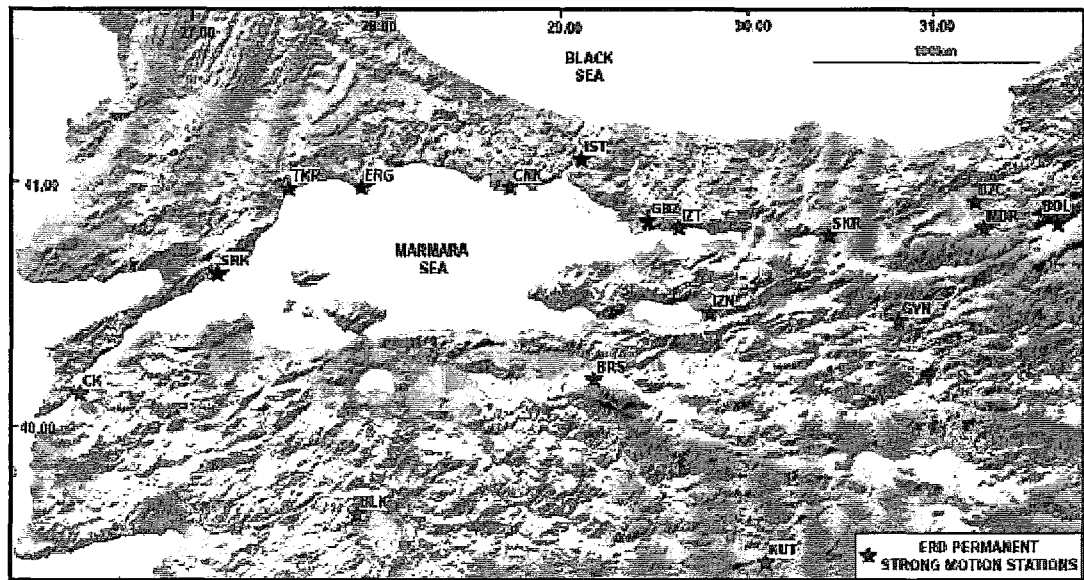


Figure 2.2. ERD permanent strong motion stations (Özbay, 2003).

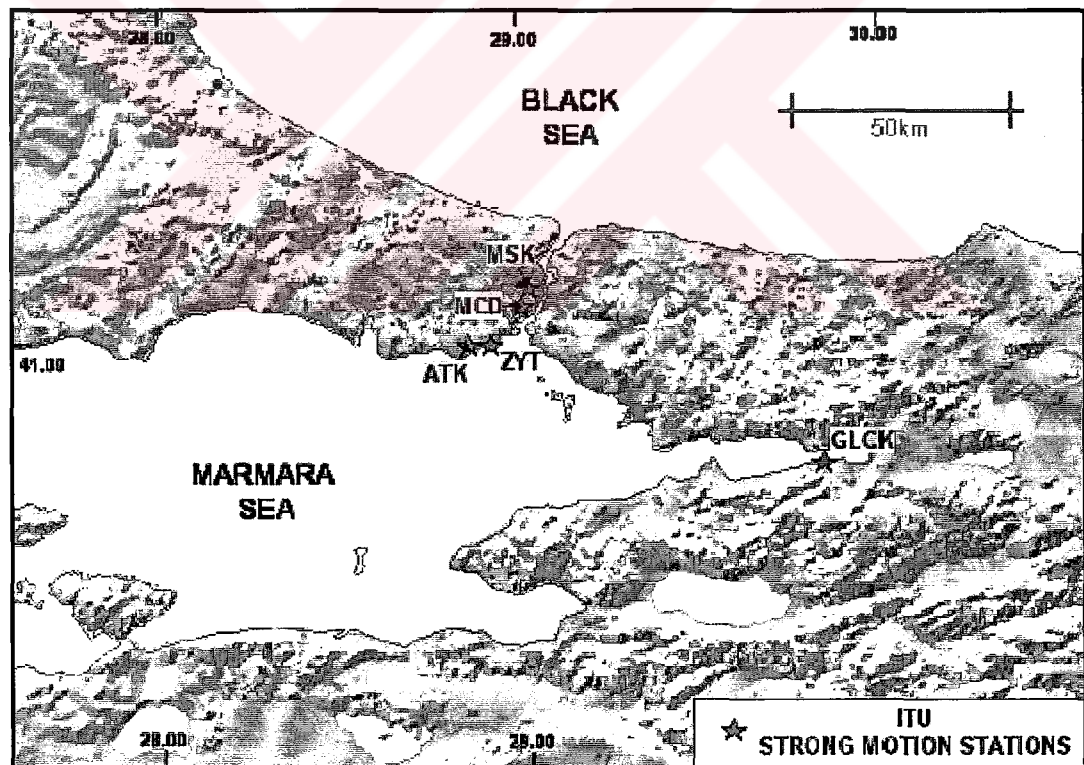


Figure 2.3. ITU permanent strong motion stations (Özbay, 2003).

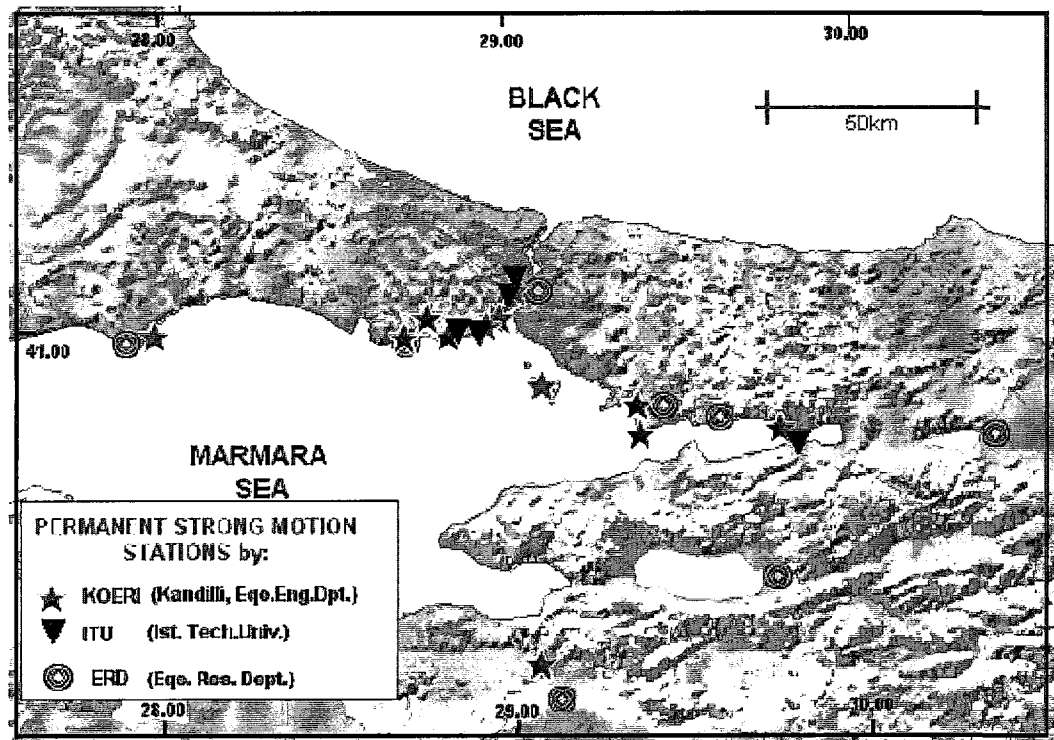


Figure 2.4a. KOERI, ITU and ERD permanent strong motion stations (Özbay, 2003).

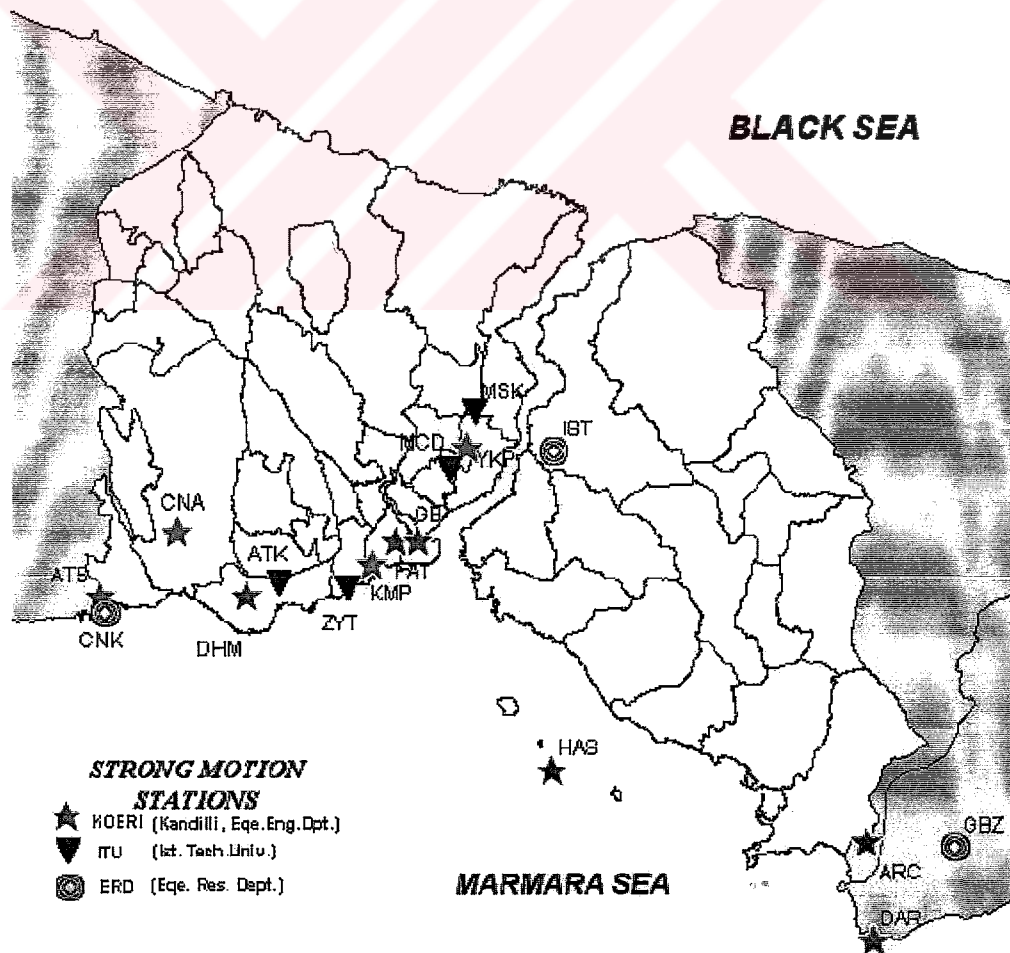


Figure 2.4b. KOERI, ITU and ERD permanent strong motion stations (Özbay, 2003).

3. GROUND MOTION ATTENUATION RELATIONSHIPS

3.1 Introduction

Earthquakes are among the most deadly and expensive natural disasters affecting humankind. Exposure and vulnerability to the effects of earthquakes is increasing as urban centers grow, especially in tectonically active areas. The economic and social effects of earthquakes (and other natural disasters) can be reduced through a comprehensive assessment of seismic hazard and risk that leads to increased public awareness, seismically sensitive land-use planning, and the implementation of seismically sound building construction codes. Clear, well-documented assessments of seismic hazard are the first and fundamental step in the mitigation process.

The need to understand seismic hazard assessments has expanded from the professional seismic engineering and scientific communities to national, state, county, city, and local public officials, the private sector, educators at all levels, and the general citizenry. Demand for information has never been greater, nor has scrutiny of all steps of the processes that were used to produce the assessments.

Seismic hazard assessments can be performed both deterministically (specific earthquake scenarios) and probabilistically (all earthquakes with their specified probabilities of occurrence). Both approaches require ground motion attenuation models. Most attenuation models are based on statistical analyses of recorded ground motions which are updated as new strong motion data become available. These updates typically have been published in gray literature and are not readily available to the seismological and engineering communities at large (<http://geohazards.cr.usgs.gov/engnseis/Eshmpage/abshed.html#shallow>).

A number of modern attenuation relations for the horizontal spectral acceleration which is one of the most important parameters are summarized in Table 3.1.

Table 3.1 Selected attenuation models for horizontal spectral acceleration.

Reference	Regression	m range	r range	r type ²	site	other
	Method ¹		(km)		parameters ³	parameters ⁴
Active Regions						
Boore et al. (1997)	2-step	5.5-7.5	0-100	r_{jb}	30-m V_s	F
Campbell (1997, 2000, 2001)	WLS	4.7-8.1	3-60	r_{seis}	S_{sr}, S_{hr}, D_b	F
Abrahamson & Silva (1997)	RE	>4.7	0-100	r	S	F, HW
Sadigh et al. (1997)	RE	4-8+	0-100	r	S	F
Idriss (1991, 1994)	judgement	4.6-7.4	1-100	r	rock only	F
Spudich et al (1999):ext only	1-step	5-7	0-100	r_{jb}	S	-
Subduction Zones						
Atkinson (1995)	2-step	4-8.2	< 500 (+/-)	r_{hypo}	S	h
Atkinson and Boore (1997a)	simulation	4-8.25	10-400	r_{hypo}	rock only	-
Anderson (1997)	none	3-8.1	14-255	r	rock only	-
Crouse (1991)	Equal	4.8-8.2	1-500	r_{cen}	firm soil only	h
Youngs et al. (1997)	RE	>5	10-500	r	S	Z_t, h
Stable Continental Regions						
Atkinson and Boore (1995, 1997b)	simulation	4-7.25	10-500	r_{hypo}	rock only	-
Toro et al. (1997)	simulation	5-8	1-500	r_{jb}	rock only	-

¹ WLS = weighted least squares; RE = random effects; Equal = all date points weighted equally

² r = site-source distance; r_{jb} = surface projection distance; r_{seis} = seismogenic depth distance r_{hypo} = hypocenter distance; r_{cen} = center of energy release distance

³ S (rock/soil); S_{sr} , S_{hr} , soft rock, hard rock factors, D_b depth to basement rock

⁴ F = style of faulting factor; HW = hanging wall factor; h = focal depth, Z_t = subduction zone source factor.

A number of ground motion parameters other than spectral acceleration and PHA can significantly affect the nonlinear response and performance of structures. For geotechnical structures, such parameters may include arias intensity, duration, mean period, and equivalent number of uniform stress cycles (e.g., Kayen and Mitchell, 1997; Bray et al., 1998; Liu et al., 2001). Attenuation relations for each of these parameters are summarized in Table 3.2.

Table 3.2 Attenuation models for ground motion parameters other than horizontal S_a

Reference	Tectonic	Regress	m range	r range	r type	site	other
	Regime	Method ¹		(km)		parameters ²	parameters ³
Peak Ground Velocity							
Campbell (1997, 2000)	Active	WLS	4.7-8.1	3-60	r_{seis}	S_{sr}, S_{hr}, D	F
Atkinson and Boore (1997a)	Subduc.	simulation	4-8.25	10-400	r_{hypo}	rock only	-
Atkinson and Boore (1997b)	Mil-Pl.	simulation	4-7.25	10-500	r_{hypo}	rock only	-
Vertical Spectral Acceleration							
Abrahamson & Silva (1997)	Active	RE	>4.7	0-100	r	S	F, HW
Campbell (1997, 2000, 2001)	Active	WLS	4.7-8.1	3-60	r_{seis}	S_{sr}, S_{hr}, D_b	F
Sadigh et al. (1993)	Active	not given	not given	not given	r	rock only	-
Anderson (1997)	Subduc.	none	3-8.1	14-255	r	rock only	-
Arias Intensity							
Wilson (1993) and Kayen	Active	not given	not given	1-100	r^*	S + soft soil	h
and Mitchell (1997)							
Duratio/N							
Abrahamson & Silva (1996)	Active	Equal	>4.7	0-100	r	S	-
Liu et al (2001)	Active	RE	>4.7	0-100	r	S	-
Mean Perion							
Rathje et al (1998)	Active	Equal	>5	0-100	r	-	-

¹WLS = weighted least squares; RE = random effects, Equal = all data equally weighted, sim.= data from simulation

²S (rock/soil); S_{sr} , S_{hr} , soft rock, hard rock factors, D_b depth to basement rock

³F = style of faulting factor; HW = hanging wall factor; h = focal depth

3.2 Factors Affecting Attenuation

The tectonic regime in which earthquakes occur is a fundamental factor affecting ground motion characteristics. Most earthquakes occur in one of three regimes: active tectonic regions (e.g., The North side of Turkey, California), subduction zones (e.g., Washington, Alaska), and stable continental regions (e.g., central and eastern United States). In this section, the effects of a number of seismological variables on spectral accelerations using earthquake data from active tectonic regions will be illustrated (Stewart et al., 2001).

3.2.1 General Formulation and Effect of Magnitude/Distance

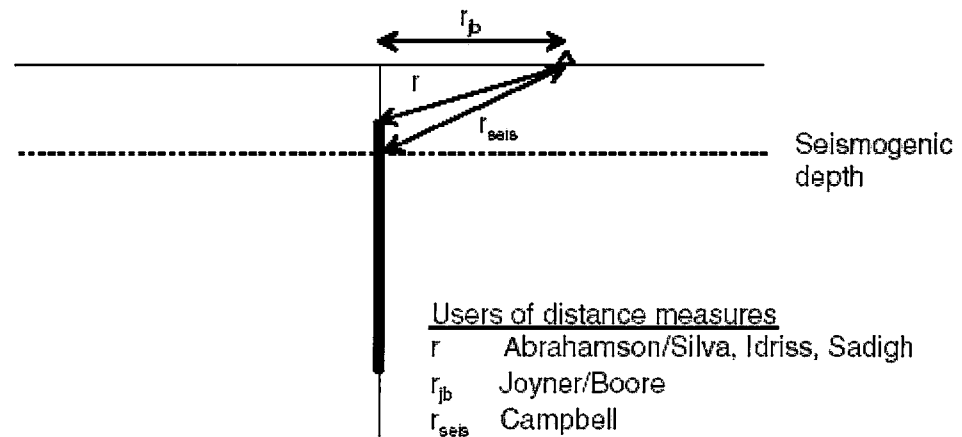
Attenuation functions for median spectral acceleration generally have a form similar to the following:

$$\ln IM = \underbrace{c_1}_{1} + \underbrace{c_2 m + c_3 m^{c_4}}_{2} + \underbrace{c_5 \ln r}_{3} + \underbrace{f(F) + f(HW) + f(S)}_{4} \quad (3.1)$$

where term m represents moment magnitude. Term r represents site-source distance, and is measured differently by different investigators. Common definitions of r are shown in Figure 3.1(a), along with the investigators using the respective distance measures. c_1 to c_5 are constants established by the regression, F is a factor related to the source rupture mechanism, HW is a hanging wall factor for dip-slip faults, and S is a site factor. Figure 3.1(b) defines the geometric limits of the hanging wall for dip-slip faults. Explanations for the numbered terms in Eq. 3.1 are as follows:

1. IM s are generally log-normally distributed, hence regressions are performed on the natural logarithm of the data, which is normally distributed.
2. Several magnitude scales are derived from the logarithm of various peak ground motion parameters. Consequently, $\ln IM$ is approximately proportional to m . However, data from recent earthquakes suggest that this proportionality may break down for high-frequency ground motion parameters (e.g., PHA) at large magnitudes.
3. As body waves travel away from a seismic source, geometric spreading reduces their amplitude by $1/r$ (term c_5 is usually close to -1.0).
4. Fault rupture mechanism (F), the location of a site on or off the hanging wall of dip-slip faults (HW), and local site conditions (S) are observed to affect spectral accelerations.

Vertical Faults



Dipping Faults

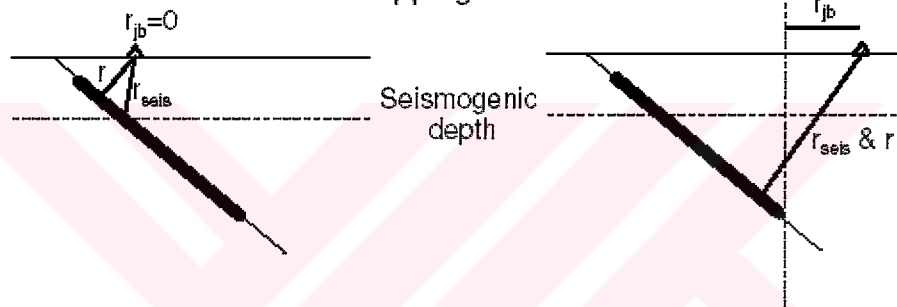


Figure 3.1(a). Site-to-source distance measures for ground motion attenuation models (after Abrahamson and Shedlock, 1997). Seismogenic depth is the depth to the top orogenic part of the crust.

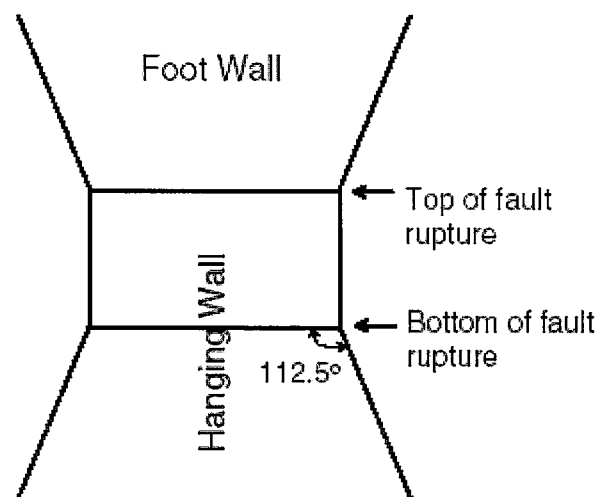


Figure 3.1(b). Definition of footwall and hanging wall. The separation point is the vertical projection of the top of the fault rupture. After Abrahamson and Somerville (1996).

Error terms in attenuation relations are generally either constant (Boore et al., 1997) or functions of magnitude (Abrahamson and Silva, 1996,1997; Idriss,1991,1994; Sadigh et al.,1993,1997). Available data generally indicate a decrease of standard error with increasing magnitude (Youngs et al., 1995). Specific regression equations used by various investigators and the corresponding regression coefficients are available on the USGS Engineering Seismology World Wide Web page, which can be found at <http://geohazards.cr.usgs.gov/engseis/Eshmpage/eshmpage.htm>

An example of the effect of m and r on ground motion is provided in Figure 3.2 which shows median values of PHA and $T=3.0$ s spectral acceleration for a strike-slip focal mechanism and rock site condition using the Abrahamson and Silva (1997) attenuation model. It can be observed from the figures that PHA attenuates more rapidly with distance than long-period spectral acceleration, and that long-period spectral acceleration is more magnitude sensitive.

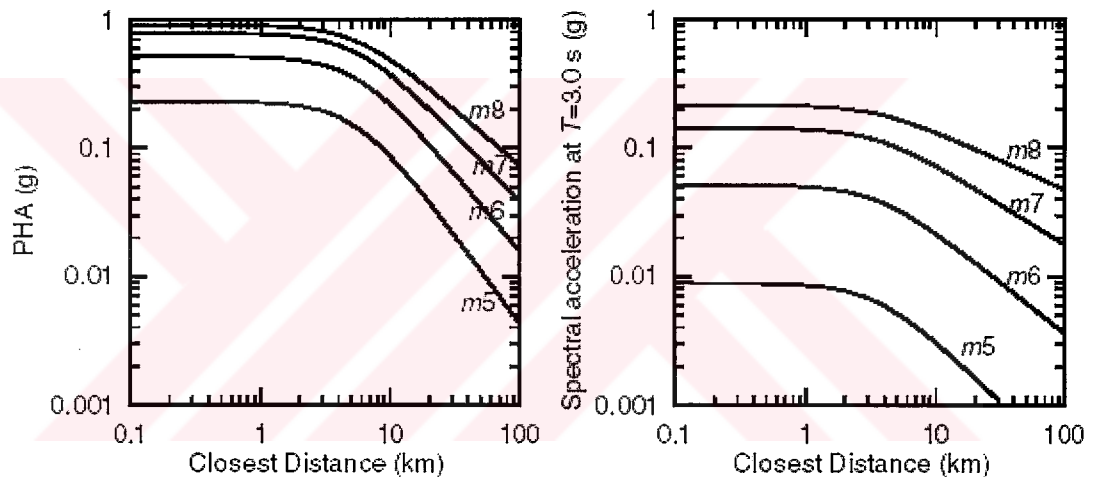


Figure 3.2. Attenuation of PHA and 3.0 s spectral acceleration for strike-slip focal mechanism and rock site condition; Abrahamson and Silva (1997) attenuation relation.

Figure 3.2. shows an increase of PHA with magnitude, although the amount of this increase is larger at large distances than at short distances. At short distances, the limited available data suggest a “saturation” of high-frequency ground motion parameters such as PHA. This effect has also been found in some simulation exercises (Anderson, 2000). Recent data from the 1999 Kocaeli, Turkey, and Chi Chi, Taiwan, earthquakes have raised the question of whether PHA could *decrease* with increasing magnitude, as observed PHAs from these events at close distance were less than expected from existing attenuation relationships. This issue remains unresolved.

3.2.2 Effect of Focal Mechanism

Most earthquakes in active tectonic regions have one of four focal mechanisms: strike-slip, reverse, oblique, and normal. The strike-slip mechanism is generally taken as a “reference” mechanism, and no correction is necessary (i.e., $f(F) = 0$). Significant differences are observed between reverse earthquake motions and strike-slip, which are discussed below. No corrections are generally made for normal-slip earthquakes, although a separate set of attenuation relations is necessary for extensional tectonic regime. Relatively little data are available for oblique-slip earthquakes, and the $f(F)$ correction for oblique-slip is often taken as half of $f(F)$ for reverse earthquakes.

Observations from the Northridge earthquake and other reverse events indicate that median ground motions from these earthquakes are higher than those from strike-slip events (e.g., Campbell, 1982 ; Somerville et al., 1996). This bias is present on both the footwall and hanging wall sides of reverse faults, but is particularly pronounced on the hanging wall side (Abrahamson and Somerville, 1996). The bias that results solely from rupture mechanism is represented in each of the major attenuation relationships for active regions (listed in Table 3.1) through use of an $f(F)$ term in the regression equation (e.g., Equation 3.1). Researchers have taken this term as constant, period-dependent, distance-dependent, and/or magnitude-dependent. The analyses presented in Figure 3.2 are repeated in Figure 3.3 for a reverse focal mechanism to illustrate the influence of style-of-faulting with the Abrahamson and Silva attenuation relation. Factor $f(F)$ generally increases median ground motion estimates, with the exception of long-period spectral components at large magnitudes, which are decreased.

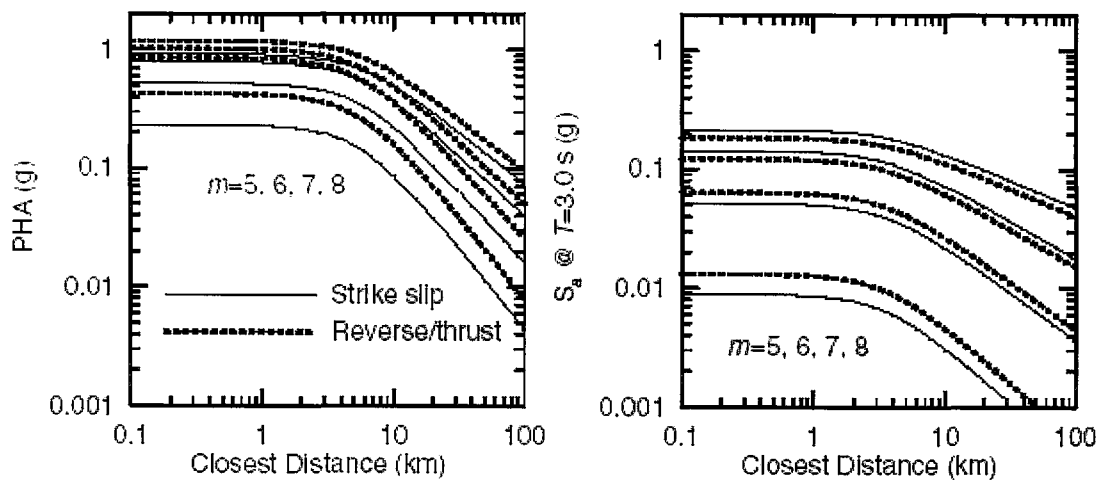


Figure 3.3. Effect of focal mechanism on attenuation of PHA and 3.0 s spectral acceleration; Abrahamson and Silva (1997) attenuation relation.

The second source of bias for ground motions near thrust faults is associated with the positioning of sites on or off the hanging wall side of the fault. Analysis of data recorded during the 1994 Northridge earthquake showed positive residuals of up to 50% for hanging wall sites, and similar effects have been observed from other events as well (Abrahamson and Somerville, 1996). This bias is not surprising, as sites located over the hanging wall are closer to a larger area of the source than footwall sites. As a result of this bias, a magnitude-dependent hanging wall factor is included in the Abrahamson and Silva attenuation model. The analyses in Figures 3.2- 3.3 are repeated in Figure 3.4 to illustrate the hanging wall effect, which diminishes attenuation with distance for $r < 25$ km. Hanging wall effects are not included in the Idriss, Sadigh et al., or Campbell attenuation relations. The distance definition used by Boore et al. incorporates the hanging wall effect to a limited extent, because $rjb = 0$ for sites located over the hanging wall (e.g., Figure 3.1a).

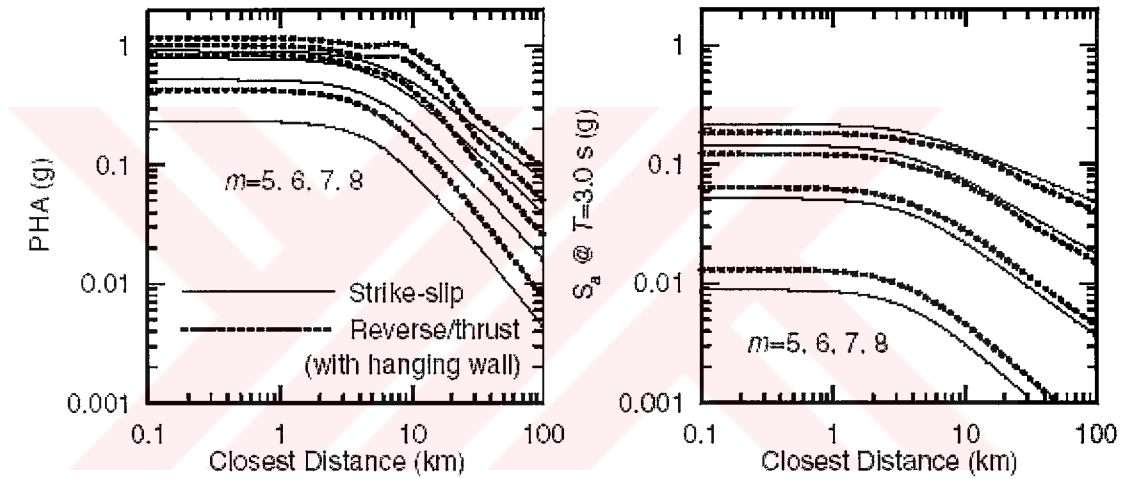


Figure 3.4. Effect of focal mechanism and hanging wall effect on attenuation of PHA and 3.0 s spectral acceleration; Abrahamson and Silva (1997) attenuation relation.

3.2.3 Effect of Site Condition

The effect of geologic and local soil conditions underlying seismographs can significantly influence the characteristics of recorded ground motion. To partially account for this effect, a site term, $f(S)$, is generally included in regression equations for median spectral acceleration (e.g., Equation 3.1). Standard error terms in attenuation relations are generally assumed to be unaffected by site condition. This section will address two issues related to the use of $f(S)$: the process by which sites are classified (i.e., quantification of S) and the form of the site term $f(S)$. The

discussion is limited to site terms that have been used to date in attenuation relations. It should be noted that these site terms are simplified so as to not over-partition the data, which could result in regression instability.

Some attenuation models use a simple rock/soil classification of ground conditions, setting $S=1$ for soil and $S=0$ for rock (e.g., Abrahamson and Silva, Sadigh et al.). Boore et al. (1997) use the 30-m shear wave velocity (V_s), calculated as 30 m/sec (shear wave travel time), as the site parameter. Campbell (1997) uses three parameters — S_{sr} and S_{hr} for local site conditions, as well as depth to basement rock (D_b). The local site condition parameters are $S_{sr} = S_{hr} = 0$ for soil (> 10 m depth), $S_{sr} = 1$ and $S_{hr} = 0$ for soft rock (Tertiary age and soft volcanics), and $S_{sr} = 0$ and $S_{hr} = 1$ for hard rock (e.g., Cretaceous, metamorphic or crystalline rock, hard volcanics). Parameter D_b is taken as the depth to Cretaceous or older deposits with $V_p \geq 5$ km/s or $V_s \geq 3$ km/s.

Analytical forms of site correction factors $f(S)$ vary from simple constants to more complex functions that attempt to account for nonlinearity in the local ground response. Boore et al. take $f(S)$ as the product of a period-dependent constant and 30-m V_s . Campbell incorporates distance r_{seis} into the site term to allow the deviation between rock and soils sites to increase with distance, as would be expected from soil nonlinearity. Abrahamson and Silva use the median peak acceleration on rock predicted by their attenuation relation as an input parameter to the site term. The value of the site term decreases as the rock acceleration increases, thus incorporating nonlinearity. Sadigh et al. do not use a site term, but perform the full regression separately for rock and soil sites.

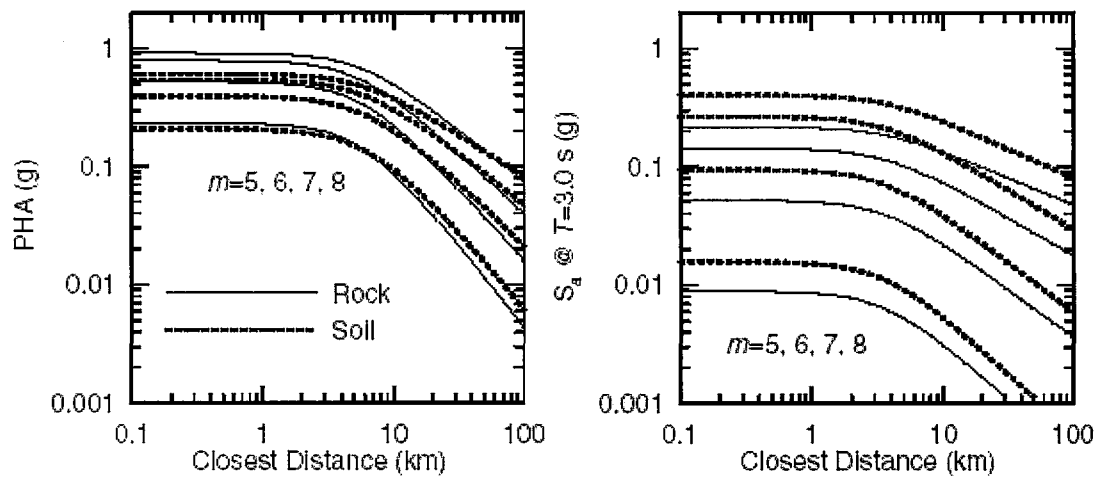


Figure 3.5. Effect of site condition on attenuation of PHA and 3.0 s spectral acceleration; Abrahamson and Silva (1997) attenuation relation.

The analyses presented in Figure 3.2 are repeated in Figure 3.5 for a soil site condition to illustrate the effect of site response in the Abrahamson and Silva attenuation relation. For PHA, de-amplification occurs for rock accelerations greater than about 0.15g, with amplification at weaker levels of shaking. Long-period spectral acceleration is essentially uniformly amplified at all shaking levels.

3.2.4 Other Effects Observed in Active Regions

The effects presented above in Sections (3.2.1)–(3.2.3) are generally well accepted as significantly influencing the attenuation of spectral acceleration. Several other effects have been postulated in the literature but are not incorporated into current attenuation relations. We discuss two such effects below, Moho bounce and surface fault rupture.

In the derivation of attenuation relations, the effects of different focal depths and travel paths on ground motion attenuation are averaged to obtain the median. The standard error reflects sources of epistemic variability such as variations in wave propagation conditions, source effects, and site effects, as well as aleatory variability. A particular path effect that can lead to localized amplification of motion at locations relatively far from the source occurs when body waves reflect at a critical angle off the Moho interface (i.e., crust-mantle boundary). A schematic illustration of this wave propagation scenario is shown in Figure 3.6. At close distances, ground motions are controlled by direct upgoing shear waves. At larger distances, reflections of shear waves off interfaces below the source reach a critical angle (i_{crit}) at which critical reflection occurs. At distances of $r \geq r_{crit}$, it has been postulated that these Moho reflections may contribute more strongly to the ground motion than the directly arriving shear waves, thus flattening the attenuation of ground motion with distance relative to what might otherwise be expected.

Empirical models have not been developed to predict the effects of Moho bounce. However, some general guidelines can be inferred from studies by Somerville et al. (1992, 1994). The effect tends to occur at $r \approx 60 - 120$ km, and can produce motion across all site conditions as high as one standard error above the median.

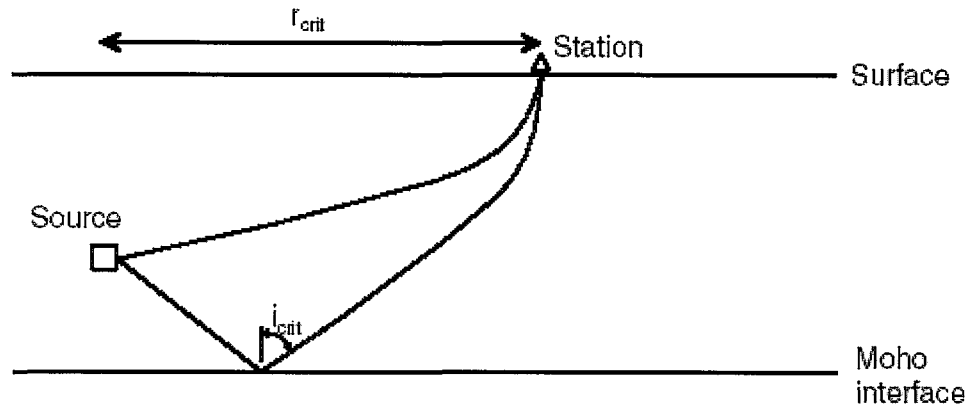


Figure 3.6. Schematic diagram of direct and Moho reflected wave path. Reflection off shallower Conrad interface is also possible but is less significant than the Moho reflection. After Somerville et al. (1994).

Recent work by Somerville (2000) has suggested that ground motion characteristics may be affected by whether a fault rupture breaks the surface. Comparing ground motions records from the 1983 Coalinga, 1989 Loma Prieta, 1995 Northridge, and 1995 Kobe earthquakes (which either did not break the surface or did so over limited areas) with those from the 1999 earthquakes in Turkey and Taiwan (which had significant surface rupture), Somerville observed significantly lower spectral accelerations at $T < 3$ s for the Turkey/Taiwan events. These trends were also present to a lesser degree from other surface rupture earthquakes including the 1992 Landers, 1978 Tabas, 1971 San Fernando, and 1979 Imperial Valley earthquakes. The cause of these variations in the data is not well understood, and could be due to factors other than surface faulting. Additional study of these effects is needed.

3.2.5 Ground Motion Variations Across Different Tectonic Regimes

As noted above, worldwide earthquakes occur in one of three tectonic regimes: active tectonic regions, subduction zones, and stable continental regions. Previous discussion in this section has focused on active tectonic regions. Attenuation relationships for active regions are based principally on strong motion data from conservative (strike-slip) and/or compressive (reverse) earthquakes. In this section attenuation relations for extensional zones within active tectonic regions, as well as attenuation models for subduction zones and stable continental regions are summarized.

An attenuation model for ground motions in extensional regimes has been presented by Spudich et al. (1999). The model was developed using a worldwide database of extensional earthquakes in active tectonic regions. Data regression was performed using the Joyner and Boore (1993, 1994) one-step regression procedure, which

produces results similar to the two-step analyses of Joyner and Boore (1981) [21]. Analyses similar to those presented in Figure 3.2 are repeated in Figure 3.7 to compare median ground motion predictions established from a global database of active tectonic regions (Boore et al., 1997) with those for extensional regions (Spudich et al., 1997). As both regressions were performed using similar data analysis procedures, the differences observed in this comparison should be meaningful. From Figure 3.7, no difference in PHA is observed for extensional regions at close distance, but more rapid attenuation occurs with distance from the source. Long-period spectral accelerations are smaller at all distances and magnitudes. It should be noted that Campbell (2000) has questioned these findings, citing controversy regarding the definitions of generic soil and generic rock between recordings in extensional regimes and other regimes, thus making direct comparisons difficult.

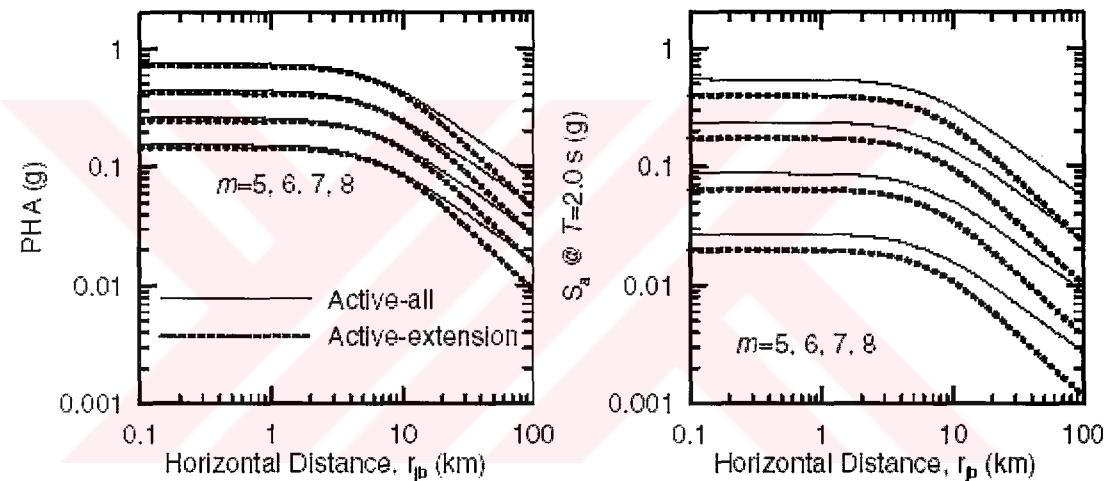


Figure 3.7. Variation of attenuation of PHA and 2.0 s spectral acceleration within active tectonic regions (rock site condition). Median accelerations shown for strike-slip earthquakes in active regions (full database) and earthquakes in extensional regions. Boore et al. (1997) and Spudich et al. (1999) attenuation relations.

A number of attenuation models are available for earthquakes in subduction zones. These are primarily based on data from Japan and South America, as few recordings were available from U.S. earthquakes prior to the February 2001 Nisqually, Washington, earthquake. The database consists mostly of recordings at large distances. The only near-fault recordings are of the 1985 Michoacan earthquake from the Guerrero array (r as small as 13 km). This paucity of near-fault data leads to large uncertainty in the attenuation models for $r < 30$ km. Recent attenuation models for subduction zones include Youngs et al. (1997), Atkinson (1995), Atkinson and Boore (1997a), and Anderson (1997). An important older attenuation model is that of Crouse (1991). The Youngs et al. (1997) model is based on analyses of worldwide data performed with the random effects regression procedure. This model

distinguishes between interslab earthquakes (i.e., reverse events at the interface of subducting and overriding plates, $Z_t = 0$) and intra-slab earthquakes (i.e., normal events resulting from tension in the down-bending subducting slab, $Z_t=1$). The model also demonstrates the importance of focal depth as a parameter independent of site-source distance. Atkinson (1995) performed Joyner-Boore two-step regression analyses using a worldwide data set somewhat smaller than that of Youngs et al., and did not distinguish between inter-slab and intra-slab earthquakes. The Atkinson and Boore (1997a) model is based on stochastic point-source simulations and is applicable to the Cascadia subduction zone only. The Anderson (1997) model is based on PHA data from only the Guerrero, Mexico seismograph network. The Youngs et al. and Atkinson models were developed using procedures most comparable to those for active tectonic regions, and thus allow direct comparisons of ground motion attenuation characteristics.

A comparison of the Youngs et al. and Abrahamson and Silva attenuation models is made in Figure 3.8, which shows that PHA and long-period spectral acceleration from inter-plate subduction zone events are smaller at close distance, but attenuate more slowly with distance, than ground motions from active regions. Intra-slab events (not shown) produce larger amplitude ground motions more comparable at close distance to those from active regions, but which still attenuate relatively slowly with distance. The Atkinson (1995) model predicts ground motion amplitudes for large ($m7$) Cascadia events which may be due to the grouping together of inter-plate and intra-slab earthquakes in the data analysis.

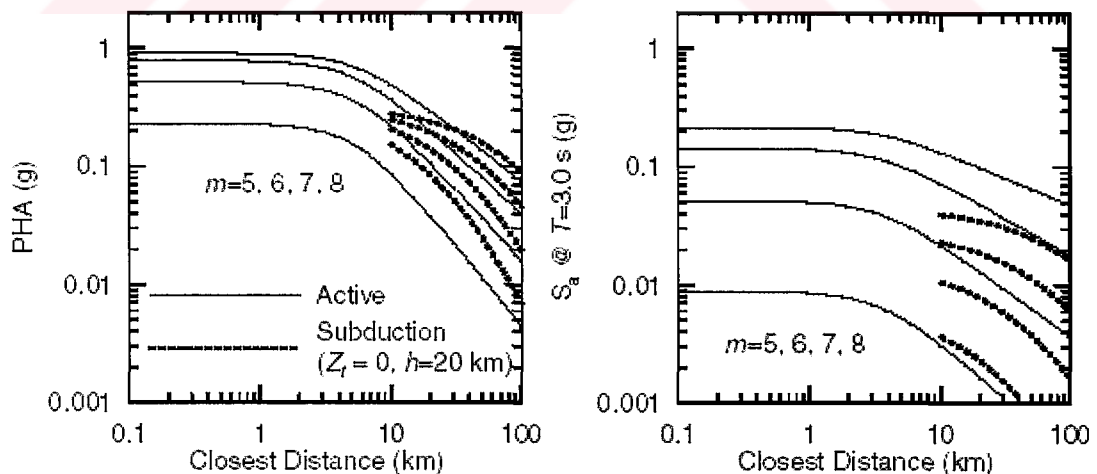


Figure 3.8. Variation of attenuation of PHA and 3.0 s spectral acceleration between active tectonic regions and subduction zones (rock site condition). Median accelerations shown for strike-slip earthquakes in active regions and interplate earthquakes in subduction zones with focal depth = 20 km. Abrahamson and Silva (1997) and Youngs et al. (1997) attenuation relations.

Very little strong motion data are available for stable continental regions, and as a result, attenuation relationships are generally based on simulated ground motions instead of recordings. Regression analyses utilizing these simulated motions are used to develop attenuation functions. Two such relations are Atkinson and Boore (1995, 1997b), and Toro et al. (1997), both of which use a stochastic point-source simulation procedure. A comparison between ground motions from stable continental and active tectonic regions is made in Figure 3.9 using the Toro et al. and Boore et al. (1997) attenuation models. The most significant difference is much larger high-frequency ground motions in stable continental regions. Figure 3.9 indicates that mid-plate earthquakes have rates of attenuation with distance that are somewhat higher for $r < 100$ km, but the attenuation at larger distance is significantly less than that for active regions (not shown in figure).

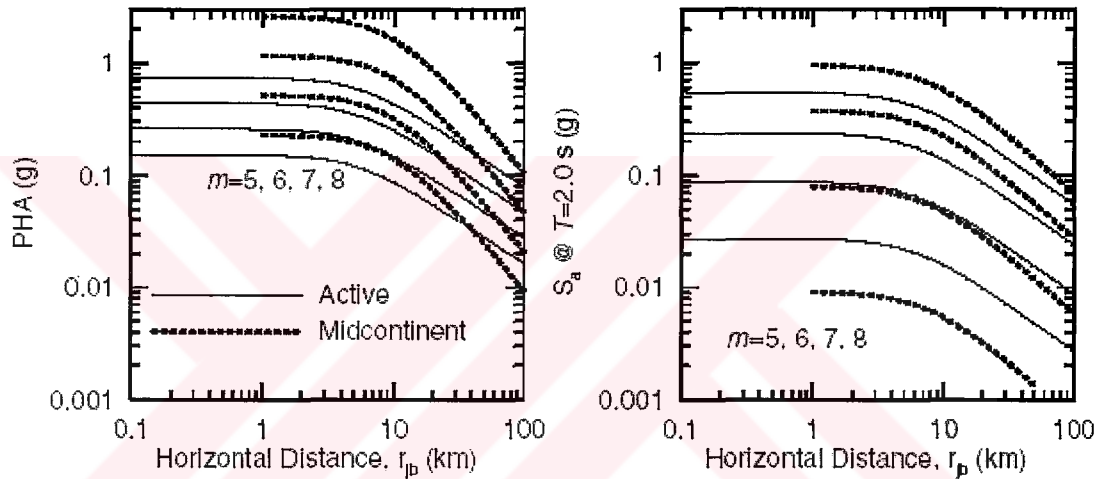


Figure 3.9. Variation of attenuation of PHA and 2.0 s spectral acceleration between active stable continental regions (rock site condition). For active regions, the median accelerations are for strike-slip earthquakes. Boore et al. (1997) and Toro et al. (1997) attenuation relations.

3.3 Attenuation Relationships for Different Regions

3.3.1 Active Regions Attenuation Relationships

Shallow earthquakes whose epicenters located below ground surface in active tectonic regions have provided the largest amount of ground motion data and the largest number of ground motion attenuation relationships. With this large data set, effects of parameters other than just magnitude, distance, and site condition can be evaluated. For example, in most recent attenuation models, there is a distinction between the ground motion from reverse events and strike-slip events called the

style-of-faulting factor. Some models include a magnitude dependence with the style-of-faulting factor.

Most of the strong motion data used in the models listed below are from reverse and strike-slip earthquakes. Due to the small number of normal faulting earthquakes in most data sets, the differences between normal and strike-slip faulting events are not statistically significant, so normal faulting events are usually assumed to generate the same level of ground motion as strike-slip events. Spudich and others (below) collected ground motions from extensional regimes throughout the world. With this larger data set, they were able to show that the commonly used attenuation relationships for the western U.S. (including those listed below) significantly overpredict the ground motions from earthquakes in extensional regimes. Their results suggest that most attenuation models will overestimate ground motions from normal faulting earthquakes. Future updates of the attenuation models will likely distinguish between normal faulting and strike-slip events or between extensional and non-extensional regimes.

(<http://geohazards.cr.usgs.gov/engseis/Eshmpage/eshmpage.htm>)

3.3.1.1 N. A. Abrahamson and W. Silva Attenuation Relationship

Using a data base of 655 recordings from 58 earthquakes, empirical response attenuation relations are derived for the average horizontal and vertical component for shallow earthquakes in active tectonic regions. A new feature in this model is the inclusion of a factor to distinguish between ground motions on the hanging wall and footwall of dipping faults. The site response is explicitly allowed to be non-linear with a dependence on the rock peak acceleration level (N. A. Abrahamson and W. Silva, 1997).

The functional form :

$$\ln Sa(g) = f_1(M, r_{rup}) + F f_3(M) + HW f_4(M, r_{rup}) + S f_5(pga_{rock}) \quad (3.2)$$

Where $Sa(g)$ is the spectral acceleration in g

M is the moment magnitude

r_{rup} is the closest distance to the rupture plane in km

F is the fault type (1 for reverse, 0.5 for reverse/oblique, 0 otherwise)

HW is hanging wall (1 for sites over the hanging wall, 0 otherwise)

S is site class (0 for rock or shallow soil, 1 for deep soil)

$$f_1(M, r_{rup}) = a_1 + a_2 (M - c_1) + a_{12} (8.5 - M)^n + [a_3 + a_{13}(M - c_1)] \ln(R) \quad \text{for } M \leq c_1 \quad (3.3)$$

$$= a_1 + a_4 (M - c_1) + a_{12} (8.5 - M)^n + [a_3 + a_{13}(M - c_1)] \ln(R) \quad \text{for } M > c_1 \quad (3.4)$$

n=2 for horizontal, 3 for vertical

$$R = \sqrt{r_{rup}^2 + c_4^2} \quad (3.5)$$

$$f_3(M) = a_5 \quad \text{for } M \leq 5.8 \quad (3.6)$$

$$= a_5 + [(a_6 - a_5)(M - 5.8)] / [(c_1 - 5.8)] \quad \text{for } 5.8 < M < c_1 \text{ (magnitude)} \quad (3.7)$$

$$= a_6 \quad \text{for } M \geq c_1 \quad (3.8)$$

$$f_4(M, r_{rup}) = f_{HW}(M) f_{HW}(r_{rup}) \quad (3.9)$$

$$f_{HW}(M) = 0 \quad \text{for } M \leq 5.5 \quad (3.10)$$

$$= M - 5.5 \quad \text{for } 5.5 < M < 6.5 \quad (3.11)$$

$$= 1 \quad \text{for } M \geq 6.5 \quad (3.12)$$

$$f_{HW}(r_{rup}) = 0 \quad r_{rup} < 4 \quad (3.13)$$

$$= a_9 (r_{rup} - 4) / 4 \quad 4 < r_{rup} < 8 \quad (3.14)$$

$$= a_9 \quad 8 < r_{rup} < 18 \quad (3.15)$$

$$= a_9 (1 - (r_{rup} - 18) / 7) \quad 18 < r_{rup} < 25 \quad (3.16)$$

$$= 0 \quad 25 < r_{rup} \quad (3.17)$$

$$f_5(pga_{rock}) = a_{10} + a_{11} \ln(pga_{rock} + c_5) \quad (3.18)$$

c₅ = 0.03 for horizontal, 0.3 for vertical

a₂ = 0.512 for horizontal, 0.909 for vertical

a₄ = -0.144 for horizontal, 0.275 for vertical

a₁₃ = 0.17 for horizontal, 0.06 for vertical

pga_{rock} is the expected peak acceleration in rock (g); for horizontal component, the geometric mean of the two horizontals is used

$$\sigma(M) = b_5 \quad \text{for } M \leq 5.0 \quad (3.19)$$

$$= b_5 \cdot b_6 (M-5) \quad \text{for } 5.0 < M < 7.0 \quad (3.20)$$

$$= b_5 - 2b_6 \quad \text{for } M \geq 7.0 \quad (3.21)$$

Table 3.3. The coefficients for the average horizontal component.

period	c4	a1	a3	a5	a6	a9	a10	a11	a12	b5	b6
0.01	5.6	1.64	-1.145	0.61	0.26	0.37	-0.417	-0.23	0	0.7	0.14
0.03	5.6	1.69	-1.145	0.61	0.26	0.37	-0.47	-0.23	0.0143	0.7	0.14
0.05	5.6	1.87	-1.145	0.61	0.26	0.37	-0.62	-0.267	0.028	0.71	0.14
0.075	5.585	2.037	-1.145	0.61	0.26	0.37	-0.628	-0.28	0.03	0.73	0.14
0.1	5.5	2.16	-1.145	0.61	0.26	0.37	-0.598	-0.28	0.028	0.74	0.14
0.12	5.395	2.277	-1.145	0.61	0.26	0.37	-0.591	-0.28	0.018	0.75	0.14
0.15	5.266	2.407	-1.145	0.61	0.26	0.37	-0.577	-0.28	0.005	0.75	0.14
0.17	5.194	2.43	-1.135	0.61	0.26	0.37	-0.522	-0.265	-0.004	0.76	0.14
0.2	5.1	2.406	-1.115	0.61	0.26	0.37	-0.445	-0.245	-0.014	0.77	0.14
0.24	4.965	2.293	-1.079	0.61	0.232	0.37	-0.35	-0.223	-0.024	0.77	0.14
0.3	4.8	2.114	-1.035	0.61	0.1977	0.37	-0.219	-0.195	-0.036	0.78	0.14
0.4	4.518	1.86	-0.988	0.61	0.1536	0.37	-0.065	-0.16	-0.052	0.79	0.14
0.5	4.3	1.615	-0.952	0.581	0.1193	0.37	0.085	-0.121	-0.064	0.8	0.13
0.75	3.9	1.16	-0.885	0.528	0.057	0.331	0.32	-0.05	-0.086	0.81	0.12
1	3.7	0.828	-0.838	0.49	0.0129	0.281	0.4231	0	-0.102	0.83	0.12
1.5	3.55	0.26	-0.772	0.438	-0.049	0.21	0.5999	0.04	-0.12	0.84	0.11
2	3.5	-0.15	-0.725	0.4	-0.094	0.16	0.61	0.04	-0.14	0.85	0.11
3	3.5	-0.69	-0.725	0.4	-0.156	0.089	0.63	0.04	-0.173	0.87	0.1
4	3.5	-1.13	-0.725	0.4	-0.2	0.039	0.64	0.04	-0.196	0.88	0.09
5	3.5	-1.46	-0.725	0.4	-0.2	0	0.6641	0.04	-0.215	0.89	0.09

Table 3.4. The coefficients for the average vertical component.

period	c4	a1	a3	a5	a6	a9	a10	a11	a12	b5	b6
0.01	6	1.642	-1.252	0.39	-0.05	0.63	-0.14	-0.22	0	0.76	0.09
0.03	6	2.1	-1.317	0.432	-0.05	0.63	-0.14	-0.22	0	0.76	0.09
0.05	6	2.62	-1.37	0.496	-0.05	0.63	-0.14	-0.22	-2E-04	0.76	0.09
0.075	6	2.75	-1.37	0.545	-0.05	0.63	-0.129	-0.22	-7E-04	0.76	0.09
0.1	6	2.7	-1.37	0.58	-0.05	0.63	-0.114	-0.22	-0.001	0.76	0.09
0.12	6	2.48	-1.299	0.58	-0.017	0.63	-0.104	-0.22	-0.002	0.74	0.08
0.15	6	2.17	-1.211	0.58	0.024	0.63	-0.093	-0.22	-0.002	0.72	0.06
0.17	5.72	1.96	-1.162	0.58	0.047	0.604	-0.087	-0.22	-0.003	0.7	0.06
0.2	5.34	1.688	-1.099	0.58	0.076	0.571	-0.078	-0.22	-0.003	0.69	0.05
0.24	4.93	1.362	-1.027	0.58	0.109	0.533	-0.069	-0.22	-0.004	0.69	0.05
0.3	4.42	0.973	-0.94	0.58	0.15	0.488	-0.057	-0.22	-0.004	0.69	0.05
0.4	3.77	0.591	-0.878	0.539	0.15	0.428	-0.043	-0.22	-0.005	0.69	0.05
0.5	3.26	0.282	-0.829	0.471	0.15	0.383	-0.031	-0.22	-0.006	0.69	0.05
0.75	2.5	-0.253	-0.749	0.348	0.15	0.299	-0.01	-0.22	-0.008	0.69	0.05
1	2.5	-0.531	-0.74	0.26	0.15	0.24	0.004	-0.22	-0.012	0.69	0.05
1.5	2.5	-0.966	-0.729	0.26	0.058	0.24	0.025	-0.22	-0.018	0.69	0.05
2	2.5	-1.294	-0.72	0.26	-0.008	0.24	0.04	-0.22	-0.024	0.69	0.05
3	2.5	-1.745	-0.72	0.26	-0.1	0.24	0.04	-0.22	-0.043	0.72	0.05
4	2.5	-2.151	-0.72	0.26	-0.1	0.24	0.04	-0.22	-0.054	0.75	0.05
5	2.5	-2.447	-0.72	0.26	-0.1	0.24	0.04	-0.22	-0.064	0.78	0.05

3.3.1.2 David M. Boore, William B. Joyner, and Thomas E. Fumal Attenuation Relationship

The authors summarize their recently published work on estimating horizontal response spectra and peak acceleration for shallow earthquakes in western North America. Although some of the sets of coefficients given here for the equations are new, for the convenience of the reader, the authors provide tables for estimating random horizontal-component peak acceleration and 5% damped pseudo-acceleration response spectra in terms of the natural, rather than common, logarithm of the ground motion parameter. The equations give ground motion in terms of moment magnitude, distance, and site conditions for strike-slip, reverse-slip, or unspecified faulting mechanisms. Site conditions are represented by the shear velocity averaged over the upper 30 m, and recommended values of average shear velocity are given for typical rock and soil sites and for site categories used in the National Earthquake Hazard Reduction Program's recommended seismic code

provisions. In addition, the authors stipulate more restrictive ranges of magnitude and distance for the use of their equations than in their previous publications. Finally, they provide tables of input parameters that include a few corrections to site classifications and earthquake magnitude (the corrections make a small enough difference in the ground motion predictions that the authors chose not to change the coefficients of the prediction equations) (Boore et.al.,1997).Equations:

Note: The equations are to used for M 5.5-7.5 and r no greater than 80 km.

$$\ln Y = b_1 + b_2 (M - 6) + b_3 (M - 6)^2 + b_5 \ln r + b_V \ln (V_S/V_A) \quad (3.22)$$

$$r = \sqrt{r_{jb}^2 + h^2} \quad (3.23)$$

$b_1 = b_{1SS}$ for strike-slip earthquakes

b_{1RS} for reverse-slip earthquakes

b_{1ALL} if mechanism is not specified

Y is the ground motion parameter (PGA, SA) in g; M is moment magnitude; r_{jb} is closest horizontal distance (km) to the vertical projection of rupture; V_S is the average shear wave velocity to 30 m, in m/sec

Table 3.5. The coefficients of Boore et al. attenuation relationship.

period	b1SS	b1RS	b1ALL	b2	b3	b5	bV	h	Va	sigma
0	-0.31	-0.12	-0.242	0.53	0	-0.78	-0.37	5.6	1396	0.52
0.1	1.006	1.087	1.059	0.75	-0.23	-0.93	-0.21	6.3	1112	0.479
0.12	1.109	1.215	1.174	0.72	-0.23	-0.94	-0.22	6.9	1452	0.485
0.15	1.128	1.264	1.204	0.7	-0.23	-0.94	-0.24	7.2	1820	0.492
0.17	1.09	1.242	1.173	0.7	-0.22	-0.93	-0.26	7.2	1977	0.497
0.2	0.999	1.17	1.089	0.71	-0.21	-0.92	-0.29	7	2118	0.502
0.24	0.847	1.033	0.941	0.73	-0.19	-0.91	-0.34	6.6	2178	0.511
0.3	0.598	0.803	0.7	0.77	-0.16	-0.89	-0.4	5.9	2133	0.522
0.4	0.212	0.423	0.311	0.83	-0.12	-0.87	-0.49	4.9	1954	0.538
0.5	-0.12	0.087	-0.025	0.88	-0.09	-0.85	-0.55	4.1	1782	0.556
0.75	-0.74	-0.56	-0.661	0.98	-0.05	-0.81	-0.65	3.1	1507	0.587
1	-1.13	-1.01	-1.08	1.04	-0.03	-0.8	-0.7	2.9	1406	0.613
1.5	-1.55	-1.54	-1.55	1.09	-0.04	-0.8	-0.7	3.9	1479	0.649
2	-1.7	-1.8	-1.743	1.09	-0.09	-0.81	-0.66	5.9	1795	0.672

3.3.1.3 Kenneth W. Campbell Attenuation Relationship

A consistent set of empirical attenuation relationships is presented for predicting free-field horizontal and vertical components of peak ground acceleration (PGA), peak ground velocity (PGV), and 5%-damped pseudo-absolute acceleration response spectra (PSA). The relationships were derived from attenuation relationships previously developed by Campbell from 1990 through 1994. The relationships were combined in such a way as to emphasize the strengths and minimize the weaknesses of each. The new attenuation relationships are considered to be appropriate for predicting free-field amplitudes of horizontal and vertical components of strong ground motion from worldwide earthquakes of moment magnitude (M) greater than or equal to 5 and sites with distances to seismogenic rupture (R_{SEIS}) less than or equal to 60 km in active tectonic regions (Campbell, 1997).

Equations:

$$\begin{aligned} \ln(A_H) = & -3.512 + 0.904 M - 1.328 \ln[\sqrt{R_{SEIS}^2 + [0.149 \exp(0.647 M)]^2}] \\ & + [1.125 - 0.112 \ln(R_{SEIS}) - 0.0957 M] F + [0.44 - 0.171 \ln(R_{SEIS})] S_{SR} \\ & + [0.405 - 0.222 \ln(R_{SEIS})] S_{HR} + \varepsilon \end{aligned} \quad (3.24)$$

A_H is mean horizontal component of peak ground acceleration, in g

ε is random error term

$$\sigma = 0.4053$$

M is the moment magnitude

R_{SEIS} is the closest distance to the seismogenic rupture surface

F is the style of faulting factor (0 for strike-slip, 1 otherwise)

S_{SR} is the soft rock site factor (1 for soft rock, 0 otherwise)

S_{HR} is the hard rock site factor (1 for hard rock, 0 otherwise)

$$\begin{aligned} \ln(SA_H) = & \ln(A_H) + c_1 + c_2 \tanh[c_3(M-4.7)] + (c_4 + c_5 M) R_{SEIS} + 0.5 c_6 S_{SR} \\ & + c_6 S_{HR} + c_7 \tanh(c_8 D)(1 - S_{HR}) + f_{SA}(D) + \varepsilon \end{aligned} \quad (3.25)$$

SA_H is the horizontal component of the 5% damped pseudo-absolute acceleration response spectra, in g

$$\sigma = 0.46615448$$

D is depth to bedrock

$$f_{SA}(D) = 0 \quad D \geq 1 \text{ km} \quad (3.26)$$

$$= c_6 (1 - S_{HR}) (1 - D) + 0.5 c_6 (1 - D) S_{SR} \quad D < 1 \text{ km} \quad (3.27)$$

Table 3.6. The coefficients of Campbell attenuation relationship.

period	c1	c2	c3	c4	c5	c6	c7	c8
0	-3.15	0	0	0	0.015	-0.001		
0.05	0.05	0	0	-0.0011	0.000055	0.2	0	0
0.075	0.27	0	0	-0.0024	0.000095	0.22	0	0
0.1	0.48	0	0	-0.0024	0.000007	0.14	0	0
0.12	0.576	0	0	-0.00184	-0.0001	0.076	0	0
0.15	0.72	0	0	-0.001	-0.00027	-0.02	0	0
0.17	0.748	0	0	-0.00016	-0.00037	-0.084	0	0
0.2	0.79	0	0	0.0011	-0.00053	-0.18	0	0
0.24	0.774	0	0	0.00302	-0.00068	-0.356	0	0
0.3	0.77	0	0	0.0035	-0.00072	-0.4	0	0
0.5	-0.28	0.74	0.66	0.0068	-0.001	-0.42	0.25	0.62
0.75	-1.08	1.23	0.66	0.0077	-0.001	-0.44	0.37	0.62
1	-1.79	1.59	0.66	0.0085	-0.001	-0.38	0.57	0.62
1.5	-2.65	1.98	0.66	0.0094	-0.001	-0.32	0.72	0.62
2	-3.28	2.23	0.66	0.01	-0.001	-0.36	0.83	0.62
3	-4.07	2.39	0.66	0.0108	-0.001	-0.22	0.86	0.62
4	-4.26	2.03	0.66	0.0112	-0.001	-0.3	1.05	0.62

3.3.1.4 K. Sadigh, C.-Y. Chang, J.A. Egan, F. Makdisi, and R.R. Youngs Attenuation Relationship.

Attenuation relationships are presented for peak acceleration and response spectral accelerations from shallow earthquakes. The relationships are based on strong motion data primarily from California earthquakes. Relationships are presented for strike-slip and reverse faulting earthquakes, rock and deep soil deposits, earthquakes of moment magnitude M 4 to 8+, and distances up to 100 km (Sadigh, 1997).

Equations:

$$\ln(y) = C_1 + C_2 M + C_3 (8.5 - M)^{2.5} + C_4 \ln(r_{rup} + \exp(C_5 + C_6 M)) + C_7 \ln(r_{rup} + 2) \quad (3.28)$$

y is PGA or SA (in g), represented by the geometric mean of the two horizontal components

M is the moment magnitude

r_{rup} is the minimum distance to the rupture surface in km

$$C_2 = 1.0 \quad \text{for } M \leq 6.5$$

$$=1.1 \quad \text{for } M > 6.5$$

$$C_3 = 1.29649 \quad \text{for } M \leq 6.5$$

$$=-0.48451 \quad \text{for } M > 6.5$$

$$C_6 = 0.25 \quad \text{for } M \leq 6.5$$

$$=0.524 \quad \text{for } M > 6.5$$

Note: Relationships for reverse/thrust faulting are obtained by multiplying these strike-slip amplitudes by 1.2.

For deep soil sites (greater than 20m of soil over bedrock):

$$\ln(y) = C_1 + C_2M + C_3 \ln(r_{rup} + C_4 \exp(C_5M)) + C_6 + C_7 \ln(8.5 - M)^{2.5} \quad (3.29)$$

$C_1 = -2.17$ for strike-slip, -1.92 for reverse and thrust earthquakes

$$C_2 = 1.0$$

$$C_3 = 1.70$$

$$C_4 = 2.1863, \quad C_5 = 0.32 \quad \text{for } M \leq 6.5$$

$$C_4 = 0.3825, \quad C_5 = 0.5882 \quad \text{for } M > 6.5$$

Table 3.7. M less than or equal to 6.5 (Sadigh et al. attenuation relationship).

Pd(s)	c1	c3	c4	c7
0	-0.624	0	-2.1	0
0.05	-0.09	0.006	-2.128	-0.082
0.075	0.1355	0.006	-2.131	-0.0745
0.1	0.275	0.006	-2.148	-0.041
0.12	0.348	0.005	-2.162	-0.014
0.15	0.285	0.002	-2.13	0
0.17	0.239	0	-2.11	0
0.2	0.153	-0.004	-2.08	0
0.24	0.06	-0.011	-2.053	0
0.3	-0.057	-0.017	-2.028	0

0.4	-0.298	-0.028	-1.99	0
0.5	-0.588	-0.04	-1.945	0
0.75	-1.208	-0.05	-1.865	0
1	-1.705	-0.055	-1.8	0
1.5	-2.407	-0.065	-1.725	0
2	-2.945	-0.07	-1.67	0
3	-3.7	-0.08	-1.615	0
4	-4.23	-0.1	-1.57	0
5	-4.714	-0.1	-1.54	0
7.5	-5.53	-0.11	-1.51	0

Table 3.8. M greater than 6.5 (Sadigh et al. attenuation relationship).

Pd (s)	c1	c3	c4	c7
0	-1.274	0	-2.1	0
0.05	-0.74	0.006	-2.128	-0.082
0.075	-0.5145	0.006	-2.131	-0.0745
0.1	-0.375	0.006	-2.148	-0.041
0.12	-0.302	0.005	-2.162	-0.014
0.15	-0.365	0.002	-2.13	0
0.17	-0.411	0	-2.11	0
0.2	-0.497	-0.004	-2.08	0
0.24	-0.59	-0.011	-2.053	0
0.3	-0.707	-0.017	-2.028	0
0.4	-0.948	-0.028	-1.99	0
0.5	-1.238	-0.04	-1.945	0
0.75	-1.858	-0.05	-1.865	0
1	-2.355	-0.055	-1.8	0
1.5	-3.057	-0.065	-1.725	0
2	-3.595	-0.07	-1.67	0
3	-4.35	-0.08	-1.61	0
4	-4.88	-0.1	-1.57	0
5	-5.364	-0.1	-1.54	0
7.5	-6.18	-0.11	-1.51	0

Table 3.9. Dispersion relationships for horizontal rock motion (Sadigh et al. attenuation relationship).

Period	Sigma [ln(y)]
PGA	1.39 - 0.14M; 0.38 for M .ge. 7.21
0.07	1.40 - 0.14M; 0.39 for M .ge. 7.21
0.1	1.41 - 0.14M; 0.40 for M .ge. 7.21
0.2	1.43 - 0.14M; 0.42 for M .ge. 7.21
0.3	1.45 - 0.14M; 0.44 for M .ge. 7.21
0.4	1.48 - 0.14M; 0.47 for M .ge. 7.21
0.5	1.50 - 0.14M; 0.49 for M .ge. 7.21
0.75	1.52 - 0.14M; 0.51 for M .ge. 7.21
1	1.53 - 0.14M; 0.52 for M .ge. 7.21
1.00+	1.53 - 0.14M; 0.52 for M .ge. 7.21

Table 3.10. The deep soil sites (Sadigh et al. attenuation relationship).

Pd (s) DSoil	c6 - SS	c6 - RV	c7
0	0	0	0
0.075	0.4572	0.4572	0.005
0.1	0.6395	0.6395	0.005
0.2	0.9187	0.9187	-0.004
0.3	0.9547	0.9547	-0.014
0.4	0.9251	0.9005	-0.024
0.5	0.8494	0.8285	-0.033
0.75	0.701	0.6802	-0.051
1	0.5665	0.5075	-0.065
1.5	0.3235	0.2215	-0.09
2	0.1001	-0.0526	-0.108
3	-0.2801	-0.4905	-0.139
4	-0.6274	-0.8907	-0.16

3.3.1.5 P. Spudich, J.B. Fletcher, M. Hellweg, J. Boatwright, C. Sullivan, W.B. Joyner, T.C. Hanks, D.M. Boore, A. McGarr, L.M. Baker, and A.G. Lindh Attenuation Relationship

P. Spudich, J.B. Fletcher, M. Hellweg, J. Boatwright, C. Sullivan, W.B. Joyner, T.C. Hanks, D.M. Boore, A. McGarr, L.M. Baker, and A.G. Lindh present a new predictive relation for horizontal peak ground acceleration and 5%-damped pseudo-velocity response spectrum derived from a global set of earthquake ground motion

data recorded in extensional tectonic regimes. The authors developed their relation based on data from extensional regime earthquakes having moment magnitude $M > 5.0$ recorded at distances less than 105 km (Spudich et al.,1999).

Equation:

$$\log_{10} Y = b_1 + b_2 (M-6) + b_3 (M-6)^2 + b_5 \log_{10} r + b_6 \Gamma \quad (3.30)$$

$$\sigma_{\log Y} = \text{sqrt}(\sigma_1^2 + \sigma_2^2) \quad (3.31)$$

$$R = \sqrt{r_{jb}^2 + h^2} \quad (3.32)$$

Y is PGA (in g) or pseudo velocity response (cm/s) at 5% damping for the geometric mean horizontal component of motion

M is moment magnitude

r_{jb} is closest horizontal distance (km) to the vertical projection of the rupture

$\Gamma = 0$ for rock

$= 1$ for soil

$\sigma_{\log Y}$ = the standard deviation of $\log_{10} Y$

Table 3.11. The coefficients of Spudich et al. attenuation relationship.

Pd (s)	b1	b2	b3	b5	b6	h	sigma1	sigma2	sigma3
0.01	0.16	0.23	0	-0.95	0.08	5.6	0.216	0	0.094
0.1	1.77	0.33	-0.1	-1.05	0.08	6.3	0.268	0	0.111
0.12	1.88	0.31	-0.1	-1.04	0.1	6.9	0.272	0	0.114
0.15	1.96	0.31	-0.1	-1.01	0.13	7.2	0.277	0.001	0.117
0.17	2	0.31	-0.1	-0.99	0.14	7.2	0.281	0.005	0.119
0.2	2.02	0.31	-0.09	-0.97	0.15	7	0.286	0.012	0.121
0.24	2.04	0.32	-0.08	-0.95	0.17	6.6	0.292	0.019	0.124
0.3	2.03	0.33	-0.07	-0.92	0.18	5.9	0.3	0.027	0.126
0.4	2	0.36	-0.05	-0.88	0.2	4.9	0.311	0.038	0.129
0.5	1.97	0.38	-0.04	-0.86	0.21	4.1	0.32	0.047	0.132
0.75	1.92	0.43	-0.02	-0.83	0.21	3.1	0.339	0.062	0.135
1	1.91	0.45	-0.01	-0.84	0.21	2.9	0.354	0.073	0.137
1.5	1.96	0.47	-0.02	-0.88	0.21	3.9	0.377	0.089	0.139
2	2.07	0.47	-0.04	-0.94	0.2	5.9	0.395	0.1	0.14

3.3.2 Stable Continental Regions Attenuation Relationships

Due to the low seismicity in stable continental regions, there are very few strong motion data available for this tectonic regime. As a result, attenuation relationships for this region are usually based on numerically simulated ground motions instead of recorded ground motions. The researchers listed below use a stochastic point source model to generate a synthetic data base of strong ground motions. They then perform regression analyses to develop simplified equations that describe the attenuation of the data in the synthetic data sets.

3.3.2.1 Atkinson and Boore Attenuation Relationship

The authors provide an overview of new ground-motion relations for Eastern North America (ENA) developed over the last five years. The empirical-stochastic relations of Atkinson and Boore (1995) are compared to relations developed by the Electric Power Research Institute (EPRI, 1993; also Toro et al., 1994) Frankel et al. (1996), and the consensus ENA ground-motion values as reported by SSHAC (1996). The main difference between their relations and those of EPRI or Frankel is in the low-frequency amplitudes ($f < 2$ Hz, all magnitudes). The authors predict lower amplitudes (by more than a factor of two) at 1 Hz, largely due to their use of an empirical source model rather than a single-corner-frequency Brune source model; the use of an empirical source model is motivated by the desire to match the ENA ground-motion database as closely as possible.

They also compare their new ENA relations to empirical relations for California. The comparison is complicated by the need to adjust the ENA hard-rock motions to obtain equivalent motions for typical California soil conditions. Two alternative methods of making this correction lead to somewhat different conclusions. One possible conclusion is that their ENA predict similar low-frequency amplitudes to those predicted by Boore et al. (1993, 1994) and Abrahamson and Silva (1996) for California, but their predicted ENA amplitudes are much higher (factor > 2) than California values at high frequencies. The alternative soil correction leads to the conclusion that their ENA relations are moderately lower (factor < 2) than the California relations at low frequencies, and moderately higher at high frequencies. Both of these conclusions imply that ground-motion relations or time series from earthquakes in one region cannot simply be modified for use in engineering analyses in another region (Atkinson and Boore, 1997b).

Equations:

$$\ln SA = c_1 + c_2 (M-6) + c_3 (M-6)^2 - \ln R - c_4 R \quad (3.33)$$

Equation gives SA, PGA in g, PGV in cm/s, where SA is the pseudo-acceleration (5% damped), for the random horizontal component on rock.

R is the hypocentral distance in km

$\sigma = 0.55$ at 1 Hz

$\sigma = 0.62$ at 10 Hz

To obtain relations for deep soil sites:

$$\log SA_{\text{soil}} = \log SA_{\text{rock}} + \text{soil factor} \quad (3.34)$$

Table 3.12. The coefficients of Atkinson and Boore attenuation relationship.

PD(S)	c1	c2	c3	c4	Soil Factor
2	-1.66	1.46	-0.039	0	0.27
1.25	-0.9	1.462	-0.071	0	0.27
1	-0.508	1.428	-0.094	0	0.27
0.7692	-0.094	1.391	-0.118	0	0.278
0.5	0.62	1.267	-0.147	0	0.29
0.3125	1.265	1.094	-0.165	0.00024	0.263
0.2	1.749	0.963	-0.148	0.00105	0.24
0.1266	2.14	0.864	-0.129	0.00207	0.18
0.1	2.301	0.829	-0.121	0.00279	0.15
0.0769	2.463	0.797	-0.113	0.00352	0.13
0.05	2.762	0.755	-0.11	0.0052	-0.03
PGA	1.841	0.686	-0.123	0.00311	-0.612
PGV	4.697	0.972	-0.086	0	

3.3.2.2 Toro, Abrahamson, and Schneider Attenuation Relationship

Ground-motion attenuation equations for rock sites in central and eastern North America are derived, based on the predictions of a stochastic ground-motion model. four sets of attenuation equations are developed (i.e., 2 crustal regions x 2 magnitude scales). The associated uncertainties are derived by considering the uncertainties in parameter values, as well as those uncertainties associated with the ground-motion model itself. Comparison to data shows a reasonable agreement. Comparisons to

other attenuation functions for the region shows consistency with most attenuation functions in current use (Toro et al., 1997).

Equation:

$$\ln Y = C_1 + C_2(M-6) - C_3(M-6)^2 - C_4 \ln r + (C_5 - C_4) \max[\ln(r/100), 0] - C_6 r + \epsilon_e + \epsilon_a \quad (3.35)$$

$$R = \sqrt{r_{jb}^2 + C_7^2} \quad (3.36)$$

Y is the ground motion parameter (PGA, SA) in g

M is moment magnitude

r_{jb} is closest horizontal distance (km) to the vertical projection of the rupture

ϵ_e is the epistemic uncertainty (see Toro et al, 1997)

ϵ_a is the aleatory uncertainty (see Toro et al, 1997)

Table 3.13. Midcontinent (Toro et al. attenuation relationship).

Pd (s)	c1	c2	c3	c4	c5	c6	c7
2	-0.74	1.86	-0.31	0.92	0.46	0.0017	6.9
1	0.09	1.42	-0.2	0.9	0.49	0.0023	6.8
0.4	1.07	1.05	-0.1	0.93	0.56	0.0033	7.1
0.2	1.73	0.84	0	0.98	0.66	0.0042	7.5
0.1	2.37	0.81	0	1.1	1.02	0.004	8.3
0.04	3.68	0.8	0	1.46	1.77	0.0013	10.5
0.029	4	0.79	0	1.57	1.83	0.0008	11.1
0.01	2.2	0.81	0	1.27	1.16	0.0021	9.3

Table 3.14. Gulf coastal plain (Toro et al. attenuation relationship).

Pd (s)	c1	c2	c3	c4	c5	c6	c7
2	-0.81	1.72	-0.26	0.74	0.71	0.0025	6.6
1	0.24	1.31	-0.15	0.79	0.82	0.0034	7.2
0.4	1.64	1.06	-0.08	0.99	1.27	0.0036	8.9
0.2	3.1	0.92	0	1.34	1.95	0.0017	11.4
0.1	5.08	1	0	1.87	2.52	0.0002	14.1
0.04	5.19	0.91	0	1.96	1.96	0.0004	12.9
0.029	4.81	0.91	0	1.89	1.8	0.0008	11.9
0.01	2.91	0.92	0	1.49	1.61	0.0014	10.9

3.3.3 Subduction Zones Attenuation Relationships

There are few strong motion recordings from subduction zone earthquakes in the United States, so most attenuation models for subduction zone events are primarily based on recordings from Japan and South America. Most subduction zone events are recorded at large distances because the events tend to be deep or offshore. the exception is the recording of the 1985 Michoacan earthquake by the Guerrero array, which had stations as close as 13 km to the epicenter. The sparse data within 30 km leads to a large uncertainty in the extrapolation of these models to short distances.

3.3.3.1 R.R. Youngs, S.-J. Chiou, W.L. Silva, and J.R. Humphrey Attenuation Relationship

R.R. Youngs, S.-J. Chiou, W.L. Silva, and J.R. Humphrey present attenuation relationships for peak ground acceleration and response spectral acceleration for subduction zone interface and intraslab earthquakes of moment magnitude M 5 and greater for distances of 10 to 500 km. The relationships were developed by regression analysis using a random effects regression model that addresses criticism of earlier regression analyses of subduction zone earthquake motions. R.R. Youngs, S.-J. Chiou, W.L. Silva, and J.R. Humphrey find that the rate of attenuation of peak ground motions from subduction zone earthquakes is lower than that for shallow crustal earthquakes in active tectonic areas. The difference is significant primarily for very large earthquakes. The peak motions increase with earthquake depth and intraslab earthquakes produce peak motions that are about 50 percent larger than interface earthquakes (Youngs et al.,1997).

Equations:

For Rock:

$$\ln(y) = 0.2418 + 1.414M + C_1 + C_2(10-M)^3 + C_3 \ln(r_{rup} + 1.7818e^{0.554M}) + 0.00607H + 0.3846Z_T \quad (3.37)$$

$$\text{Standard Deviation} = C_4 + C_5M \quad (3.38)$$

y is spectral acceleration in g

M is moment magnitude

r_{rup} is the source-to-site distance in km

H is focal depth in km

Z_T is source type (0 for interface and 1 for intraslab events)

Table 3.15. The coefficients of Youngs et. al attenuation relationship for rocks.

Pd(s)	c1	c2	c3	c4	c5	Sigma	SA(g)
0.01	0	0	-2.552	1.45	-0.1	1.45	0.068736
0.08	1.275	0	-2.707	1.45	-0.1	1.45	0.206868
0.1	1.188	-0.001	-2.655	1.45	-0.1	1.45	0.066899
0.2	0.722	-0.003	-2.528	1.45	-0.1	1.45	0.009768
0.3	0.246	-0.004	-2.454	1.45	-0.1	1.45	0.00268
0.4	-0.12	-0.004	-2.401	1.45	-0.1	1.45	0.000984
0.5	-0.4	-0.005	-2.36	1.45	-0.1	1.45	0.00047
0.75	-1.15	-0.006	-2.286	1.45	-0.1	1.45	9.81E-05
1	-1.74	-0.006	-2.234	1.45	-0.1	1.45	2.87E-05
1.5	-2.64	-0.007	-2.16	1.5	-0.1	1.5	5.14E-06
2	-3.33	-0.008	-2.107	1.55	-0.1	1.55	1.34E-06
3	-4.51	-0.009	-2.033	1.65	-0.1	1.65	1.80E-07

$$\ln(y) = -0.6687 + 1.438M + C_1 + C_2(10-M)^3 + C_3 \ln(r_{rup} + 1.097e^{0.617M}) + 0.00648H + 0.3643Z_T \quad (\text{For Soils}) \quad (3.39)$$

$$\text{Standard Deviation} = C_4 + C_5M \quad (3.40)$$

y is spectral acceleration in g; M is moment magnitude; r_{rup} is the source-to-site distance in km; H is focal depth in km; Z_T is source type (0 for interface and 1 for intraslab event)

Table 3.16. The coefficients of Youngs et. al attenuation relationship for soils.

Pd(s)	c1	c2	c3	c4	c5	Sigma	SA(g)
0.01	0	0	-2.329	1.45	-0.1	1.45	0.046113
0.08	2.4	-0.002	-2.697	1.45	-0.1	1.45	0.047961
0.1	2.516	-0.002	-2.697	1.45	-0.1	1.45	0.05386
0.2	1.549	-0.002	-2.464	1.45	-0.1	1.45	0.027415
0.3	0.793	-0.002	-2.327	1.45	-0.1	1.45	0.013827
0.4	0.144	-0.002	-2.23	1.45	-0.1	1.45	0.008158
0.5	-0.44	-0.004	-2.14	1.45	-0.1	1.45	0.001138
0.75	-1.7	-0.005	-1.952	1.45	-0.1	1.45	0.000111
1	-2.87	-0.007	-1.785	1.45	-0.1	1.45	7.03E-06
1.5	-5.1	-0.011	-1.47	1.5	-0.1	1.5	9.28E-09
2	-6.43	-0.016	-1.29	1.55	-0.1	1.55	2.08E-11
3	-6.67	-0.022	-1.347	1.65	-0.1	1.65	5.18E-14

3.3.3.2 Gail M. Atkinson and David M. Boore Attenuation Relationship

A stochastic model is used to develop preliminary ground motion relations for the Cascadia region, for rock sites. The model parameters are derived from empirical analyses of seismographic data from the Cascadia region. The model is based on a Brune point-source characterized by a stress parameter of 50 bars. The model predictions are compared to ground motion data from the Cascadia region and to data from large earthquakes in other subduction zones. The point-source simulations match the observations from moderate events ($M < 7$) in the Cascadia region. The simulations predict steeper attenuation than observed for very large subduction events $M(7.5)$ in other regions; motions are overpredicted near the earthquake source and underpredicted at large distances (> 100 km). The discrepancy at large magnitudes suggests further work on modeling finite-fault effects and regional attenuation is warranted. In the meantime, the preliminary equations are satisfactory for predicting motions from events of $M < 7$ and provide conservative estimates of motions from larger events at distances less than 100 km (Atkinson et al., 1997a).

Equation :

$$\ln SA = c_1 + c_2 (M-6) + c_3 (M-6)^2 - \ln r_{\text{hypo}} - c_4 r_{\text{hypo}} \quad (3.41)$$

Equation gives SA, PGA in g, PGV in cm/s, where SA is the pseudo-acceleration (5% damped), for the median horizontal component on rock.

$\sigma = 0.78$ at 1 Hz

$\sigma = 0.55$ at 10 Hz

M is moment magnitude

r_{hypo} is the hypocentral distance in km

Table 3.17. The coefficients of Atkinson and Boore attenuation relationship.

Pd (s)	c1	c2	c3	c4
0.03	0.68	0.733	0	0.00645
0.05	1.47	0.733	0	0.00921
0.1	1.53	0.809	-0.032	0.00829
0.125	1.472	0.851	-0.044	0.00783
0.2	1.273	0.929	-0.076	0.00645
0.313	1.001	1.041	-0.117	0.0053
0.5	0.65	1.174	-0.165	0.00414
0.769	0.232	1.322	-0.195	0.00345
1	-0.033	1.388	-0.201	0.00299
1.25	-0.295	1.457	-0.201	0.00276
2	-0.912	1.565	-0.172	0.00207

3.3.3.3 John G. Anderson Attenuation Relationship

This paper summarizes the nonparametric model for peak acceleration as a function of magnitude, distance, and site in Guerrero, Mexico that was prepared by Anderson and Lei (1994). The shallow part of this subduction zone dips at 15 degrees, and in this way is similar to the Alaska and the Pacific Northwest (Cascadia) subduction zones in the United States. The data used in this study were obtained from the Guerrero accelerograph network. The sites in the Guerrero network were selected to be on the best rock available, consistent with network geometry and secondary siting criteria. All but one station is on a rock site. This nonparametric model was determined using 528 recordings (each three components) from 146 earthquakes, with magnitudes ranging from under 3 to 8.1, that occurred between 1985 to 1990. There is an average of about 18 records for each station (.Anderson, 1997).

4. ARTIFICIAL INTELLIGENCE METHOD

4.1 Introduction: Neural Networks

Neural Networks, which are a form of artificial intelligence, are information processing computational tools emulating a biological nervous system. Today, many scientists are looking at the development of artificial intelligence from the basis of a developing understanding of the architecture of the human brain. The brain is a collection of about 10 billion interconnected neurons and each neuron is a cell that uses biochemical reactions to receive, process and transmit information. All together, highly interconnected processing neurons work in union to solve specific problem. In this respect, Neural networks are parallel systems to biological nervous system with relying on dense arrangements of interconnections and simple processors. That is why they have the name Artificial Neural Networks.

The neural networks are like people, they learn by examples. This flexibility makes them very powerful. There is no need run an algorithm to perform a specific task. Sometimes scientists, researchers and engineers have difficulty to understand the internal mechanism of the task they are dealing, that is the main obstacle resulting with failure. In neural networks you do not need to know the internal mechanism, because neurons have huge potential to understand the internal mechanism on its own. This power of the network lies in the tremendous number of interconnections, just like the human brain.

The neural networks provide an effective approach for a broad spectrum of applications. Stock market predictions, cost analysis, geophysical and seismological research problems, water resources management, water quality control, analysis of medical test, managerial decision making, troubleshooting of scientific instruments, computer aided design, analytical chemistry applications, fault tracing system etc. There are many more applications yet to be discovered. Their wide spectrum involving pattern mapping, pattern completion, pattern classification makes them significant application for common predictions and evaluations.

It is obvious that the computing world has a lot of gain from neural networks. Neural networks are generating much interest among engineers and scientist, with its powerful capabilities and potential to solve problems.

4.2 Basic Structure

The basic building block of neural network technology is the simulated neuron (depicted in Figure 4.1 as a circle). Independent neurons are of little use, however, unless they are interconnected in a network of neurons. The network processes a number of inputs from the outside world to produce an output, the network's classifications and predictions. The neurons are connected by weights, (depicted as lines) which are applied to values passed from one neuron on to the next.

A group of neurons is called a slab. Neurons are also grouped into layers by their connection to the outside world. For example, if a neuron receives data from outside of the network, it is considered to be in the input layer. If a neuron contains the network's predictions or classifications, it is in the output layer. Neurons in between the input and output layers are in the hidden layer(s). A layer may contain one or more slabs of neurons.

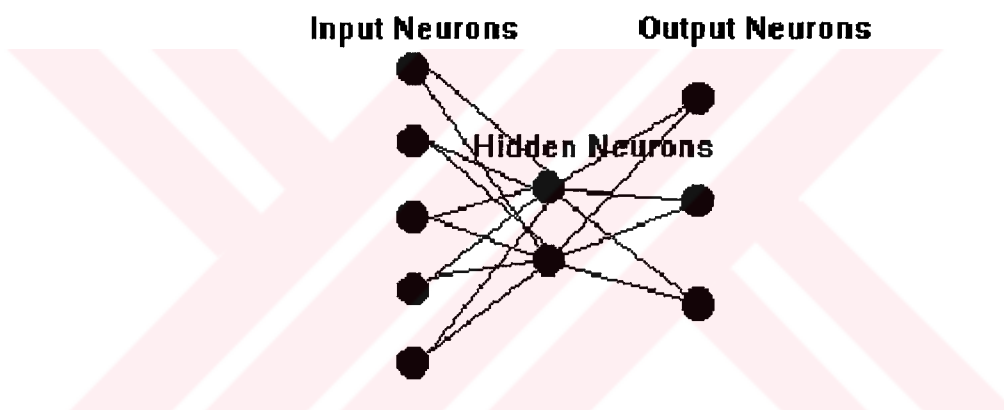


Figure 4.1. Neural networks structure (Ural and Bayrak, 2003)

4.3 Neural Network Characteristics

Neural networks are not programmed; they learn by example. Typically, a neural network is presented with a training set consisting of a group of examples from which the network can learn. These examples, known as training patterns, are represented as vectors, and can be taken from such sources as images, speech signals, sensor data, and financial data. In this study, examples (training patterns) are obtained from the August 17, 1999 Kocaeli, November 12, 1999 Duzce, their aftershocks, and several earthquakes from the same region.

The most common training scenarios utilize supervised learning, during which the network is presented with an input pattern together with the target output for that

pattern. The target output usually constitutes the correct answer, or correct classification for the input pattern. In response to these paired examples, the neural network adjusts the values of its internal weights. If training is successful, the internal parameters are then adjusted to the point where the network can produce the correct answers in response to each input pattern. Usually the set of training examples is presented many times during training to allow the network to adjust its internal parameters gradually.

The neural network approach does not require human development of algorithms and programs that are specific to the classification problem hand, suggesting that time and human effort can be saved. There are drawbacks to the neural network approach, however: the time to train the network may not be known beforehand, and the process of designing a network that successfully solves an application problem may be involved.

It is possible to develop a network that can generalize on the tasks for which it is trained, enabling the network to provide the correct answer when presented with a new input pattern that is different from the input in the training set. To develop a neural network that can generalize, the training set must include a variety of examples that are good preparation for the generalization task. In addition, the training session must be limited in iterations, so that no “overlearning” takes place (i.e., the learning of specific examples instead of classification criteria, which is effective and general). Thus, special considerations in constructing the training set and the training presentations must be made to permit effective generalization behavior from a neural network.

All of these characteristics of neural networks may be explained through the simple mathematical structure of the neural net models. The computations performed in the neural net may be specified mathematically.

4.4 Design Choices

Many design choices are involved in developing a neural network applications.

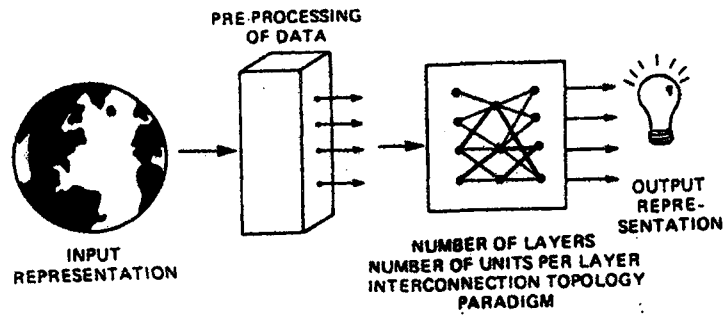


Figure 4.2. Design choices for a neural network application (Dayhoff, 1990).

The first option is in choosing the general area of application. Usually this is an existing problem that appears amenable to solution with a neural network. Next the problem must be identified specially so that a selection of inputs and outputs to the network may be made. Choices for inputs and outputs involve identifying the types of pattern that go into and out of the network. In addition, the researcher must design how those patterns are to represent the needed information (the representation scheme).

Next, internal design choices must be made including the topology and size of the network. The number of processing units are specified, along with the specific interconnections that the network is to have. Processing units are usually organized into distinct layers, which are either fully or partially interconnected.

There are additional choices for the dynamic activity of processing units. A variety of neural net paradigms are available; these differ in the specifics of the processing done at each unit and in how their internal parameters are updated. Each paradigm dictates how the readjustments of parameters take place. This readjustment results in ‘learning’ by the network.

Next there are internal parameters that must be “tuned” to optimize the neural net design. One such parameter is the learning rate from the back-error propagation paradigm (Rumelhart and McClelland, 1986). The value of this parameter influences the rate of learning by the network, and may possibly influence how successful the network learns. These are experiments that indicate “Learning” occurs at more successful rates if this parameter is decreased during the learning session. Some

paradigms utilize more than one parameter that must be tuned. Typically, network parameters are tuned with the help of experimental results and experience on the specific applications problem under study.

Finally, the selection of training of training data presented to the neural network influences whether or not the network “learns” a particular task. How well a network will learn depends on the examples presented. A good set of examples, which illustrate the tasks to be learned well, is necessary for the desired learning to take place; a poor set of examples will result in poor learning on the part of the network. The set of training examples must also reflect the variability in the patterns that the network will encounter after training.

4.5 Neural Network Architectures

4.5.1 GRNN Architecture

General Regression Neural Networks, GRNN, which is invented by Dr. Donald Specht (1996), is a three-layer network having one hidden neuron for every training pattern, in addition to the total number of neurons equal to sum of input and output number.

Unlike Back-propagation Networks, there is a smoothing factor instead of training parameters; learning rate and momentum. The success of GRNN networks is dependent upon the smoothing factor. The individual smoothing factor adjustments values may be used as a sensitivity analysis tool: Inputs with low smoothing factor adjustments are candidates for removal for a later trial, especially if the smoothing factor adjustments gets to zero.

The fact that the GRNN network centers are determined by the training data vectors and not some artificial centers best for optimization gives the network stability and it ensures that it cannot be over-trained. This is the main feature along with its simplicity that distinguishes it from most other approaches.

GRNN is especially useful for continuous function approximations. GRNN can have multidimensional input, and it will fit multidimensional surfaces through data. GRNN work by measuring how far a given sample pattern is from patterns in the training set in N dimensional space, where N is the number of inputs in the problem.

When a new pattern is presented to the network, that input pattern is compared in N dimensional space to all of the patterns in the training set to determine how far in distance it is from those patterns. The output that is predicted by the network is a proportional amount of all of the outputs in the training set. The proportion is based upon how far the new pattern is from the given patterns in the training set.

Advantages:

- i. GRNN can handle both linear and non-linear data.
- ii. Adding new samples to the training set does not require re-calibration the model.
- iii. Only one adjustable parameter thereby making overtraining less likely.

Disadvantages:

- i. Requires many training samples to adequately span the variation in the data.
- ii. Requires that all the training samples be stored for future use (i.e., prediction).
- iii. Has trouble with irrelevant inputs.
- iv. No intuitive method for selecting the optimal smoothing parameter.

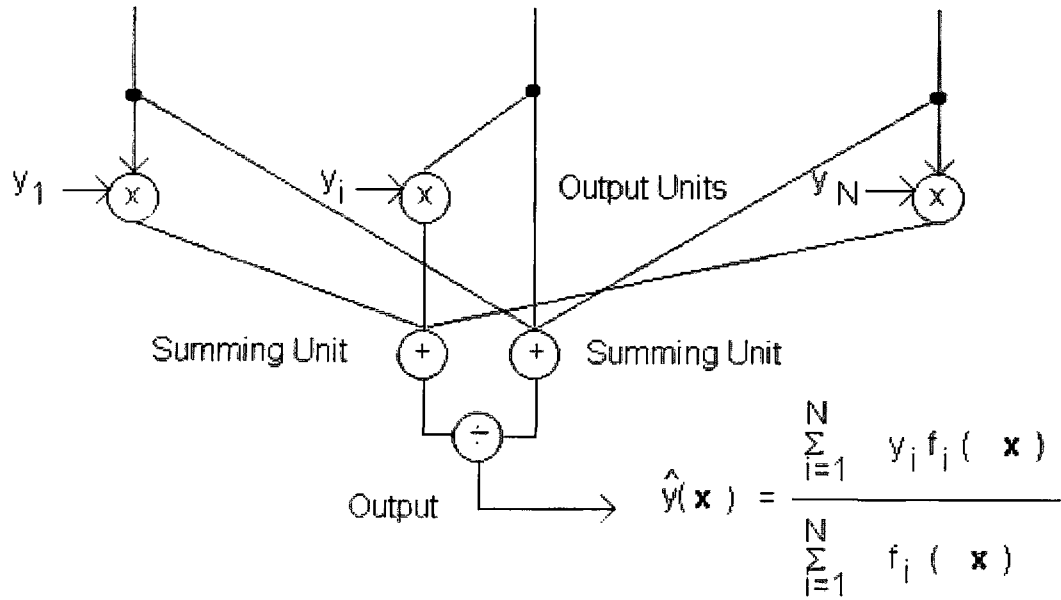


Figure 4.3. The basic GRNN architecture.

4.5.1.1 GRNN Architecture Learning Algorithm

The general regression NN (GRNN) is a three layer network having one hidden neuron for every training pattern (Lawrence,1993). In addition to the total number of neurons is equal to the sum of the number of inputs and the outputs (Specht,1991). The regression is the estimation of the least mean squares of variables based on the available data. In other words, the regression decision in the GRNN architecture reveals the most probable value of all the patterns in an N-dimensional space (where N is the number of inputs). Output values correspond to the weighted average of the target values. The target values are weights which exceed from the hidden layers to the output layers. During the GRNN training process, smoothing factors (or bandwidths) are the only weights which need to be calculated. The success of the GRNN is dependent upon the smoothing factor, however, there is no intuitive method for selecting the optimal smoothing factor (Ural and Bayrak, 2003).

The GRNN utilizes a probabilistic model between an independent single training vector in the input space ($\mathbf{X}$) and a dependent scalar output (Y). $\mathbf{X}_i$ is defined as the input vector of the i^{th} training data set, and Y_i is the output related to $\mathbf{X}_i$. It is assumed that x and y are defined as measured values of $\mathbf{X}$ and Y , respectively, and the regression of Y on x is defined as $\hat{y}$ such that;

$$\hat{y}(x) = \frac{\sum_{i=1}^p y_i f_i(x)}{\sum_{i=1}^p f_i(x)} \quad (4.1)$$

$$f_i(x) = \exp \left[\frac{-(x-x_i)^T (x-x_i)}{2\sigma^2} \right] \quad (4.2)$$

By substituting Eq. (4.2) in Eq. (4.1).

$$\hat{y}(x) = \frac{\sum_{i=1}^p y_i \exp \left[\frac{-(x-x_i)^T (x-x_i)}{2\sigma^2} \right]}{\sum_{i=1}^p \exp \left[\frac{-(x-x_i)^T (x-x_i)}{2\sigma^2} \right]} \quad (4.3)$$

Eqs. (3) is known as the Specht's GRNN. In Specht's GRNN, σ , is a smoothing factor shared by all the inputs and the pattern nodes. Assigning an independent smoothing factor for each of the variables may improve accuracy ; however, this may be impractical in many simulations (Specht, 1996).

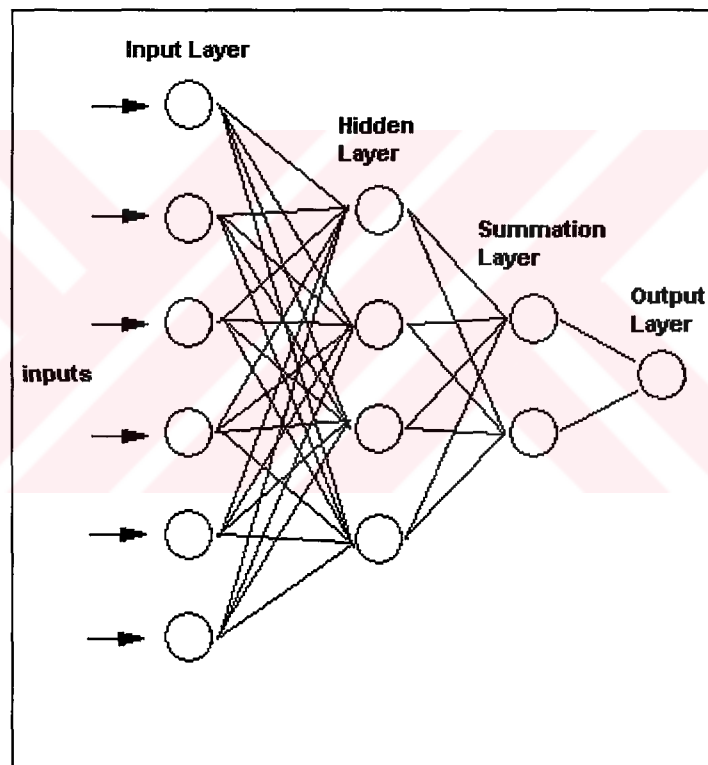


Fig. 4.4. The GRNN architecture (Specht, 1996).

As shown in Fig. 4.4, the GRNN is composed of one input layer, one hidden layer, a summation layer, and one output layer. The GRNN models are trained by a one-pass learning algorithm. In order to estimate an output, the presented input is subtracted from each stored vector in the hidden layers. The probability density functions or radial basis functions are applied in order to evaluate the squared or absolute difference between the hidden neurons and inputs. The summation unit computes the

sum of the outputs from all hidden neurons. The network's final output is obtained at the output layer, where a normalization is performed. The normalized output is computed by dividing the value of the weighted sum of hidden layer outputs, by the value in the summation layer.

4.5.2 PNN Architecture

Probabilistic Neural Networks are (PNN) are known for their ability to train quickly on sparse data sets. PNN separates data into a specified number of output categories.

PNN networks are three layer networks wherein the training patterns are presented to the input layer and the output layer has one neuron for each possible category. There must be as many neurons in the hidden layer as there are training patterns.

The network produces activations in the output layer corresponding to the probability density function estimate for that category. The highest output represents the most probable category (Frederick, 1996).

4.5.3 Backpropagation Architecture

Backpropagation networks are known for their ability to generalize well on a wide variety of problems. That is why they are used for the vast majority of working neural network applications. Backpropagation networks are a supervised type of network, e.g., trained with both inputs and outputs. Depending upon the number of patterns, training may be slower than other paradigms. When using Backpropagation networks, you can increase the precision of the network by creating a separate network for each output if your outputs are not categories (Frederick, 1996).

4.5.4 Kohonen Architecture

The Kohonen Self Organizing Map network used in NeuroShell 2 is a type of unsupervised network, which has the ability to learn without being shown correct outputs in sample patterns. These networks are able to separate data into a specific number of categories. There are only two layers: an input layer and an output layer which has one neuron for each possible output category.

The training patterns are presented to the input layer, then propagated to the output layer and evaluated. One output neuron is the "winner". The network weights are adjusted during training. This process is repeated for all patterns for a number of epochs chosen in advance.

This network is very sensitive to learning rate. It is lowered slightly but steadily by NeuroShell 2 as the training progresses, causing smaller and smaller weight changes. This causes the network to stabilize.

The network adjusts the weights for the neurons in a neighborhood around the winning neuron. The neighborhood size is variable, starting off fairly large (sometimes even close to the number of categories) and decreasing with learning until during the last training events the neighborhood is zero, meaning by then only the winning neuron's weights are changed. By that time the learning rate is very small, and the clusters have been defined. NeuroShell 2 automatically adjusts learning rate and neighborhood size for you, but you have to specify the initial values as well as the total number of epochs that learning will continue (Frederick, 1996).

4.5.5 GMDH Architecture

The technique called Group Method of Data Handling (GMDH) was invented by A.G.Ivakhnenko in the former Soviet Union, but enhanced by others, including A.R.Barron. This technique has also been called "polynomial nets".

GMDH works by building successive layers with complex links (or connections) that are the individual terms of a polynomial. These polynomial terms are created by using linear and non-linear regression. The initial layer is simply the input layer. The first layer created is made by computing regressions of the input variables and then choosing the best ones. The second layer is created by computing regressions of the values in the first layer along with the input variables. Again, only the best are chosen by the algorithm. These are called survivors. This process continues until the net stops getting better (according to a prespecified selection criterion).

The resulting network can be represented as a complex polynomial (i.e., a familiar formula) description of the model. You may view the formula, which contains the most significant input variables. In some respects, it is very much like using regression analysis. GMDH can build very complex models while avoiding overfitting problems.

GMDH contains several evaluation methods, called selection criteria, to determine when it should stop training. One of these, called Regularity, is similar to Calibration in that the net uses the constructed architecture that works the best on the test set.

The other selection criteria do not need a test set because the network automatically penalized models that become too complex in order to prevent overtraining. The advantage of this is that you can use all available data to train the network.

A by-product of GMDH is that it recognizes the most significant variables as it trains, and will display a list of them (Frederick, 1996).



5. AUGUST 17,1999 AND NOVEMBER 12, 1999 EARTHQUAKES

5.1 Introduction

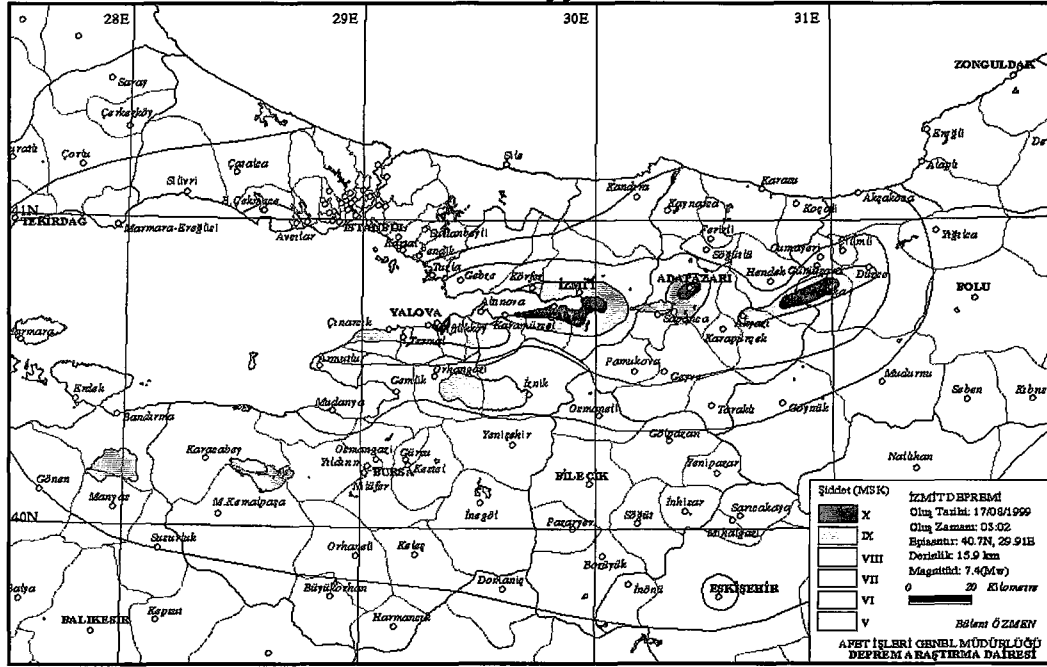
On August 17, 1999 a magnitude $M_w = 7.4$ earthquake struck the Kocaeli and Sakarya provinces in northwestern Turkey, a densely populated region home to 40% of the industrial potential of the country. The earthquake claimed about 18,000 lives, resulted in the dislocation of about 200,000 families and caused very heavy structural damage. Three months after the Kocaeli earthquake, the $M_w = 7.2$ Duzce earthquake took place to the immediate east of the fault rupture of the Kocaeli earthquake. Being associated with the 'Duzce fault', a segment at the eastern terminus of the Kocaeli rupture, Duzce earthquake was interpreted as an aftershock of the Kocaeli earthquake, as well as an independent event. Nevertheless, it completed the rupture on this portion of the North Anatolian fault leaving the segments within the Marmara sea unruptured.

The August 17, 1999, Kocaeli earthquake produced right-lateral surface displacements over a distance of about 120 km between the Hersek delta to the west of Golcuk on the west and Akyazi on the east. Measured displacements along the fault rupture were changing between 2.5 and 4.5 m. Maximum measured slip was measured as about 5 m at a distance of about 30 km to the east of Golcuk.

Duzce earthquake produced a surface fault rupture of approximately 40 km on the Duzce fault between the eastern terminus of the Koceli Earthquake rupture at Eften Lake and Bolu Tunnels at Elmalik. The maximum right-lateral offset were measured to be about 4 m. The rupture had a significant vertical component as well ranging between 10 and 150 cm.

Maximum MSK intensity of the Kocaeli earthquake was X, essentially assigned on the basis of fault rupture and excessive ground deformations. Fig. 5.1 provides an isoseismal map of the earthquake (Özmen, 2000; www.deprem.gov.tr) No official intensity map exists for the Duzce earthquake essentially due to the difficulty in separating the effects of the two earthquakes from each other. According to the estimations, maximum MSK intensity in the Duzce earthquake was IX. (Durukal, 2002).

İZMİT DEPREMİNİN EŞİDDET HARİTASI



Şekil 3 : İzmit depreminin eşidket haritası

Figure 5.1. Isosismal map of the August 17, 1999 Kocaeli earthquake (www.deprem.gov.tr).

5.2 Seismological Background

The North Anatolian Fault was the seismically most active tectonic entity during the last 25 years in the Anatolian plateau. The most important earthquakes are the Erzincan earthquake of 13 March 1992, the Dinar earthquake of 1 October 1995, Adana-Ceyhan earthquake of 4 July 1998, Izmit-Kocaeli earthquake of 17 August 1999, and the Duzce earthquake of 12 November 1999. August 17, 1999 ($M_w=7.4$) Kocaeli and November 12, 1999 ($M_w=7.2$) Duzce earthquakes are consequences of the motion of a wedge of continental crust, known as the Anatolian Block, being squeezed between the Arabian and the Eurasian plates. This motion is accommodated by two major strike-slip faults: the North Anatolian fault and the East Anatolian faults (Fig. 5.2). The August 17 Kocaeli and November 12, 1999 Duzce earthquakes were both associated with the North Anatolian fault. This major fault is predominantly a single right-lateral strike-slip fault with a differential slip rate of 10–20 mm/yr. The faulting on this mega tectonic entity has a segmental character with a characteristic earthquake in the $M_w=7+$ range. The last earthquake sequence began with the 1939 Erzincan earthquake, followed by earthquakes in 1942, 1943, 1944, 1951, 1957, 1967, and finally by the 1999 earthquakes (Fig. 5.3). The Duzce earthquake is associated with the so-called Duzce fault, which forms a morphological boundary at the south of the Duzce Plain and extends for 70 km between Akyazi and

Kaynasli. At Adapazari and Bolu, the Duzce fault joins to the North Anatolian Fault System. The historical seismicity of the region during the last two millennia is well studied (Ambrasey, 1991; Parsons et al. 2000). In this century, starting with 1939, the North Anatolian Fault Zone had a generally westward migrating sequence of earthquakes, which, for long, has indicated the potential for the Kocaeli and Duzce earthquakes (Toksöz et al., 1979; Barka, 1988). USGS rapid moment tensor solution provides the following parameters for the two events:

17.08.1999 Kocaeli Earthquake: Epicenter: 40.639N 29.830E, $m_b=6.3$; $M_s=7.8$;; Seismic Moment: $M_0=1.4 \times 10^{20}$ Nm; $M_w=7.4$.

11.12.1999 Duzce Earthquake: Epicenter: 40.768N 31.148E, $m_b=6.5$; $M_s=7.3$;; Seismic Moment: $M_0=4.5 \times 10^{19}$ Nm; $M_w=7.1$.

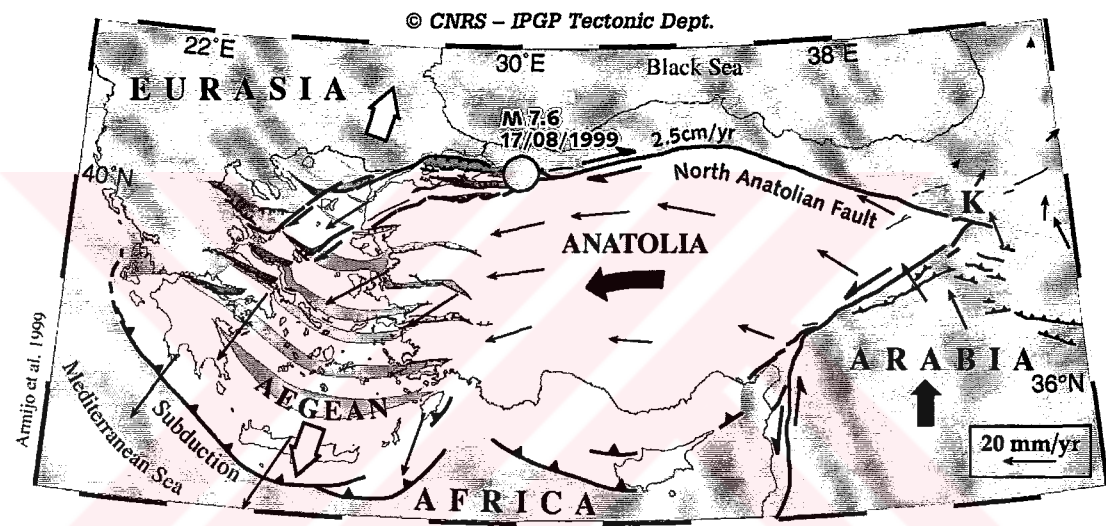


Figure 5.2. Regional tectonic map (www.jpgp.jussieu.fr).

The North Anatolian Fault splays westward into two main branches, NAF(N) and NAF (S), 100 km apart. The Northern branch (N) bounds the southern side of the Gulf of Izmit, outlines the Marmara pull apart basin, cuts the Dardanelles structure, and marks the southern side of the Saros Gulf. The Izmit earthquake occurred on that branch, east of the Marmara Sea (www.jpgp.jussieu.fr).

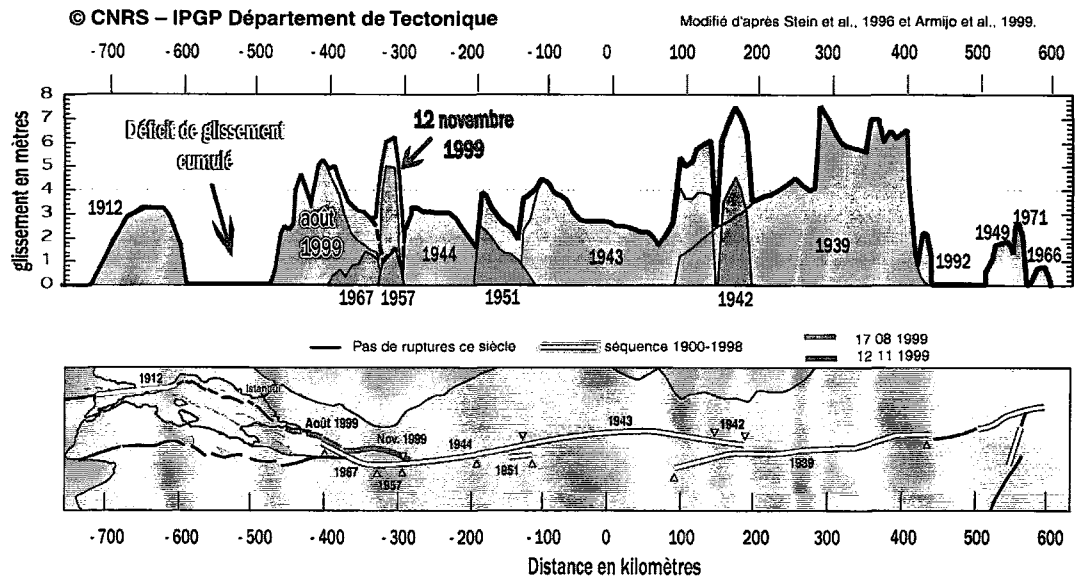


Figure 5.3. Migration of earthquakes on the North Anatolian Fault in this century and distribution of fault offsets. The deficit in Marmara sea is indicated map (www.jpgp.jussieu.fr).

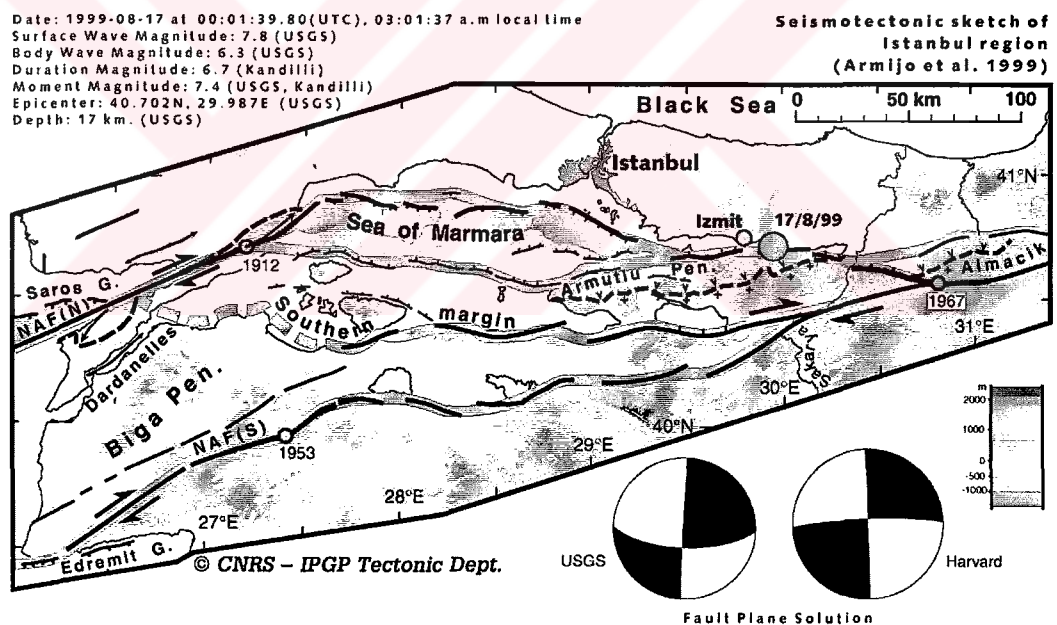


Figure 5.4. Fault Plane Solutions (www.jpgp.jussieu.fr).

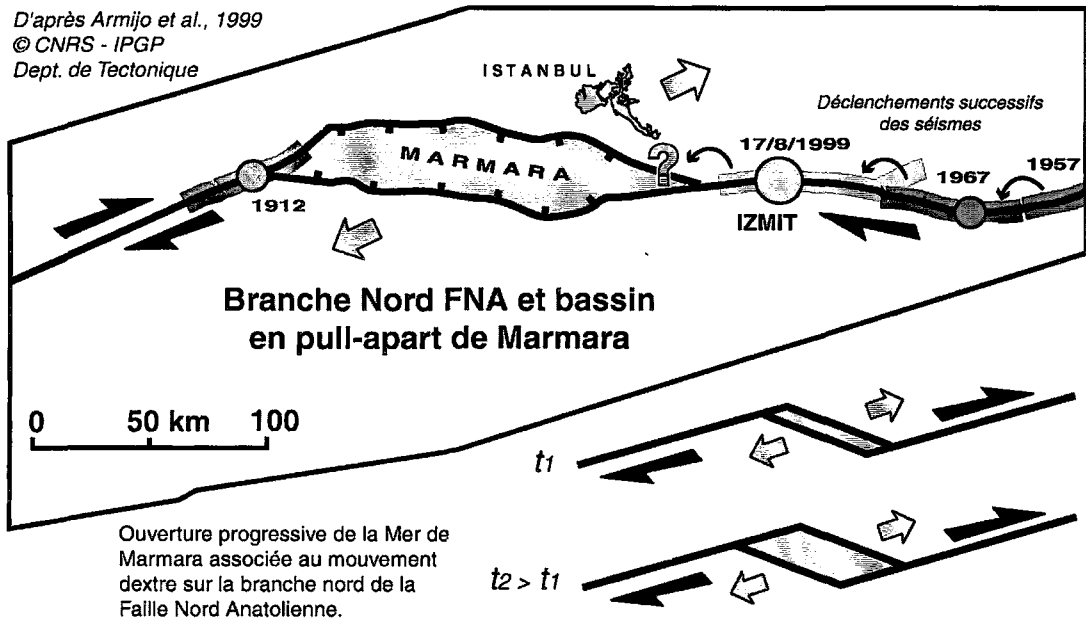


Figure 5.5. A Simplified sketch of the pull apart (www.jpgp.jussieu.fr).

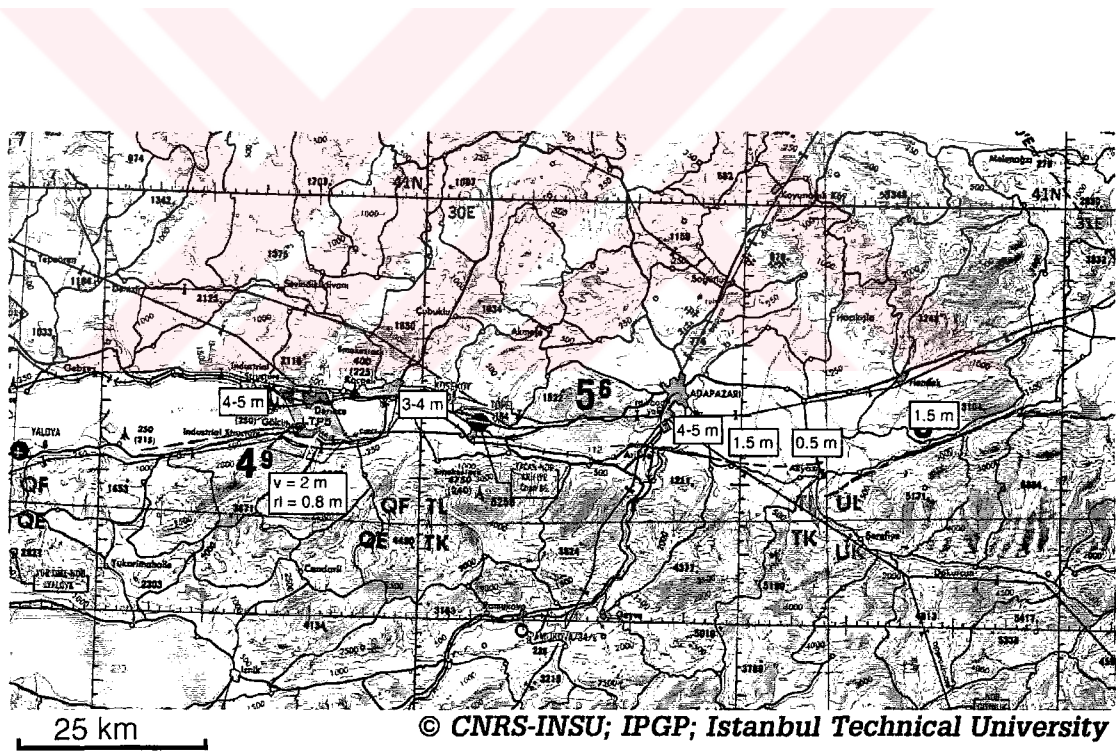


Figure 5.6. Surface Ruptures due to Kocaeli earthquake (www.jpgp.jussieu.fr).

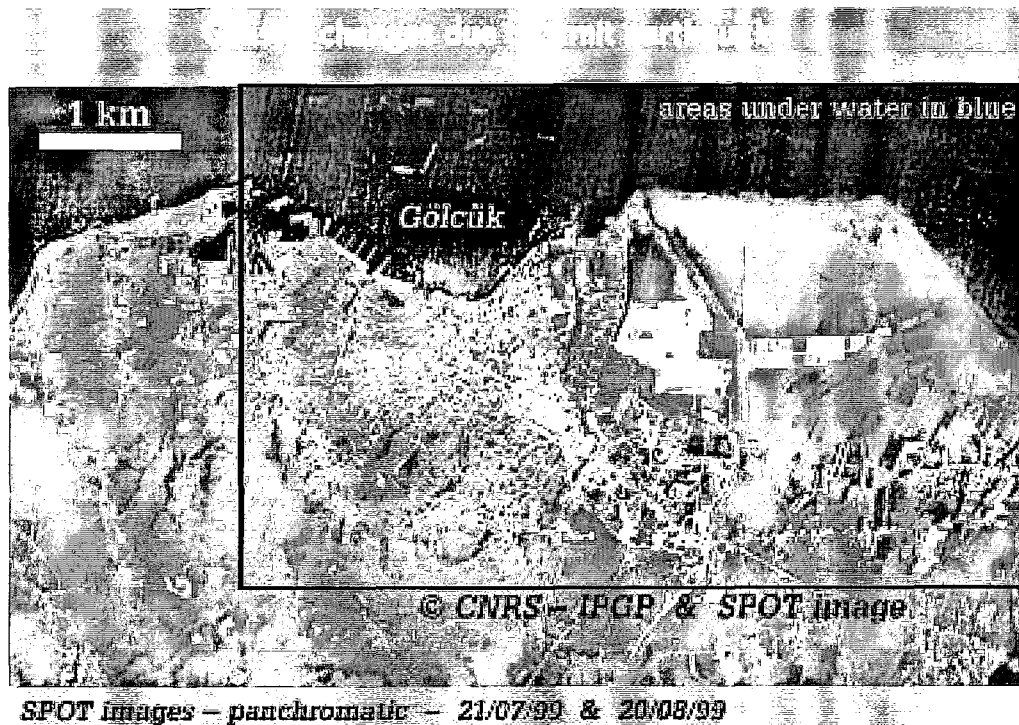


Figure 5.7. Coastal changes due to Kocaeli Earthquake (www.jpgp.jussieu.fr). Comparison of SPOT scenes taken before and after the earthquake. Areas under water appear in blue.

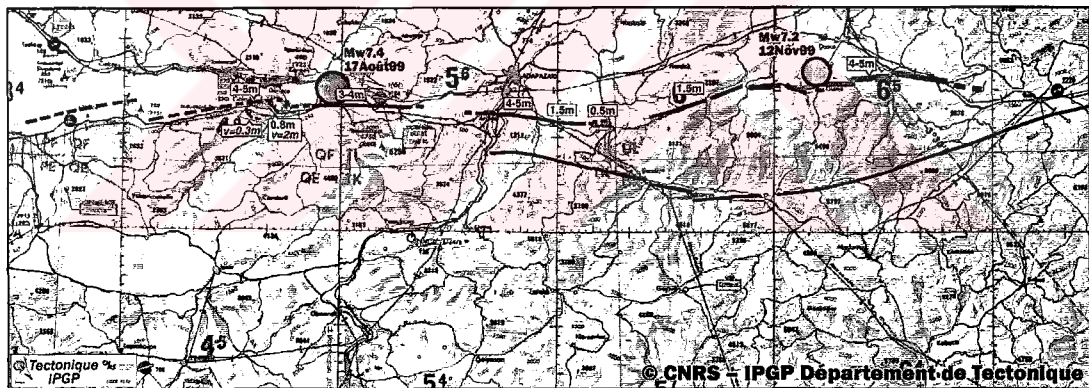


Figure 5.8. Preliminary report of fault segments with surface breaks by Izmit earthquake (in purple). Fault segments broken by Duzce earthquake are in red. Boxes give average horizontal coseismic offsets on the different segments, and vertical throw at Golcuk (www.jpgp.jussieu.fr).

5.3 Other earthquakes used in analysis

The earthquakes information that are used in the artificial intelligence strong ground motion attenuation model are given in Table 5.1. The earthquakes whose magnitudes are equal and higher than 5.0 are chosen as database for the model.

Table 5.1. The earthquakes used in the analyses.

No	Earthquake	Date	M _w
1	Kocaeli	August 17, 1999	7.4
2	Düzce	November 12, 1999	7.1
3	Hendek - Akyazi	August 23, 2000	5.8
4	Izmit Turkey	September 13, 1999	5.8
5	Sapanca - Adapazari	November 11, 1999	5.7
6	Akyazi - Adapazari	August 17, 1999	5.5
7	Duzce Turkey Aftershock	December 11, 1999	5.4
8	Duzce Turkey Aftershock	December 11, 1999	5.2
9	Izmit Turkey	August 31, 1999	5.2
10	Northeast of Bolu	February 14, 2000	5.0
11	Duzce - Bolu	November 19, 1999	5.0
12	Kaynasli - Bolu	December 11, 1999	5.0
13	Hendek - Adapazari	July 11, 1999	5.0
14	Marmara Sea	September 20, 1999	5.0
15	Hendek Adapazari	August 22, 1999	5.0
16	Cinarcik - Yalova	August 19, 1999	5.0

6. DATASET INFORMATION

6.1 Strong-Motion Stations and Site Classification Information

The recordings employed are obtained from strong motion stations operating in Northwestern Turkey and resulted from events that include the Kocaeli ($M_w=7.4$) and the Duzce ($M_w=7.1$) earthquakes and their aftershocks as well as other events. A database consisting of 202 recordings from 16 recent events is employed to develop attenuation relationship for the geometric mean of horizontal peak ground acceleration (PHA) and peak vertical ground acceleration (PVA).

The strong motion records used in this study are obtained from stations operated by Bogazici University's Kandilli Observatory and Earthquake Research Institute (KOERI), by Istanbul Technical University (ITU), and by the General Directorate of Disaster Affairs' Earthquake Research Department (ERD). In addition, a valuable data set have been obtained by the Columbia University Lamont-Doherty group (LD) during the Duzce Earthquake in Karadere. Those records are obtained from a database maintained at the Pacific Earthquake Engineering Research Center (PEER) website (<http://peer.berkeley.edu>) and at the The Consortium of Organizations for Strong-Motion Observation Systems (COSMOS) website (<http://www.cosmos-eq.org/default.html>) Among a very large database, a subset of 202 records from 16 earthquakes with $M_w \geq 5.0$ are used in the analysis. All earthquakes used in the analysis occurred in the northwestern part of the Turkey. So, it must be clarified that the proposed attenuation model obtained from the neural network analysis is valid just for Northwestern Turkey.

Table 6.1. Database of strong motion records used in the neural network analysis.

Event No	Earthquake	Event Date	Epicenter Coordinates		Depth (km)	Mw
1	Kocaeli	August 17, 1999	40.64N	29.83E	17	7.4
2	Düzce	November 12, 1999	40.77N	31.15E	14	7.1
3	Hendek - Akyazi	August 23, 2000	40.68N	30.10E	15.3	5.8
4	Izmit Turkey	September 13, 1999	40.77N	30.10E	19.6	5.8
5	Sapanca - Adapazari	November 11, 1999	40.74N	30.27E	22	5.7
6	Akyazi - Adapazari	August 17, 1999	40.64N	30.65E	15.3	5.5
7	Duzce Turkey Aftershock	December 11, 1999	40.74N	31.05E	10	5.4
8	Duzce Turkey Aftershock	December 11, 1999	40.75N	31.10E	10	5.2
9	Izmit Turkey	August 31, 1999	40.75N	29.92E	17.7	5.2
10	Northeast of Bolu	February 14, 2000	40.90N	31.75E	15.7	5.0
11	Duzce - Bolu	November 19, 1999	40.78N	30.97E	9.2	5.0
12	Kaynasli - Bolu	December 11, 1999	40.75N	31.36E	10	5.0
13	Hendek - Adapazari	July 11, 1999	40.71N	30.70E	10	5.0
14	Marmara Sea	September 20, 1999	40.69N	27.58E	16.4	5.0
15	Hendek Adapazari	August 22, 1999	40.74N	30.68E	5.4	5.0
16	Cinarcik - Yalova	August 19, 1999	40.59N	29.08E	11.5	5.0

The records are obtained on different soil conditions. The effect of local site conditions is also included in the neural network attenuation models studied. Parameters in the models are included to represent the different site classes. Currently, there are several site classification systems that are used to distinguish between different site conditions at strong motion stations. Since some of the site classification systems divide the soil into three, some into four, and some into five, and since the limits of shear wave velocity for this divisions are different from each other even they have same number of divisions, a new site classification system enclose all other classification systems is generated to use in the neural network analysis, which is given in Table 6.2. below. Site class definitions use in our analysis are given in Table 6.2.

Table 6.2. Definition of site classes used in the attenuation models.

Site Class	Shear wave velocity
A	>750 m/s
B	180-750 m/s
C	<180m/s

Other site classification systems which are widely used are given in Tables from 6.3- to 6.9.

Table 6.3 USGS Site Classification System (<http://peer.berkeley.edu>).

Site Class	Shear wave velocity
A	>750 m/s
B	360-750 m/s
C	180-360 m/s
D	<180m/s

Table 6.4. GM-Geomatrix (1993).

Site Category	Description	Comments
A	Rock	Soil depth<6m
B	Shallow Soil	Soil depth<20m
C	Deep Soil, Narrow Canyon	Depth>20m, Canyon<2km wide
D	Deep Soil, Wide Canyon	Depth>20m, Canyon>2km wide
E	Soft Soil	$V_s < 150 \text{ m/s}$

Table 6.5. BRM-Rodriguez-Marek et al. (2001).

Site Category	Description	Comments
BRM-A	Hard Rock	$V_s \geq 1500 \text{ m/s}$, $T_s \leq 0.1 \text{ s}$
BRM-B	Rock	$V_s \geq 760 \text{ m/s}$ or $< 6 \text{ m soil}$, $T_s \leq 0.2 \text{ s}$
BRM-C	Weathered Rock, Shallow Stiff Soil	Soil Depth<60m, $T_s \leq 0.8 \text{ s}$
BRM-D	Deep Stiff Soil	Soil Depth>60m, $T_s \leq 2 \text{ s}$
BRM-E	Soft Soil	Soft clay thickness>3m, $T_s \leq 1.4 \text{ s}$

Table 6.6. Uniform Building Code (1997).

Site Category	Description	Comments
S _A	Hard Rock	$V_s \geq 1500 \text{ m/s}^1$
S _B	Rock	$V_s = 760-1500 \text{ m/s}$
S _C	Very Dense Soil, Soft Rock	$V_s = 360-760 \text{ m/s}$
S _D	Stiff Soil Profile	$V_s = 180-360 \text{ m/s}$
S _E	Soft Soil Profile ²	$V_s < 180 \text{ m/s}$

¹ V_s is averaged over the top 30m using the travel time of a shear wave

² Site class S_E includes sites with greater than 3m of soft clay

Table 6.7. NEHRP (1997).

Site Category	Description
A	$V_s \geq 1500$ m/s
B	$V_s = 760-1500$ m/s
C	$V_s = 360-760$ m/s
D	$V_s = 180-360$ m/s
E	$V_s < 180$ m/s

Table 6.8. Soil group definitions from Turkish Building Code
(adapted from Ministry of Public Works 1998).

Soil Group	Description of Soil Group	Shear Wave Velocity (m/s)
(A)	1) Unweathered rock	>1000
	2) Very dense sand, gravel	>700
	3) Hard clay, silty clay	>700
(B)	1) Soft rock	700-1000
	2) Dense sand, gravel	400-700
	3) Very stiff clay, silty clay	300-700
(C)	1) Highly weathered soft rocks	400-700
	2) Medium dense sand and gravel	200-400
	3) Stiff clay, silty clay	200-300
(D)	1) Soft, deep alluvial layers	<200
	2) Loose sand	<200
	3) Soft clay, silty clay	<200

Table 6.9. Site class definitions from Turkish Building Code
(adapted from Ministry of Public Works 1998).

Site Class	General Description	Soil Group and Topmost Soil Layer Thickness (h_1)
Z1	Rock	Group (A) soils Group (B) soils with $h_1 \leq 15\text{m}$
Z2	Shallow Stiff Soil	Group (B) soils with $h_1 > 15\text{m}$ Group (C) soils with $h_1 \leq 15\text{m}$
Z3	Stiff Soil	Group (C) soils with $15\text{m} < h_1 \leq 50\text{m}$ Group (D) soils with $h_1 < 10\text{m}$
Z4	Soft Soil	Group (C) soils with $h_1 > 50\text{m}$ Group (D) soils with $h_1 > 10\text{m}$

Zare and Bard (2002) have studied the strong ground motion dataset of Turkey to prepare a catalog to be used as a database for further studies. Some of the information used in our analysis has been taken from this database. According to their classifications, site category 1 corresponds to rock and hard alluvial sites, with $V_s > 800$ m/s over the uppermost 30 m and fundamental frequency (f_0) larger than 15 Hz. Site category 2 relates to alluvial sites; thin soft alluviums, with $500 < V_s < 700$ over the uppermost 30 m and $5 < f_0 < 15$ Hz. Site category 3 corresponds to soft gravel and sandy sites, with $300 < V_s < 500$ over the uppermost 30 m and $2 < f_0 < 5$ Hz. Finally site category 4 relates to soft soil sites; thick soft alluviums with $V_s < 300$ m/s over the uppermost 35 m and $f_0 < 2$ Hz.

In the study which is prepared with the recent strong motion data set of Turkey by Gulkan and Kalkan (2002) the soil groups for Turkey were divided into three in ascending order for shear velocity: soft soil, soil, and rock. The average shear-wave velocities assigned for these groups are 200, 400 and 700 m/s, respectively.

While deciding the site classifications for ground motion stations, different data sources are used but no information can be gathered regarding the soil condition for some strong motion stations. Unfortunately, the actual shear-wave velocity and detailed site description are not available for most stations in Turkey. Since the lack of this important parameter, several records are extracted from our database. Among the available stations, 61 stations whose site classifications are known and estimated were selected for the analysis.

There are 32 strong-motion stations installed by Earthquake Engineering Department of Bogazici University, Kandilli Observatory and Earthquake Research Institute (KOERI), 5 strong-motion stations installed by Istanbul Technical University (ITU), 20 strong-motion stations installed by Earthquake Research Department of General Directorate of Disaster Affairs (ERD), and are 4 strong-motion stations installed by the Columbia University Lamont-Doherty group (LD) in the neural network attenuation model. These strong-motion stations and their site class determined by using the above site classification systems are given in the Table 6.10.

Table 6.10 Site classification for the ground motion stations used in analysis.

No	Station	Data Source	Site Classification
1	Ambarli	KOERI	C
2	Adapazari-A.Babalioglu	"	B
3	Adapazari-BahtiyarTopcu	"	B
4	Adapazari-Bayindirlik Directory	"	B
5	Adapazari-Hendek Orman Fidanligi	"	B
6	Adapazari - Kadin D. Cocuk B. Residence	"	B
7	Adapazari - Seker FB.	"	B
8	Adapazari - Seker MH. Genc Street	"	B
9	Adapazari - Toyotasa	"	B
10	Akyazi	"	B
11	Arcelik Darica	"	B
12	Aslan R. Darica	"	C
13	Botas	"	B
14	Bursa Tofas	"	B
15	Cekmece	"	B
16	Eminonu - Galata Kop.	"	B
17	Fatih	"	C
18	Hava Alani	"	B
19	Heybeliada	"	B
20	K.Mustafa Pasa	"	B
21	LeventYapiKrediPlz	"	A
22	Yalova AhmetTas	"	B
23	Yalova BaglaraltiC	"	B
24	Yalova BahcevanS	"	B
25	Yalova DevletHas.	"	B

26	Yalova Gir	"	B
27	Yalova HilalStreet	"	B
28	Yalova Kasif	"	B
29	Yalova Rad	"	B
30	Yalova Ruzgar Street	"	B
31	Yalova Tarim Directory	"	B
32	Yarimca	"	B
33	Atakoy	ITU	B
34	Golcuk		B
35	Maslak	"	A
36	Mecidiyekoy	"	B
37	Zeytinburnu	"	B
38	Afyon Bay	ERD	C
39	Aydin	"	C
40	Bolu	"	C
41	Bornova	"	C
42	Bursa Sivil	"	A
43	Canakkale	"	C
44	Duzce	"	C
45	Eregli	"	A
46	Gebze	"	A
47	Goynuk	"	B
48	Istanbul	"	B
49	Izmit	"	A
50	Iznik	"	C
51	Kutahya	"	B
52	Manisa	"	A
53	Mudurnu		C
54	Sakarya	"	B
55	Tekirdag	"	A
56	Tokat	"	C
57	Tosya	"	A
58	375 Lamont 375	LAMONT	A
59	362 Lamont 362	"	B
60	1061 Lamont 1061	"	B
61	1060 Lamont 1060	"	A

6.2 Earthquake Information

In addition to the Site Class, the other parameters used in the model are earthquake magnitude, site-source distance, earthquake depth, and the three-component acceleration values. Most of the data used in this study are downloaded from the PEER (<http://peer.berkeley.edu>) and COSMOS (<http://www.cosmos-eq.org/default.html>) websites. Also, these data are presented on the internet by the "General Directorate of Disaster Affairs, GDDA, (<http://angora.deprem.gov.tr>)". Most of these records belong to the National Strong Motion Network that is the largest network operator in Turkey.

Magnitude is a number that characterizes the relative size of an earthquake. Magnitude is based on measurement of the maximum motion recorded by a seismograph which is an instrument used to detect and record earthquakes. Several scales have been defined, but the most commonly used are (1) local magnitude (ML), commonly referred to as "Richter magnitude," (2) surface-wave magnitude (Ms), (3) body-wave magnitude (Mb), and (4) moment magnitude (Mw). Scales 1-3 have limited range and applicability and do not satisfactorily measure the size of the largest earthquakes. The moment magnitude (Mw) scale, based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes but is more difficult to compute than the other types. In our analysis, moment magnitude (Mw) is used as an input parameter.

Another parameter used in the neural network attenuation model is distance. Different distances are used in different attenuation relationships proposed by other researchers. In this study, hypocenter distance is used in the model. Hypocenter is the point within the earth where an earthquake rupture starts and it is also commonly termed the focus. For some stations, exact hypocenter distances are given for specific earthquakes. If it has not been given, it is calculated by using the epicenter distance and earthquake depth. Calculated value is assumed equal to the hypocenter distance. Epicenter is the point on the earth's surface vertically above the point in the crust where a seismic rupture begins.

The inventory of strong motion recordings from shallow crustal earthquakes in northeast Turkey (from the earthquakes given in Table 6.1) are given in Figure 6.1.

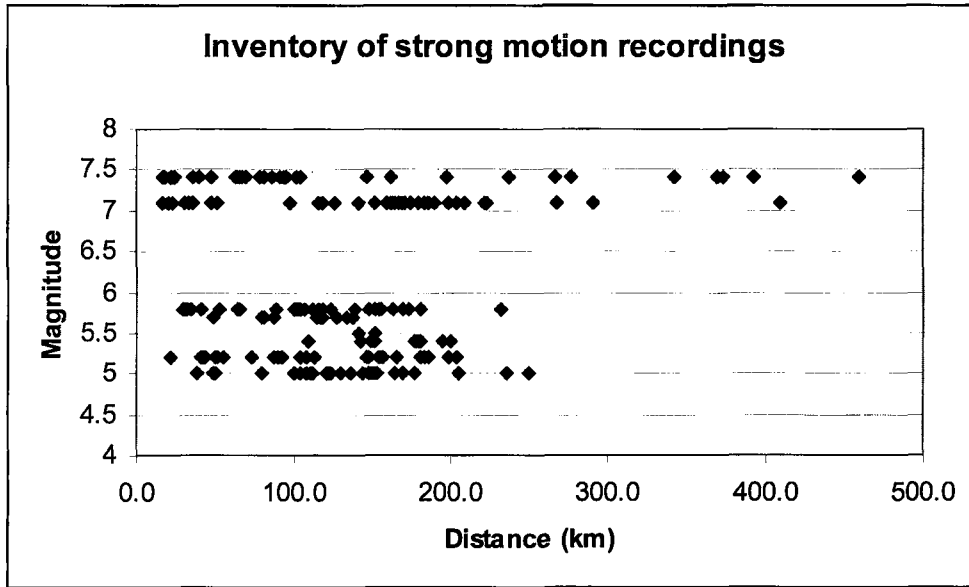


Figure 6.1. The inventory of strong motion recordings used in the analysis.

The earthquake depth is used as another input parameter. This information is obtained from the sources explained before.

In recent attenuation relationship models, (Campbell et al., 2003) in addition to above parameters, the faulting mechanism and hanging wall effects have been taken into consideration. Since hanging wall effects are assumed in the region less than 5 km to the earthquake source, this effect has not been selected as parameter due to lack of the stations installed within this specific distance to the fault. It is known that faulting mechanism is another important parameter that effects the attenuation. Earthquakes records used in study are in approximately in the same region, and strike-slip faulting mechanism is predominant style of faulting in NAF in northwestern Turkey. Since strike-slip faulting mechanism is approximately valid for all the database in this study, it is not used as an parameter in this model.

6.3 Dataset used in the neural network attenuation model

The whole data set is given in Appendix A.

Table 6.11. Summary of the three-component data set.

Station	Data Source	Record Component	PGA(g)
Kocaeli Earthquake, August 17, 1999			
Arcelik	KOERI	KOCAELI/ARCDWN	0.0860
		KOCAELI/ARC000	0.2180
		KOCAELI/ARC090	0.1490
Cekmece	KOERI	KOCAELI/CNA-UP	0.0570
		KOCAELI/CNA000	0.1790
		KOCAELI/CNA090	0.1330
Hava Alani	KOERI	KOCAELI/DHM-UP	0.0550
		KOCAELI/DHM000	0.0900
		KOCAELI/DHM090	0.0830
Fatih	KOERI	KOCAELI/FAT-UP	0.1280
		KOCAELI/FAT000	0.1870
		KOCAELI/FAT090	0.1590
Botas	KOERI	KOCAELI/BTS-UP	0.0240
		KOCAELI/BTS000	0.1030
		KOCAELI/BTS090	0.0890
Bursa Tofas	KOERI	KOCAELI/BUR-UP	0.0480
		KOCAELI/BUR000	0.1030
		KOCAELI/BUR090	0.1080
Yarimca	KOERI	KOCAELI/YPT-UP	0.2420
		KOCAELI/YPT060	0.2680
		KOCAELI/YPT330	0.3490
Ambarli	KOERI	KOCAELI/ATS-UP	0.0790
		KOCAELI/ATS000	0.2490
		KOCAELI/ATS090	0.1840
Heybeliada	KOERI	Station 770 -UP	0.1433
		Station 770 -90	0.1100
		Station 770 -180	0.0561
K.MustafaPasa	KOERI	Station KMP - UP	0.0829
		Station KMP 0	0.1072
		Station KMP 90	0.1277
LeventYapiKrediPlz	KOERI	Station 769 - UP	0.0271

7. PROPOSED ATTENUATION MODEL

7.1 Input Parameters Information

In this study, there are two data sets which are the PHA data set, and PVA data set. In the proposed neural network models, GRNN architecture is used as mentioned earlier.

3 different slabs are used in the both proposed GRNN models. The number of neurons in the input layer (Slab1) is selected as the number of inputs in our problem, and the number of neurons in the output layer (Slab 3) corresponds to the number of outputs. In addition, the number of neurons in the hidden layer (Slab2) is selected as 202. For GRNN networks, the numbers is usually the number of patterns in the training and testing set because the hidden layer consists of one neuron for each pattern in the sets. One may want to add more patterns, in that case one can make it larger, but cannot make it smaller.

The activation functions that are used in the analysis are “linear [-1,1] activation function” for the PHA model and “logistic activation function” for the PVA Model (Frederick, 1996).

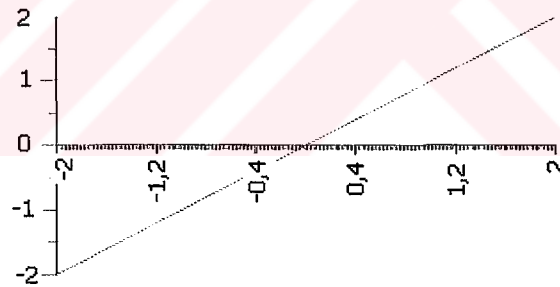


Figure 7.1. Linear activation function for the PHA model.

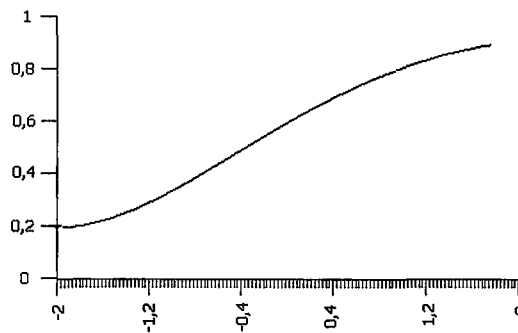


Figure 7.2. Logistic activation function for the PVA model.

The proposed models are run with different smoothing factors to discover which works best for our problem. Using different smoothing factors, 0.0294118 gives the best result for the peak horizontal acceleration model and 0.003 gives the best result for the peak vertical acceleration model.

GRNN networks work by comparing patterns based upon their distance from each other. NeuroShell 2 gives two methods of computing this distance. The City Block distance metric is selected for the analysis. The city block distance metric is the sum of the absolute values of the differences in all dimensions between the pattern and the weight factor for that neuron.

If there is a test set for a GRNN network, it is better to use calibration to decide which smoothing factor is best for the problem. Since ten percent of all data is selected for the test set (20 pattern) in this study, the calibration module is used. There are two options for implementing calibration for GRNN networks: iterative and genetic adaptive. The genetic adaptive option is selected for the PHA and PVA attenuation models.

The genetic adaptive option uses a genetic algorithm to find appropriate individual smoothing factor adjustments for each input as well as an overall smoothing factor. (The input smoothing factor is an adjustment used to modify the overall smoothing factor to provide a new value for each input.) Training takes longer than when using the iterative option.

Training for GRNN nets using the genetic adaptive option also proceeds in two parts. The first part trains the network with the data in the training set. The second part uses calibration to test a whole range of smoothing factor adjustments, trying to converge on a combination that works best on the test set with the network created in the first part. The genetic algorithm is looking for a smoothing factor adjustment for each input.

The individual smoothing factor adjustment values may be used as a sensitivity analysis tool: the larger the factor for a given input, the more important that input is to the model at least as far as the test is concerned. Inputs with low smoothing factor adjustments are candidates for removal for a later trial, especially if the smoothing factor adjustment gets set to zero.

The overall and individual smoothing factors for each input for the PHA and PVA models are given in Chapter 8 in detail.

The architecture and the configuration of both models are given in Table 7.1 and Table 7.2.

Table 7.1 The architecture and the configuration of the PHA attenuation model.

Smoothing Factor: **0.0294118**
Activation Function: **Linear [-1, 1]**
Distance Metric: **City Block**
Calibration: **Genetic, adaptive**
Missing values: **Error Condition**
Genetic Breeding pool size: **300**
Extraction: **10%**
Number of Inputs: **4**
Number of Outputs: **1**
Number of Training Patterns: **182**
Number of Test Patterns: **20**
 R^2 : **0.9640**

Table 7.2 The architecture and the configuration of the PVA attenuation model.

Smoothing Factor: **0.003**
Activation Function: **Logistic**
Distance Metric: **City Block**
Calibration: **Genetic, adaptive**
Missing values: **Error Condition**
Genetic Breeding pool size: **20**
Extraction: **10%**
Number of Inputs: **4**
Number of Outputs: **1**
Number of Training Patterns: **182**
Number of Test Patterns: **20**
 R^2 : **0.9484**

8. RESULTS

To reach the best results, different configurations and architectures are trained. In this chapter, the best configurations and architectures for both PHA and PVA models are presented with the corresponding error graphs. In addition, some important information about the input parameters for the strong motion records are given.

The 1999 Kocaeli (moment magnitude, $M_w=7.4$) and Duzce ($M_w=7.1$) earthquakes in Turkey have generated significant interest in the earthquake engineering community because of the strong motion recordings collected. In total, 606 records are obtained from the strong ground motion stations in the earthquakes given in table 8.1. Each recording gives just one component of ground motion acceleration (two horizontal + one vertical). For the PHA model, the acceleration value is taken as the geometric mean of two horizontal acceleration components and vertical acceleration for the PVA model is taken as directly as it is read. Therefore, 202 horizontal and 202 vertical acceleration records are obtained. The entire records for three components are given in Table 6.11.

Table 8.1 The number of strong motion recordings for each earthquake.

No	Earthquake	Date	M_w	Records
1	Kocaeli	August 17, 1999	7.4	102
2	Düzce	November 12, 1999	7.1	135
3	Hendek - Akyazi	August 23, 2000	5.8	33
4	Izmit Turkey	September 13, 1999	5.8	66
5	Sapanca - Adapazari	November 11, 1999	5.7	39
6	Akyazi - Adapazari	August 17, 1999	5.5	6
7	Duzce Turkey Aftershock	December 11, 1999	5.4	42
8	Duzce Turkey Aftershock	December 11, 1999	5.2	36
9	Izmit Turkey	August 31, 1999	5.2	48
10	Northeast of Bolu	February 14, 2000	5.0	6
11	Duzce - Bolu	November 19, 1999	5.0	3
12	Kaynasli - Bolu	December 11, 1999	5.0	6
13	Hendek - Adapazari	July 11, 1999	5.0	12
14	Marmara Denizi	September 20, 1999	5.0	39
15	Hendek Adapazari	August 22, 1999	5.0	15
16	Cinarcik - Yalova	August 19, 1999	5.0	18

As mentioned before, the earthquakes whose magnitudes equal or higher than 5.0 are selected for the database for both models. The minimum magnitude is 5.0 and the maximum magnitude is 7.4 in the database.

The farthest distance to the hypocenter of the earthquake within all dataset is the 459.3 km (Station Tosya, ERD) and the closest distance is the 16.2 km (Station Duzce, ERD and Station 1059, Lamont).

The closest earthquake to the ground surface in the data set is the Hendek-Sapanca Earthquake which occurred at a depth of 5.4 km and the deepest one is the Sapanca-Adapazari Earthquake which occurred at a depth of 22 km.

The maximum peak horizontal acceleration value is recorded as 1.0980 g for the Duzce Earthquake in Lamont1059 and Lamont375 Stations installed by the Lamont-Doherty group (LD) at distances of 16.2 and 22.5 km, respectively. The minimum horizontal acceleration value is recorded as 0.0142 g for the Kocaeli Earthquake in the Tokat Station installed by ERD at a distance of 373.3 km. In addition, the maximum peak vertical acceleration value is recorded as 0.357 g for the Duzce Earthquake in Duzce Station installed by ERD in a distance of 16.2 km and minimum vertical acceleration value is recorded as 0.0004 g for the Kocaeli Earthquake in the Tosya Station installed by ERD in a distance of 459.3 km. These recorded values are the maximum and minimum acceleration records in the dataset used for the attenuation neural network model.

The variation of attenuation of peak horizontal accelerations (PHA) and peak vertical accelerations (PVA) and the comparison of the PHA and PVA records used in this study given in the figures below.

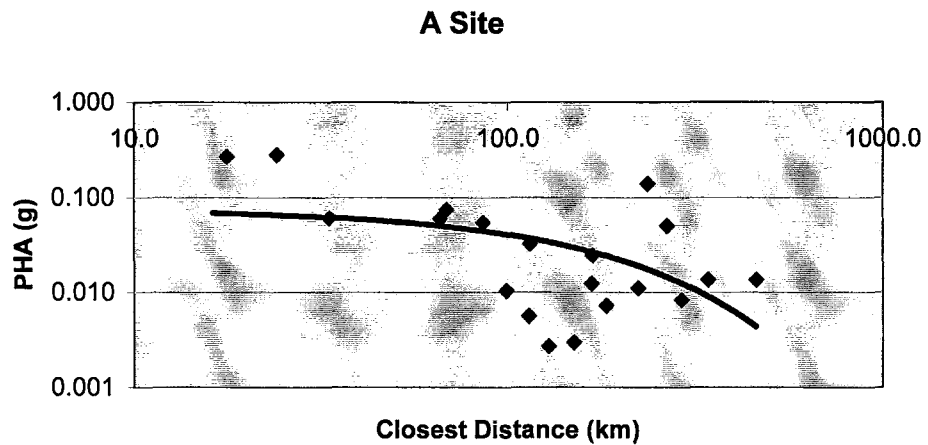


Figure 8.1. Variation of attenuation of PHA for A sites used in the analyses.

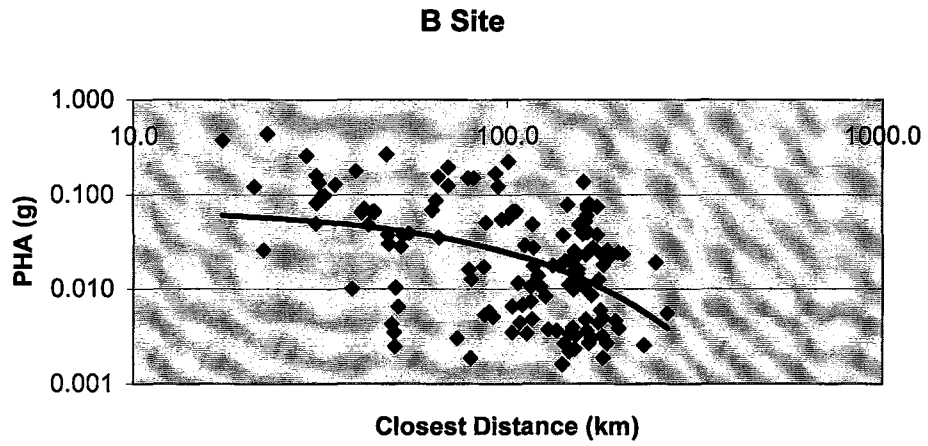


Figure 8.2. Variation of attenuation of PHA for B sites used in the analyses.

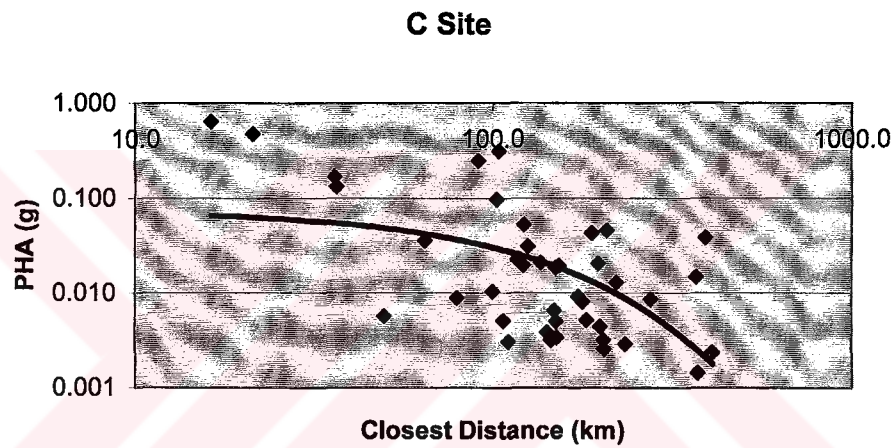


Figure 8.3. Variation of attenuation of PHA for C sites used in the analyses.

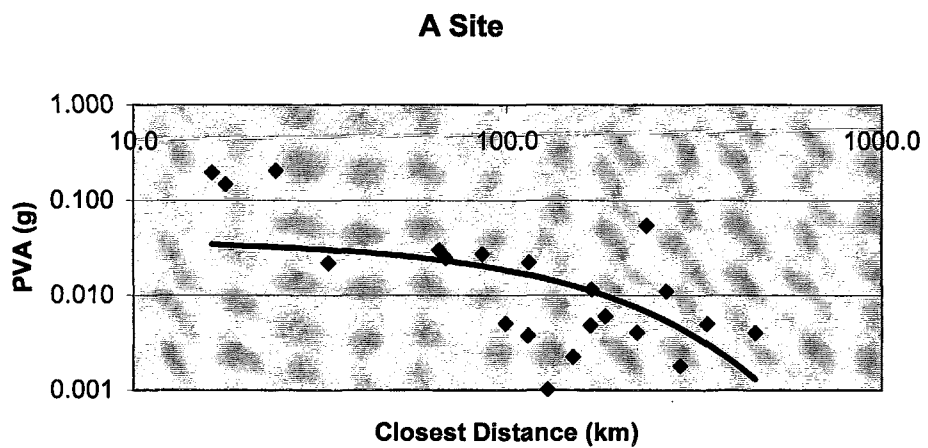


Figure 8.4. Variation of attenuation of PVA for A sites used in the analyses.

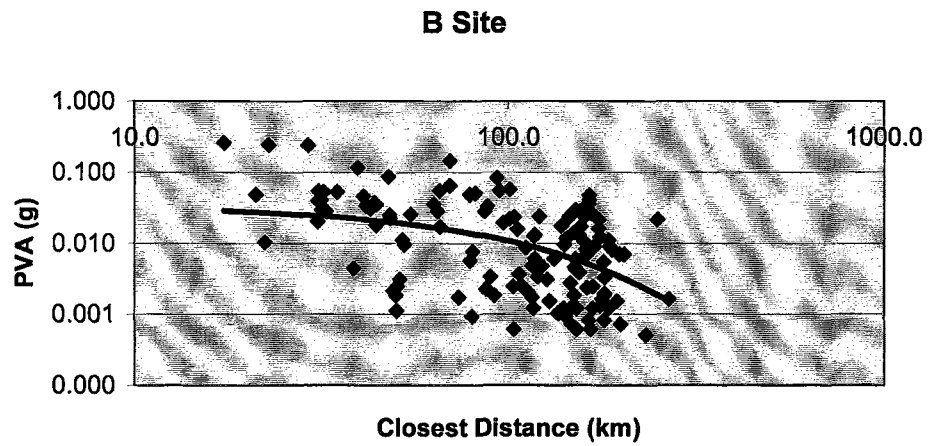


Figure 8.5. Variation of attenuation of PVA for B sites used in the analyses.

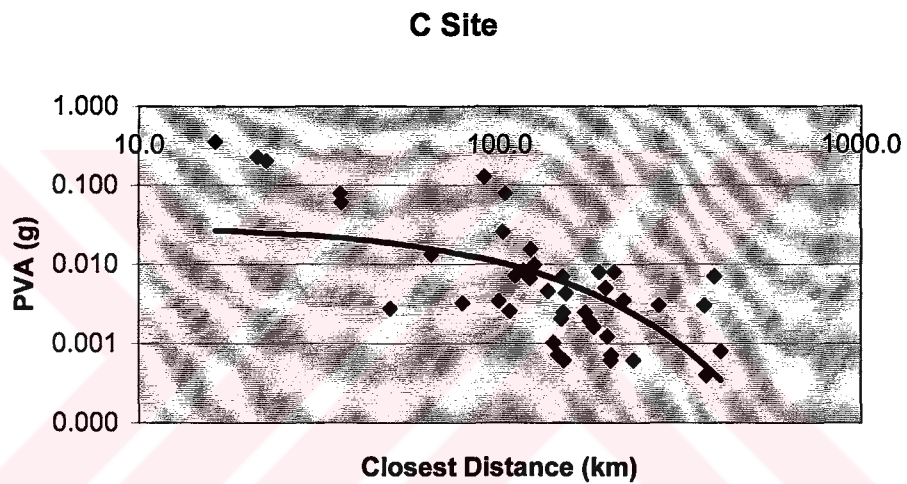


Figure 8.6. Variation of attenuation of PVA for C sites used in the analyses.

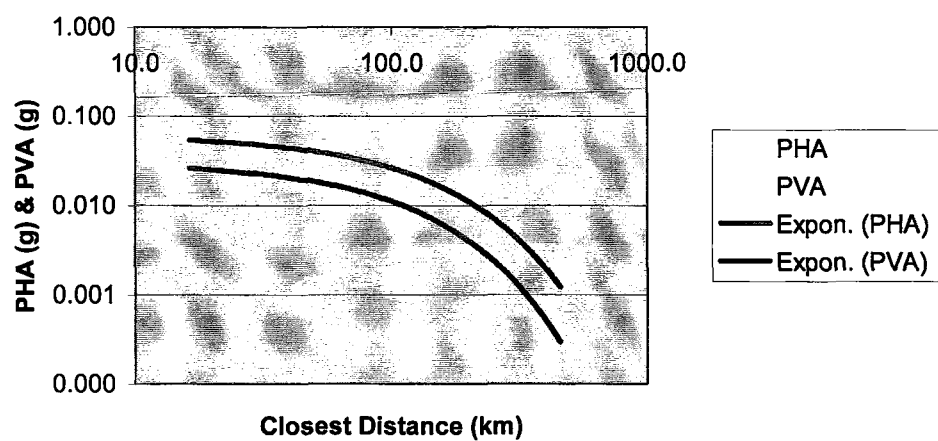


Figure 8.7. Comparison of PHA and PVA records for A,B, and C sites

Table 8.2. Summary of the input parameters and corresponding outputs for PHA data analysis (Kocaeli Earthquake).

INPUTS				OUTPUT
Magnitude	Distance(km)	Depth(km)	Site Class	PHA
7.4	47.6	17	2	0.264
7.4	101.1	17	2	0.223
7.4	94.6	17	2	0.122
7.4	91.3	17	3	0.245
7.4	160.9	17	2	0.136
7.4	78.8	17	2	0.149
7.4	22.7	17	2	0.440
7.4	104.4	17	3	0.310
7.4	69.6	17	2	0.123
7.4	93.2	17	2	0.167
7.4	86.3	17	1	0.054
7.4	66.1	17	1	0.059
7.4	64.6	17	2	0.087
7.4	69.6	17	2	0.195
7.4	65.3	17	2	0.154
7.4	68.7	17	1	0.073
7.4	24.0	17	1	0.280
7.4	17.7	17	1	0.267
7.4	267.3	17	1	0.050
7.4	39.4	17	2	0.178

Table 8.3. Summary of the actual and program outputs of PHA model.

Actual PHA	Network PHA estimation	Difference between the actual and network results
0.2641	0.2574	0.01
0.2230	0.2186	0.00
0.1224	0.1385	-0.02
0.2455	0.2366	0.01
0.1361	0.0775	0.06
0.1492	0.1477	0.00
0.4400	0.4217	0.02
0.3096	0.3026	0.01
0.1235	0.1437	-0.02
0.1668	0.1459	0.02
0.0542	0.0611	-0.01
0.0595	0.0790	-0.02
0.0868	0.1089	-0.02
0.1947	0.1438	0.05
0.1542	0.1173	0.04
0.0734	0.0875	-0.01
0.2798	0.2972	-0.02
0.2674	0.2760	-0.01
0.0502	0.0501	0.00
0.1777	0.1824	0.00

Table 8.4. Summary of the input parameters and corresponding outputs for PVA data analysis (Duzce Earthquake).

INPUTS				OUTPUT
Magnitude	Distance(km)	Depth(km)	Site Class	PVA
7.1	203.5	14	2	0.007
7.1	198.5	14	2	0.007
7.1	189.5	14	3	0.008
7.1	189.5	14	2	0.008
7.1	185.5	14	2	0.011
7.1	117.8	14	2	0.013
7.1	150.7	14	3	0.007
7.1	208.5	14	3	0.008
7.1	186.5	14	2	0.009
7.1	174.6	14	2	0.016
7.1	183.5	14	1	0.006
7.1	268.4	14	2	0.002
7.1	162.6	14	2	0.007
7.1	162.6	14	2	0.035
7.1	159.6	14	2	0.010
7.1	163.6	14	2	0.036
7.1	163.6	14	2	0.035
7.1	164.6	14	2	0.041
7.1	164.6	14	2	0.047
7.1	163.6	14	2	0.029
7.1	166.6	14	2	0.027
7.1	141.3	14	2	0.010
7.1	221.7	14	3	0.004
7.1	409.6	14	3	0.001
7.1	167.6	14	1	0.005
7.1	169.4	14	1	0.012
7.1	47.9	14	2	0.025
7.1	161.3	14	2	0.008
7.1	125.8	14	3	0.010
7.1	115	14	1	0.022

Table 8.5. Summary of the actual and program outputs of PVA model.

Actual PVA	Network PVA estimation	Difference between the actual and network results
0.0070	0.0070	0.00
0.0070	0.0070	0.00
0.0080	0.0080	0.00
0.0080	0.0080	0.00
0.0110	0.0109	0.00
0.0130	0.0130	0.00
0.0070	0.0070	0.00
0.0080	0.0080	0.00
0.0090	0.0091	0.00
0.0160	0.0187	0.00
0.0060	0.0115	-0.01
0.0016	0.0016	0.00
0.0069	0.0212	-0.01
0.0346	0.0212	0.01
0.0105	0.0105	0.00
0.0363	0.0319	0.00
0.0351	0.0319	0.00
0.0408	0.0431	0.00
0.0466	0.0431	0.00
0.0286	0.0319	0.00
0.0271	0.0272	0.00
0.0095	0.0095	0.00
0.0035	0.0035	0.00
0.0008	0.0008	0.00
0.0048	0.0048	0.00
0.0115	0.0115	0.00
0.0249	0.0249	0.00
0.0082	0.0087	0.00
0.0098	0.0098	0.00
0.0224	0.0224	0.00

R^2 , defined in NeuroShell 2, is a statistical indicator usually applied to multiple regression analysis. It compares the accuracy of the model to the accuracy of a trivial benchmark model wherein the prediction is just the mean of all of the samples. A perfect fit would result in an R squared value of 1, a very good fit near 1, and a very poor fit near 0. the formula that NeuroShell 2 uses is defined as the following:

$$R^2 = 1 - \frac{SSE}{SS_{YY}} \quad (8.1)$$

where

$$SSE = \sum (y - \hat{y})^2 \quad (8.2)$$

$$SS_{YY} = \sum (y - \bar{y})^2 \quad (8.3)$$

Where y is the actual value, $\hat{y}$ is the predicted value of y , and $\bar{y}$ is the mean of the y values.

Table 8.6. The results of the PHA attenuation model.

R squared: **0.9637**
r squared: **0.9640**
Mean squared error: **0.001**
Mean absolute error: **0.009**
Min. absolute error: **0.000**
Max. absolute error: **0.253**
Correlation coefficient, r: **0.9818**

Table 8.7. Input smoothing factor adjustment (sensitivity) for PHA model.

M_w	R(km)	Site	H(km)
2.88235	2.25882	0.04706	0.02353

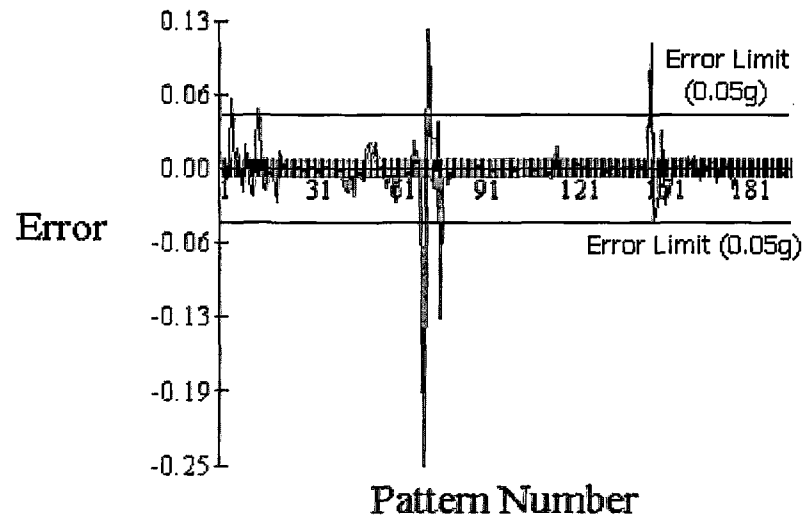


Figure 8.8. Error through patterns for PHA model.

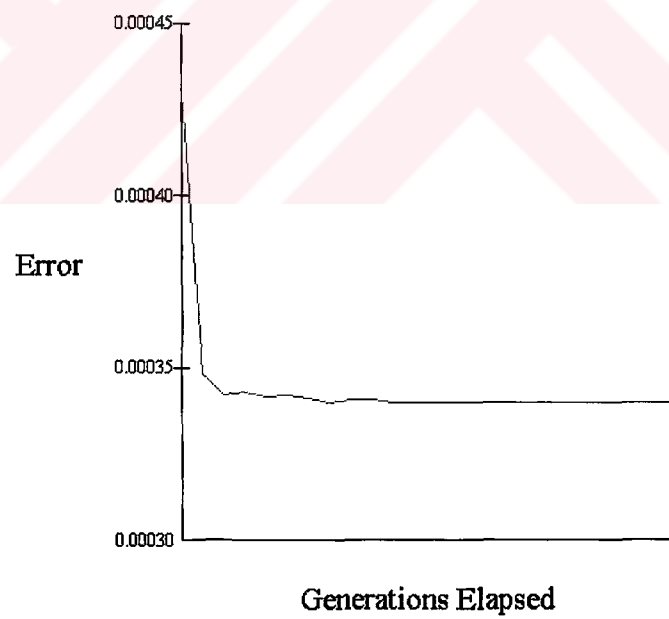


Figure 8.9. Test-Set average error graph for PHA model.

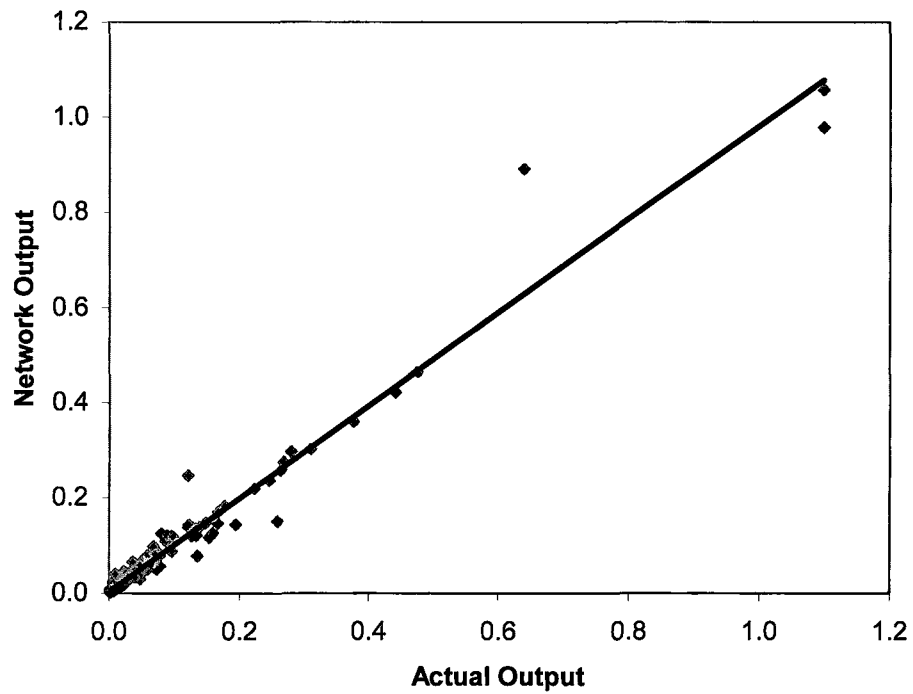


Figure 8.10. Actual-Network output scatter graph for PHA model.

Table 8.8. The results of the PVA attenuation model.

R squared: **0.9428**
r squared: **0.9484**
Mean squared error: **0.000**
Mean absolute error: **0.002**
Min. absolute error: **0.000**
Max. absolute error: **0.154**
Correlation coefficient, r: **0.9739**

Table 8.9. Input smoothing factor adjustment (sensitivity) for PVA model.

R (km)	Site	M_w	H(km)
2.98824	2.69412	0.85882	0.11765

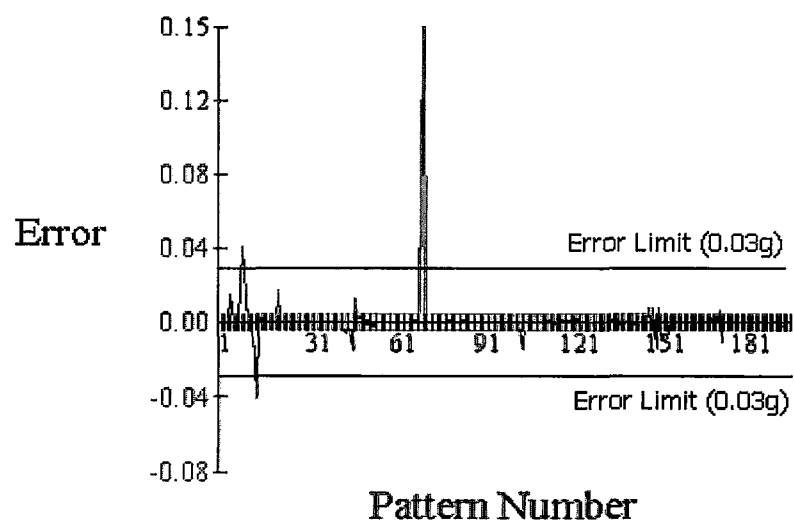


Figure 8.11. Error through patterns for PVA model.

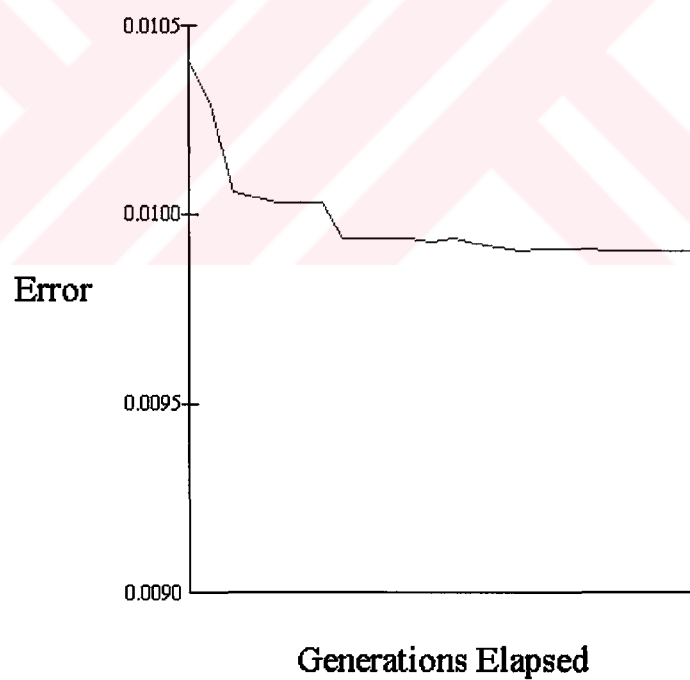


Figure 8.12. Test-Set average error graph for PVA model.

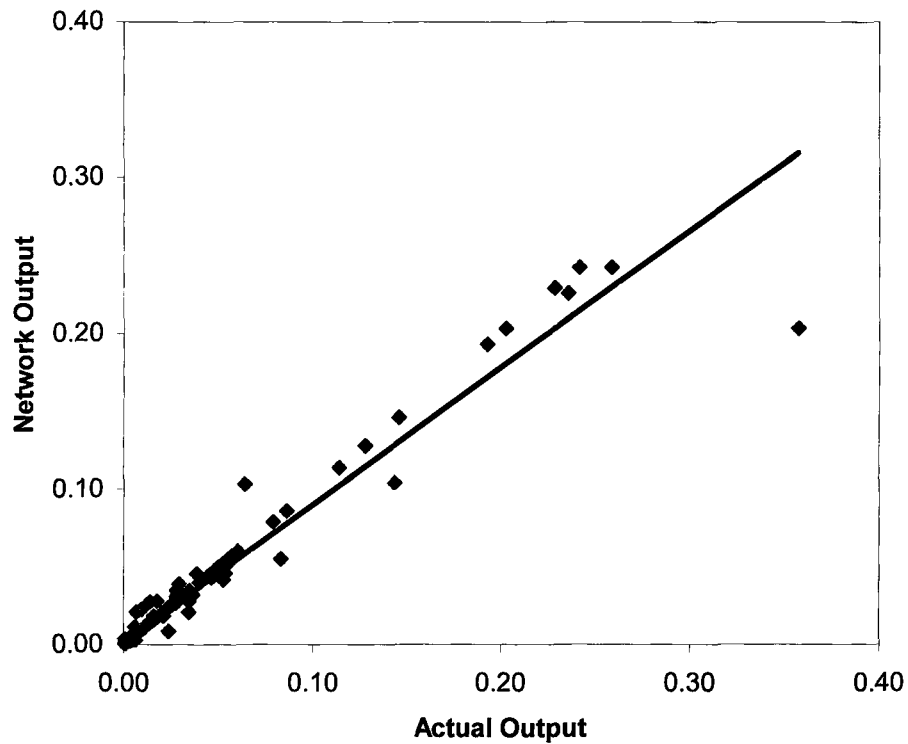


Figure 8.13. Actual-Network output scatter for PVA model.

In this study, the error limit is taken as 0.05g for the PHA model and 0.03g for the PVA model, which means that when the difference between the target output and network result is greater than 0.05g, the network result is considered as an incorrect simulation. According to this assumption, if the error graphs of each model is considered, it is seen that the best network gives only 5 incorrect simulations, out of 202 data set for the PHA model, and 3 incorrect simulations, out of 202 data set for the PVA model. The errors for the test and training data sets are given in Table 8.10. and Table 8.11.

Table 8.10. The success rate of the PHA model for 0.05g error limit.

	Test Set (20)	Training Set (182)	Overall (202)
Number of Errors	1	4	5
Success Rate	95%	97.8%	97.5%

Table 8.11. The success rate of the PVA model for 0.03g error limit.

	Test Set (20)	Training Set (182)	Overall (202)
Number of Errors	1	2	3
Success Rate	95%	98.9%	98.5%

9. CONCLUSIONS AND DISCUSSION

Neural Networks (NN) have recently received lots of attention and contributed in a wide variety of applications in civil engineering as well as in other fields. They have been found to be useful for modeling the complex relationships involved in physical phenomena and used in place of equation-based models. A neural network is a massively parallel-distributed processor made up of simple processing units, which has a natural propensity for storing experiential knowledge and making it available for use. This work studies the performance of various types of these networks to verify their feasibility and performance.

In this study, an investigation on the application of neural computing methods in prediction of attenuation of the peak horizontal and vertical accelerations recorded in different stations has been performed using actual strong-motion records. The emphasis is on obtaining optimized neural network architecture to model the complex relationship between the earthquake source parameters, site effects, and the attenuation of ground motions. For this purpose, programs written in GRNN algorithm is used. Basically, four earthquake and site parameters are selected as input, and different models are constructed to reach the best results. The performance of the neural network models improved as more records are provided. Different network configurations and architectures are used by the changing the network's internal parameters (i.e. number of hidden layers and neurons, smoothing factors, genetic breeding pool size, calibration type, test set extraction, etc). The ideal network architecture, for which network response compared to the target ones is the best, is determined.

The proposed attenuation relationship model presented in detail in this study is considered to be appreciate for the estimation of geometric mean of the horizontal peak ground acceleration and vertical peak ground acceleration for earthquakes with magnitude in the range M_w 5 to 7.4 in northwestern part of the Turkey. The attenuation models developed here have been proposed due to the availability of numerous strong ground motion records from recent earthquakes in Northwestern Turkey.

In the first part of the study, a total of 202 strong ground motion records are used to estimate the geometric mean of horizontal peak ground acceleration. As the input smoothing factor of each input parameter of the PHA model is considered, it is observed that the most important parameters on attenuation are 1) magnitude, 2)

hypocentral distance, 3) site classification, and 4) depth of the earthquake, respectively.

The proposed ground motion attenuation relation model describes the dependence of the strength of the ground motions on the earthquake magnitude and on the distance from the earthquake. They have great influence on ground motion. It is seen in the analyses that if the magnitude of the earthquake is high, the recorded peak ground accelerations are high, too. In addition, distance and horizontal acceleration are inversely proportional. According to the results, the site classification and the depth of earthquake parameters have less influence on the attenuation of the horizontal ground acceleration.

In the second part of the study, a total of 202 strong ground motion records are used to estimate the vertical peak ground acceleration. The directions of the horizontal and vertical accelerations are perpendicular to each other so, it is observed that the influence of the input parameters on attenuation changed when compared with the PHA model. As the input smoothing factor of each input parameter of the PVA model is considered, it is observed that the most important parameters on attenuation are 1) hypocentral distance, 2) site classification, 3) magnitude, and 4) the depth of the earthquake, respectively. The biggest difference from the PHA model is that the importance of the site classification parameter increased significantly. In fact, distance and site category parameters have a stronger influence on peak ground vertical acceleration than do magnitude and depth of earthquake parameters in the PVA model. Since the vertical acceleration records are related with the vertical component of the earthquake waves, it is logical that site category's influence increased when it is compared with the peak horizontal acceleration model. Actually, the magnitude has great influence on ground motion as it is known from the literature. However, the analysis results in PVA model show that the magnitude is the third important parameter. This result may be due to the closeness of the values of the peak vertical acceleration records. Therefore, the importance level of the magnitude is not represented very well. The depth of the earthquake is the less important parameter in both PHA and PVA models. Since some accelerations are recorded in considerably far distances, the influence of the depth of earthquake is very low, especially in far distances.

The results, with an overall success rate of 98% in PHA and 99% in PVA (by the assumed error limits), indicates the reliability of neural networks to examine relationships between the soil and the seismic parameters on attenuation of the strong ground motions.

One of the most important advantages of this study is that the proposed attenuation relationship models are the first models developed by using neural network methodology.

Since the accuracy of a neural network is affected by the quality and size of the database utilized in the architecture, this study is also unique as the PHA and PVA data sets compared with previous are the largest by number. In previous studies Gulkan and Kalkan (2002) used in the analyses 47 strong ground motion records recorded in Turkey and Özbay (2004) employed a database consisting of 195 recordings from recent seismic events from Northwestern Turkey.

This study is region-specific as only recordings from earthquakes that have occurred in Northwestern Turkey were used in the analyses. The models developed are, therefore, only recommended for prediction of ground motions in Northwestern Turkey.

The neural network method is a viable alternative to the more traditional intensity, stochastic, and theoretical methods that are presently used to develop ground-motion relations in similar regions throughout the world.

As future work, as strong ground motion records, shear wave velocity profiles for recording sites, and better determined distance data become available for northwestern part of the Turkey, the attenuation relationship model proposed in this study can be modified and improved. With larger number of data, a more accurate sensitivity analysis can be attained for earthquake and site parameters. In addition to the network configurations and architectures tried in this study, different network architectures can be used in the training of the network by changing the network's internal parameters. Different models can also be constructed by changing the input parameters, and network performance for these models can be investigated. Besides the GRNN algorithm used in this study, other well-known neural network types such as Back-Propagation neural network (BP), probabilistic neural network (PNN) and polynomial (GMDH) neural network whose learning algorithms are different from the GRNN can also be used.

REFERENCES

- Abrahamson, N.A., and Litehiser, J.J., 1989.** "Attenuation of vertical peak acceleration," *Bulletin of Seismological Society of America*, Vol.79, pp.549-580.
- Abrahamson, N.A., and Shedlock, K.M., 1997.** "Overview (of modern attenuation relationships)," *Seism. Res. Letters*, 68(1), 9-23.
- Abrahamson, N.A., and Silva, W.J., 1997.** "Empirical response spectral attenuation relations for shallow crustal earthquakes," *Seism. Res. Letters*, 68(1), 94-127.
- Abrahamson, N.A., and Silva, W.J., 1996.** *Empirical ground motion models*, Report to Brookhaven National Laboratory.
- Abrahamson, N.A., and Somerville, P.G., 1996.** "Effects of the hanging wall and footwall on ground motions recorded during the Northridge earthquake," *Bull. Seism. Soc. Am.*, 86, S93-S99.
- Abrahamson, N.A., and Youngs, R.R., 1992.** "A stable algorithm for regression analyses using the random effects model," *Bull. Seism. Soc. Am.*, 82, 505-510.
- Ambraseys, N.N. and Douglas, J., 2003.** Near-field horizontal and vertical earthquake ground motions. *Bulletin of the Seismological Society of America*, Vol.23, 1-18. (21)
- Ambraseys, N.N., and Finkel, C.F., 1991.** Long-term seismicity of Istanbul and of the Marmara sea region. *Terra Nova*, 3, 527-39.
- Anderson, J.G., 1997.** "Nonparametric description of peak acceleration above a subduction thrust", *Seism. Res. Letters*, 68(1), 86-93.
- Anderson, J.G., 2000.** "Expected shape of regressions for ground motion parameters on rock," *Bull. Seism. Soc. Am.*, 90, S43-S52.
- Arben Pitarka, Paul G. Somerville, Yoshimitsu Fukushima, and Tomiichi Uetake, 2002.** Ground-Motion attenuation from the 1995 Kobe earthquake based on simulations using the hybrid green's function method, *Bulletin of the Seismological Society of America*, Vol.92, No.3. 1025-1031 (14).

- Atkinson, G.M.**, 1995. "Empirical ground motion relations for earthquakes in the Cascadia region," *Canadian J. Civil Engrg.*, 24, 64-77.
- Atkinson, G.M., and Boore, D.M.**, 1995. "New ground motion relations for eastern North America," *Bull. Seism. Soc. Am.*, 85, 17-30.
- Atkinson, G.M., and Boore, D.M.**, 1997a. "Stochastic point source modeling of ground motions in the Cascadia region", *Seism. Res. Letters*, 68(1), 74-85.
- Atkinson, G.M., and Boore, D.M.**, 1997b. "Some comparisons between recent ground motion relations", *Seism. Res. Letters*, 68(1), 24-40.
- Atkinson, G.M. and Silva, W.**, 2000. Stochastic Modeling of California Ground Motions, *Bulletin of the Seismological Society of America*, Vol.90, No.2, 255-274. (17)
- Barka, A.A., and Kadinsky-Cade, K.**, 1988. Strike-slip fault geometry in Turkey and its influence on earthquake activity, *Tectonics*, 7(3):663-84.
- Bayrak B.**, 2002. Liquefaction Potential: A neural network approach. *Senior Thesis*, I.T.U. Civil Engineering Faculty, Istanbul.
- Boore, D.M., Joyner, W.B., and Fumal, T.E.**, 1997. "Equations for estimating horizontal response spectra and peak acceleration from western North American earthquakes: A summary of recent work," *Seism. Res. Letters*, 68(1), 128-153.
- Bray, J.D., Rathje, E.M., Augello, A.J., and Merry, S.M.**, 1998. "Simplified seismic design procedure for geosynthetic-lined, solid-waste landfills," *Geosynthetics International*, 5(1-2), 203-235.
- Brillinger, D.R., and Priesler, H.K.**, 1984. "An exploratory analysis of the Joyner-Boore attenuation data," *Bull. Seism. Soc. Am.*, 74, 1441-1450.
- Brillinger, D.R., and Priesler, H.K.**, 1985. "Further analysis of the Joyner-Boore attenuation data," *Bull. Seism. Soc. Am.*, 75, 611-614.
- Campbell, K.W.**, 1981. "Near source attenuation of peak horizontal acceleration," *Bull. Seism. Soc. Am.*, 71, 2039-2070.
- Campbell, K.W.**, 1982. "Near-source scaling characteristics of peak horizontal acceleration for moderate-to-large earthquakes," in *The Dynamic Characteristics of Faulting Inferred from Recordings of Strong Ground Motion*, Vol. I , Open-File Report 82-591, U.S. Geological Survey, Menlo Park, California, 120-184.

- Campbell, K.W.**, 1985. "Strong ground motions attenuation relations: A ten-year perspective", *Earthquake spectra*, Vol.1, No.4, pp.759-804.
- Campbell, K.W.**, 1997. "Empirical near-source attenuation relations for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra," *Seism. Res. Letters*, 68(1), 154-179.
- Campbell, K.W.**, 2000. Erratum to Campbell, 1997, *Seism. Res. Letters*, 71(3), 352-354.
- Campbell, K.W.**, 2001. Erratum to Campbell, 2000, *Seism. Res. Letters*, 72(4), 474.
- Campbell, K.W.**, 2003. Prediction of strong ground motion using the hybrid empirical method and its use in the development of ground-motion (Attenuation) relations in Eastern North America, *Bulletin of the Seismological Society of America*, Vol.93, No.3, 1012-1033. (12).
- Campbell, K.W. and Bozorgnia, Y.**, 2003. Erratum to Campbell, 2003, *Bulletin of Seismological Society of America*, 93(1), 314-331. (9)
- Campbell, K.W., and Bozorgnia, Y.**, 2003. 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, No.1, 324-331. (9).
- Campbell, K.W. and Yousef Bozorgnia**, 2003. "Updated near-source ground motion (attenuation) relations for horizontal and vertical components of peak ground acceleration, and acceleration response spectra," *Bulletin of Seismological Society of America*, 93(1), 314-331. (9)
- Campbell, K.W. and Yousef Bozorgnia**, 2003. Erratum to Campbell, 2003, *Bulletin of Seismological Society of America*, 93(1), 314-331. (9)
- Castro, R.R., Fabriol, H., Bour, M., and Brun, B.L.**, 2003. Attenuation and site effects in the region of Guadeloupe, Lesser Antilles. *Bulletin of the Seismological Society of America*, Vol.93, No.2, 612-626. (10).
- Chapman, M.C., Talwani, P., and Cannon, R.C.**, 2003. Groun-Motion Attenuation in the Atlantic Coastal Plain near Charleston, south Carolina, *Bulletin of the Seismological Society of America*, Vol.93, No.3, 998-1011. (11)

- Chen, Y.H., and Tsai, C.C.P., 2002.** A new method for estimation of the attenuation relationship with variance components, *Bulletin of the Seismological Society of America*, Vol.92, No.5. 1984-1991 (13).
- Crouse, C.B., 1991.** "Ground-motion attenuation equations for earthquakes on the Cascadia subduction zone", *Earthquake Spectra*, 7(2), 201-236.
- Dayhoff, J., 1990.** Neural network Architecture: An introduction.", Van Nostrand Reinhold Press.
- Douglas, J. and Smit, P.M., 2001.** How accurate can strong ground motion attenuation relations be?, *Bulletin of the Seismological Society of America*, Vol.91.No.6 1917-1923. (16)
- Durukal, E., 2002.** Critical Evaluation of Strong motion in Kocaeli and Duzce (Turkey) earthquakes, *Soil Dynamics and Earthquake Engineering*, 589-609.
- Durukal, E., Erdik, M., Avci, J., Yüzügüllü, Ö., Alpay, Y., Avar, B., Zülfikar, C., Biro, T. and Mert, A., 1998.** Analysis of the strong ground motion data of the 1995 Dinar, Turkey earthquake. *Soil Dynamics and Earthquake Engineering*, Special Issue SDEE'97.Vol.17, No 7-8.557-578. (8).
- Gregor, N.J., Silva, W.J., Wong, I.G., and Youngs., R.R., 2002.** Ground-Motion Attenuation relationships for cascadia subduction zone megathrust earthquakes based on a stochastic finite-fault model, *Bulletin of the Seismological Society of America*, Vol.92, No.5. 1923-1932 (15).
- Hwang, H., and Huo, J.R., 1997.** Attenuation relations of ground motion for rock and soil sites in eastern United States, *Soil Dynamics and Earthquake Engineering*, 363-372. (24)
- Field, E.H., 2000.** A modified ground-motion attenuation relationship for southern California that accounts for detailed site classification and a Basin-Depth effect, *Bulletin of the Seismological Society of America*, Vol.90, No:6B, 209-221. (18)
- Frederick, M.D., 1996.** NeuroShell2 user's manual-version 3.0. Ward Systems Group.

- Geomatrix Consultants**, 1993. Compilation of geotechnical data for strong-motion stations in the Western United States, Report to Lawrence Livermore National Laboratory, Project No, 2256.
- Gulkan, P., Kalkan, E.**, 2002. Attenuation Characteristics of Turkey Based on Recent Strong ground motion data, *Fifth International Congress on Advances in Civil Engineering*, Istanbul Technical University, Istanbul, Turkey, 25-27 September,. (6)
- Idriss, I.M.**, 1991. "Procedures for selecting earthquake ground motions at rock sites," *Report to U.S. Department of Commerce, revised 1993*.
- Idriss, I.M.**, 1994. Personal communication regarding revision to Idriss 1991 document to incorporate Northridge recordings.
- Jennings, P.C.**, 1985. "Ground motion parameters that influence structural damage,"in R.E.Scholl and J.L.King, eds. *Strong Ground Motion Simulation and Engineering Applications*, EERI Publication 85-02, *Earthquake Engineering Research Institute*, Berkeley, California.
- Joyner, W.B., and Boore, D.M.**, 1981. "Peak horizontal acceleration and velocity from strong motion records including records from the 1979 Imperial Valley, California, earthquake," *Bull. Seism. Soc. Am.*, 71, 2011-2038.
- Joyner, W.B. and Boore, D.M.**, 1988. "Measurement, characterization, and prediction of strong ground motion," in *Earthquake Engineering and Soil Dynamics II – Recent Advances in Ground Motion Evaluation*, Geotechnical Special Publication 20, ASCE, New York, pp.43-102.
- Joyner, W.B., and Boore, D.M.**, 1993. "Method for regression analysis of strong motion data," *Bull. Seism. Soc. Am.*, 83, 469-487.
- Joyner, W.B., and Boore, D.M.**, 1994. "Errata: Method for regression analysis of strong motion data," *Bull. Seism. Soc. Am.*, 84, 955-956.
- Kayen, R.E., and Mitchell, J.K.**, 1997. "Assessment of liquefaction potential during earthquakes by Arias Intensity," *J. Geotech. & Geoenv. Engrg.*, ASCE, 123(12), 1162-1174.
- Kramer, S.L.**, 1996. *Geotechnical Earthquake Engineering*, Prentice Hall, New Jersey .
- Krinitzsky, E.L., and Chang, F.K.**, 1987. "Parameters for specifying intensity-related earthquake ground motions," *Miscellaneous Paper S-73-1*,

Report 25, U.S. Army Corps of Engineering Waterways Experiment Station, Vicksburg, Mississippi, pp. 43.

Lawrence, J., 1993. Introduction to Neural Networks. California: California Scientific Software. Press, Nevada,

Lee, Y., Zeng, Y., and Anderson, J.G., 1998. A simple strategy to examine the sources of errors in attenuation relations, *Bulletin of the Seismological Society of America*, Vol.88, No.1, 291-296. (20)

Liu, A.H., Stewart, J.P., Abrahamson, N.A., and Moriwaki, Y., 2001. "Equivalent number of uniform stress cycles for soil liquefaction analysis," *J. Geotech. & Geoenv. Engrg.*, ASCE, 127(12).

Murphy, J.R., and O'Brien, L.J., 1977. The correlation of peak ground acceleration amplitude with seismic intensity and other physical parameters, *Bulletin of Seismological Society of America*, Vol.67, pp.877-915.

Newmark, N.M., and Hall, W.J., 1982. *Earthquake Spectra and Design*, EERI Monograph, Earthquake Engineering Research Institute, Berkeley, California, pp.103.

Özbay, C., Fahjan, Y., Erdik, M., and Şafak, E., 2003. Strong Ground Motion Data Base for the 17 August, 1999 Kocaeli and 12 November, 1999 Düzce Earthquakes, (www.koeri.boun.edu.tr) .

Özbay, C., Sari, A., Manuel, L., Fahjan, Y., and Erdik, M., 2004. An empirical attenuation relationship for Northwestern Turkey ground motion using a random effects approach, *Soil Dynamics and Earthquake Engineering*, (In Press).

Özbay, C., Sari, A., Manuel, L., Fahjan, Y., and Erdik, M., 2003. Empirical strong ground motion attenuation relations for Northwestern Turkey, *Besinci Ulusal Deprem Muhendisligi Konferansi*.

Özmen, B., 2000. Izmit korfezi depreminin hasar durumu (Rakamsal verilerle), published by Türkiye Deprem Vakfi, Istanbul.

Parsons, T., Toda, S., Stein, S., Barka, A., and Dietrich J.H., 2000. Heightened odds of a large earthquake near Istanbul: an interaction based probability calculation. *Science*, 288.

- Pestana, J.M. et. al.**, 2002. Strong ground motions, *Earthquake Spectra*, Vol 18, No 3, 481-489. (35)
- Rathje, E.M., Abrahamson, N.A., and Bray, J.D.**, 1998. "Simplified frequency content estimates of earthquake ground motions," *J. Geotech. & Geoenv. Engrg.*, ASCE, 124(2), 150-159.
- Rathje, E.M., Stokoe II, K.H., and Rosenblad, B.**, 2003. Strong motion station characterization and site effects during the 1999 earthquakes in Turkey, *Earthquake Spectra*, Vol.19, No 3, 653-675.
- Rodriguez-Marek, A., Bray, J.D., and Abrahamson, N.**, 2001. An empirically based geotechnical seismic site response procedure. *Earthquake Spectra* 17(1),65-88.
- Rumelhart, D.E., and McClelland, J.L.**, 1986. Parallel distributed processing, Vols.1&2. Cambridge, Mass. MIT press.
- Sadigh, K., Chang, C.-Y., Abrahamson, N.A., Chiou, S.J., and Power, M.S.**, 1993. "Specification of long-period ground motions: updated attenuation relationships for rock site conditions and adjustment factors for near-fault effects," *Proc. Seminar on Seismic Isolation, Passive Energy Dissipation, and Active Control*, Applied Technology Council Publication No. 17-1, Vol. 1, 59-70.
- Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F., and Youngs, R.R.**, 1997. "Attenuation relations for shallow crustal earthquakes based on California strong motion data," *Seism. Res. Letters*, 68(1), 180-189.
- Sharma, M.L.**, 1998. Attenuation Relationship for estimation of peak ground horizontal acceleration using data from strong-motion arrays in India. *Bulletin of the Seismological Society of America*, Vol.88, No.4, 1063-1069. (19)
- Somerville, P.G.**, 2000. "Magnitude scaling of near fault ground motion," *Proc. Int. Workshop on Annual Commemoration of Chi-Chi earthquake*, Vol. 1, 59-70.
- Somerville, P.G., Smith, N.F., and Dreger, D.S.**, 1992. The influence of critical Moho reflections on strong ground motion attenuation in California, *A report to the California Division of Mines and Geology Strong Motion Instrumentation Program*, 82 p.

- Somerville, P.G., Smith, N.F., and Graves, R.W., 1994.** "Effect of critical reflections from the Moho on the attenuation of strong ground motion," in *The Loma Prieta, California, earthquake of October 17, 1989 — Strong Ground Motion*, R.D. Borcherdt (ed.), *U.S. Geological Survey Professional Paper* 1551-A, A67-A76.
- Somerville, P.G., Saikia, C., Wald, D., Graves, R., 1996.** "Implications of the Northridge earthquake for strong ground motions from thrust faults," *Bull. Seism. Soc. Am.*, 86, S115-S125.
- Specht, D.F., 1991.** A generalized regression neural network, *IEEE Transactions on Neural Networks*, 568-576.
- Specht, D.F., 1996.** *Fuzzy Logic and Neural Network Handbook*, McGraw-Hill Companies, Inc.,
- Spudich, P., Joyner, W.B., Lindh, A.G., Boore, D.M., Margaris, B.M., and Fletcher, J.B., 1999.** "SEA99: A revised ground motion prediction relation for use in extensional tectonic regimes", *Bull. Seism. Soc. Am.*, 89, 1156-1170.
- Stewart, J.P., Chiou, S.J., Bray, J.D., Graves, R.W., and Somerville, P.G., 2001.** Ground motion evaluation procedures for performance-based design, PEER Report, California, USA.
- Stewart, J.P., Chiou, S.J., Bray, J.D., Graves, R.W., Somerville, P.G., and Abrahamson, N.A., 2002.** Ground motion evaluation procedures for performance-based design. *Soil Dynamics and Earthquake Engineering*, Special Issue, SDDE'01. Vol 22, No9-12, 765-772. (31)
- Toksoz, M.N., Shakal, A.F., Michael, A.J., 1979.** Space-time migration of earthquakes along the North Anatolian Fault Zone and seismic gaps. *Pageoph*, 117, 1258-70.
- Toro, G.R., Abrahamson, N.A., and Schneider, J.F., 1997.** "Model of strong ground motions from earthquakes in central and eastern North America: Best estimates and uncertainty," *Seism. Res. Letters*, 68(1), 41-57.
- Trifunac, M.D., and Brady, A.G., 1975a.** "On the correlation of seismic intensity with peaks of recorded strong ground motion," *Bulletin of the Seismological Society of America*, Vol.65, pp.139-162.

- Ulutas, E., Ozer, M.F., 2003.** Attenuation relationship for estimation of peak ground horizontal acceleration in eastern Marmara region of Turkey. *Geophysical Research Abstracts*, Vol.5, 00175. (5)
- Ural, D.N., Bayrak, M.B., and Saygili, G., 2003.** Liquefaction potential assessment by neural networks based on the Kocaeli, Turkey earthquake. *Soil Dyn. Earth. Engr.*(Submitted 2003).
- Ural, D.N., 2004.** Personal interview.
- Wilson, R.C., 1993.** "Relation of Arias intensity to magnitude and distance in California," *Open File Rpt. No. 93-0556*, U.S. Geological Survey, Menlo Park, CA, 42 p.
- Youngs, R.R., Abrahamson, N.A., Makdisi, F.I., and Sadigh, K., 1995.** "Magnitude-dependent variance of peak ground acceleration," *Bull. Seism. Soc. Am.*, 85, 1161-1176.
- Youngs, R.R., Chiou, S.-J., Silva, W.J., and Humphrey, J.R., 1997.** "Strong ground motion attenuation relationships for subduction zone earthquakes," *Seism. Res. Letters*, 68(1), 58-73.
- Zare, M., and Bard, P.Y., 2002.** Strong Motion Dataset of Turkey: data processing and site classification, *Soil Dynamics and Earthquake Engineering* 22, 703-718. (23)
- http://www.seismo.unr.edu/htdocs/academic/ANDERSON/GE679/07StrongMo/IUGG03_7.pdf
- <http://geohazards.cr.usgs.gov/engnseis/Eshmpage/eshmpage.htm>
- <http://www.deprem.gov.tr>
- <http://www.jpgp.jussieu.fr>
- <http://www.ipgp.jussieu.fr/%7Elacassin/WebTecto/rech/tectorecherche/IzmitWEB/IzmitUK.html>
- <http://nisee.berkeley.edu/lessons/arnold.html>
- <http://peer.berkeley.edu/smcat/>

<http://www.cosmos-eq.org/default.html>

<http://angora.depren.gov.tr>

<http://www.cs.msstate.edu/~gboggess/>

http://www.maths.uwa.edu.au/~rkealley/ann_all/index.html



APPENDIXES

Appendix A. The three component acceleration records data set.

Appendix B. The input parameters and corresponding outputs for PHA data analysis.

Appendix C. The actual accelerations and neural network estimations for PHA model.

Appendix D. The input parameters and corresponding outputs for PVA data analysis.

Appendix E. The actual accelerations and neural network estimations for PVA model.

Appendix F. Strong ground motion stations in Marmara region.

Appendix G. Kocaeli and Duzce earthquakes three components acceleration records.

Appendix A. The three component acceleration records data set.

Station	Data Source	Record Component	PGA(g)
Kocaeli Earthquake, August 17, 1999			
Arcelik	KOERI	KOCAELI/ARCDWN	0.0860
		KOCAELI/ARC000	0.2180
		KOCAELI/ARC090	0.1490
Cekmece	KOERI	KOCAELI/CNA-UP	0.0570
		KOCAELI/CNA000	0.1790
		KOCAELI/CNA090	0.1330
Hava Alani	KOERI	KOCAELI/DHM-UP	0.0550
		KOCAELI/DHM000	0.0900
		KOCAELI/DHM090	0.0830
Fatih	KOERI	KOCAELI/FAT-UP	0.1280
		KOCAELI/FAT000	0.1870
		KOCAELI/FAT090	0.1590
Botas	KOERI	KOCAELI/BTS-UP	0.0240
		KOCAELI/BTS000	0.1030
		KOCAELI/BTS090	0.0890
Bursa Tofas	KOERI	KOCAELI/BUR-UP	0.0480
		KOCAELI/BUR000	0.1030
		KOCAELI/BUR090	0.1080
Yarimca	KOERI	KOCAELI/YPT-UP	0.2420
		KOCAELI/YPT060	0.2680
		KOCAELI/YPT330	0.3490
Ambarli	KOERI	KOCAELI/ATS-UP	0.0790
		KOCAELI/ATS000	0.2490
		KOCAELI/ATS090	0.1840
Heybeliada	KOERI	Station 770 -UP	0.1433
		Station 770 -90	0.1100
		Station 770 -180	0.0561
K.MustafaPasa	KOERI	Station KMP - UP	0.0829
		Station KMP 0	0.1072
		Station KMP 90	0.1277
LeventYapiKrediPlz	KOERI	Station 769 - UP	0.0271

		Station 769 - 90	0.0355
		Station 769 - 180	0.0410
Maslak	ITU	KOCAELI/MSK-UP	0.0300
		KOCAELI/MSK000	0.0440
		KOCAELI/MSK090	0.0400
Mecidiyekoy	ITU	KOCAELI/MCD--V	0.0280
		KOCAELI/MCD000	0.0540
		KOCAELI/MCD090	0.0680
Atakoy	ITU	KOCAELI/ATK-UP	0.0640
		KOCAELI/ATK000	0.1050
		KOCAELI/ATK090	0.1640
Zeytinburnu	ITU	KOCAELI/ZYT-UP	0.0540
		KOCAELI/ZYT000	0.1080
		KOCAELI/ZYT090	0.1100
Bursa Sivil	ERD	KOCAELI/BRs-UP	0.0250
		KOCAELI/BRs090	0.0450
		KOCAELI/BRs180	0.0580
Gebze	ERD	KOCAELI/GBZ-UP	0.2030
		KOCAELI/GBZ000	0.2440
		KOCAELI/GBZ270	0.1370
Izmit	ERD	KOCAELI/IZT-UP	0.1460
		KOCAELI/IZT180	0.1520
		KOCAELI/IZT090	0.2200
Tekirdag	ERD	KOCAELI/TKR-UP	0.0110
		KOCAELI/TKR180	0.0360
		KOCAELI/TKR090	0.0350
Goynuk	ERD	KOCAELI/GYN-UP	0.1140
		KOCAELI/GYN000	0.1320
		KOCAELI/GYN090	0.1190
Istanbul	ERD	KOCAELI/IST-UP	0.0350
		KOCAELI/IST090	0.0440
		KOCAELI/IST180	0.0530
Sakarya	ERD	KOCAELI/SKR-UP	0.2590
		KOCAELI/SKR090	0.3760
Duzce	ERD	KOCAELI/DZC-UP	0.2290
		KOCAELI/DZC180	0.3120
		KOCAELI/DZC270	0.3580

Iznik	ERD	KOCAELI/IZN-UP	0.0790
		KOCAELI/IZN180	0.0980
		KOCAELI/IZN090	0.1360
Kutahya	ERD	KOCAELI/KUT-UP	0.0230
		KOCAELI/KUT090	0.0600
		KOCAELI/KUT180	0.0490
Afyon Bay	ERD	KOCAELI/AFYDWN	0.0050
		KOCAELI/AFY000	0.0130
		KOCAELI/AFY090	0.0160
Aydin	ERD	KOCAELI/AYD-UP	0.0030
		KOCAELI/AYD090	0.0050
		KOCAELI/AYD180	0.0070
Bornova	ERD	KOCAELI/BRN-UP	0.0030
		KOCAELI/BRN090	0.0110
		KOCAELI/BRN180	0.0100
Canakkale	ERD	KOCAELI/CNK-UP	0.0070
		KOCAELI/CNK090	0.0290
		KOCAELI/CNK180	0.0250
Manisa	ERD	KOCAELI/MNSDWN	0.0050
		KOCAELI/MNS000	0.0120
		KOCAELI/MNS090	0.0060
Tokat	ERD	KOCAELI/TKT-UP	0.0004
		KOCAELI/TKT090	0.0011
		KOCAELI/TKT180	0.0009
Tosya	ERD	KOCAELI/TOS-UP	0.0040
		KOCAELI/TOS090	0.0080
		KOCAELI/TOS180	0.0110
Eregli	ERD	KOCAELI/ERG-UP	0.0540
		KOCAELI/ERG090	0.0900
		KOCAELI/ERG180	0.1060
Cekmece	ERD	UD	0.0498
		EW	0.0896
		NS	0.1180
Duzce Earthquake, November 12, 1999			
Arcelik	KOERI	DUZCE/ARC--V	0.0060
		DUZCE/ARC000	0.0080
		DUZCE/ARC270	0.0090

Cekmece	KOERI	DUZCE/CNA--V	0.0070
		DUZCE/CNA090	0.0170
		DUZCE/CNA180	0.0160
Hava Alani	KOERI	DUZCE/DHM--V	0.0070
		DUZCE/DHM090	0.0170
		DUZCE/DHM180	0.0170
Fatih	KOERI	DUZCE/FAT--V	0.0080
		DUZCE/FAT000	0.0350
		DUZCE/FAT270	0.0250
Kocamustafapasa	KOERI	DUZCE/KMP--V	0.0080
Tomb		DUZCE/KMP000	0.0150
		DUZCE/KMP090	0.0180
Bursa Tofas	KOERI	DUZCE/BUR--V	0.0110
		DUZCE/BUR090	0.0180
		DUZCE/BUR180	0.0180
Yarimca	KOERI	DUZCE/YPT--V	0.0130
		DUZCE/YPT060	0.0220
		DUZCE/YPT330	0.0160
Aslan R.	KOERI	DUZCE/DAR--V	0.0070
		DUZCE/DAR090	0.0170
		DUZCE/DAR180	0.0070
Ambarli	KOERI	DUZCE/ATS--V	0.0080
		DUZCE/ATS030	0.0380
		DUZCE/ATS300	0.0250
Galata Kop.	KOERI	DUZCE/GB--V	0.0090
		DUZCE/GB--L	0.0150
		DUZCE/GB--T	0.0150
Heybeliada	KOERI	Station 770 - UP	0.0160
		Station 770 - 90	0.0281
		Station 770 - 180	0.0241
LeventYapiKrediPlz	KOERI	Station 769 - UP	0.0060
		Station 769 - 90	0.0045
		Station 769 - 180	0.0057
Botas	KOERI	Station 766 - UP	0.0016
		Station 766 - 0	0.0043
		Station 766 - 90	0.0036
Yalova Gir	KOERI	Station Gir - UP	0.0069

		Station Gir - 0	0.0179
		Station Gir - 270	0.0145
Yalova AhmetTas	KOERI	Station Kas - UP	0.0346
		Station Kas - 0	0.0421
		Station Kas - 90	0.0297
Yalova Rad	KOERI	Station Rad - UP	0.0105
		Station Rad - 0	0.0259
		Station Rad - 270	0.0283
Yalova BaglaraltiC	KOERI	Station Bag - UP	0.0363
		Station Bag - 0	0.0301
		Station Bag - 270	0.0278
Yalova BahcevanS	KOERI	Station Bah - UP	0.0351
		Station Bah - 0	0.0309
		Station Bah - 90	0.0244
Yalova DevletHas.	KOERI	Station Has - UP	0.0408
		Station Has - 0	0.0537
		Station Has - 90	0.0466
Yalova HilalStreet	KOERI	Station Hil - UP	0.0466
		Station Hil - 0	0.0535
		Station Hil - 90	0.0547
Yalova RuzgarStreet	KOERI	Station Ruz - UP	0.0286
		Station Ruz - 0	0.0401
		Station Ruz - 270	0.0443
Yalova Tarim Directory	KOERI	Station Tar - UP	0.0271
		Station Tar - 0	0.0363
		Station Tar - 90	0.0697
Yalova(Kasif)	KOERI(TEMP)	UD	0.0095
		EW	0.0095
		NS	0.0248
Afyon	ERD	UD	0.0268
		EW	0.0035
		NS	0.0100
Bornova	ERD	UD	0.0080
		EW	0.0008
		NS	0.0015
Bursa 1	ERD	UD	0.0018
		EW	0.0048

		NS	0.0080
Bursa 2	ERD	UD	0.0093
		EW	0.0115
		NS	0.0169
Göynük	ERD	UD	0.0179
		EW	0.0249
		NS	0.0248
Istanbul	ERD	UD	0.0278
		EW	0.0082
		NS	0.0052
Iznik	ERD	UD	0.0090
		EW	0.0098
		NS	0.0214
Izmit	ERD	UD	0.0220
		EW	0.0224
		NS	0.0238
Tekirdag	ERD	UD	0.0222
		EW	0.0018
		NS	0.0061
Tosya	ERD	UD	0.0057
		EW	0.0041
		NS	0.0076
Atakoy	ITU	UD	0.0079
		EW	0.0055
		NS	0.0163
Golcuk	ITU	UD	0.0164
		EW	0.0194
		NS	0.0409
Zeytinburnu	ITU	UD	0.0355
		EW	0.0213
		NS	0.0583
Mudurnu	ERD	DUZCE/ATS-UP	0.0452
		DUZCE/ATS000	0.1200
		DUZCE/ATS090	0.0560
Sakarya	ERD	DUZCE/SKR-UP	0.0110
		DUZCE/SKR180	0.0230
		DUZCE/SKR090	0.0160

Duzce	ERD	DUZCE/DZC-UP	0.3570
		DUZCE/DZC180	0.3480
		DUZCE/DZC270	0.5350
Kutahya	ERD	DUZCE/KUT-UP	0.0090
		DUZCE/KUT090	0.0220
		DUZCE/KUT180	0.0160
Bolu	ERD	DUZCE/BOL-UP	0.2030
		DUZCE/BOL000	0.7280
		DUZCE/BOL180	0.8220
1060 Lamont 1060	LAMONT	DUZCE/1060-V	0.0220
		DUZCE/1060-N	0.0280
		DUZCE/1060-E	0.0530
362 Lamont 362	LAMONT	DUZCE/362-V	0.0200
		DUZCE/362-N	0.0420
		DUZCE/362-E	0.0260
375 Lamont 375	LAMONT	DUZCE/375-V	0.1930
		DUZCE/375-N	0.9700
		DUZCE/375-E	0.5140
1061 Lamont 1061	LAMONT	DUZCE/1061-V	0.0480
		DUZCE/1061-N	0.1070
		DUZCE/1061-E	0.1340
Hendek - Akyazi Earthquake, August 23, 2000			
Ambarli	KOERI	Station 767 - UP	0.0024
		Station 767 - 0	0.0059
		Station 767 - 270	0.0070
Bursa-Tofas	KOERI	Station Bur - DWN	0.0028
		Station Bur - 90	0.0087
		Station Bur - 180	0.0069
Arcelik	KOERI	Station Arc - DWN	0.0017
		Station Arc - 0	0.0035
		Station Arc - 270	0.0065
Galata Kop.	KOERI	Station Gal - DWN	0.0042
		Station Gal - 0	0.0064
		Station Gal - 270	0.0092
Fatih	KOERI	Station 777 - UP	0.0043
		Station 777 - 0	0.0126
		Station 777 - 270	0.0146

Heybeliada	KOERI	Station 770 - UP	0.0173
		Station 770 - 90	0.0142
		Station 770 - 180	0.0107
Cekmece	KOERI	Station 768 - UP	0.0024
		Station 768 - 90	0.0043
		Station 768 - 180	0.0074
KocaMustafapasa	KOERI	Station KMP - UP	0.0039
		Station KMP - 0	0.0081
		Station KMP - 90	0.0093
Levent YpiKrediPlz	KOERI	Station 769 - UP	0.0022
		Station 769 - 90	0.0018
		Station 769 - 180	0.0023
Botas	KOERI	Station 766 - UP	0.0005
		Station 766 - 0	0.0019
		Station 766 - 90	0.0016
Havaalani	KOERI	Station 779 - DWN	0.0023
		Station 779 - 90	0.0035
		Station 779 - 180	0.0033
Northeast of Bolu Earthquake, February 14, 2000			
Fatih	KOERI	Station 777 - Up	0.0006
		Station 777 - 0	0.0024
		Station 777 - 270	0.0015
Yarimca	KOERI	Station 772 - Up	0.0012
		Station 772 - 0	0.0019
		Station 772 - 270	0.0023
Duzce - Bolu Earthquake, November 19, 1999			
Ayd	KOERI	Station Ayd - Up	0.0122
		Station Ayd - 0	0.0161
		Station Ayd - 270	0.0112
Kaynasli - Bolu Earthquake, November 12, 1999			
Fatih	KOERI	Station 777 - Up	0.0007
		Station 777 - 0	0.0020
		Station 777 - 270	0.0015
Yalova RuzgarStr	KOERI	Station Ruz - Up	0.0122
		Station Ruz - 0	0.0056
		Station Ruz - 270	0.0112
Duzce Turkey Aftershock, November 12, 1999			

Ambarli	KOERI	Station 767 - Up	0.0012
		Station 767 - 0	0.0034
		Station 767 - 270	0.0029
Bursa Tofas	KOERI	Station Bur - DWN	0.0013
		Station Bur - 90	0.0034
		Station Bur - 180	0.0029
Arcelik	KOERI	Station Arc - DWN	0.0009
		Station Arc - 0	0.0020
		Station Arc - 270	0.0016
Aslan R.	KOERI	Station Dar - DWN	0.0010
		Station Dar - 90	0.0032
		Station Dar - 180	0.0021
Galata Kop.	KOERI	Station GAL - DWN	0.0016
		Station GAL - 0	0.0046
		Station GAL - 270	0.0037
Fatih	KOERI	Station 777 - UP	0.0019
		Station 777 - 0	0.0071
		Station 777 - 270	0.0038
Cekmece	KOERI	Station 768 - UP	0.0015
		Station 768 - 90	0.0031
		Station 768 - 180	0.0035
K.MustafaPasa	KOERI	Station KMP - UP	0.0019
		Station KMP - 0	0.0033
		Station KMP - 90	0.0037
Yalova AhmetTas	KOERI	Station Kas - UP	0.0261
		Station Kas - 0	0.0171
		Station Kas - 90	0.0120
Yalova BaglaraltiC	KOERI	Station Bag - UP	0.0273
		Station Bag - 0	0.0098
		Station Bag - 270	0.0110
Yalova Devlet Hast.	KOERI	Station Has - UP	0.0283
		Station Has - 0	0.0232
		Station Has - 90	0.0083
Yalova HilalStreet	KOERI	Station Hil - UP	0.0291
		Station Hil - 0	0.0131
		Station Hil - 90	0.0161
Yalova RuzgarStreet	KOERI	Station Ruz - UP	0.0142

		Station Ruz - 0	0.0095
		Station Ruz - 270	0.0156
Yarimca	KOERI	Station 772 - UP	0.0025
		Station 772 - 0	0.0029
		Station 772 - 270	0.0034
Duzce Turkey Aftershock, November 12, 1999			
Ambarli	KOERI	Station 767 - Up	0.0006
		Station 767 - 0	0.0024
		Station 767 - 270	0.0020
Bursa Tofas	KOERI	Station Bur - DWN	0.0008
		Station Bur - 90	0.0024
		Station Bur - 180	0.0020
Arcelik	KOERI	Station Arc - DWN	0.0007
		Station Arc - 0	0.0016
		Station Arc - 270	0.0014
Aslan R.	KOERI	Station Dar - DWN	0.0007
		Station Dar - 90	0.0027
		Station Dar - 180	0.0017
Galata Kop.	KOERI	Station GAL - DWN	0.0018
		Station GAL - 0	0.0016
		Station GAL - 270	0.0009
Fatih	KOERI	Station 777 - UP	0.0016
		Station 777 - 0	0.0034
		Station 777 - 270	0.0039
Cekmece	KOERI	Station 768 - UP	0.0007
		Station 768 - 90	0.0028
		Station 768 - 180	0.0027
K.MustafaPasa	KOERI	Station KMP - UP	0.0012
		Station KMP - 0	0.0020
		Station KMP - 90	0.0017
Yalova HilalStreet	KOERI	Station Hil - UP	0.0278
		Station Hil - 0	0.0095
		Station Hil - 90	0.0129
Yalova RuzgarStreet	KOERI	Station Ruz - UP	0.0129
		Station Ruz - 0	0.0066
		Station Ruz - 270	0.0127
Yalova Tarim Directory	KOERI	Station Tar - UP	0.0171

		Station Tar - 0	0.0139
		Station Tar - 90	0.0459
Yarimca	KOERI	Station 772 - UP	0.0020
		Station 772 - 0	0.0024
		Station 772 - 270	0.0023
Sapanca - Adapazari Earthquake, November 11, 1999			
Ambarli	KOERI	Station 767 - Up	0.0046
		Station 767 - 0	0.0183
		Station 767 - 270	0.0099
Bursa Tofas	KOERI	Station Bur - DWN	0.0047
		Station Bur - 90	0.0065
		Station Bur - 180	0.0090
Arcelik	KOERI	Station Arc - DWN	0.0075
		Station Arc - 0	0.0100
		Station Arc - 270	0.0077
Galata Kop.	KOERI	Station GAL - DWN	0.0048
		Station GAL - 0	0.0067
		Station GAL - 270	0.0082
Fatih	KOERI	Station 777 - UP	0.0084
		Station 777 - 0	0.0177
		Station 777 - 270	0.0138
Heybeliada	KOERI	Station 770 - DWN	0.0056
		Station 770 - 90	0.0136
		Station 770 - 180	0.0086
Cekmece	KOERI	Station 768 - UP	0.0060
		Station 768 - 90	0.0117
		Station 768 - 180	0.0130
KocaMustafapasa	KOERI	Station KMP - UP	0.0060
		Station KMP - 0	0.0117
		Station KMP - 90	0.0129
Levent YpiKrediPlz	KOERI	Station 769 - UP	0.0038
		Station 769 - 90	0.0029
		Station 769 - 180	0.0049
Botas	KOERI	Station 766 - UP	0.0012
		Station 766 - 0	0.0037
		Station 766 - 90	0.0031
Yalova BahcevanS	KOERI	Station Bah - UP	0.0278

		Station Bah - 0	0.0122
		Station Bah - 90	0.0120
Yarimca	KOERI	Station 772 - UP	0.0223
		Station 772 - 0	0.0244
		Station 772 - 270	0.0175
Havaalani	KOERI	Station 779 - DWN	0.0031
		Station 779 - 90	0.0057
		Station 779 - 180	0.0060
Hendek - Adapazari Earthquake, November 7, 1999			
Fatih	KOERI	Station 777 - UP	0.0024
		Station 777 - 0	0.0028
		Station 777 - 270	0.0042
KocaMustafapasa	KOERI	Station KMP - UP	0.0012
		Station KMP - 0	0.0019
		Station KMP - 90	0.0025
Yalova HilalStreet	KOERI	Station Hil - UP	0.0236
		Station Hil - 0	0.0076
		Station Hil - 90	0.0115
Yarimca	KOERI	Station 772 - UP	0.0009
		Station 772 - 0	0.0014
		Station 772 - 270	0.0012
Marmara Sea Earthquake, September 20, 1999			
Akyazi	KOERI	Station 1414 - UP	0.0212
		Station 1414 - 0	0.0056
		Station 1414 - 270	0.0182
Ambarli	KOERI	Station 767 - Up	0.0035
		Station 767 - 0	0.0085
		Station 767 - 270	0.0061
Bursa Tofas	KOERI	Station Bur - DWN	0.0010
		Station Bur - 90	0.0028
		Station Bur - 180	0.0023
Arcelik	KOERI	Station Arc - DWN	0.0006
		Station Arc - 0	0.0017
		Station Arc - 270	0.0015
Aslan R.	KOERI	Station Dar - DWN	0.0006
		Station Dar - 90	0.0024
		Station Dar - 180	0.0023

Galata Kop.	KOERI	Station GAL - DWN	0.0047
		Station GAL - 0	0.0085
		Station GAL - 270	0.0062
Fatih	KOERI	Station 777 - UP	0.0066
		Station 777 - 0	0.0159
		Station 777 - 270	0.0113
Heybeliada	KOERI	Station 770 - UP	0.0015
		Station 770 - 90	0.0023
		Station 770 - 180	0.0029
Cekmece	KOERI	Station 768 - UP	0.0037
		Station 768 - 90	0.0073
		Station 768 - 180	0.0089
KocaMustafapasa	KOERI	Station KMP - UP	0.0034
		Station KMP - 0	0.0070
		Station KMP - 90	0.0091
Levent YpiKrediPlz	KOERI	Station 769 - UP	0.0010
		Station 769 - 90	0.0015
		Station 769 - 180	0.0022
Botas	KOERI	Station 766 - UP	0.0024
		Station 766 - 0	0.0075
		Station 766 - 90	0.0070
Havaalani	KOERI	Station 779 - DWN	0.0023
		Station 779 - 90	0.0037
		Station 779 - 180	0.0057
Izmit Turkey Eartquake, September 13, 1999			
Adapazari-A.Babalioglu	KOERI	Station 1411 - UP	0.0400
		Station 1411 - 0	0.0933
		Station 1411 - 270	0.0961
Adapazari-BahtiyatTopcu	KOERI	Station 1409 - UP	0.2362
		Station 1411 - 180	0.2092
		Station 1411 - 270	0.1532
Adapazari-BayindirlikDirectory	KOERI	Station 1415 - UP	0.0535
		Station 1415 - 0	0.0597
		Station 1415 - 270	0.0542
Adapazari-HendekOrmanFidanligi	KOERI	Station 1412 - UP	0.0095
		Station 1412 - 0	0.0188
		Station 1412 - 270	0.0320

Adapazari - Kadin D. Cocuk B. Residence	KOERI	Station 1417 - UP	0.0527
		Station 1417 - 0	0.0749
		Station 1417 - 90	0.0597
Adapazari - Seker FB.	KOERI	Station Sek - UP	0.0386
		Station Sek - 90	0.0684
		Station Sek - 180	0.1444
Adapazari - Seker MH. Genc Street	KOERI	Station Gen - UP	0.0293
		Station Gen - 90	0.0551
		Station Gen - 180	0.0702
Adapazari - Toyotasa	KOERI	Station 1410 - UP	0.0281
		Station 1410 - 0	0.0912
		Station 1410 - 270	0.0374
Akyazi	KOERI	Station 1414 - UP	0.0330
		Station 1414 - 0	0.0396
		Station 1414 - 270	0.0586
Ambarli	KOERI	Station 767 - Up	0.0154
		Station 767 - 0	0.0402
		Station 767 - 270	0.0334
Bursa Tofas	KOERI	Station Bur - DWN	0.0156
		Station Bur - 90	0.0427
		Station Bur - 180	0.0510
Arcelik	KOERI	Station Arc - DWN	0.0168
		Station Arc - 0	0.0233
		Station Arc - 270	0.0261
Aslan R.	KOERI	Station Dar - DWN	0.0131
		Station Dar - 90	0.0291
		Station Dar - 180	0.0208
Galata Kop.	KOERI	Station GAL - DWN	0.0216
		Station GAL - 0	0.0336
		Station GAL - 270	0.0454
Fatih	KOERI	Station 777 - UP	0.0256
		Station 777 - 0	0.0709
		Station 777 - 270	0.0646
Heybeliada	KOERI	Station 770 - UP	0.0333
		Station 770 - 90	0.0430
		Station 770 - 180	0.0255
Cekmece	KOERI	Station 768 - UP	0.0123

		Station 768 - 90	0.0293
		Station 768 - 180	0.0378
KocaMustafapasa	KOERI	Station KMP - UP	0.0230
		Station KMP - 0	0.0381
		Station KMP - 90	0.0548
Levent YpiKrediPlz	KOERI	Station 769 - UP	0.0051
		Station 769 - 90	0.0060
		Station 769 - 180	0.0085
Botas	KOERI	Station 766 - UP	0.0033
		Station 766 - 0	0.0114
		Station 766 - 90	0.0139
Yarimca	KOERI	Station 772 - UP	0.0524
		Station 772 - 0	0.0932
		Station 772 - 270	0.0869
Havaalani	KOERI	Station 779 - DWN	0.0086
		Station 779 - 90	0.0228
		Station 779 - 180	0.0182
Izmit Turkey Earthquake, August 31, 1999			
Adapazari-A.Babalioglu	KOERI	Station 1411 - UP	0.0364
		Station 1411 - 0	0.0481
		Station 1411 - 270	0.0443
Adapazari-BahtiyatTopcu	KOERI	Station 1409 - UP	0.0452
		Station 1411 - 180	0.0432
		Station 1411 - 270	0.0476
Adapazari-BayindirlikDirectory	KOERI	Station 1415 - UP	0.0303
		Station 1415 - 0	0.0443
		Station 1415 - 270	0.0182
Adapazari - Kadin D. Cocuk B. Residence	KOERI	Station 1417 - UP	0.0344
		Station 1417 - 0	0.0510
		Station 1417 - 90	0.0422
Adapazari - Toyotasa	KOERI	Station 1410 - UP	0.0178
		Station 1410 - 0	0.0574
		Station 1410 - 270	0.0293
Akyazi	KOERI	Station 1414 - UP	0.0254
		Station 1414 - 0	0.0203
		Station 1414 - 270	0.0336
Ambarli	KOERI	Station 767 - Up	0.0025

		Station 767 - 0	0.0037
		Station 767 - 270	0.0035
Bursa Tofas	KOERI	Station Bur - DWN	0.0018
		Station Bur - 90	0.0037
		Station Bur - 180	0.0035
Arcelik	KOERI	Station Arc - DWN	0.0031
		Station Arc - 0	0.0038
		Station Arc - 270	0.0053
Aslan R.	KOERI	Station Dar - DWN	0.0028
		Station Dar - 90	0.0045
		Station Dar - 180	0.0035
Galata Kop.	KOERI	Station GAL - DWN	0.0022
		Station GAL - 0	0.0032
		Station GAL - 270	0.0043
Heybeliada	KOERI	Station 770 - UP	0.0017
		Station 770 - 90	0.0019
		Station 770 - 180	0.0023
Cekmece	KOERI	Station 768 - UP	0.0024
		Station 768 - 90	0.0040
		Station 768 - 180	0.0053
KocaMustafapasa	KOERI	Station KMP - UP	0.0034
		Station KMP - 0	0.0046
		Station KMP - 90	0.0035
Botas	KOERI	Station 766 - UP	0.0006
		Station 766 - 0	0.0020
		Station 766 - 90	0.0017
Yarimca	KOERI	Station 772 - UP	0.0103
		Station 772 - 0	0.0212
		Station 772 - 270	0.0143
Hendek Adapazari Earthquake, August 22, 1999			
Aslan R.	KOERI	Station Dar - DWN	0.0071
		Station Dar - 90	0.0027
		Station Dar - 180	0.0014
Galata Kop.	KOERI	Station GAL - DWN	0.0012
		Station GAL - 0	0.0020
		Station GAL - 270	0.0027
Fatih	KOERI	Station 777 - UP	0.0020

		Station 777 - 0	0.0037
		Station 777 - 270	0.0053
Cekmece	KOERI	Station 768 - UP	0.0008
		Station 768 - 90	0.0028
		Station 768 - 180	0.0023
KocaMustafapasa	KOERI	Station KMP - UP	0.0018
		Station KMP - 0	0.0030
		Station KMP - 90	0.0025
Cinarcik - Yalova Earthquake, August 19, 1999			
Bursa Tofas	KOERI	Station Bur - DWN	0.0044
		Station Bur - 90	0.0069
		Station Bur - 180	0.0073
Galata Kop.	KOERI	Station GAL - DWN	0.0018
		Station GAL - 0	0.0024
		Station GAL - 270	0.0024
Fatih	KOERI	Station 777 - UP	0.0033
		Station 777 - 0	0.0073
		Station 777 - 270	0.0049
KocaMustafapasa	KOERI	Station KMP - UP	0.0021
		Station KMP - 0	0.0034
		Station KMP - 90	0.0027
Botas	KOERI	Station 766 - UP	0.0006
		Station 766 - 0	0.0029
		Station 766 - 90	0.0020
Havaalani	KOERI	Station 779 - DWN	0.0011
		Station 779 - 90	0.0015
		Station 779 - 180	0.0019
Akyazi - Adapazari Earthquake, August 17, 1999			
Bursa Tofas	KOERI	Station Bur - DWN	0.0012
		Station Bur - 90	0.0012
		Station Bur - 180	0.0010
KocaMustafapasa	KOERI	Station KMP - UP	0.0046
		Station KMP - 0	0.0061
		Station KMP - 90	0.0077

Appendix B. The input parameters and corresponding outputs for PHA data analysis.

INPUTS				OUTPUT
Magnitude	Distance (km)	Depth (km)	Site Class	PHA(g)
7.4	47.6	17	2	0.264
7.4	101.1	17	2	0.223
7.4	94.6	17	2	0.122
7.4	91.3	17	3	0.245
7.4	160.9	17	2	0.136
7.4	78.8	17	2	0.149
7.4	22.7	17	2	0.440
7.4	104.4	17	3	0.310
7.4	69.6	17	2	0.123
7.4	93.2	17	2	0.167
7.4	86.3	17	1	0.054
7.4	66.1	17	1	0.059
7.4	64.6	17	2	0.087
7.4	69.6	17	2	0.195
7.4	65.3	17	2	0.154
7.4	68.7	17	1	0.073
7.4	24.0	17	1	0.280
7.4	17.7	17	1	0.267
7.4	267.3	17	1	0.050
7.4	39.4	17	2	0.178
7.4	63.0	17	2	0.069
7.4	17.3	17	2	0.376
7.4	21.2	17	3	0.475
7.4	36.1	17	3	0.168
7.4	145.6	17	2	0.077
7.4	197.6	17	3	0.021
7.4	276.5	17	3	0.009
7.4	369.3	17	3	0.015
7.4	392.3	17	3	0.038
7.4	342.4	17	1	0.013
7.4	373.3	17	3	0.001
7.4	459.3	17	1	0.014
7.4	237.1	17	1	0.139
7.4	81.4	17	2	0.148
7.1	151.6	14	2	0.012
7.1	203.5	14	2	0.023
7.1	198.5	14	2	0.024
7.1	189.5	14	3	0.043
7.1	189.5	14	2	0.023
7.1	185.5	14	2	0.025
7.1	117.8	14	2	0.027
7.1	150.7	14	3	0.018
7.1	208.5	14	3	0.045
7.1	186.5	14	2	0.021
7.1	174.6	14	2	0.037
7.1	183.5	14	1	0.007
7.1	268.4	14	2	0.006

7.1	162.6	14	2	0.023
7.1	162.6	14	2	0.052
7.1	159.6	14	2	0.038
7.1	163.6	14	2	0.041
7.1	163.6	14	2	0.039
7.1	164.6	14	2	0.071
7.1	164.6	14	2	0.077
7.1	163.6	14	2	0.060
7.1	166.6	14	2	0.079
7.1	141.3	14	2	0.037
7.1	221.7	14	3	0.013
7.1	409.6	14	3	0.002
7.1	167.6	14	1	0.012
7.1	169.4	14	1	0.025
7.1	47.9	14	2	0.037
7.1	161.3	14	2	0.010
7.1	125.8	14	3	0.031
7.1	115	14	1	0.033
7.1	290.7	14	1	0.008
7.1	223	14	1	0.011
7.1	179.4	14	2	0.023
7.1	97	14	2	0.054
7.1	174.6	14	2	0.074
7.1	36.4	14	3	0.132
7.1	51.8	14	2	0.028
7.1	16.2	14	3	0.638
7.1	170.1	14	2	0.027
7.1	22.5	14	3	1.098
7.1	33.3	14	1	0.060
7.1	30.8	14	2	0.049
7.1	16.2	14	1	1.098
7.1	21.0	14	2	0.121
5.8	173.7	15.3	3	0.009
5.8	146.8	15.3	2	0.011
5.8	116	15.3	2	0.007
5.8	151.8	15.3	2	0.011
5.8	153.8	15.3	3	0.019
5.8	138.8	15.3	2	0.018
5.8	168.7	15.3	2	0.009
5.8	154.8	15.3	2	0.012
5.8	150.8	15.3	1	0.003
5.8	232.5	15.3	2	0.003
5.8	162.7	15.3	2	0.005
5.0	235.5	15.7	3	0.003
5.0	168.7	15.7	2	0.003
5.0	143.3	9.2	2	0.020
5.0	205.2	10	3	0.003
5.0	176.3	10	2	0.013
5.4	200.2	10	3	0.004
5.4	176.3	10	2	0.004
5.4	142.4	10	2	0.003

5.4	142.4	10	3	0.004
5.4	178.3	10	2	0.006
5.4	179.3	10	3	0.008
5.4	195.3	10	2	0.005
5.4	181.3	10	2	0.005
5.4	148.3	10	2	0.021
5.4	150.3	10	2	0.015
5.4	151.3	10	2	0.025
5.4	151.3	10	2	0.021
5.4	150.3	10	2	0.018
5.4	108.5	10	2	0.004
5.2	204.2	10	3	0.003
5.2	180.3	10	2	0.003
5.2	147.3	10	2	0.002
5.2	146.3	10	3	0.003
5.2	181.3	10	2	0.002
5.2	183.3	10	3	0.005
5.2	199.3	10	2	0.004
5.2	185.3	10	2	0.003
5.2	155.3	10	2	0.016
5.2	154.3	10	2	0.014
5.2	156.3	10	2	0.048
5.2	113.4	10	2	0.003
5.7	136.8	22	3	0.021
5.7	117.1	22	2	0.011
5.7	80.2	22	2	0.013
5.7	116.1	22	2	0.011
5.7	117.1	22	3	0.022
5.7	79.1	22	2	0.016
5.7	132.8	22	2	0.018
5.7	118.1	22	2	0.017
5.7	114.1	22	1	0.006
5.7	117.1	22	2	0.005
5.7	86.6	22	2	0.017
5.7	48.1	22	2	0.030
5.7	126.9	22	2	0.008
5.0	151.3	10	3	0.005
5.0	152.3	10	2	0.003
5.0	121.4	10	2	0.014
5.0	79.8	10	2	0.002
5.0	249.5	16.4	2	0.019
5.0	100.3	16.4	3	0.010
5.0	136	16.4	2	0.004
5.0	151.9	16.4	2	0.002
5.0	151.9	16.4	3	0.003
5.0	123.1	16.4	2	0.010
5.0	122.1	16.4	3	0.020
5.0	129	16.4	2	0.004
5.0	107.3	16.4	2	0.012
5.0	120.1	16.4	2	0.011
5.0	129	16.4	1	0.003

5.0	50.3	16.4	2	0.010
5.0	110.2	16.4	2	0.007
5.8	31.4	19.6	2	0.134
5.8	29	19.6	2	0.259
5.8	30.8	19.6	2	0.081
5.8	52.5	19.6	2	0.037
5.8	31.8	19.6	2	0.096
5.8	30.7	19.6	2	0.160
5.8	31.5	19.6	2	0.089
5.8	32.3	19.6	2	0.099
5.8	41.4	19.6	2	0.071
5.8	122.6	19.6	3	0.052
5.8	105.8	19.6	2	0.066
5.8	65.5	19.6	2	0.035
5.8	64.7	19.6	3	0.036
5.8	100.8	19.6	2	0.056
5.8	102.9	19.6	3	0.096
5.8	88	19.6	2	0.050
5.8	117.6	19.6	2	0.048
5.8	103.9	19.6	2	0.067
5.8	99.6	19.6	1	0.010
5.8	181.1	19.6	2	0.018
5.8	34.6	19.6	2	0.127
5.8	111.7	19.6	2	0.029
5.2	43.6	17.7	2	0.065
5.2	40.7	17.7	2	0.064
5.2	42.5	17.7	2	0.048
5.2	44	17.7	2	0.066
5.2	44	17.7	2	0.064
5.2	54.6	17.7	2	0.039
5.2	107.5	17.7	3	0.005
5.2	91.9	17.7	2	0.005
5.2	51	17.7	2	0.007
5.2	49.8	17.7	3	0.006
5.2	87.1	17.7	2	0.005
5.2	73.5	17.7	2	0.003
5.2	103.5	17.7	2	0.007
5.2	89.7	17.7	2	0.006
5.2	165.9	17.7	2	0.003
5.2	22.2	17.7	2	0.026
5.0	111.1	5.4	3	0.003
5.0	147.1	5.4	2	0.003
5.0	149.1	5.4	3	0.006
5.0	164.1	5.4	2	0.004
5.0	150.1	5.4	2	0.004
5.0	38.4	11.5	2	0.010
5.0	49.9	11.5	2	0.003
5.0	79.3	11.5	3	0.009
5.0	49.1	11.5	2	0.004
5.0	103.6	11.5	2	0.004
5.0	50.1	11.5	2	0.002

5.5	140.8	15.3	2	0.002
5.5	150.8	15.3	2	0.010



Appendix C. The actual accelerations and neural network estimations for PHA model.

Actual PHA	Network PHA estimation	Difference between the actual and network results
0.2641	0.2574	0.01
0.2230	0.2186	0.00
0.1224	0.1385	-0.02
0.2455	0.2366	0.01
0.1361	0.0775	0.06
0.1492	0.1477	0.00
0.4400	0.4217	0.02
0.3096	0.3026	0.01
0.1235	0.1437	-0.02
0.1668	0.1459	0.02
0.0542	0.0611	-0.01
0.0595	0.0790	-0.02
0.0868	0.1089	-0.02
0.1947	0.1438	0.05
0.1542	0.1173	0.04
0.0734	0.0875	-0.01
0.2798	0.2972	-0.02
0.2674	0.2760	-0.01
0.0502	0.0501	0.00
0.1777	0.1824	0.00
0.0689	0.0979	-0.03
0.3760	0.3602	0.02
0.4749	0.4648	0.01
0.1676	0.1708	0.00
0.0775	0.0775	0.00
0.0206	0.0206	0.00
0.0086	0.0087	0.00
0.0149	0.0122	0.00
0.0383	0.0382	0.00
0.0134	0.0134	0.00
0.0014	0.0041	0.00
0.0136	0.0136	0.00
0.1391	0.1391	0.00
0.1482	0.1463	0.00
0.0120	0.0173	-0.01
0.0233	0.0241	0.00
0.0240	0.0242	0.00
0.0430	0.0380	0.00
0.0234	0.0256	0.00
0.0255	0.0248	0.00
0.0272	0.0276	0.00
0.0184	0.0183	0.00
0.0455	0.0443	0.00

0.0212	0.0242	0.00
0.0370	0.0502	-0.01
0.0073	0.0261	-0.02
0.0056	0.0056	0.00
0.0231	0.0451	-0.02
0.0515	0.0451	0.01
0.0384	0.0393	0.00
0.0410	0.0498	-0.01
0.0393	0.0498	-0.01
0.0711	0.0546	0.02
0.0766	0.0546	0.02
0.0598	0.0498	0.01
0.0786	0.0559	0.02
0.0365	0.0357	0.00
0.0128	0.0131	0.00
0.0023	0.0023	0.00
0.0123	0.0278	-0.02
0.0246	0.0273	0.00
0.0373	0.0357	0.00
0.0104	0.0400	-0.03
0.0307	0.0307	0.00
0.0325	0.0322	0.00
0.0083	0.0083	0.00
0.0110	0.0110	0.00
0.0231	0.0314	-0.01
0.0542	0.0541	0.00
0.0738	0.0502	0.02
0.1324	0.1362	0.00
0.0280	0.0300	0.00
0.6382	0.8911	-0.25
0.0272	0.0436	-0.02
1.0980	0.9783	0.12
0.0599	0.0636	0.00
0.0494	0.0657	-0.02
1.0978	1.0573	0.04
0.1205	0.2476	-0.13
0.0092	0.0092	0.00
0.0111	0.0112	0.00
0.0074	0.0208	-0.01
0.0112	0.0102	0.00
0.0193	0.0188	0.00
0.0178	0.0173	0.00
0.0086	0.0083	0.00
0.0123	0.0122	0.00
0.0030	0.0036	0.00
0.0025	0.0025	0.00
0.0048	0.0053	0.00
0.0029	0.0029	0.00

0.0030	0.0034	0.00
0.0196	0.0152	0.00
0.0025	0.0063	0.00
0.0125	0.0121	0.00
0.0044	0.0044	0.00
0.0044	0.0050	0.00
0.0026	0.0061	0.00
0.0038	0.0044	0.00
0.0059	0.0055	0.00
0.0081	0.0074	0.00
0.0046	0.0046	0.00
0.0049	0.0053	0.00
0.0209	0.0190	0.00
0.0147	0.0192	0.00
0.0247	0.0204	0.00
0.0208	0.0204	0.00
0.0183	0.0192	0.00
0.0044	0.0061	0.00
0.0032	0.0032	0.00
0.0032	0.0027	0.00
0.0022	0.0052	0.00
0.0032	0.0035	0.00
0.0019	0.0026	0.00
0.0051	0.0046	0.00
0.0038	0.0038	0.00
0.0027	0.0028	0.00
0.0160	0.0241	-0.01
0.0144	0.0215	-0.01
0.0479	0.0293	0.02
0.0034	0.0035	0.00
0.0208	0.0208	0.00
0.0111	0.0111	0.00
0.0126	0.0142	0.00
0.0106	0.0110	0.00
0.0224	0.0180	0.00
0.0160	0.0148	0.00
0.0175	0.0119	0.01
0.0175	0.0123	0.01
0.0057	0.0066	0.00
0.0048	0.0111	-0.01
0.0172	0.0167	0.00
0.0300	0.0300	0.00
0.0083	0.0088	0.00
0.0050	0.0047	0.00
0.0032	0.0036	0.00
0.0138	0.0130	0.00
0.0019	0.0088	-0.01
0.0191	0.0191	0.00

0.0104	0.0086	0.00
0.0036	0.0043	0.00
0.0023	0.0031	0.00
0.0034	0.0041	0.00
0.0105	0.0112	0.00
0.0195	0.0177	0.00
0.0037	0.0047	0.00
0.0115	0.0102	0.00
0.0115	0.0122	0.00
0.0027	0.0032	0.00
0.0103	0.0061	0.00
0.0068	0.0080	0.00
0.1339	0.1214	0.01
0.2593	0.1510	0.11
0.0807	0.1256	-0.04
0.0371	0.0664	-0.03
0.0958	0.1192	-0.02
0.1598	0.1269	0.03
0.0893	0.1206	-0.03
0.0986	0.1182	-0.02
0.0707	0.0823	-0.01
0.0523	0.0515	0.00
0.0665	0.0629	0.00
0.0350	0.0351	0.00
0.0357	0.0356	0.00
0.0565	0.0577	0.00
0.0960	0.0869	0.01
0.0500	0.0501	0.00
0.0478	0.0370	0.01
0.0668	0.0643	0.00
0.0104	0.0197	-0.01
0.0180	0.0178	0.00
0.1274	0.1193	0.01
0.0292	0.0344	-0.01
0.0654	0.0605	0.00
0.0643	0.0604	0.00
0.0479	0.0589	-0.01
0.0662	0.0607	0.01
0.0644	0.0607	0.00
0.0393	0.0333	0.01
0.0050	0.0051	0.00
0.0050	0.0053	0.00
0.0065	0.0225	-0.02
0.0057	0.0113	-0.01
0.0053	0.0054	0.00
0.0030	0.0031	0.00
0.0066	0.0065	0.00
0.0057	0.0055	0.00

0.0027	0.0037	0.00
0.0256	0.0257	0.00
0.0030	0.0035	0.00
0.0033	0.0052	0.00
0.0064	0.0047	0.00
0.0036	0.0037	0.00
0.0039	0.0041	0.00
0.0101	0.0097	0.00
0.0035	0.0045	0.00
0.0088	0.0088	0.00
0.0043	0.0045	0.00
0.0035	0.0100	-0.01
0.0025	0.0046	0.00
0.0016	0.0018	0.00
0.0099	0.0096	0.00



Appendix D. The input parameters and corresponding outputs for PVA data analysis.

INPUTS				OUTPUT
Magnitude	Distance (km)	Depth (km)	Site Class	PVA(g)
7.4	47.6	17	2	0.086
7.4	101.1	17	2	0.057
7.4	94.6	17	2	0.055
7.4	91.3	17	3	0.128
7.4	160.9	17	2	0.024
7.4	78.8	17	2	0.048
7.4	22.7	17	2	0.242
7.4	104.4	17	3	0.079
7.4	69.6	17	2	0.143
7.4	93.2	17	2	0.083
7.4	86.3	17	1	0.027
7.4	66.1	17	1	0.030
7.4	64.6	17	2	0.028
7.4	69.6	17	2	0.064
7.4	65.3	17	2	0.054
7.4	68.7	17	1	0.025
7.4	24.0	17	1	0.203
7.4	17.7	17	1	0.146
7.4	267.3	17	1	0.011
7.4	39.4	17	2	0.114
7.4	63.0	17	2	0.035
7.4	17.3	17	2	0.259
7.4	21.2	17	3	0.229
7.4	36.1	17	3	0.079
7.4	145.6	17	2	0.023
7.4	197.6	17	3	0.005
7.4	276.5	17	3	0.003
7.4	369.3	17	3	0.003
7.4	392.3	17	3	0.007
7.4	342.4	17	1	0.005
7.4	373.3	17	3	0.000
7.4	459.3	17	1	0.004
7.4	237.1	17	1	0.054
7.4	81.4	17	2	0.050
7.1	151.6	14	2	0.006
7.1	203.5	14	2	0.007
7.1	198.5	14	2	0.007
7.1	189.5	14	3	0.008
7.1	189.5	14	2	0.008
7.1	185.5	14	2	0.011
7.1	117.8	14	2	0.013
7.1	150.7	14	3	0.007
7.1	208.5	14	3	0.008
7.1	186.5	14	2	0.009
7.1	174.6	14	2	0.016
7.1	183.5	14	1	0.006
7.1	268.4	14	2	0.002

7.1	162.6	14	2	0.007
7.1	162.6	14	2	0.035
7.1	159.6	14	2	0.010
7.1	163.6	14	2	0.036
7.1	163.6	14	2	0.035
7.1	164.6	14	2	0.041
7.1	164.6	14	2	0.047
7.1	163.6	14	2	0.029
7.1	166.6	14	2	0.027
7.1	141.3	14	2	0.010
7.1	221.7	14	3	0.004
7.1	409.6	14	3	0.001
7.1	167.6	14	1	0.005
7.1	169.4	14	1	0.012
7.1	47.9	14	2	0.025
7.1	161.3	14	2	0.008
7.1	125.8	14	3	0.010
7.1	115	14	1	0.022
7.1	290.7	14	1	0.002
7.1	223	14	1	0.004
7.1	179.4	14	2	0.005
7.1	97	14	2	0.019
7.1	174.6	14	2	0.021
7.1	36.4	14	3	0.060
7.1	51.8	14	2	0.011
7.1	16.2	14	3	0.357
7.1	170.1	14	2	0.009
7.1	22.5	14	3	0.203
7.1	33.3	14	1	0.022
7.1	30.8	14	2	0.020
7.1	16.2	14	1	0.193
7.1	21.0	14	2	0.048
5.8	173.7	15.3	3	0.002
5.8	146.8	15.3	2	0.003
5.8	116	15.3	2	0.002
5.8	151.8	15.3	2	0.004
5.8	153.8	15.3	3	0.004
5.8	138.8	15.3	2	0.017
5.8	168.7	15.3	2	0.002
5.8	154.8	15.3	2	0.004
5.8	150.8	15.3	1	0.002
5.8	232.5	15.3	2	0.001
5.8	162.7	15.3	2	0.002
5.0	235.5	15.7	3	0.001
5.0	168.7	15.7	2	0.001
5.0	143.3	9.2	2	0.012
5.0	205.2	10	3	0.001
5.0	176.3	10	2	0.012
5.4	200.2	10	3	0.001
5.4	176.3	10	2	0.001
5.4	142.4	10	2	0.001

5.4	142.4	10	3	0.001
5.4	178.3	10	2	0.002
5.4	179.3	10	3	0.002
5.4	195.3	10	2	0.002
5.4	181.3	10	2	0.002
5.4	148.3	10	2	0.026
5.4	150.3	10	2	0.027
5.4	151.3	10	2	0.028
5.4	151.3	10	2	0.029
5.4	150.3	10	2	0.014
5.4	108.5	10	2	0.003
5.2	204.2	10	3	0.001
5.2	180.3	10	2	0.001
5.2	147.3	10	2	0.001
5.2	146.3	10	3	0.001
5.2	181.3	10	2	0.002
5.2	183.3	10	3	0.002
5.2	199.3	10	2	0.001
5.2	185.3	10	2	0.001
5.2	155.3	10	2	0.028
5.2	154.3	10	2	0.013
5.2	156.3	10	2	0.017
5.2	113.4	10	2	0.002
5.7	136.8	22	3	0.005
5.7	117.1	22	2	0.005
5.7	80.2	22	2	0.008
5.7	116.1	22	2	0.005
5.7	117.1	22	3	0.008
5.7	79.1	22	2	0.006
5.7	132.8	22	2	0.006
5.7	118.1	22	2	0.006
5.7	114.1	22	1	0.004
5.7	117.1	22	2	0.001
5.7	86.6	22	2	0.028
5.7	48.1	22	2	0.022
5.7	126.9	22	2	0.003
5.0	151.3	10	3	0.002
5.0	152.3	10	2	0.001
5.0	121.4	10	2	0.024
5.0	79.8	10	2	0.001
5.0	249.5	16.4	2	0.021
5.0	100.3	16.4	3	0.003
5.0	136	16.4	2	0.001
5.0	151.9	16.4	2	0.001
5.0	151.9	16.4	3	0.001
5.0	123.1	16.4	2	0.005
5.0	122.1	16.4	3	0.007
5.0	129	16.4	2	0.002
5.0	107.3	16.4	2	0.004
5.0	120.1	16.4	2	0.003
5.0	129	16.4	1	0.001

5.0	50.3	16.4	2	0.002
5.0	110.2	16.4	2	0.002
5.8	31.4	19.6	2	0.040
5.8	29	19.6	2	0.236
5.8	30.8	19.6	2	0.054
5.8	52.5	19.6	2	0.009
5.8	31.8	19.6	2	0.053
5.8	30.7	19.6	2	0.039
5.8	31.5	19.6	2	0.029
5.8	32.3	19.6	2	0.028
5.8	41.4	19.6	2	0.033
5.8	122.6	19.6	3	0.015
5.8	105.8	19.6	2	0.016
5.8	65.5	19.6	2	0.017
5.8	64.7	19.6	3	0.013
5.8	100.8	19.6	2	0.022
5.8	102.9	19.6	3	0.026
5.8	88	19.6	2	0.033
5.8	117.6	19.6	2	0.012
5.8	103.9	19.6	2	0.023
5.8	99.6	19.6	1	0.005
5.8	181.1	19.6	2	0.003
5.8	34.6	19.6	2	0.052
5.8	111.7	19.6	2	0.009
5.2	43.6	17.7	2	0.036
5.2	40.7	17.7	2	0.045
5.2	42.5	17.7	2	0.030
5.2	44	17.7	2	0.034
5.2	44	17.7	2	0.018
5.2	54.6	17.7	2	0.025
5.2	107.5	17.7	3	0.003
5.2	91.9	17.7	2	0.002
5.2	51	17.7	2	0.003
5.2	49.8	17.7	3	0.003
5.2	87.1	17.7	2	0.002
5.2	73.5	17.7	2	0.002
5.2	103.5	17.7	2	0.002
5.2	89.7	17.7	2	0.003
5.2	165.9	17.7	2	0.001
5.2	22.2	17.7	2	0.010
5.0	111.1	5.4	3	0.007
5.0	147.1	5.4	2	0.001
5.0	149.1	5.4	3	0.002
5.0	164.1	5.4	2	0.001
5.0	150.1	5.4	2	0.002
5.0	38.4	11.5	2	0.004
5.0	49.9	11.5	2	0.002
5.0	79.3	11.5	3	0.003
5.0	49.1	11.5	2	0.002
5.0	103.6	11.5	2	0.001
5.0	50.1	11.5	2	0.001

5.5	140.8	15.3	2	0.001
5.5	150.8	15.3	2	0.005



Appendix E. The actual accelerations and neural network estimations for PVA model.

Actual PVA	Network PVA estimation	Difference between the actual and network results
0.0860	0.0860	0.00
0.0570	0.0570	0.00
0.0550	0.0550	0.00
0.1280	0.1280	0.00
0.0240	0.0088	0.02
0.0480	0.0480	0.00
0.2420	0.2420	0.00
0.0790	0.0790	0.00
0.1433	0.1041	0.04
0.0829	0.0550	0.03
0.0271	0.0271	0.00
0.0300	0.0300	0.00
0.0280	0.0309	0.00
0.0640	0.1032	-0.04
0.0540	0.0511	0.00
0.0250	0.0250	0.00
0.2030	0.2030	0.00
0.1460	0.1460	0.00
0.0110	0.0110	0.00
0.1140	0.1140	0.00
0.0350	0.0349	0.00
0.2590	0.2420	0.02
0.2290	0.2290	0.00
0.0790	0.0790	0.00
0.0230	0.0230	0.00
0.0050	0.0050	0.00
0.0030	0.0030	0.00
0.0030	0.0027	0.00
0.0070	0.0070	0.00
0.0050	0.0050	0.00
0.0004	0.0007	0.00
0.0040	0.0040	0.00
0.0540	0.0540	0.00
0.0500	0.0500	0.00
0.0060	0.0060	0.00
0.0070	0.0070	0.00
0.0070	0.0070	0.00
0.0080	0.0080	0.00
0.0080	0.0080	0.00
0.0110	0.0109	0.00
0.0130	0.0130	0.00
0.0070	0.0070	0.00
0.0080	0.0080	0.00

0.0090	0.0091	0.00
0.0160	0.0187	0.00
0.0060	0.0115	-0.01
0.0016	0.0016	0.00
0.0069	0.0212	-0.01
0.0346	0.0212	0.01
0.0105	0.0105	0.00
0.0363	0.0319	0.00
0.0351	0.0319	0.00
0.0408	0.0431	0.00
0.0466	0.0431	0.00
0.0286	0.0319	0.00
0.0271	0.0272	0.00
0.0095	0.0095	0.00
0.0035	0.0035	0.00
0.0008	0.0008	0.00
0.0048	0.0048	0.00
0.0115	0.0115	0.00
0.0249	0.0249	0.00
0.0082	0.0087	0.00
0.0098	0.0098	0.00
0.0224	0.0224	0.00
0.0018	0.0018	0.00
0.0041	0.0041	0.00
0.0055	0.0055	0.00
0.0194	0.0194	0.00
0.0213	0.0187	0.00
0.0600	0.0600	0.00
0.0110	0.0110	0.00
0.3570	0.2030	0.15
0.0090	0.0090	0.00
0.2030	0.2030	0.00
0.0220	0.0220	0.00
0.0200	0.0200	0.00
0.1930	0.1930	0.00
0.0480	0.0480	0.00
0.0024	0.0024	0.00
0.0028	0.0028	0.00
0.0017	0.0017	0.00
0.0042	0.0028	0.00
0.0043	0.0043	0.00
0.0173	0.0173	0.00
0.0024	0.0024	0.00
0.0039	0.0025	0.00
0.0022	0.0022	0.00
0.0005	0.0005	0.00
0.0023	0.0023	0.00
0.0006	0.0006	0.00

0.0012	0.0012	0.00
0.0117	0.0117	0.00
0.0007	0.0006	0.00
0.0122	0.0122	0.00
0.0012	0.0012	0.00
0.0013	0.0013	0.00
0.0009	0.0009	0.00
0.0010	0.0010	0.00
0.0016	0.0016	0.00
0.0019	0.0019	0.00
0.0015	0.0015	0.00
0.0019	0.0019	0.00
0.0261	0.0261	0.00
0.0273	0.0274	0.00
0.0283	0.0287	0.00
0.0291	0.0287	0.00
0.0142	0.0274	-0.01
0.0025	0.0020	0.00
0.0006	0.0006	0.00
0.0008	0.0009	0.00
0.0007	0.0007	0.00
0.0007	0.0007	0.00
0.0018	0.0018	0.00
0.0016	0.0016	0.00
0.0007	0.0007	0.00
0.0012	0.0012	0.00
0.0278	0.0268	0.00
0.0129	0.0136	0.00
0.0171	0.0176	0.00
0.0020	0.0020	0.00
0.0046	0.0046	0.00
0.0047	0.0030	0.00
0.0075	0.0075	0.00
0.0048	0.0030	0.00
0.0084	0.0084	0.00
0.0056	0.0057	0.00
0.0060	0.0031	0.00
0.0060	0.0058	0.00
0.0038	0.0038	0.00
0.0012	0.0030	0.00
0.0278	0.0278	0.00
0.0223	0.0223	0.00
0.0031	0.0031	0.00
0.0024	0.0024	0.00
0.0012	0.0012	0.00
0.0236	0.0236	0.00
0.0009	0.0017	0.00
0.0212	0.0212	0.00

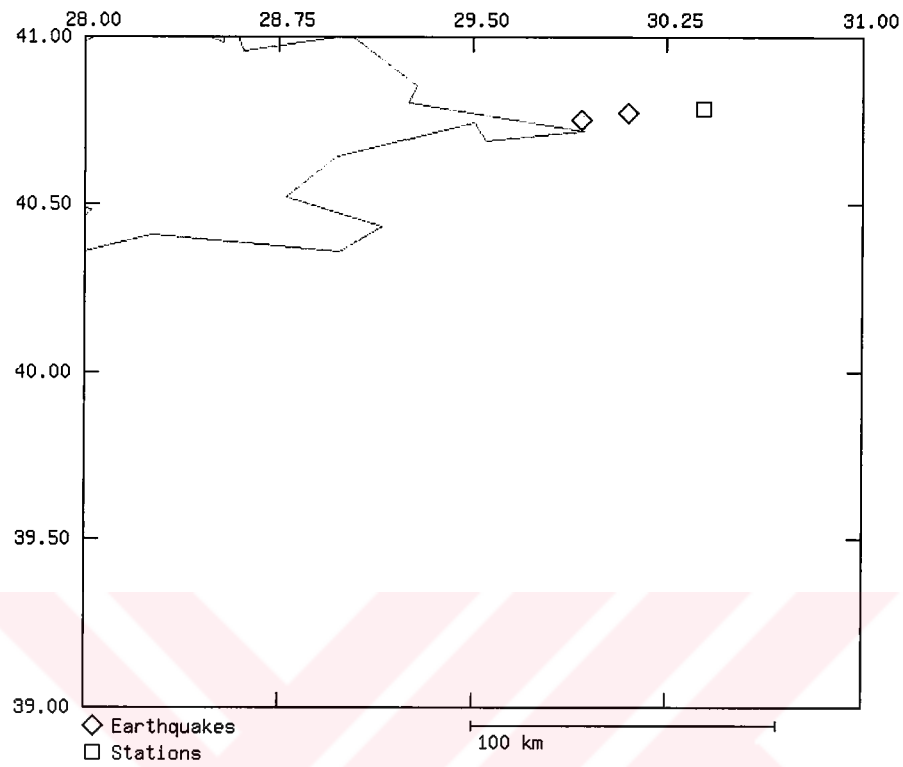
0.0035	0.0025	0.00
0.0010	0.0010	0.00
0.0006	0.0006	0.00
0.0006	0.0024	0.00
0.0047	0.0047	0.00
0.0066	0.0066	0.00
0.0015	0.0015	0.00
0.0037	0.0037	0.00
0.0034	0.0047	0.00
0.0010	0.0010	0.00
0.0024	0.0024	0.00
0.0023	0.0023	0.00
0.0400	0.0398	0.00
0.2362	0.2256	0.01
0.0535	0.0461	0.01
0.0095	0.0224	-0.01
0.0527	0.0420	0.01
0.0386	0.0457	-0.01
0.0293	0.0391	-0.01
0.0281	0.0349	-0.01
0.0330	0.0330	0.00
0.0154	0.0154	0.00
0.0156	0.0156	0.00
0.0168	0.0168	0.00
0.0131	0.0131	0.00
0.0216	0.0216	0.00
0.0256	0.0256	0.00
0.0333	0.0333	0.00
0.0123	0.0123	0.00
0.0230	0.0230	0.00
0.0051	0.0051	0.00
0.0033	0.0033	0.00
0.0524	0.0522	0.00
0.0086	0.0086	0.00
0.0364	0.0319	0.00
0.0452	0.0449	0.00
0.0303	0.0306	0.00
0.0344	0.0278	0.01
0.0178	0.0278	-0.01
0.0254	0.0254	0.00
0.0025	0.0025	0.00
0.0018	0.0018	0.00
0.0031	0.0031	0.00
0.0028	0.0028	0.00
0.0022	0.0022	0.00
0.0017	0.0017	0.00
0.0024	0.0024	0.00
0.0034	0.0034	0.00

0.0006	0.0006	0.00
0.0103	0.0103	0.00
0.0071	0.0071	0.00
0.0012	0.0012	0.00
0.0020	0.0024	0.00
0.0008	0.0008	0.00
0.0018	0.0018	0.00
0.0044	0.0044	0.00
0.0018	0.0016	0.00
0.0033	0.0033	0.00
0.0021	0.0020	0.00
0.0006	0.0036	0.00
0.0011	0.0014	0.00
0.0012	0.0012	0.00
0.0046	0.0046	0.00

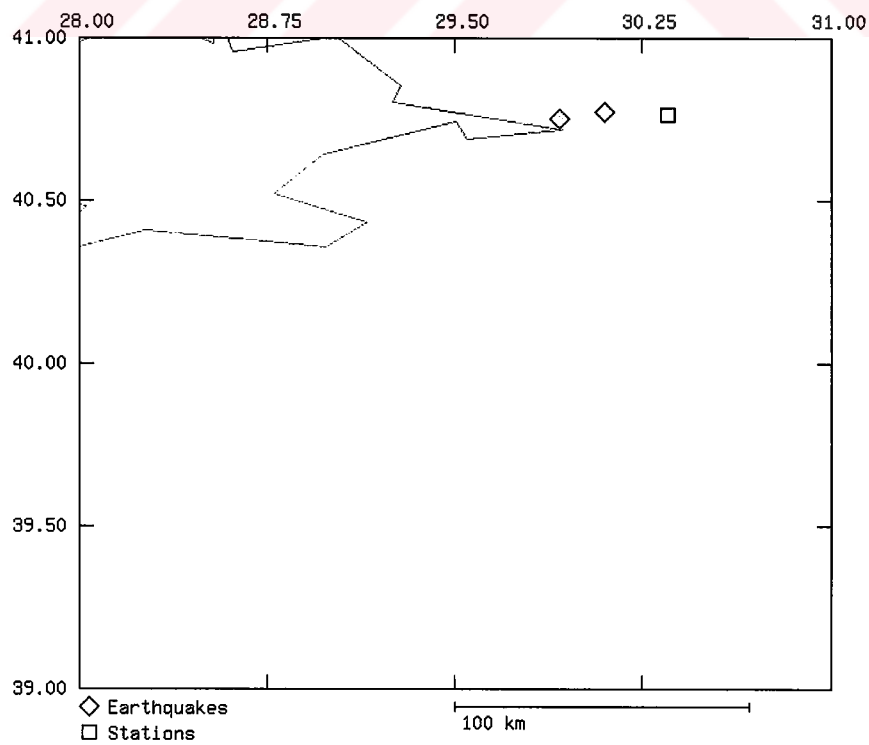


Appendix F. Strong ground motion stations in Marmara region.

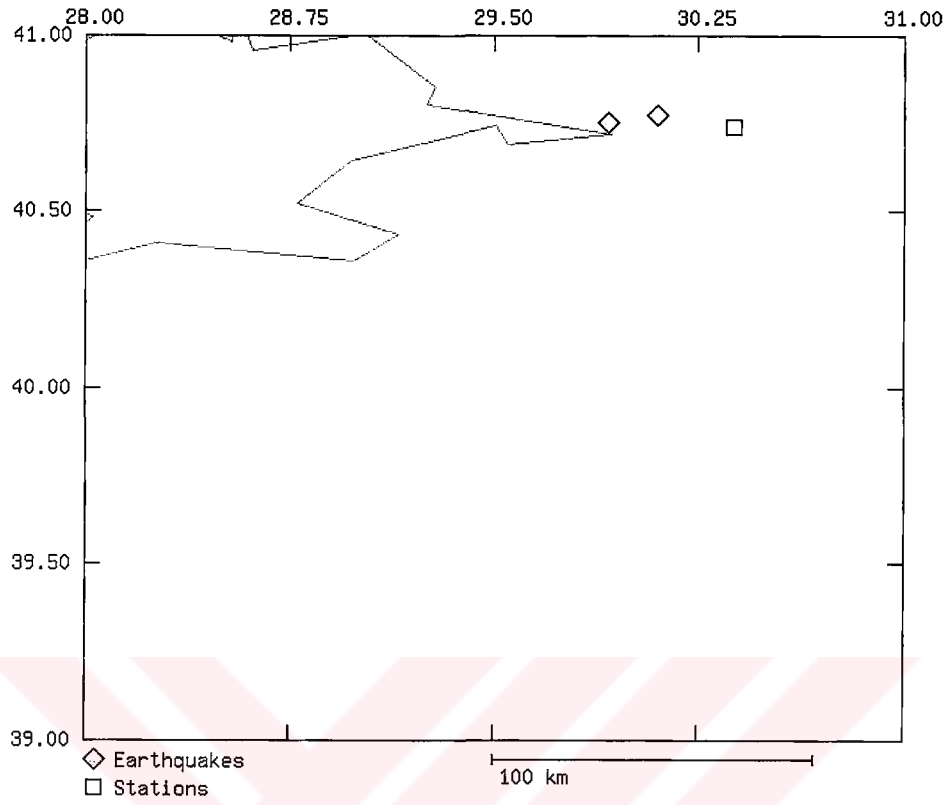
Koeri Adapazari A.Babalioglu Residence Station



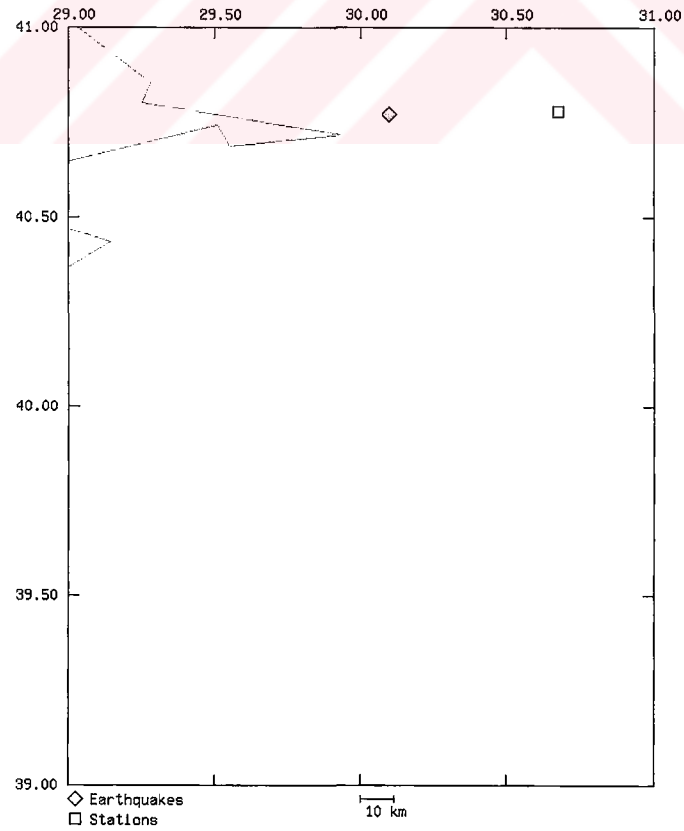
Koeri Adapazari - Bahtiyat Topcu Residence Station



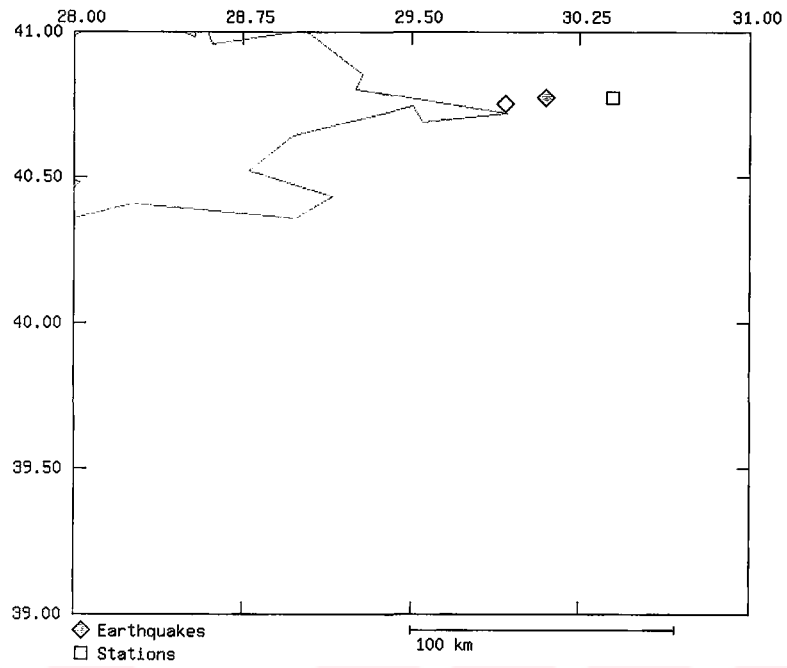
Koeri Adapazari Bayindirlik Directory Station



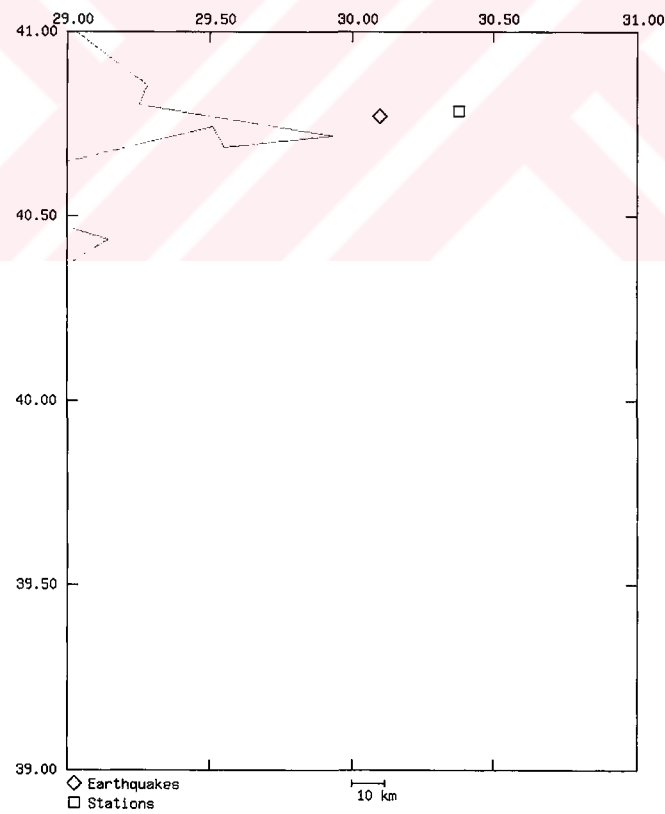
Koeri Adapazari Hendek Orman Fidanligi Station



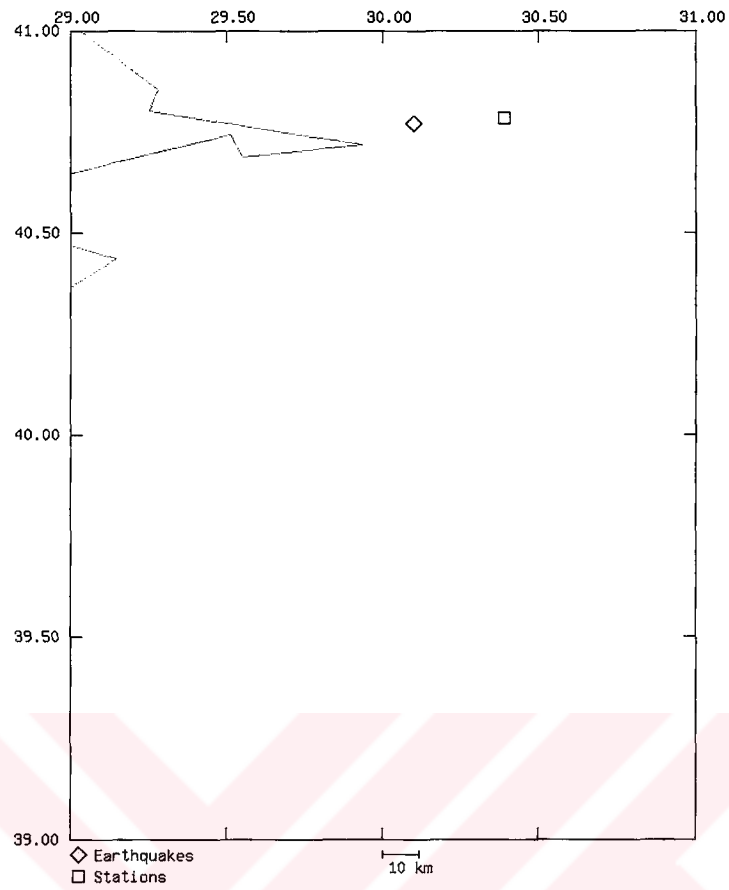
Koeri Adapazari Kadin D. Cocuk B. Residence Station



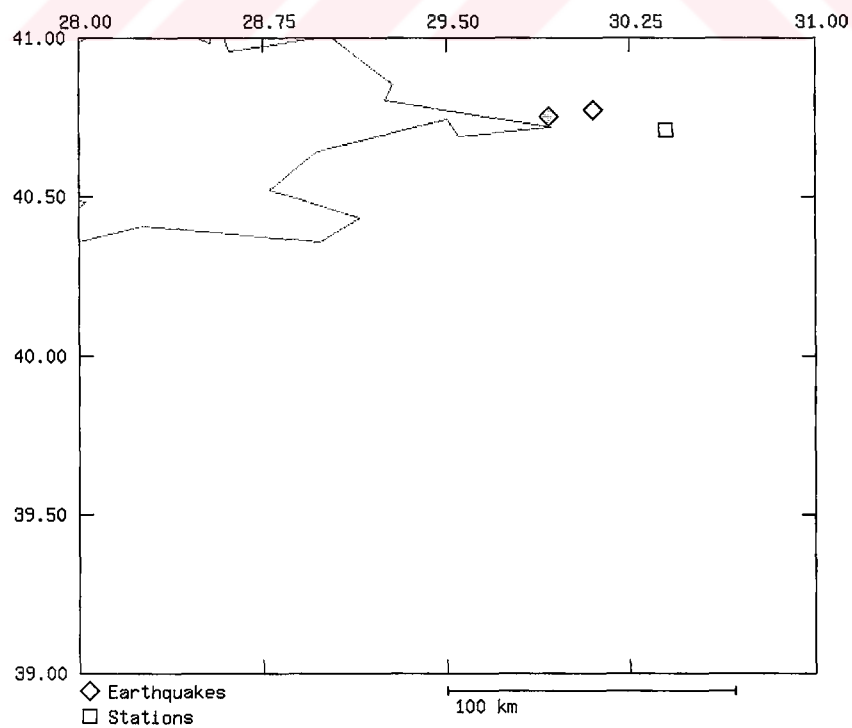
Koeri Adapazari Seker Fb. Station



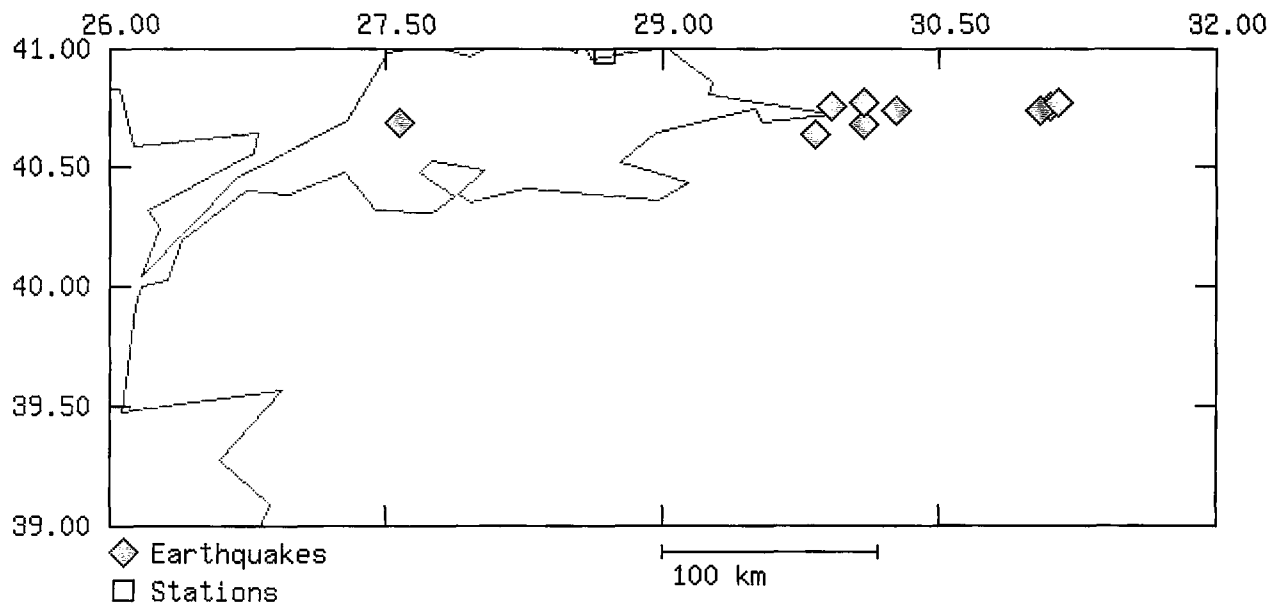
Koeri Adapazari - Seker MH. Genc Street Station



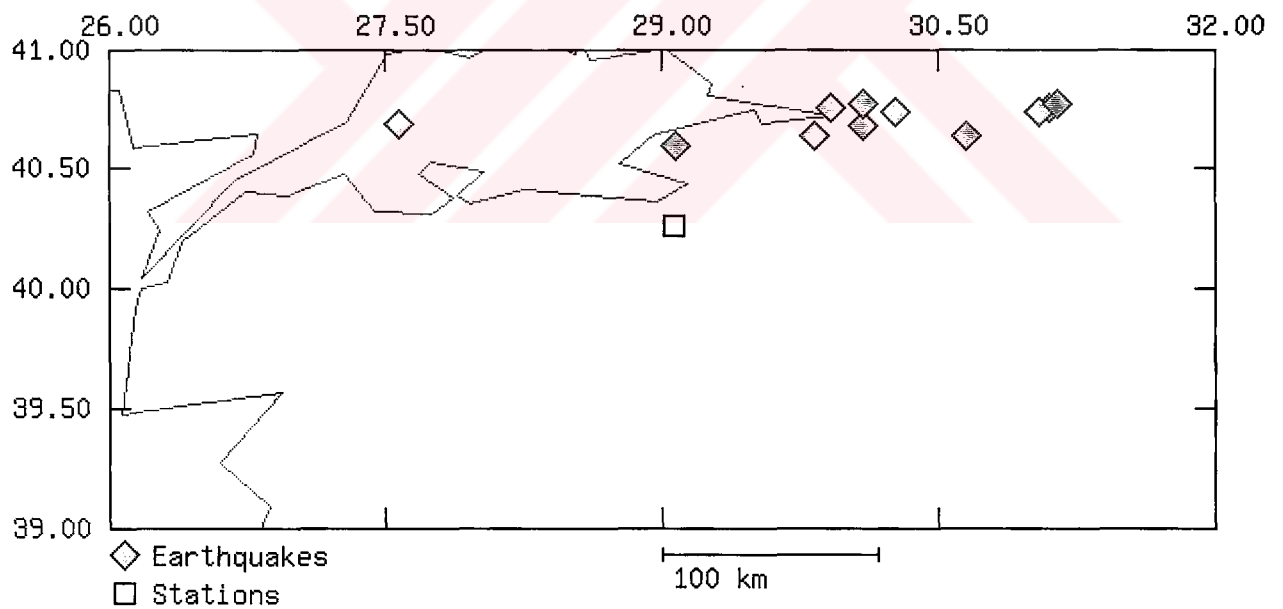
Koeri Adapazari – Toyotasa Station



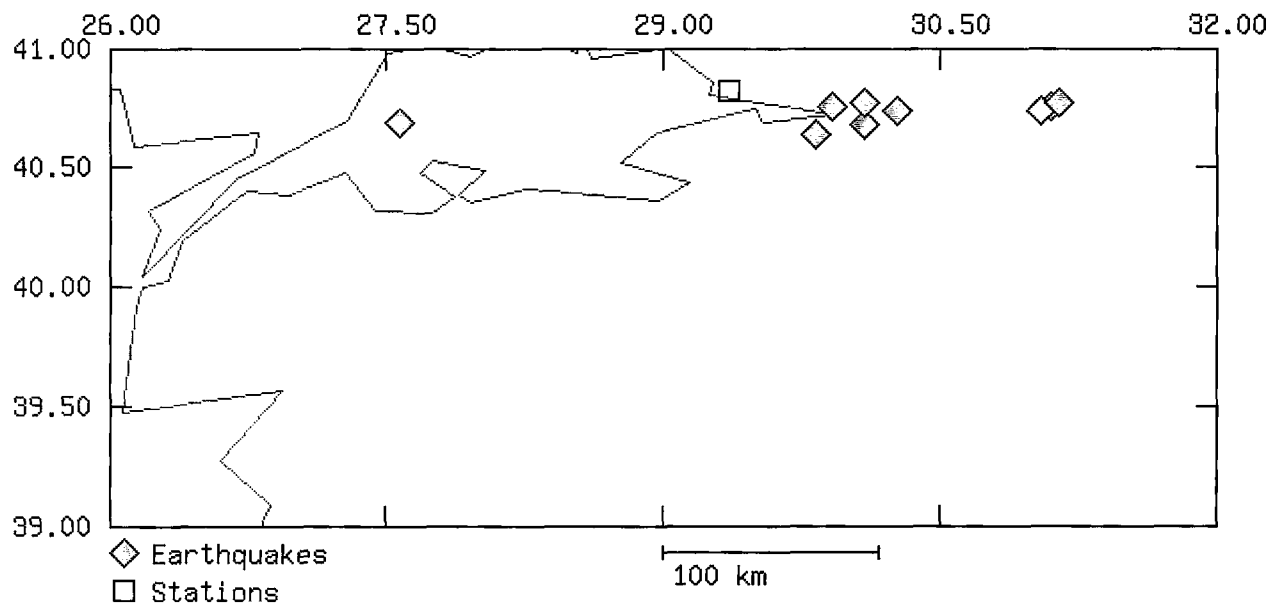
Koeri Ambarli - Ambarli Thermic Power Plant Station



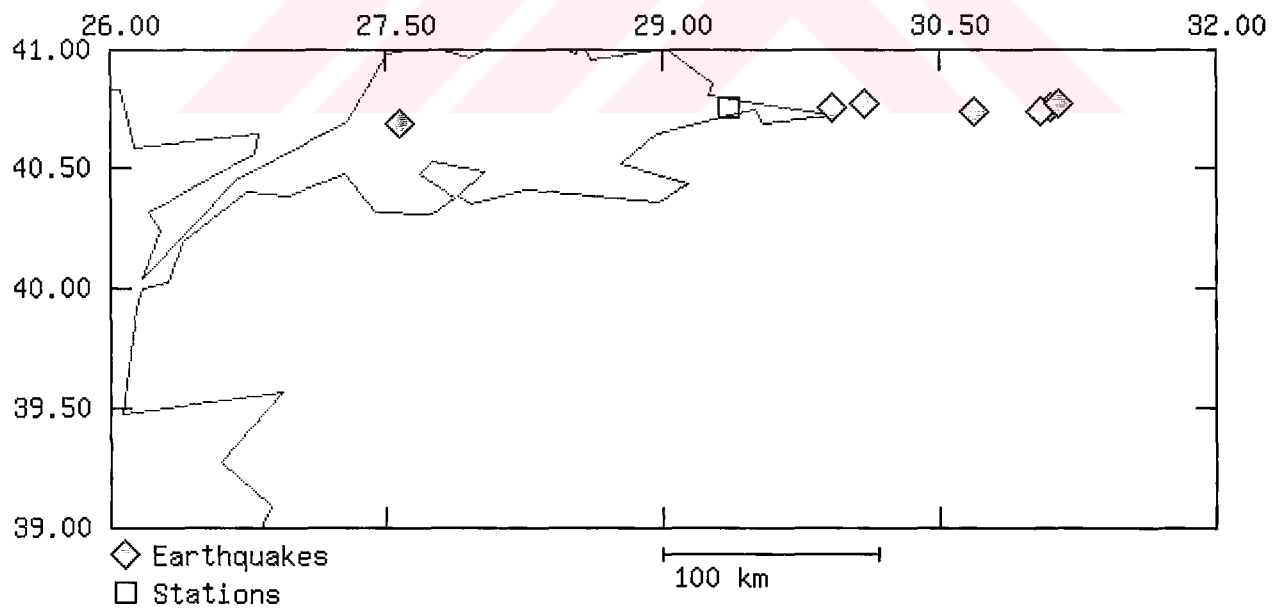
Koeri Bursa - Tofas Factory Station



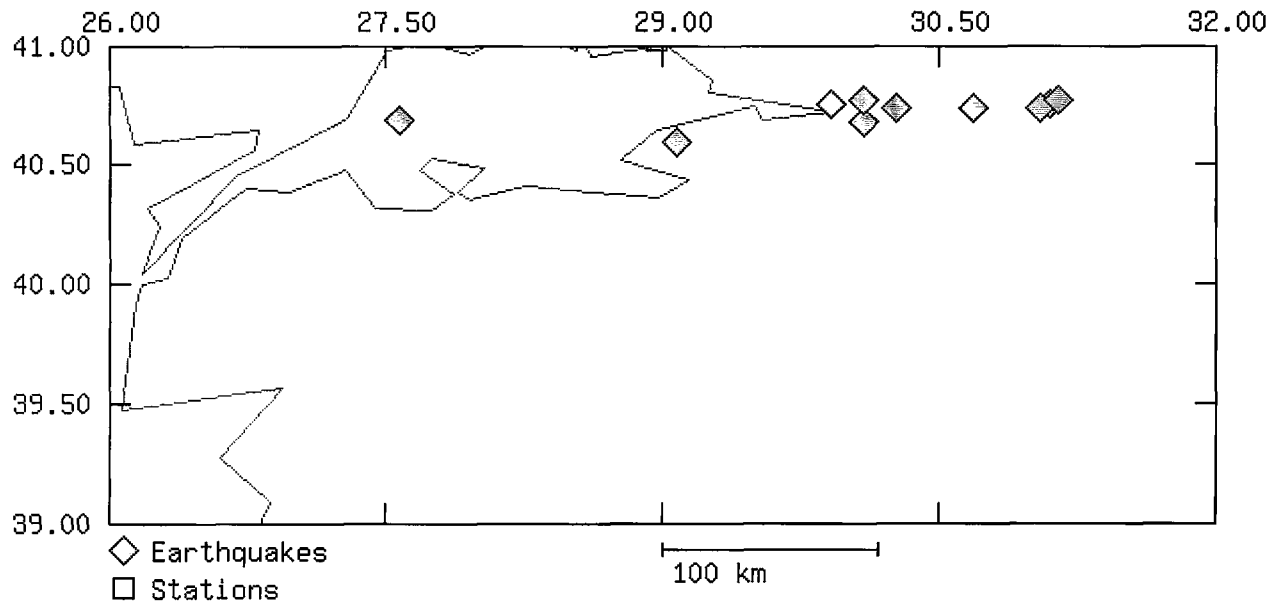
Koeri Darica – Arcelik Station



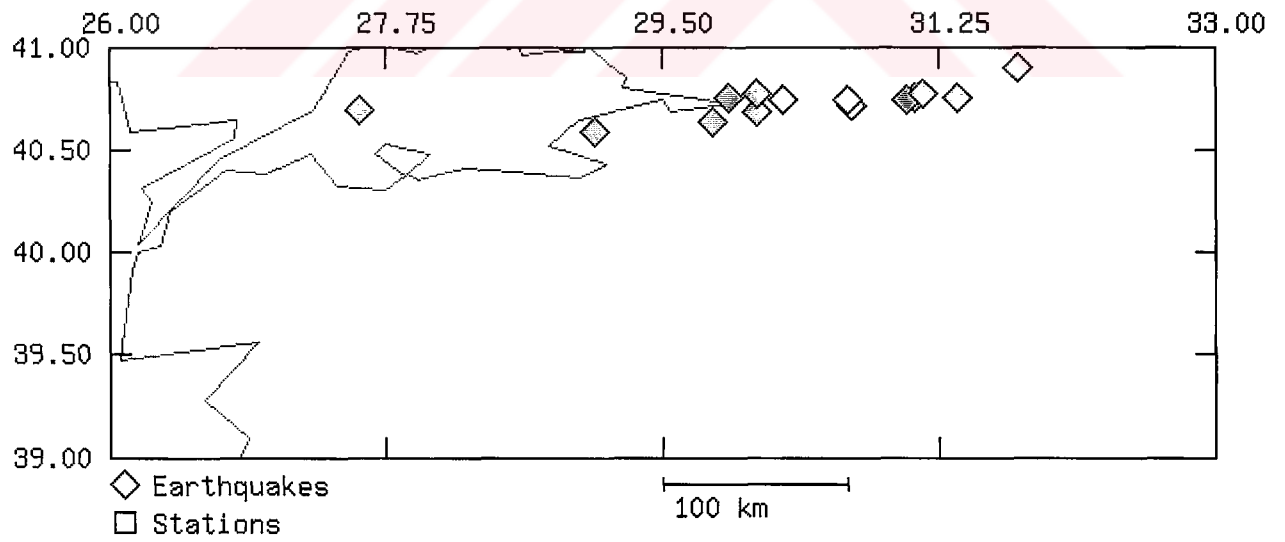
Koeri Darica - Arslan Cimento Factory Station



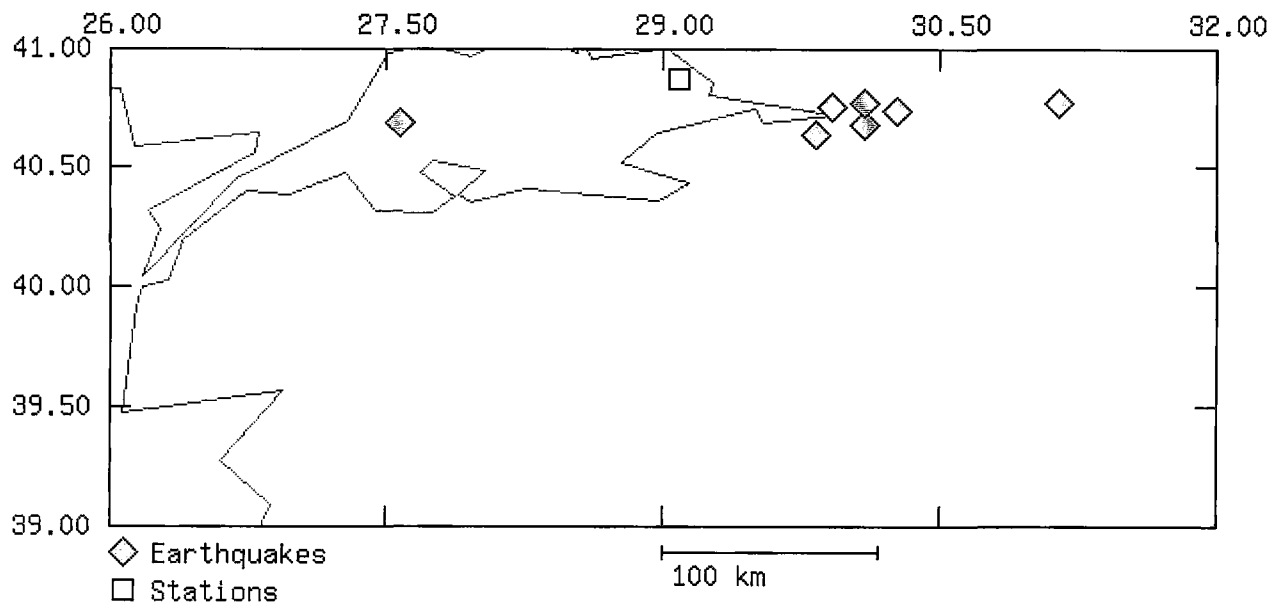
Koeri Eminonu - Galata Koprusu Station



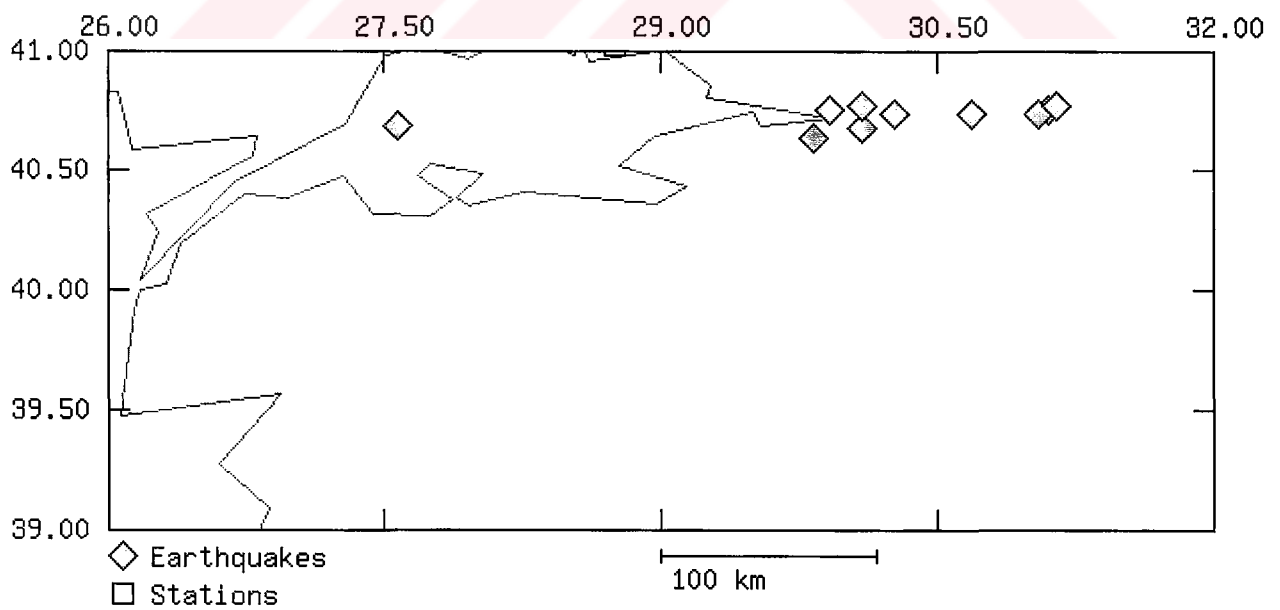
Koeri Fatih - Fatih Tomb Station



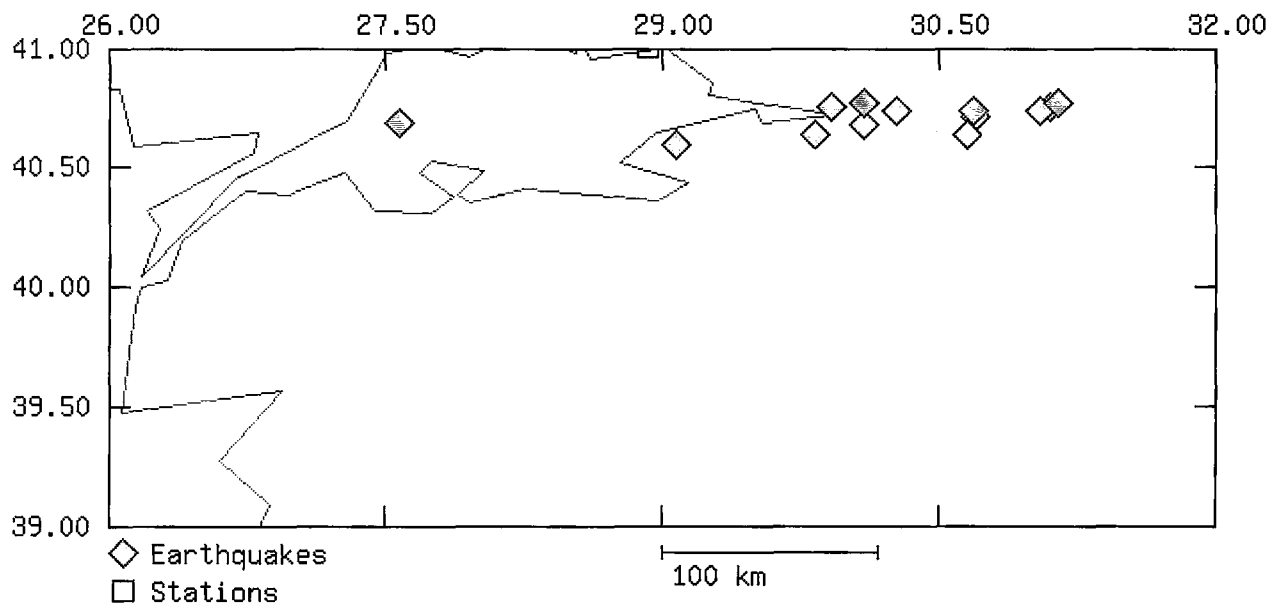
Koeri Heybeliada - Heybeliada Hospital Station



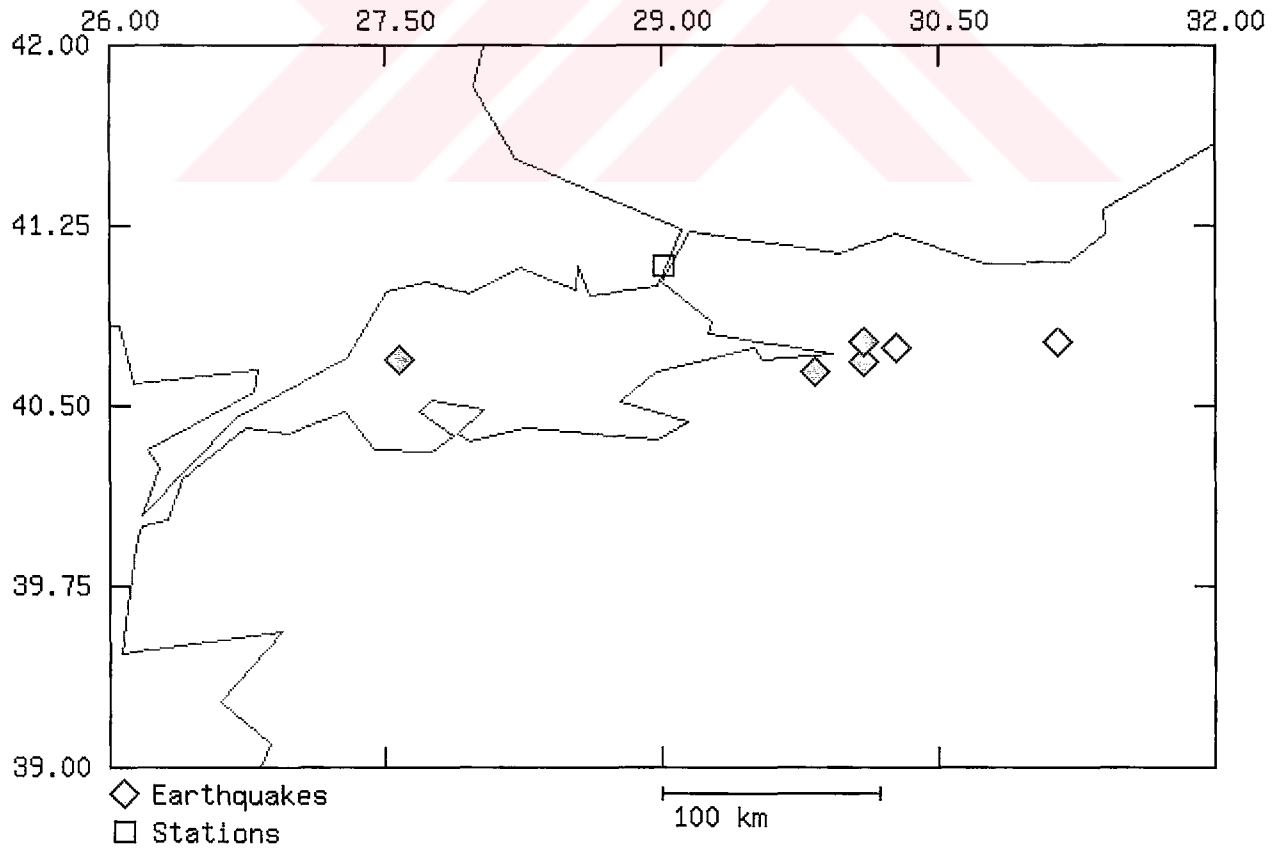
Koeri K. Cekmece Nuclear Research Central Station



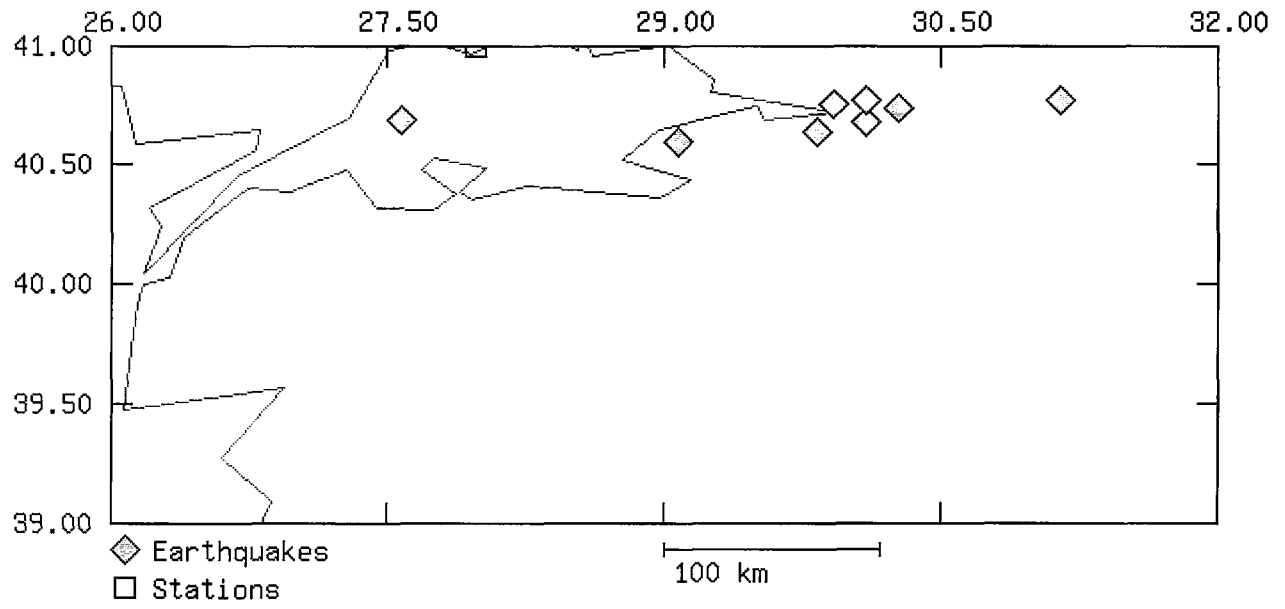
Koeri K. Mustalfa Pasa – Tomb Station



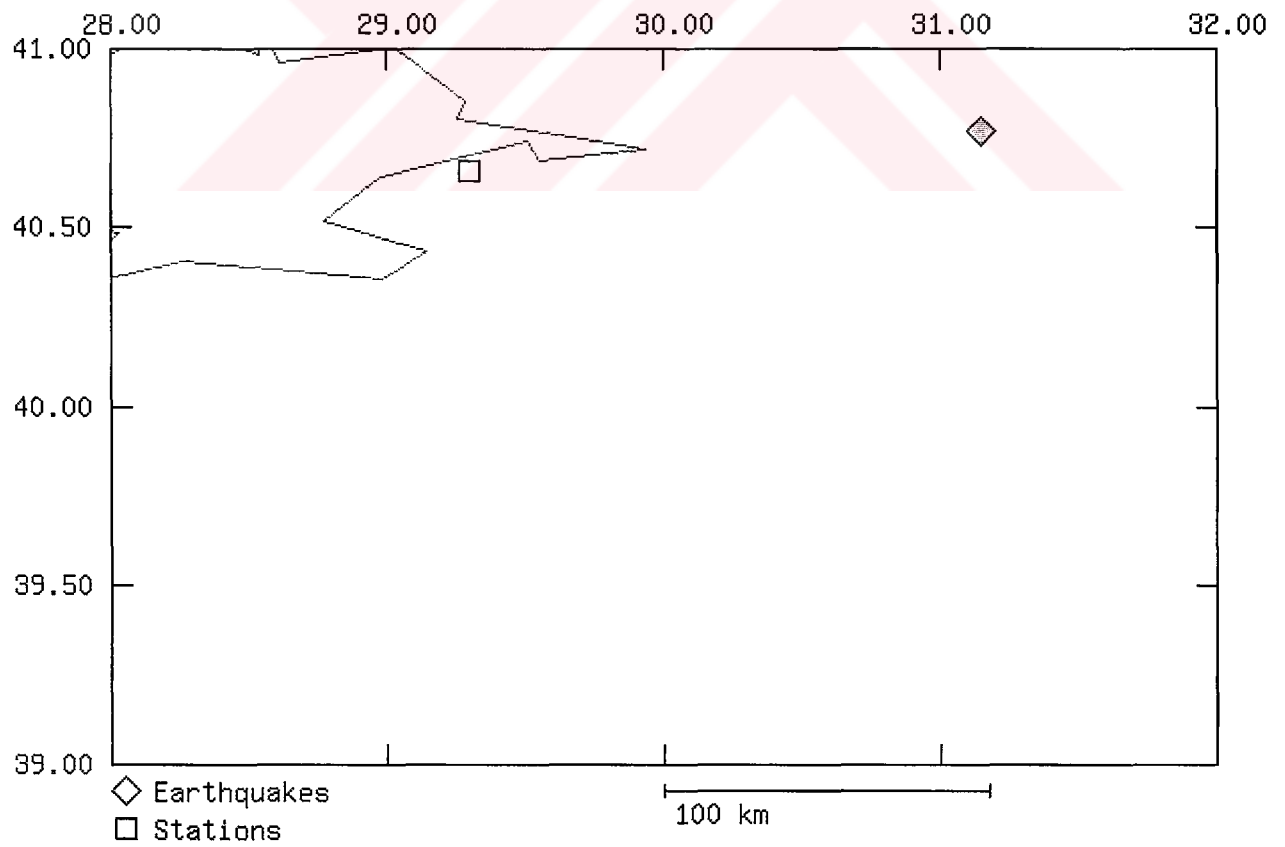
Koeri Levent - Yapi-Kredi Plaza Station



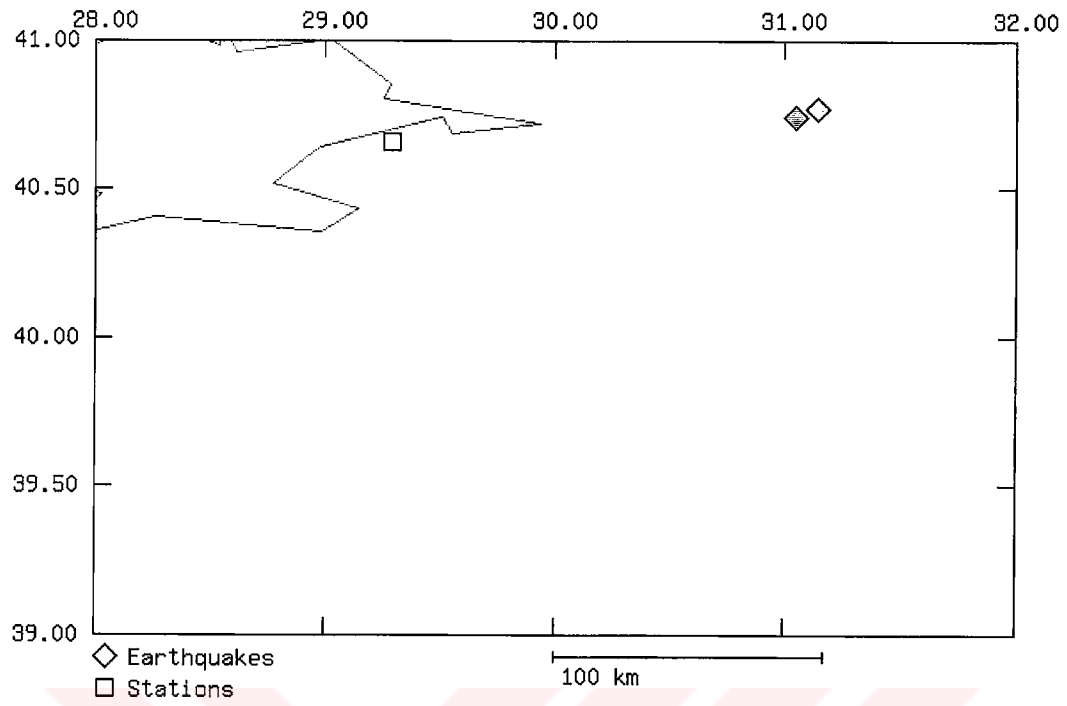
Koeri M. Ereglisi Botas Gas Terminal Station



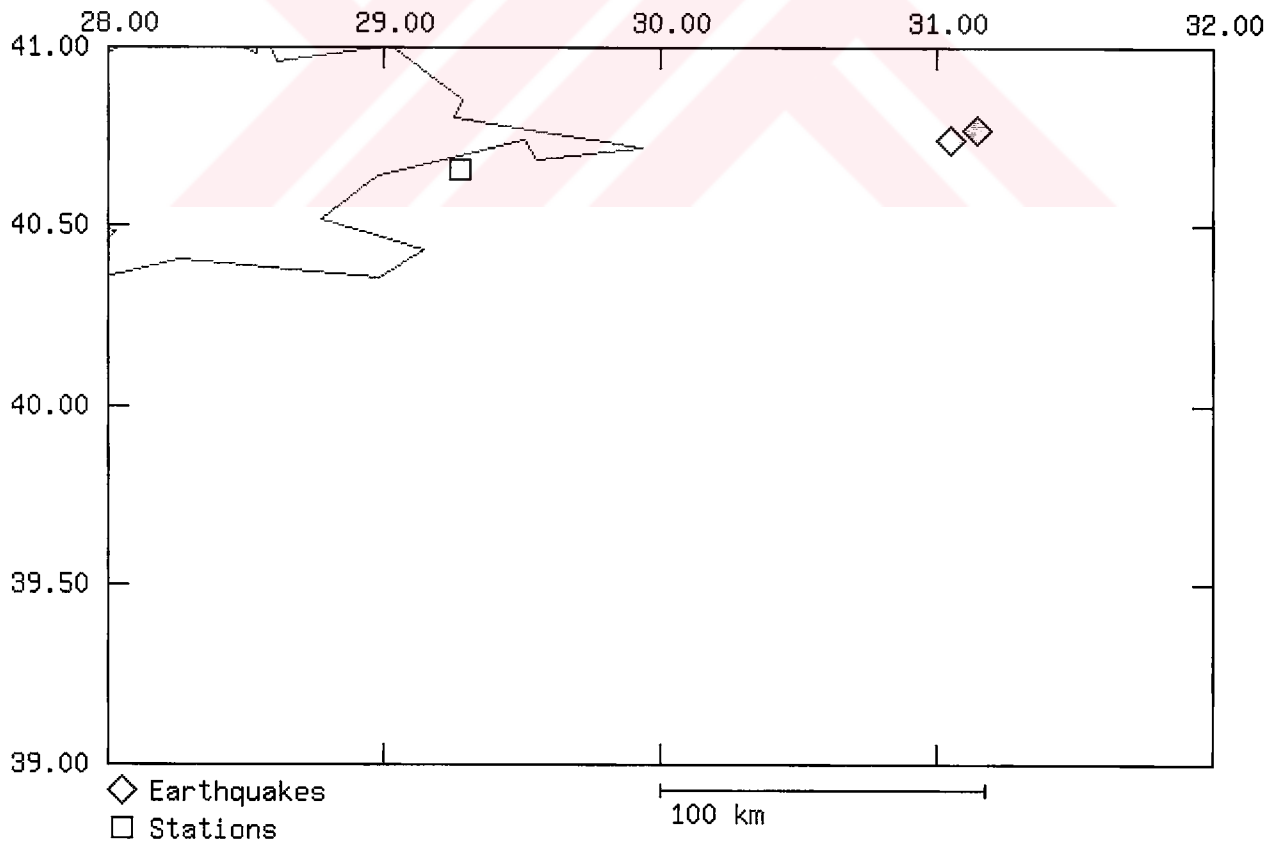
Koeri Yalova Station



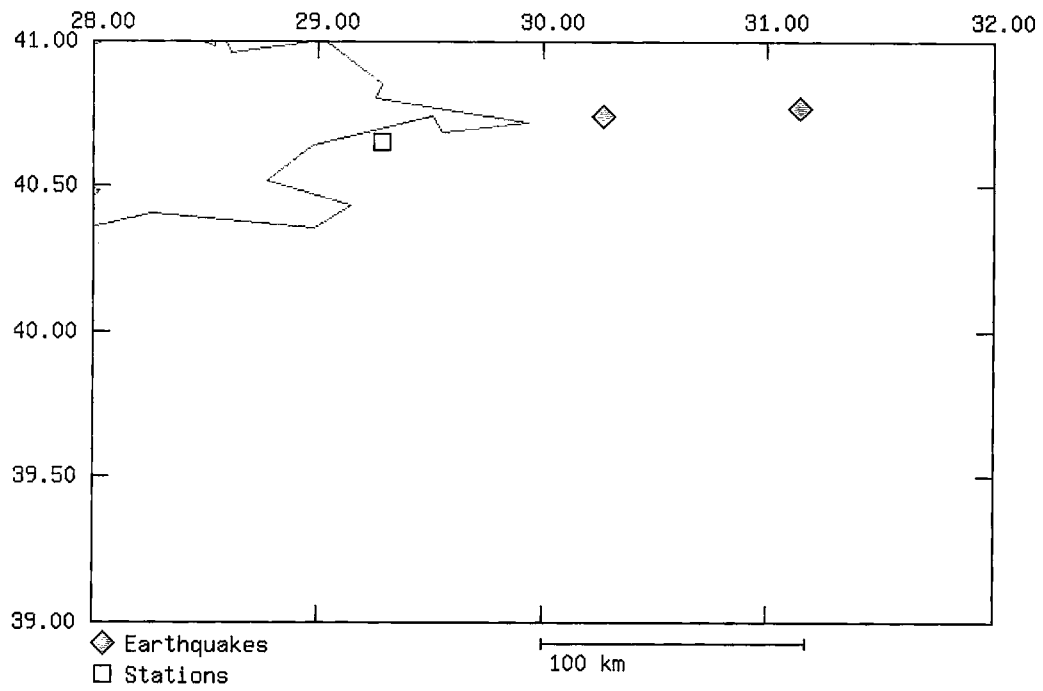
Koeri Yalova Ahmet Tas Residence Station



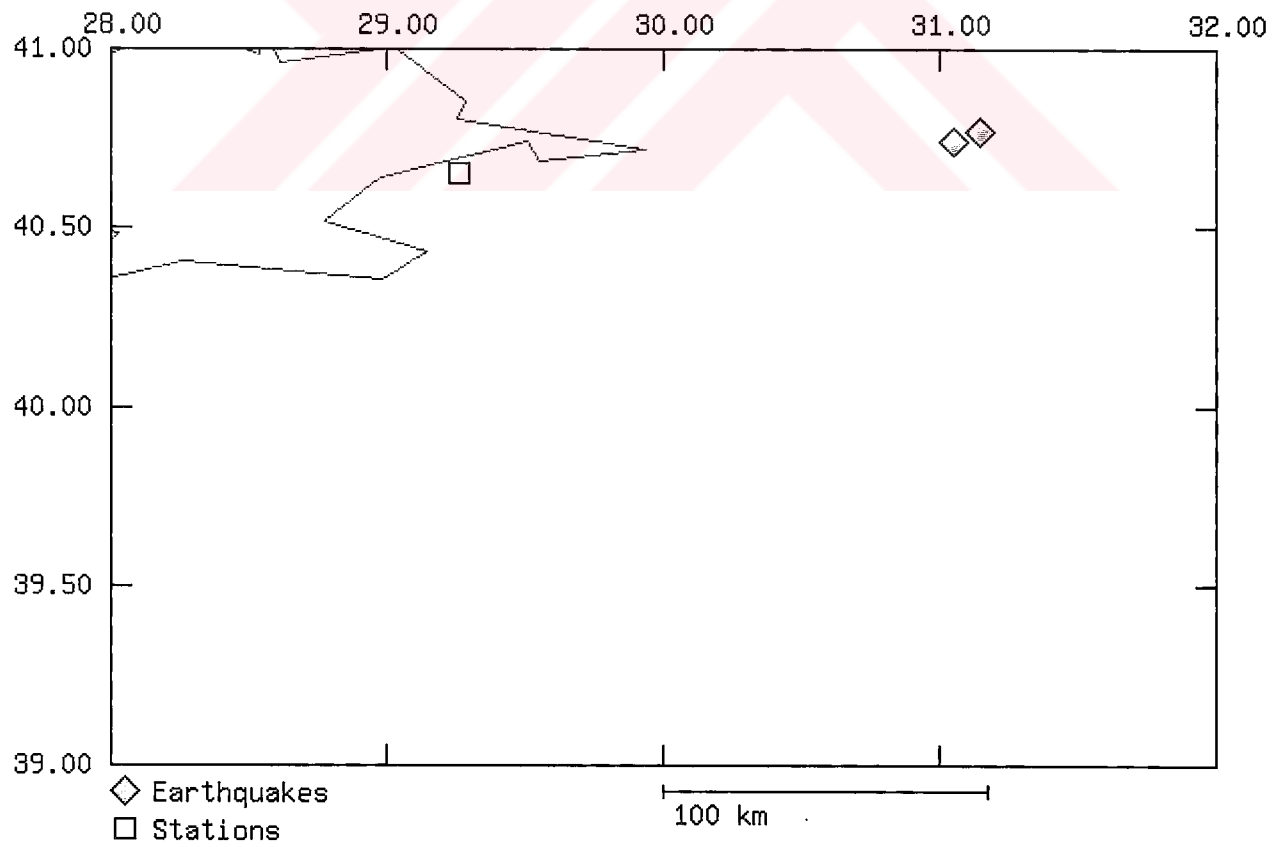
Koeri Yalova - Baglaralti CD. Station



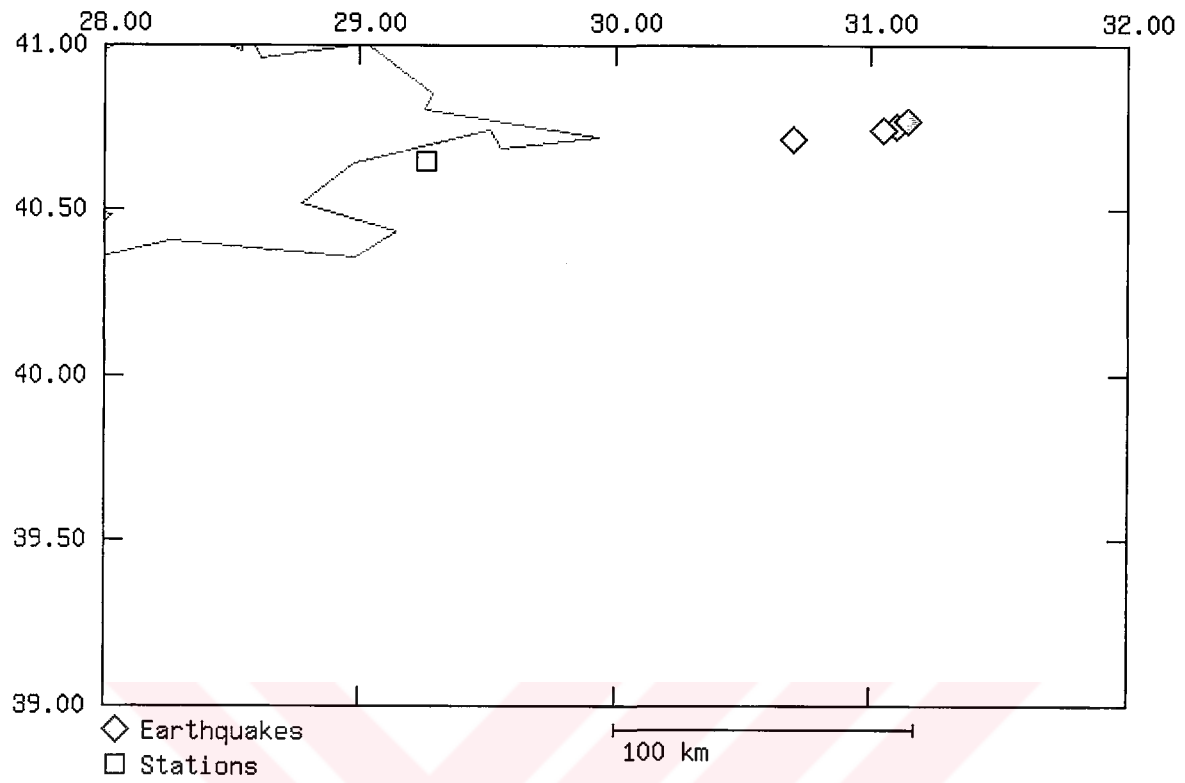
Koeri Yalova Bahcevan Street Station



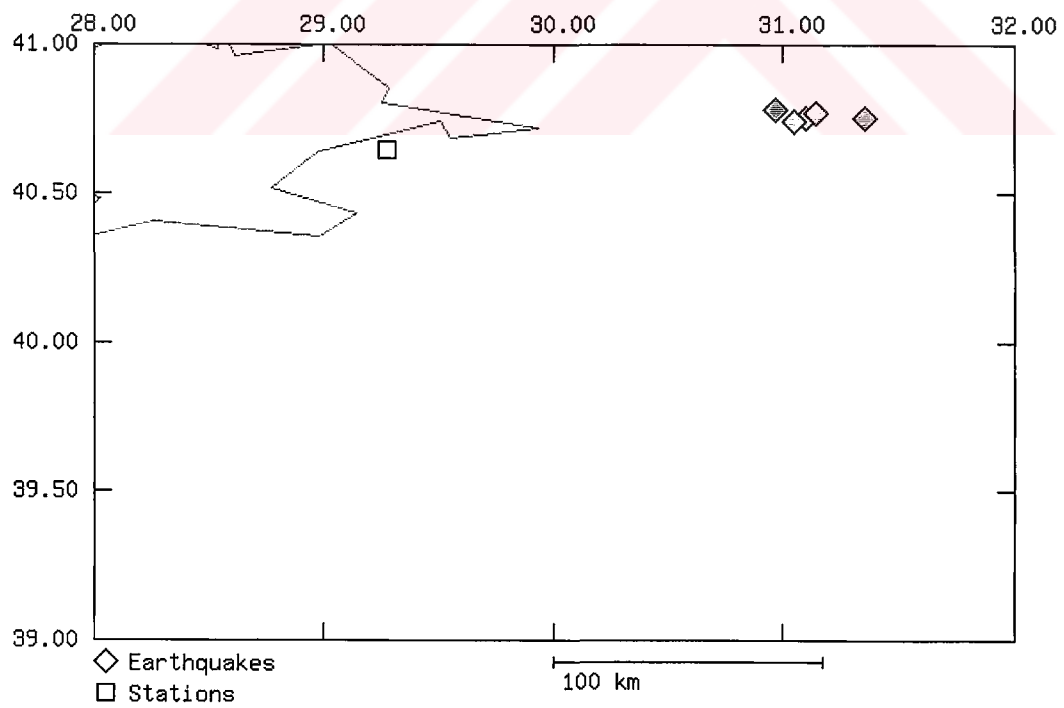
Koeri Yalova Devlet Hastanesi Station



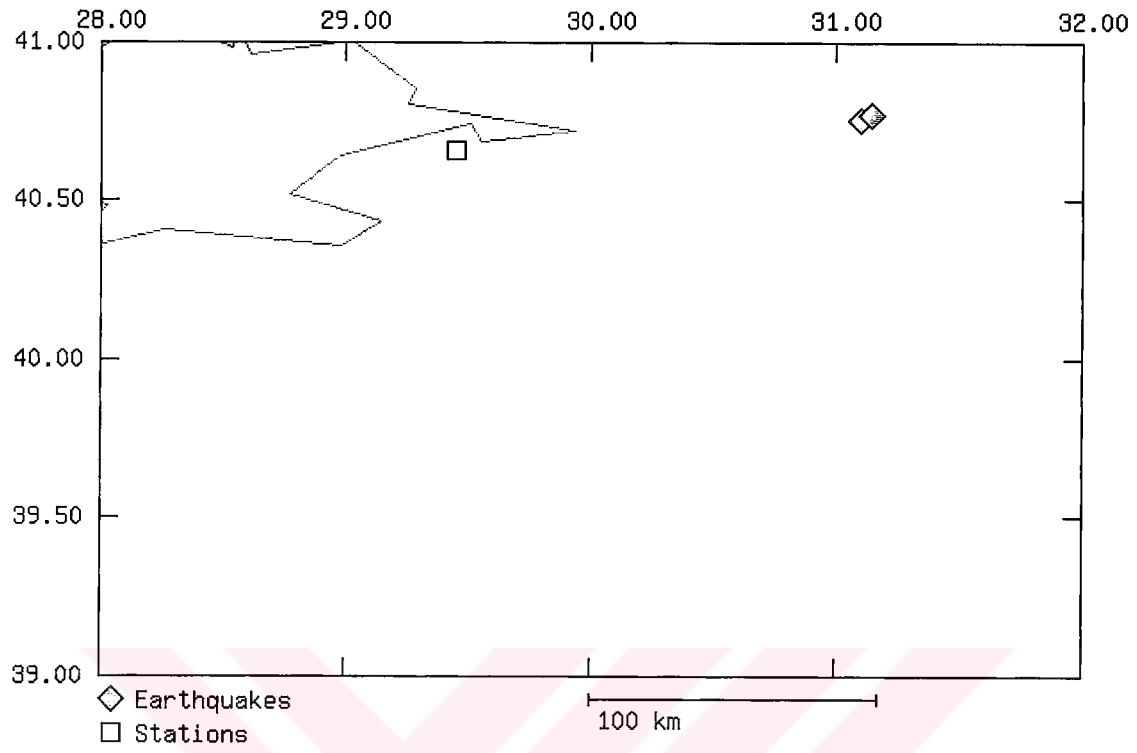
Koeri Yalova Hilal Street Station



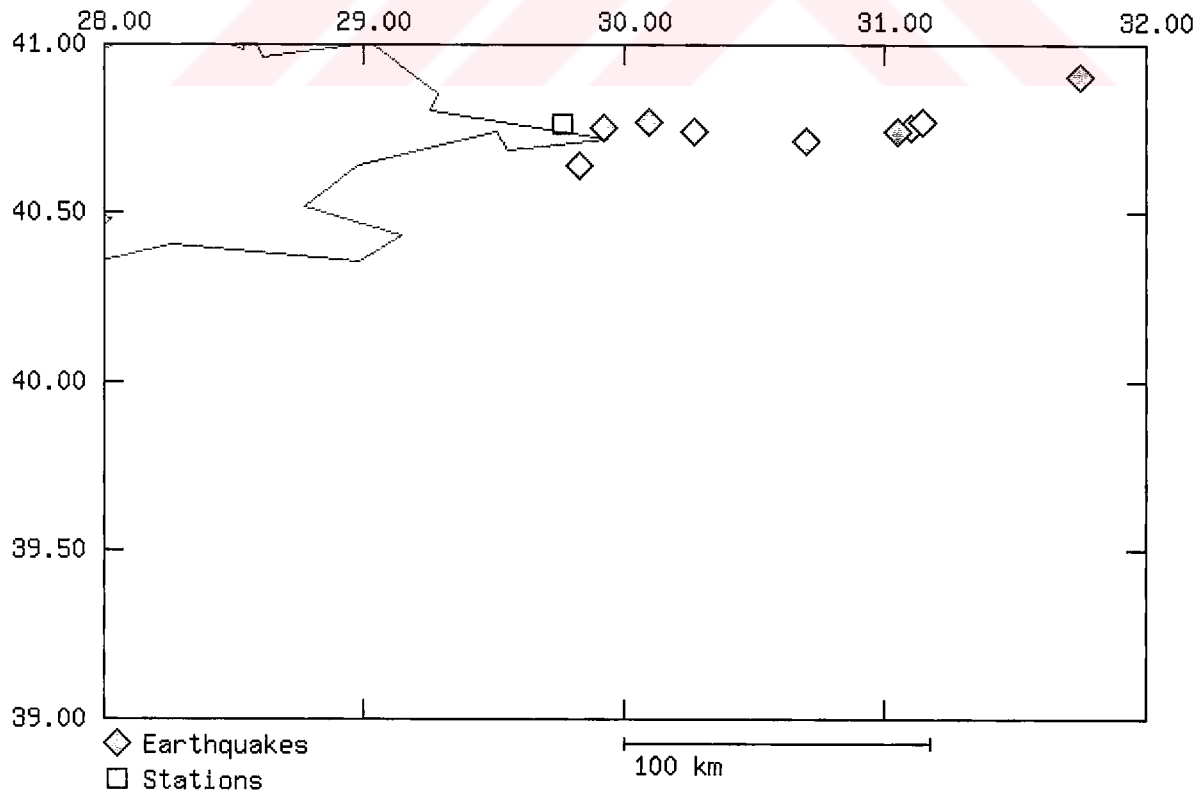
Koeri Yalova Ruzgar Street Station



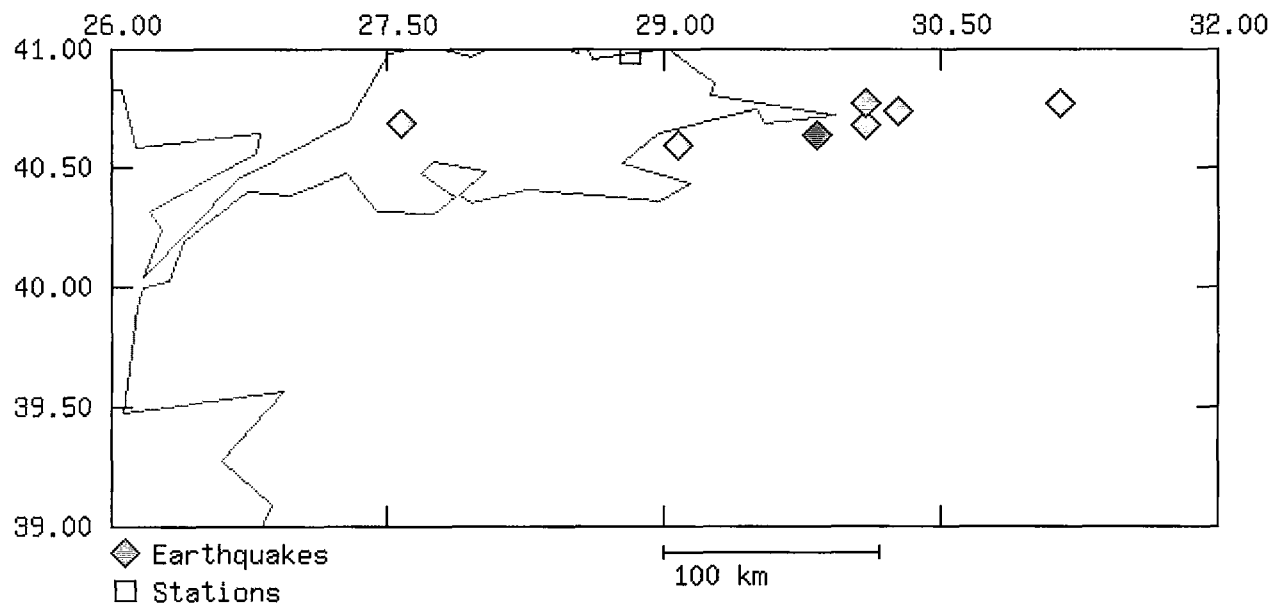
Koeri Yalova Tarim Directory Station



Koeri Yarimca Yarimca Petkim Station

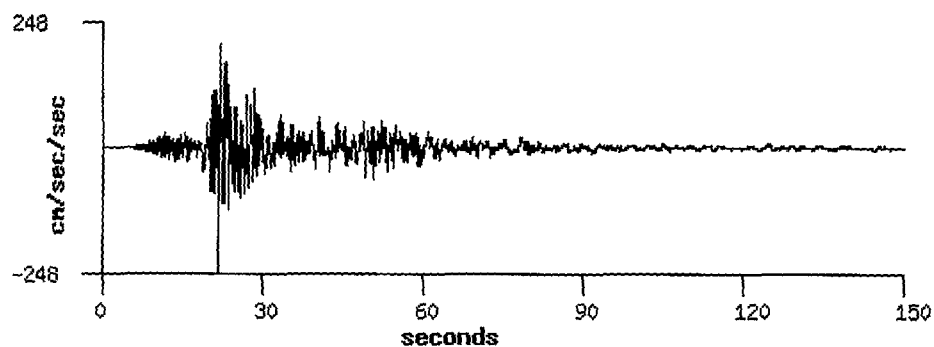


Koeri Yesilkoy - Yesilkoy Airport Station

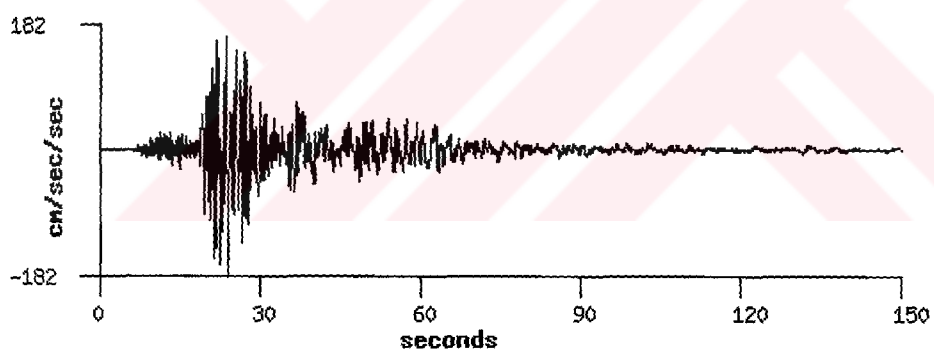


Appendix G. Kocaeli and Duzce earthquakes three components acceleration records.

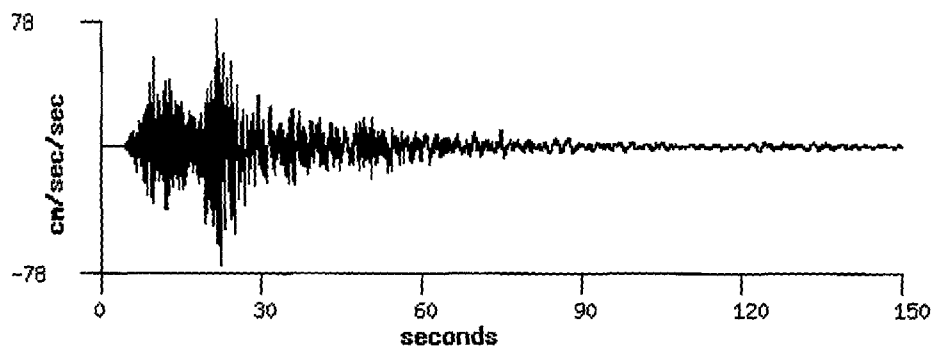
Kocaeli Earthquake-Ambarli Station Acceleration Record (0)



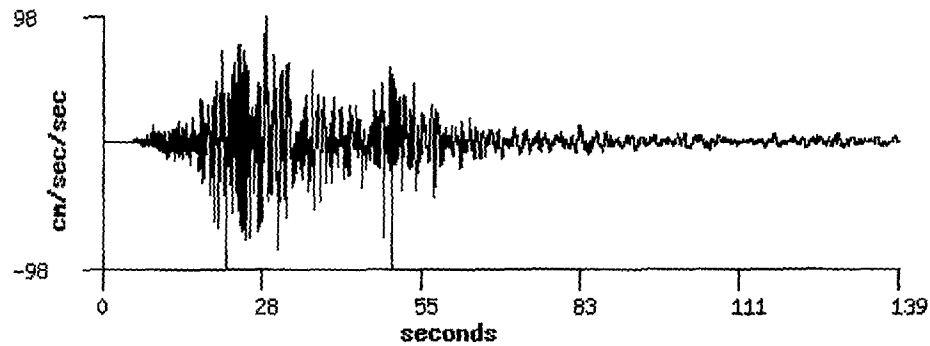
Kocaeli Earthquake-Ambarli Station Acceleration Record (270)



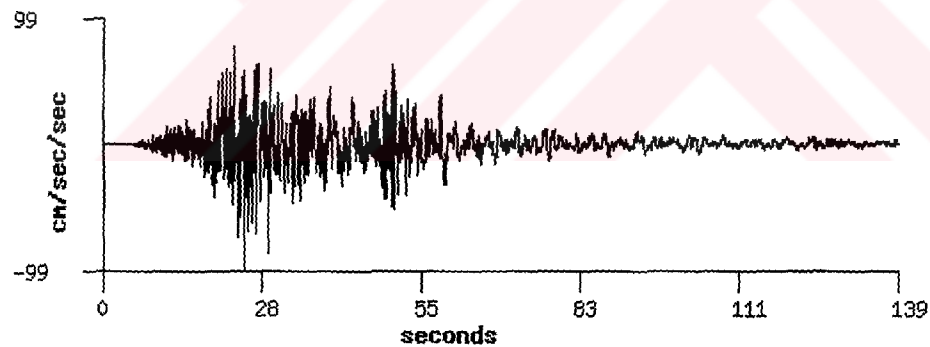
Kocaeli Earthquake-Ambarli Station Acceleration Record (UP)



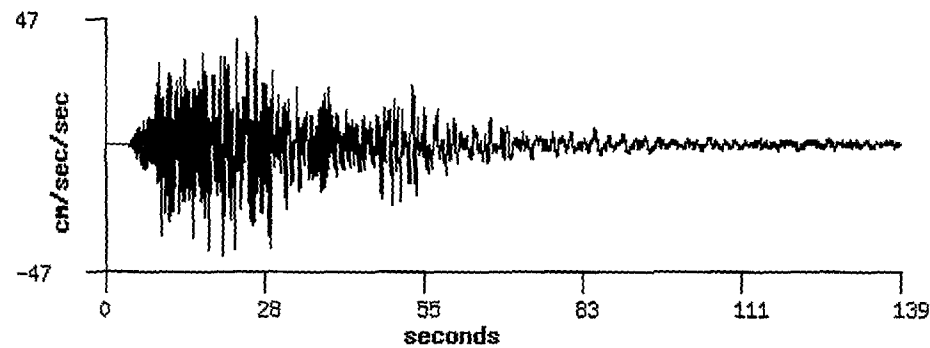
Kocaeli Earthquake-Bursa Tofas Station Acceleration Record (90)



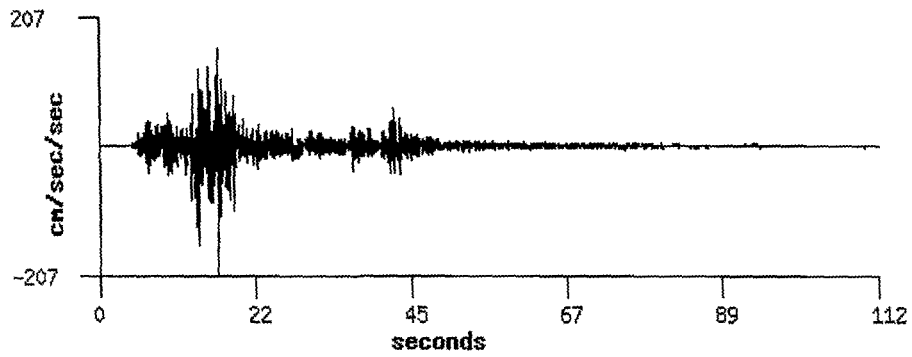
Kocaeli Earthquake- Bursa Tofas Station Acceleration Record (180)



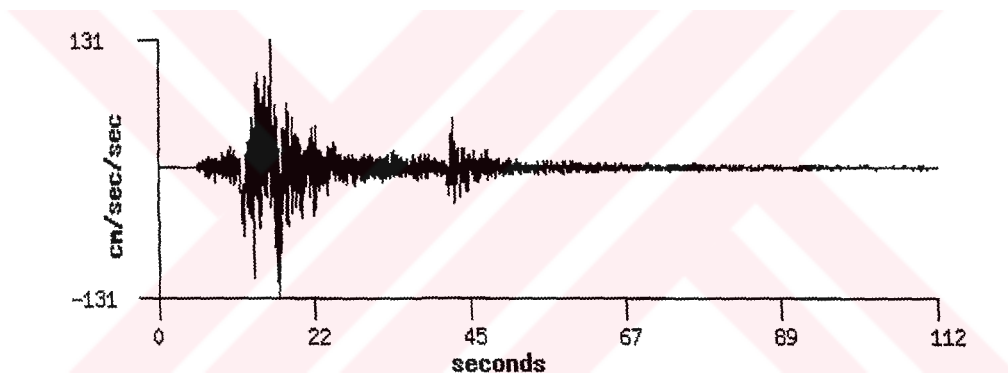
Kocaeli Earthquake- Bursa Tofas Station Acceleration Record (DOWN)



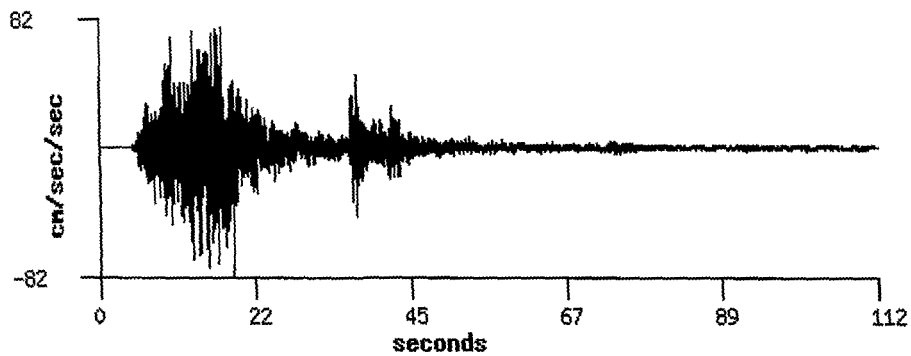
Kocaeli Earthquake- Darica Station Acceleration Record (0)



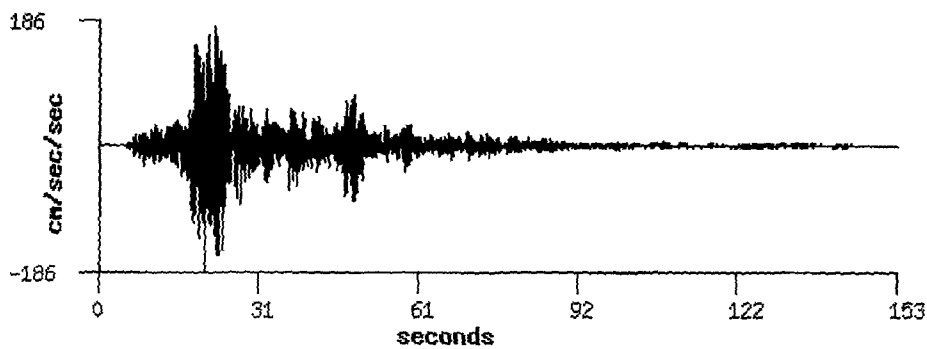
Kocaeli Earthquake- Darica Station Acceleration Record (270)



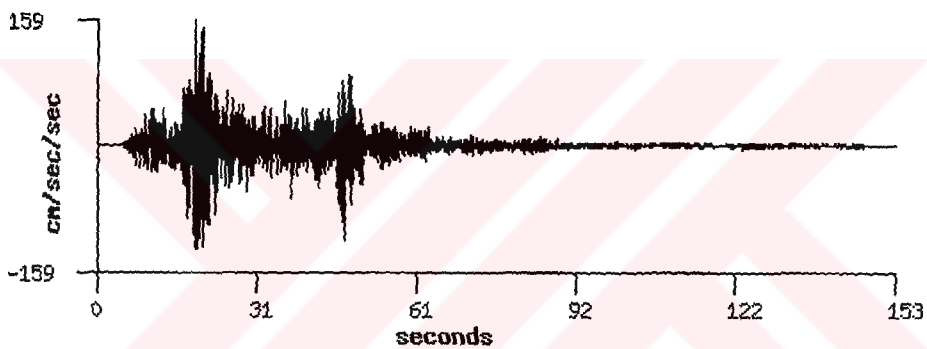
Kocaeli Earthquake- Darica Station Acceleration Record (DOWN)



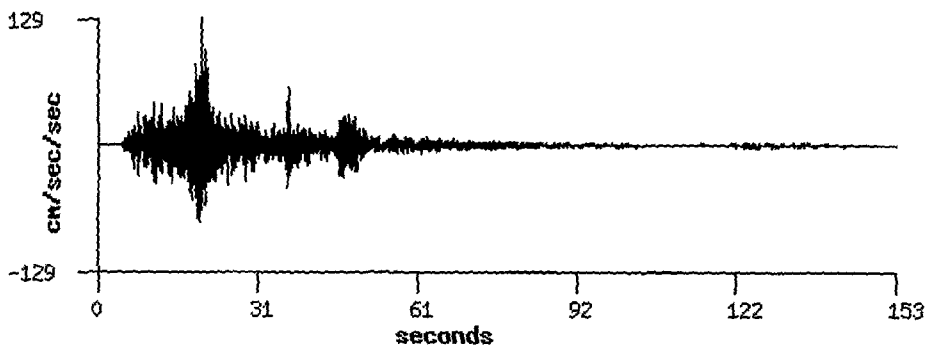
Kocaeli Earthquake- Fatih Station Acceleration Record (0)



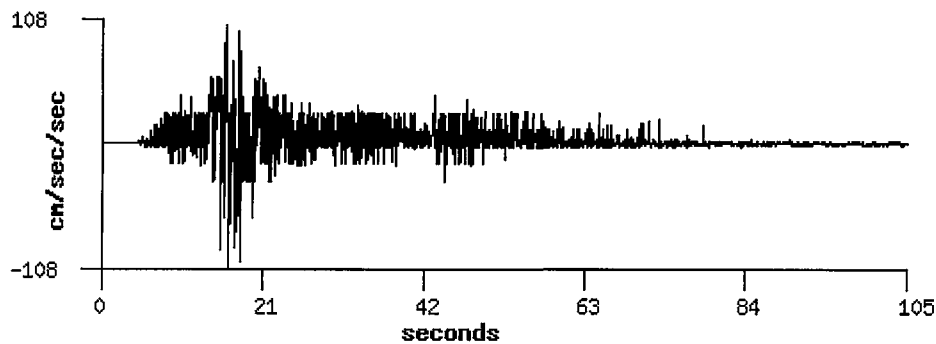
Kocaeli Earthquake- Fatih Station Acceleration Record (270)



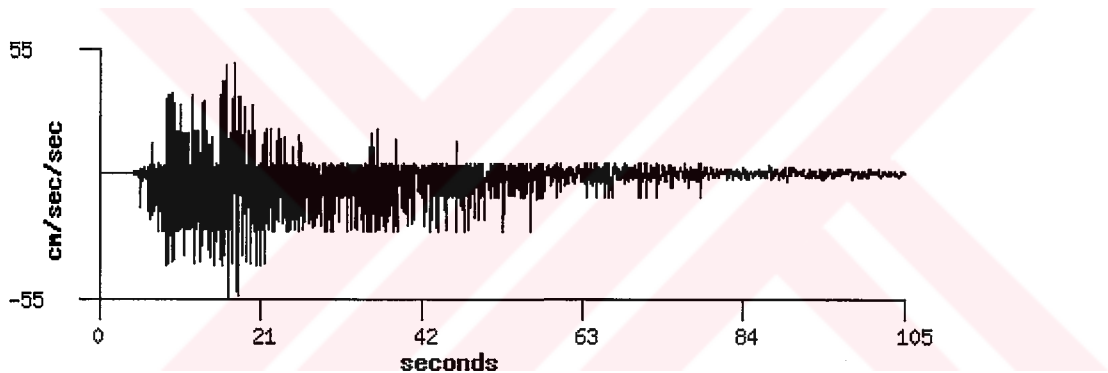
Kocaeli Earthquake- Fatih Station Acceleration Record (UP)



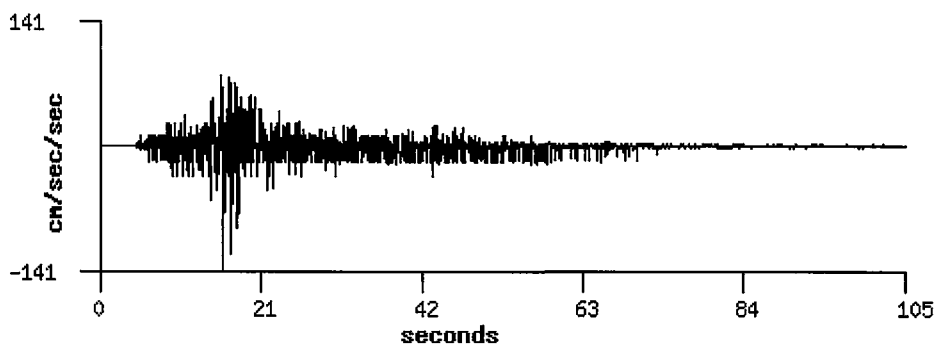
Kocaeli Earthquake- Heybeliada Station Acceleration Record (90)



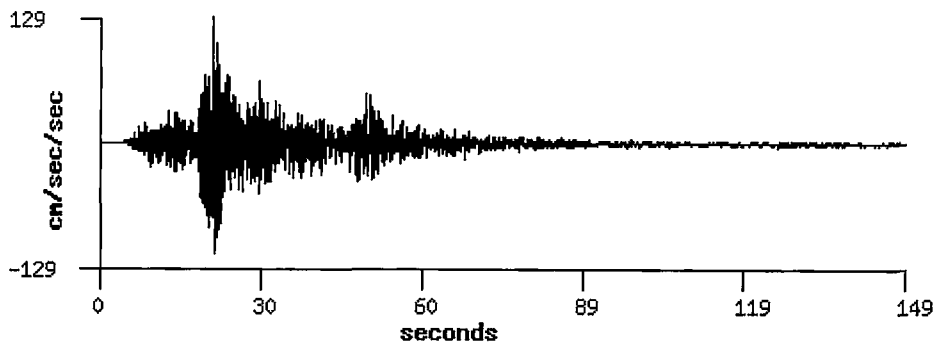
Kocaeli Earthquake- Heybeliada Station Acceleration Record (180)



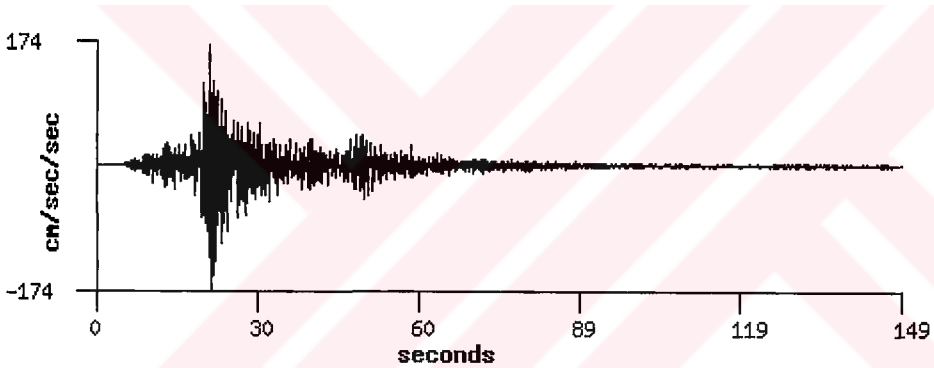
Kocaeli Earthquake- Heybeliada Station Acceleration Record (UP)



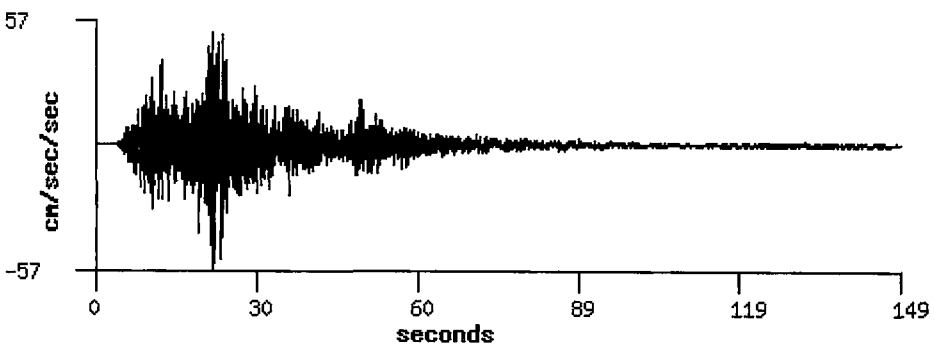
Kocaeli Earthquake- Kucuk Cekmece Station Acceleration Record (90)



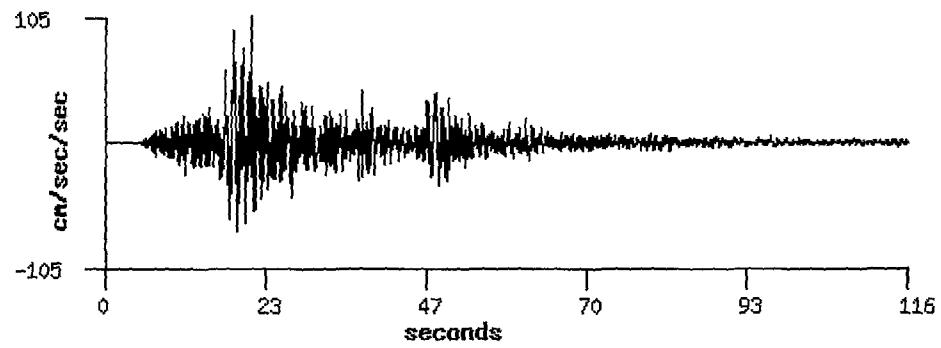
Kocaeli Earthquake- Kucuk Cekmece Station Acceleration Record (180)



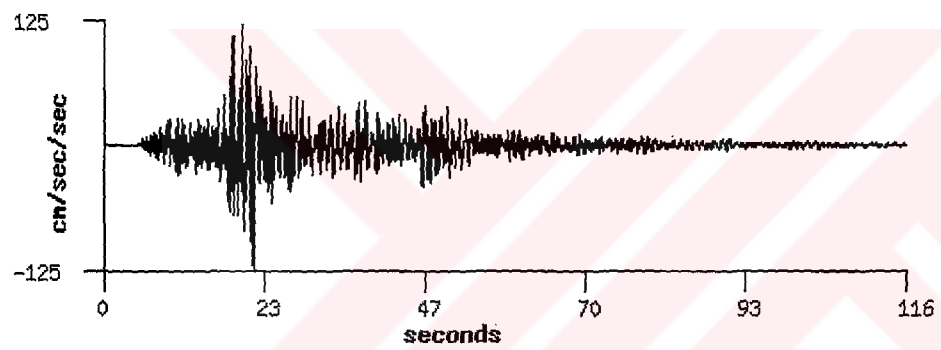
Kocaeli Earthquake- Kucuk Cekmece Station Acceleration Record (UP)



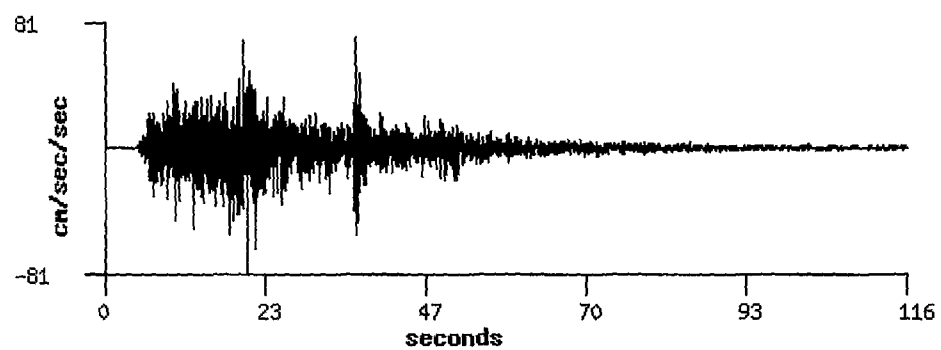
Kocaeli Earthquake- Koca Mustafa Pasa Station Acceleration Record (0)



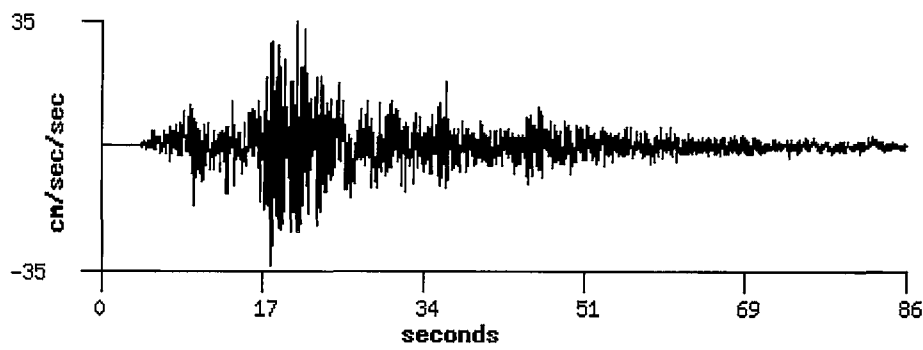
Kocaeli Earthquake- Koca Mustafa Pasa Station Acceleration Record (90)



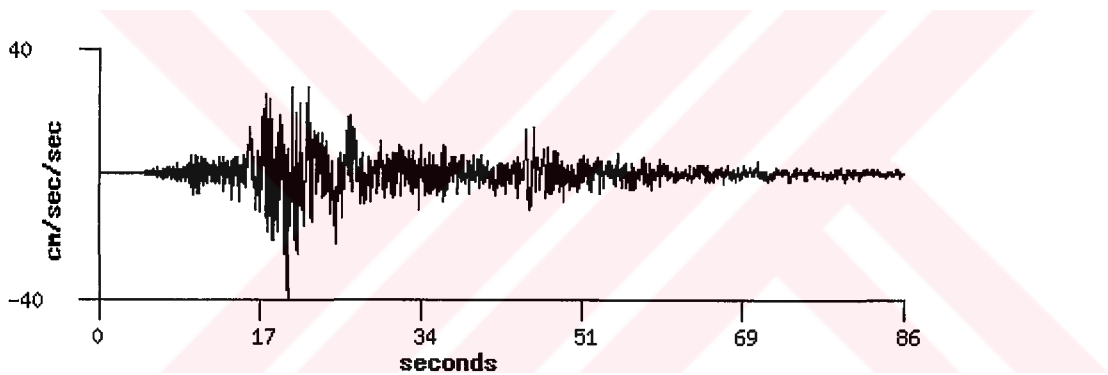
Kocaeli Earthquake- Koca Mustafa Pasa Station Acceleration Record (UP)



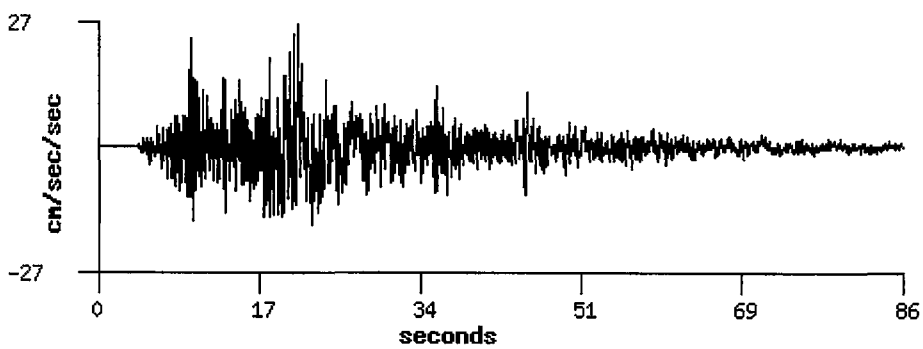
Kocaeli Earthquake- Levent Station Acceleration Record (90)



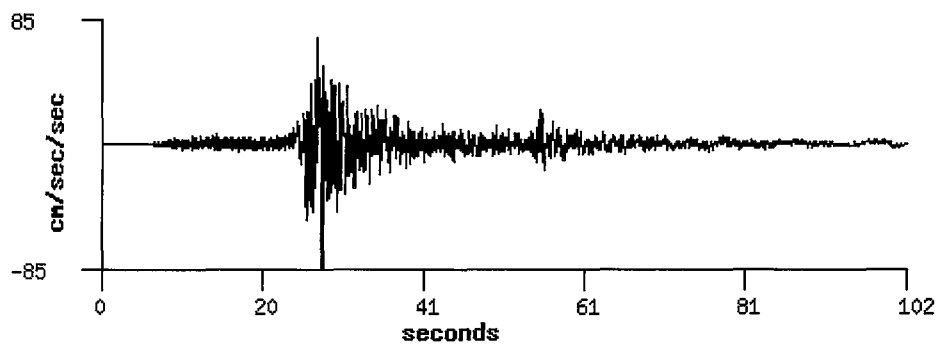
Kocaeli Earthquake- Levent Station Acceleration Record (180)



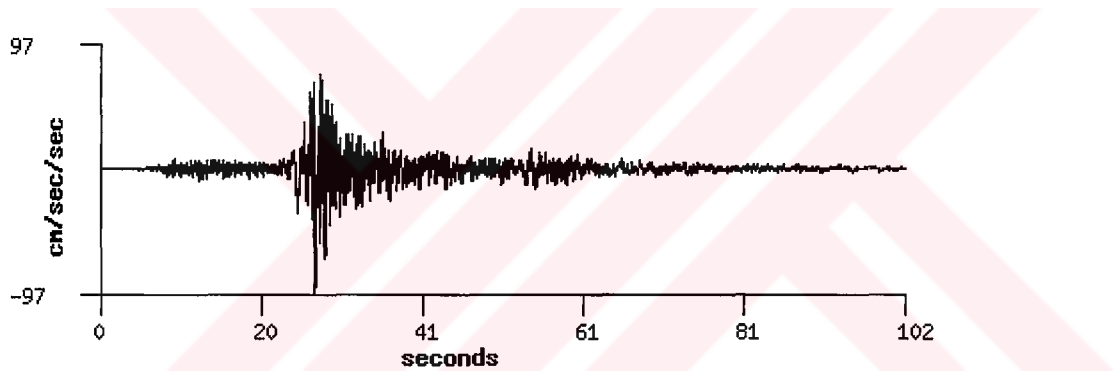
Kocaeli Earthquake- Levent Station Acceleration Record (UP)



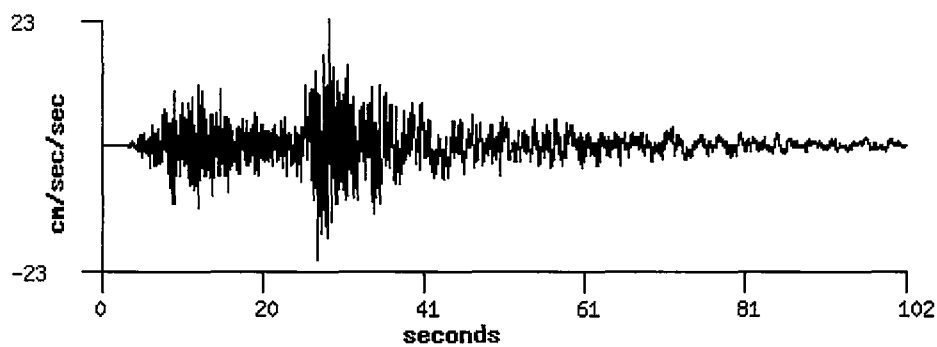
Kocaeli Earthquake- Marmara Ereglisi-Botas Station Acceleration Record (0)



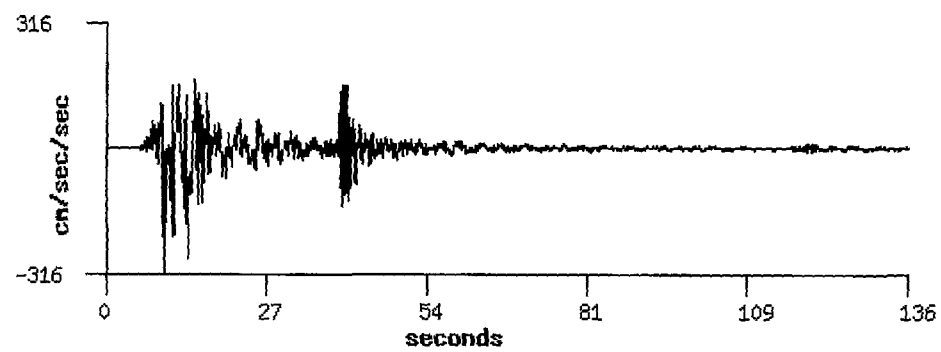
Kocaeli Earthquake- Marmara Ereglisi-Botas Station Acceleration Record (90)



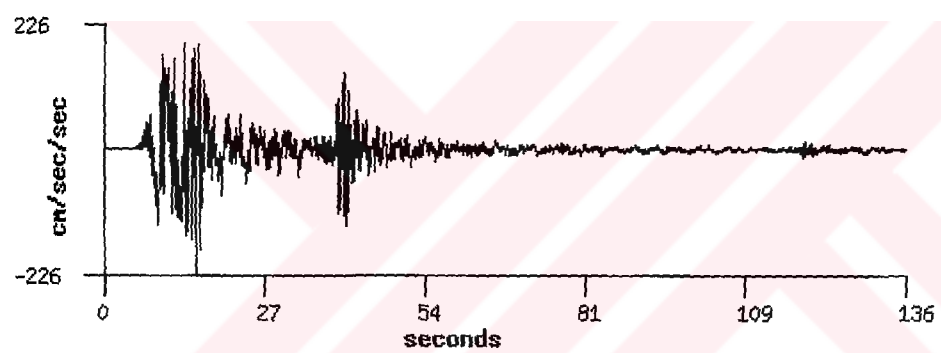
Kocaeli Earthquake- Marmara Ereglisi-Botas Station Acceleration Record (UP)



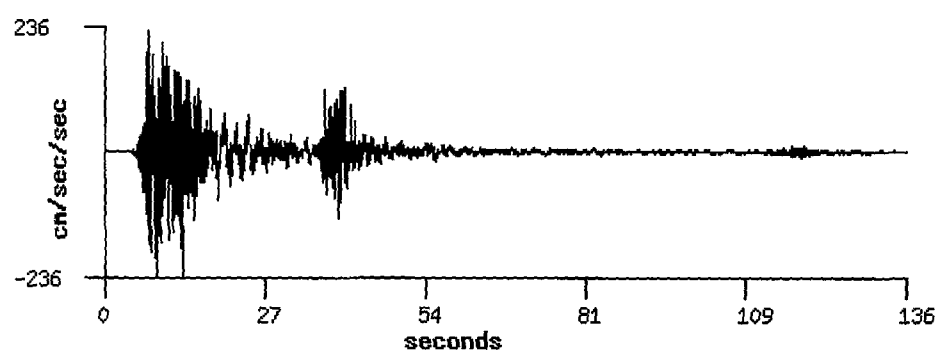
Kocaeli Earthquake- Yarimca Station Acceleration Record (0)



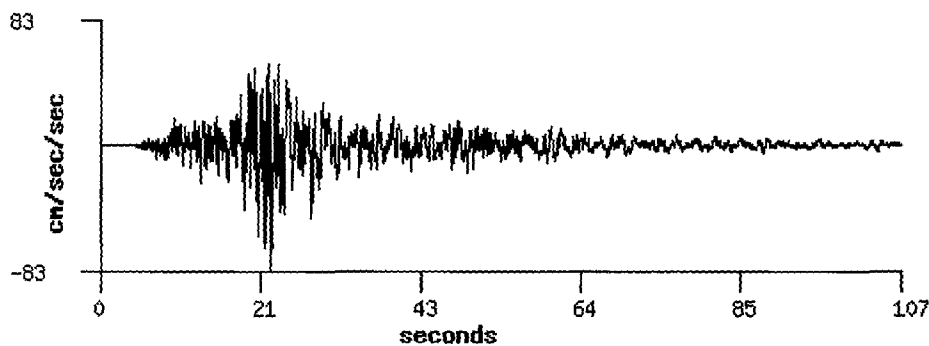
Kocaeli Earthquake- Yarimca Station Acceleration Record (90)



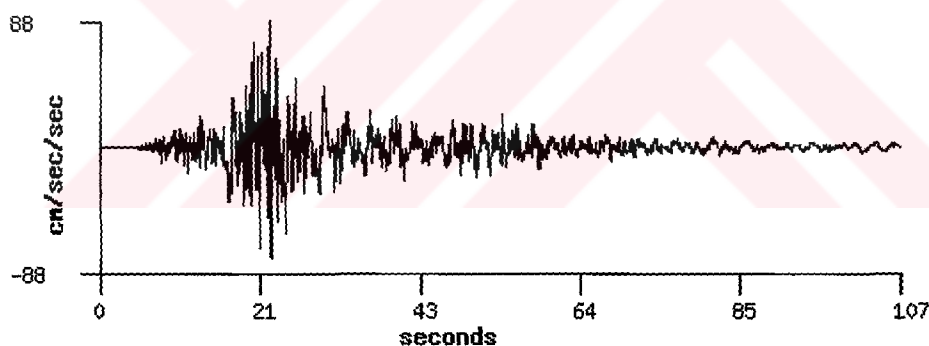
Kocaeli Earthquake- Yarimca Station Acceleration Record (UP)



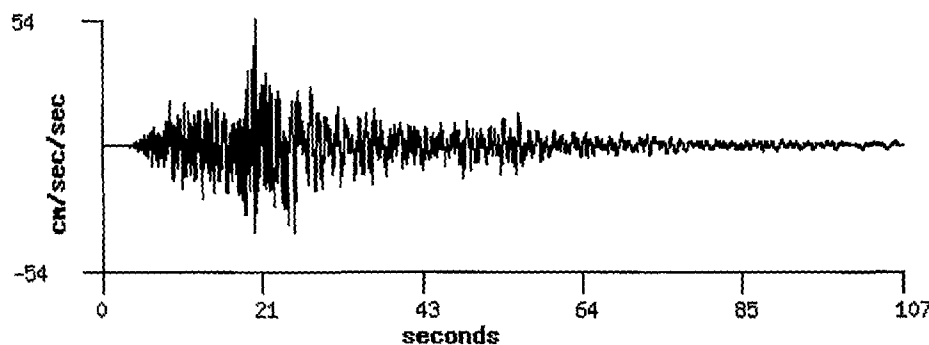
Kocaeli Earthquake- Yesilkoy Station Acceleration Record (90)



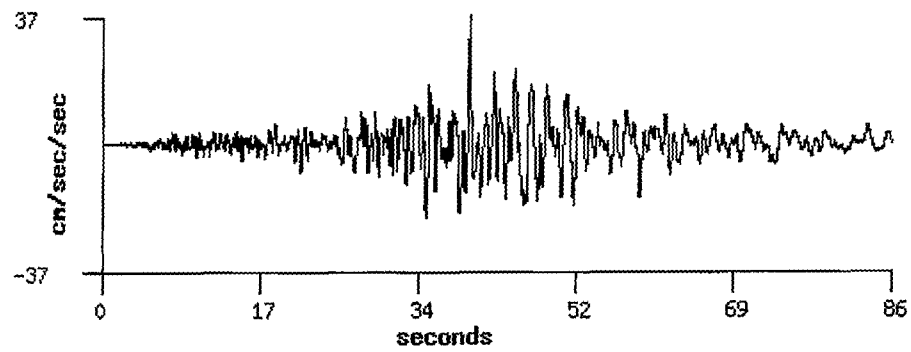
Kocaeli Earthquake- Yesilkoy Station Acceleration Record (180)



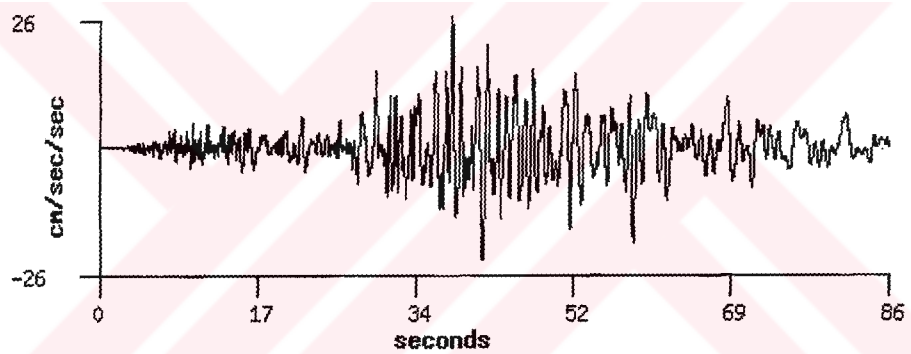
Kocaeli Earthquake- Yesilkoy Station Acceleration Record (DOWN)



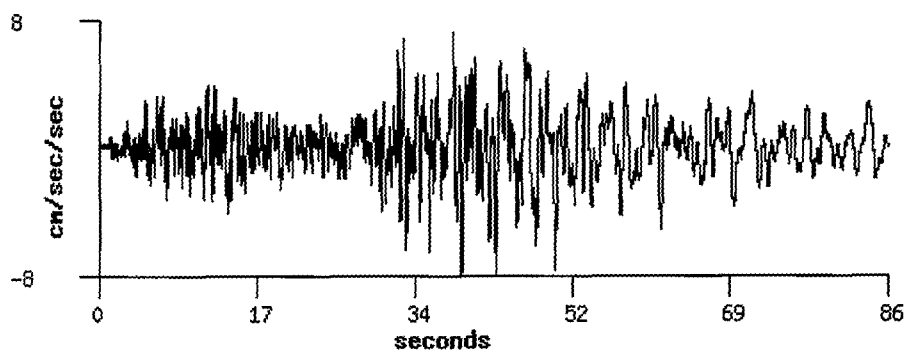
Duzce Earthquake- Ambarli Station Acceleration Record (0)



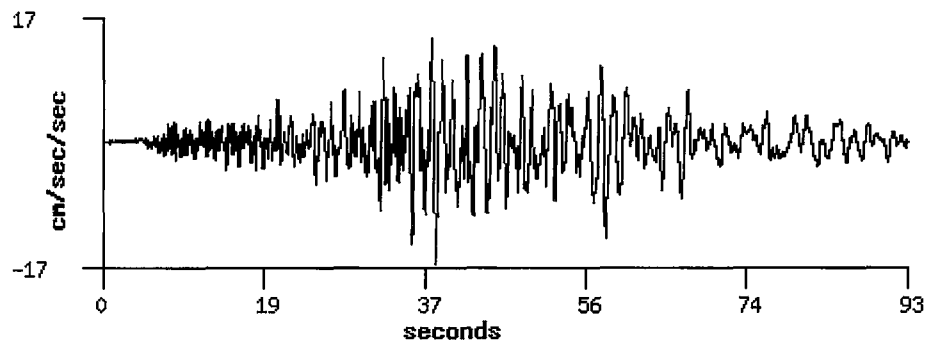
Duzce Earthquake- Ambarli Station Acceleration Record (270)



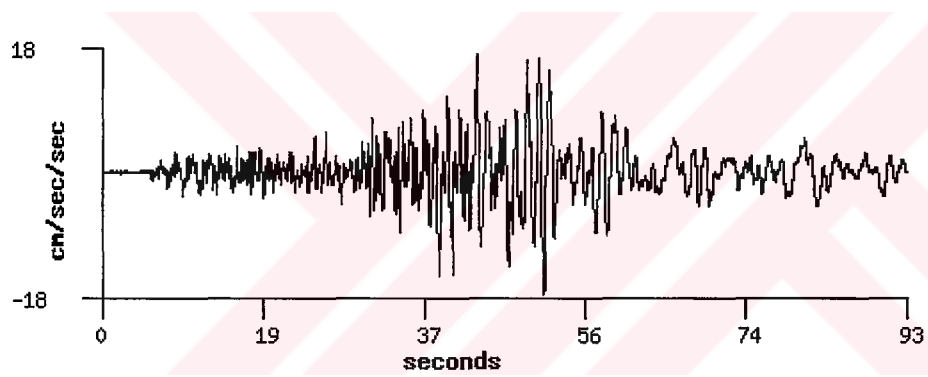
Duzce Earthquake- Ambarli Station Acceleration Record (UP)



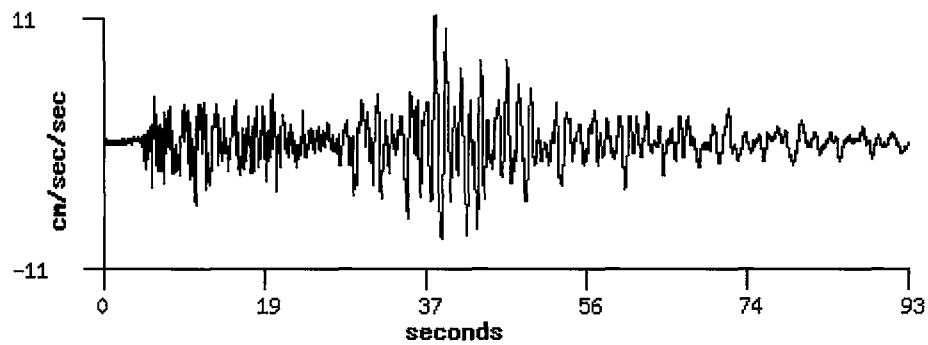
Duzce Earthquake - Bursa Tofas Station Acceleration Record (90)



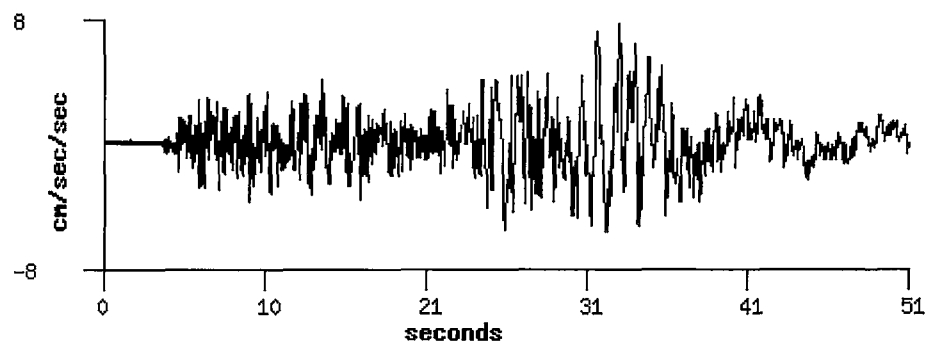
Duzce Earthquake - Bursa Tofas Station Acceleration Record (180)



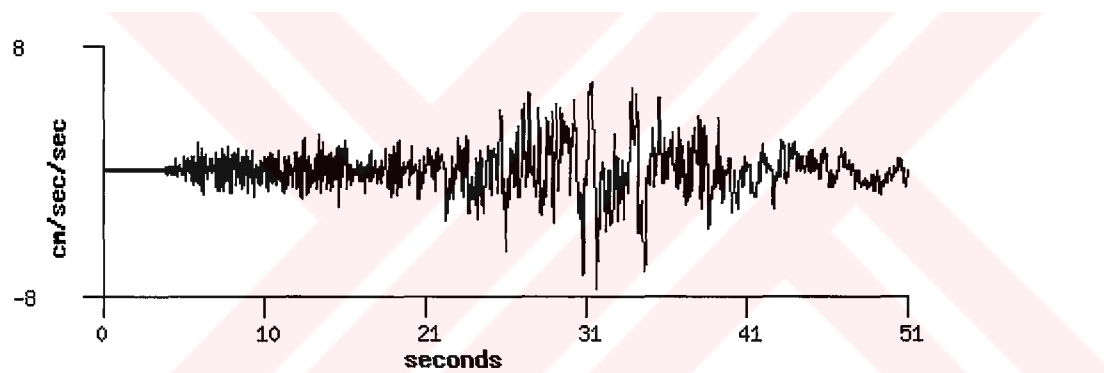
Duzce Earthquake - Bursa Tofas Station Acceleration Record (DOWN)



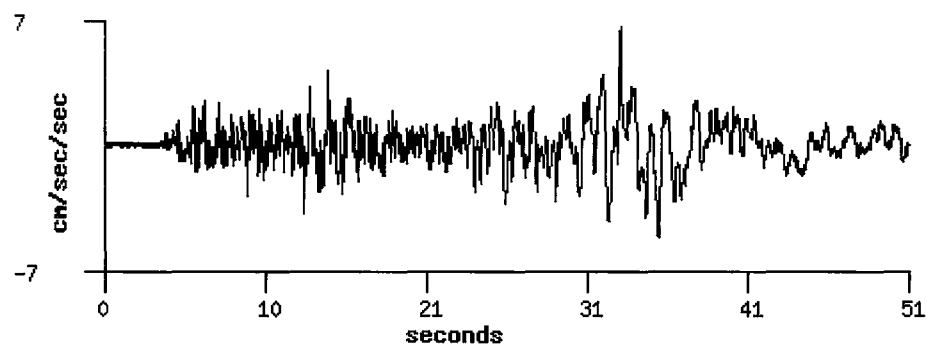
Duzce Earthquake – Darica Arcelik Station Acceleration Record (0)



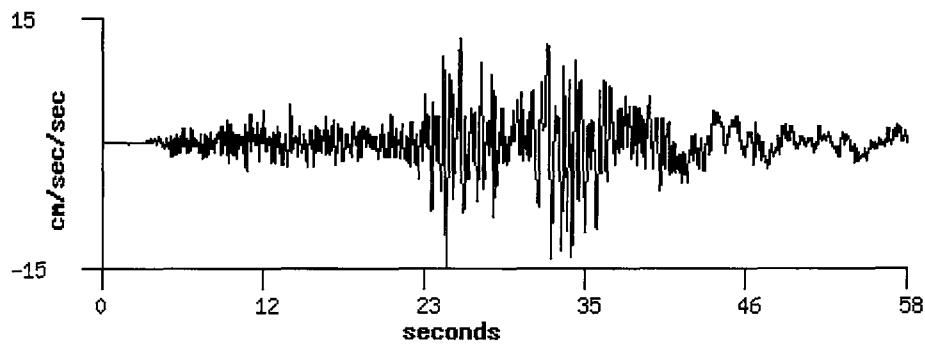
Duzce Earthquake – Darica Arcelik Station Acceleration Record (270)



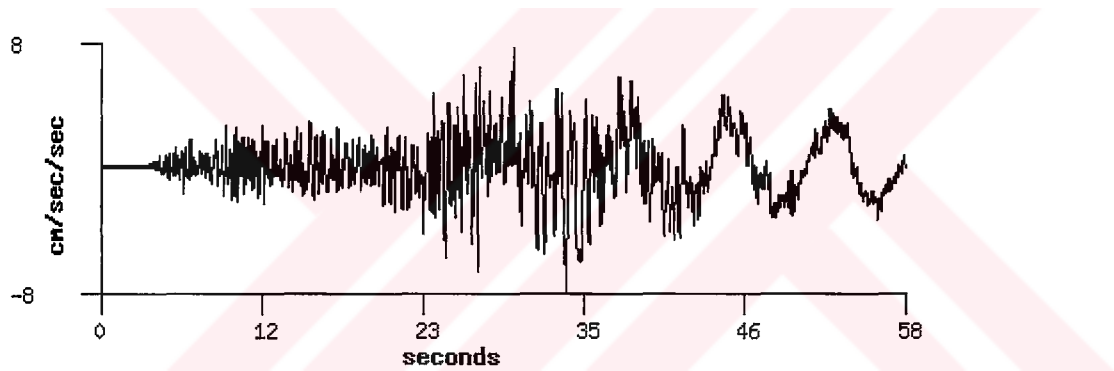
Duzce Earthquake – Darica Arcelik Station Acceleration Record (DOWN)



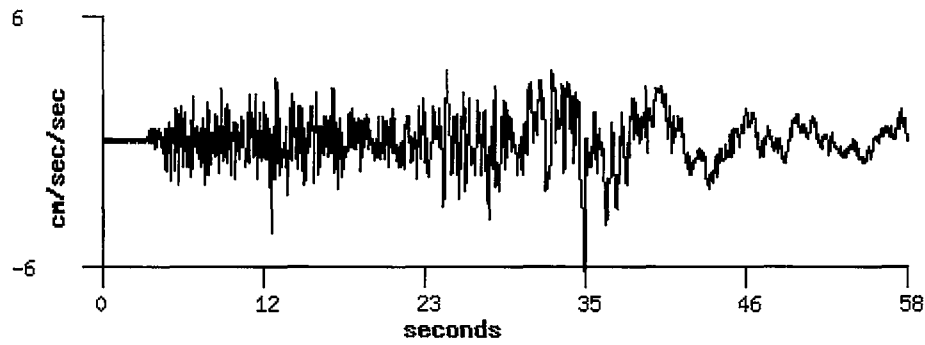
Duzce Earthquake – Darica Arslan Station Acceleration Record (90)



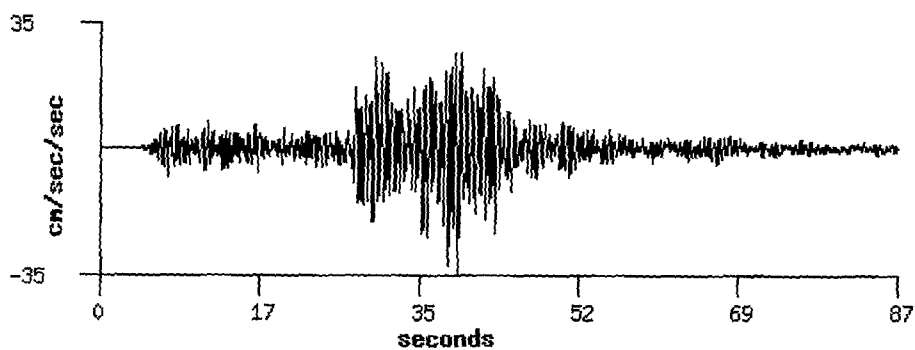
Duzce Earthquake – Darica Arslan Station Acceleration Record (180)



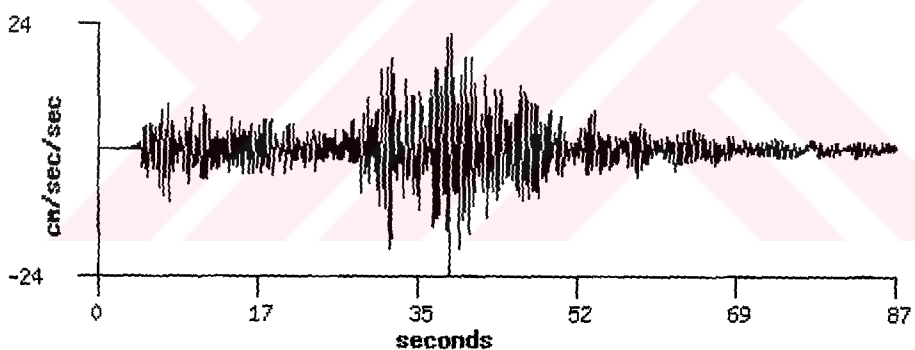
Duzce Earthquake – Darica Arslan Station Acceleration Record (DOWN)



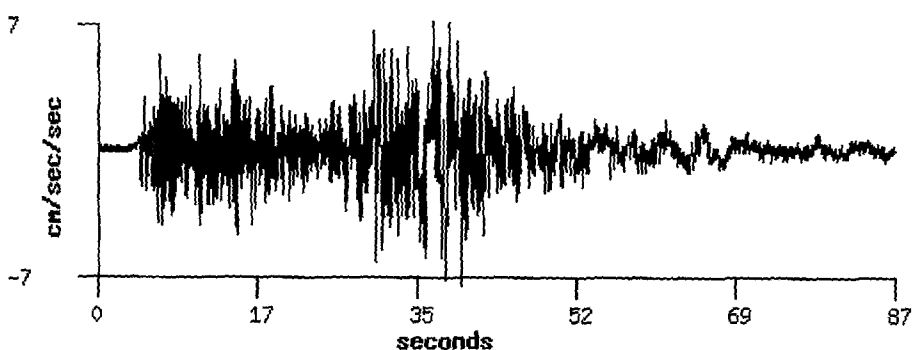
Duzce Earthquake – Fatih Station Acceleration Record (0)



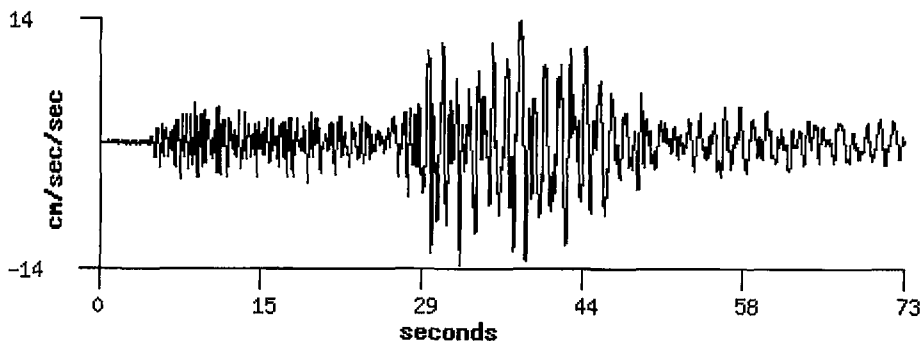
Duzce Earthquake – Fatih Station Acceleration Record (270)



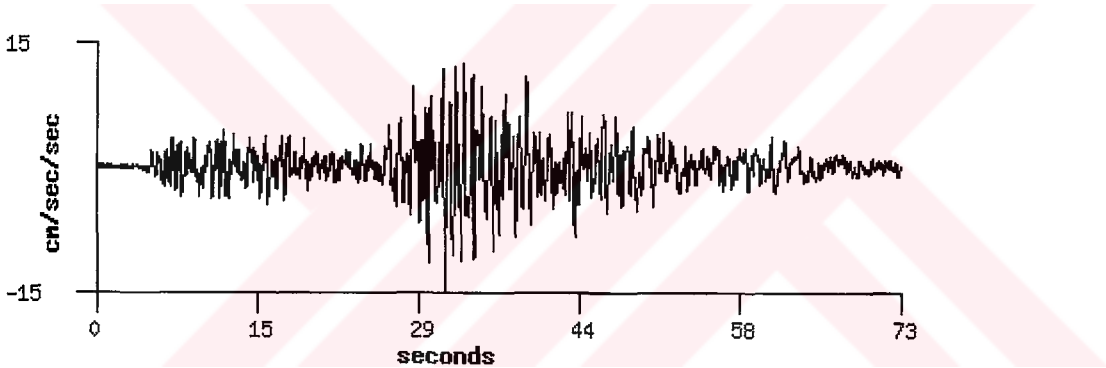
Duzce Earthquake – Fatih Station Acceleration Record (UP)



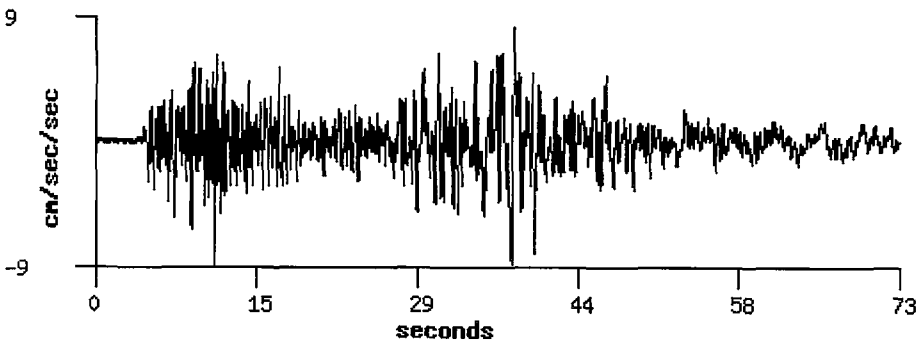
Duzce Earthquake – Galata Koprusu Station Acceleration Record (0)



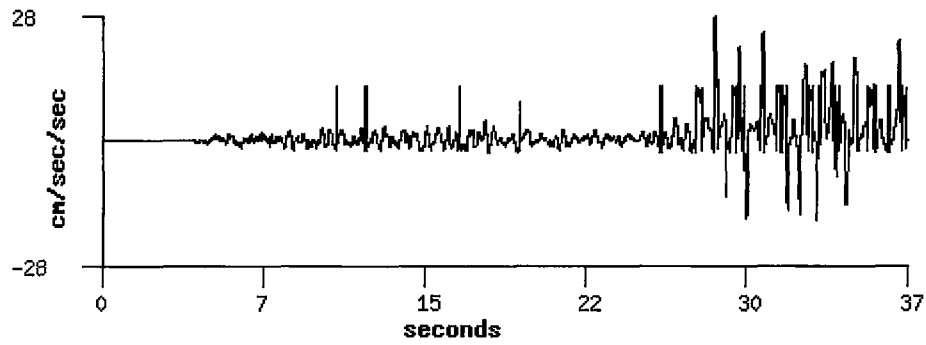
Duzce Earthquake – Galata Koprusu Acceleration Record (270)



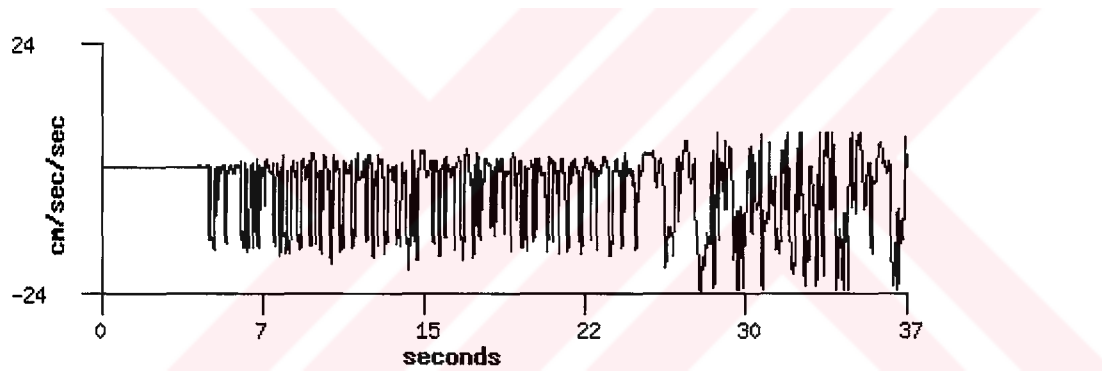
Duzce Earthquake – Galata Koprusu Acceleration Record (DOWN)



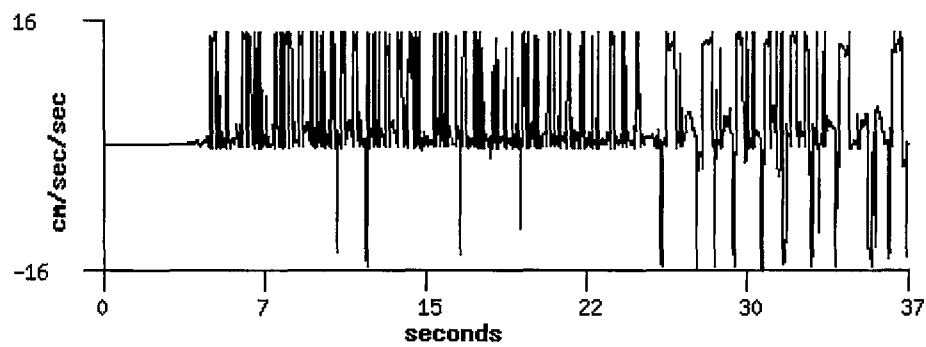
Duzce Earthquake – Heybeli Ada Acceleration Record (90)



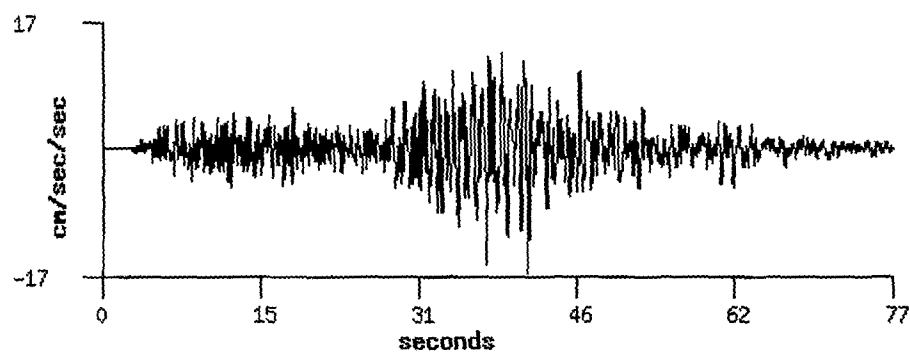
Duzce Earthquake – Heybeli Ada Acceleration Record (180)



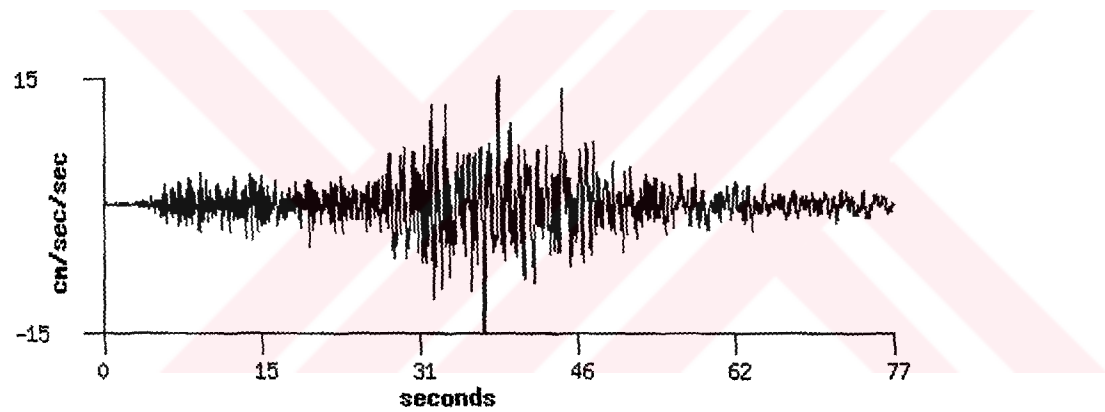
Duzce Earthquake – Heybeli Ada Acceleration Record (UP)



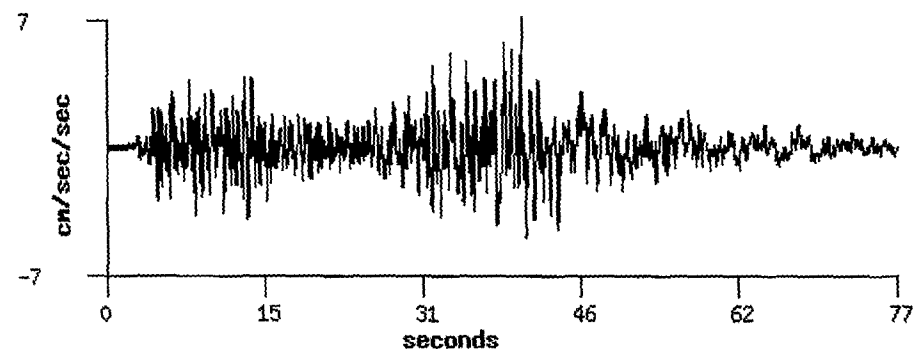
Duzce Earthquake – Kucuk Cekmece Acceleration Record (90)



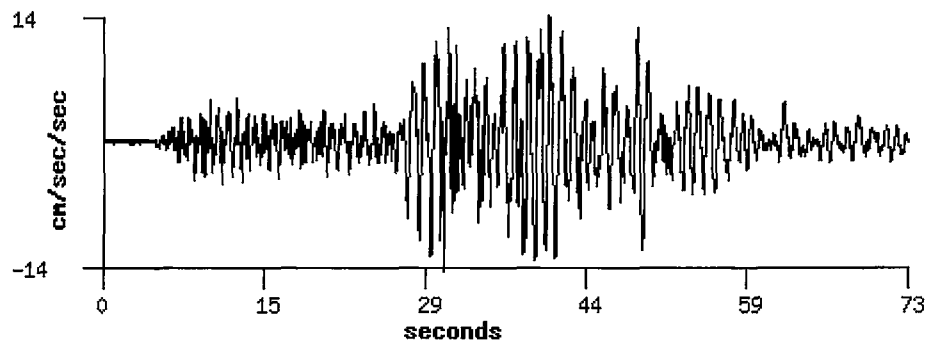
Duzce Earthquake – Kucuk Cekmece Acceleration Record (180)



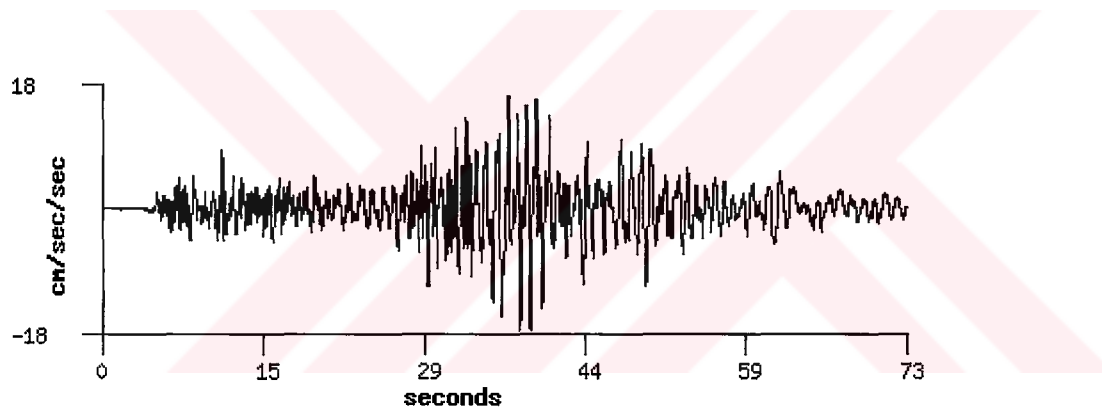
Duzce Earthquake – Kucuk Cekmece Acceleration Record (UP)



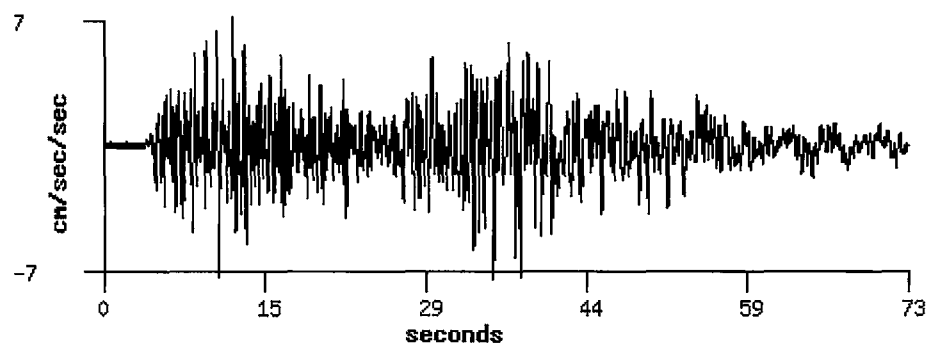
Duzce Earthquake – KocaMustafaPasa Station Acceleration Record (0)



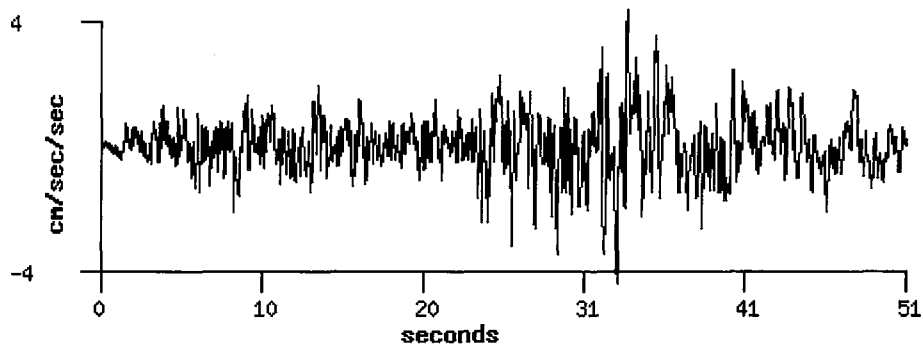
Duzce Earthquake – KocaMustafaPasa Station Acceleration Record (90)



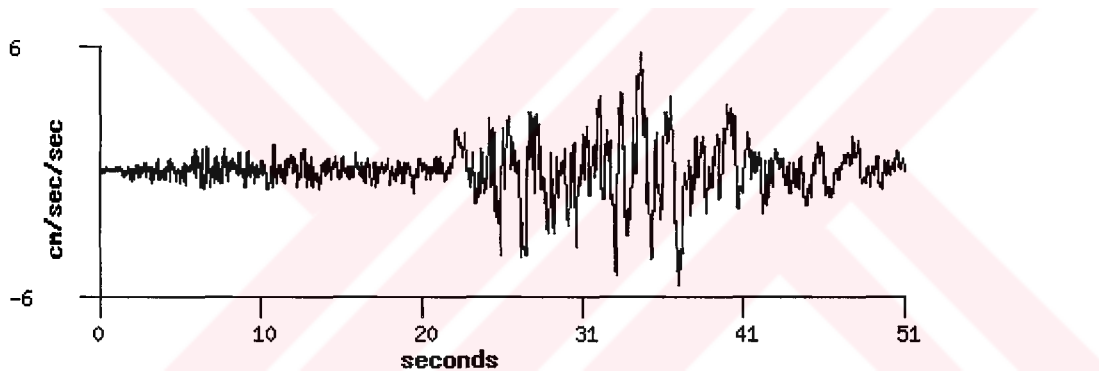
Duzce Earthquake – KocaMustafaPasa Station Acceleration Record (UP)



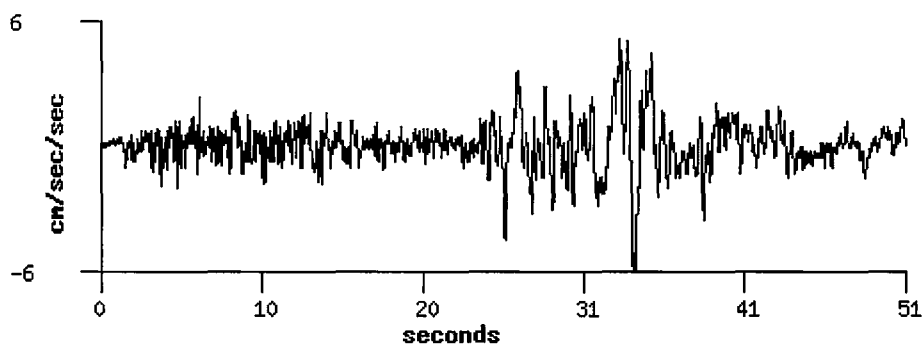
Duzce Earthquake – Levent Station Acceleration Record (90)



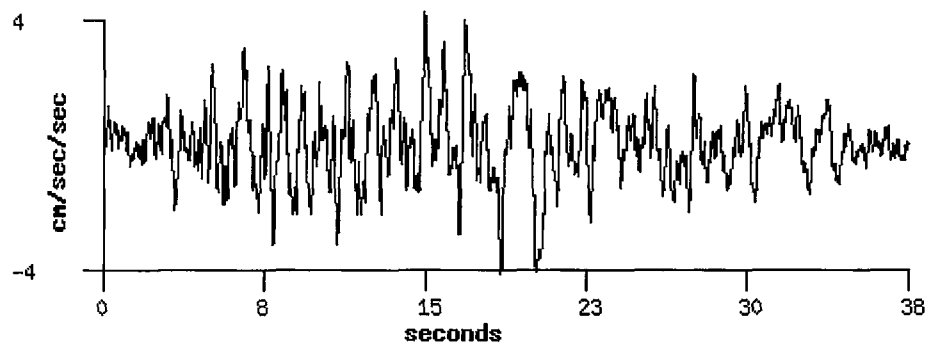
Duzce Earthquake – Levent Station Acceleration Record (180)



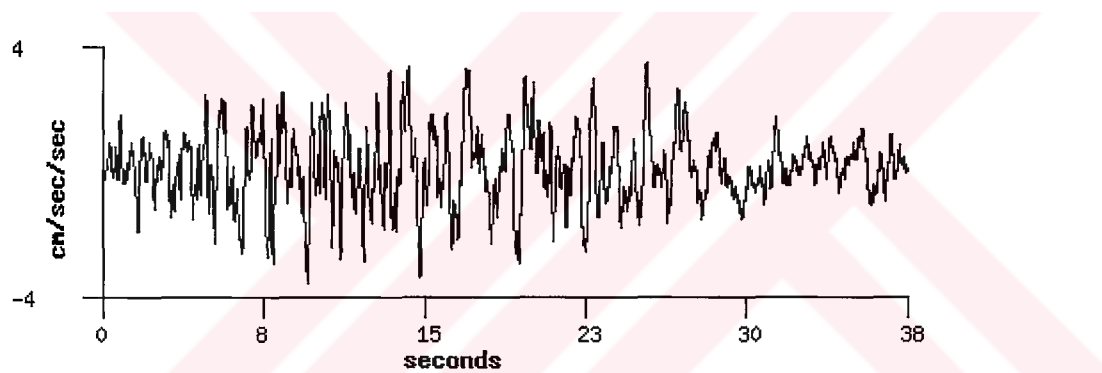
Duzce Earthquake – Levent Station Acceleration Record (UP)



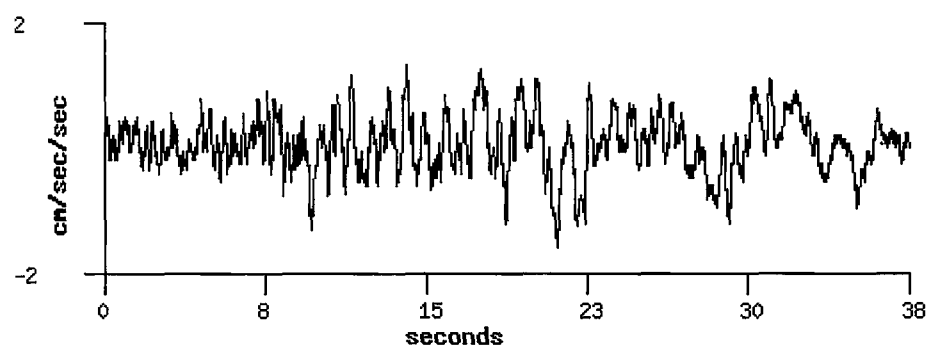
Duzce Earthquake – Marmara Ereğlisi Botas Station Acceleration Record (0)



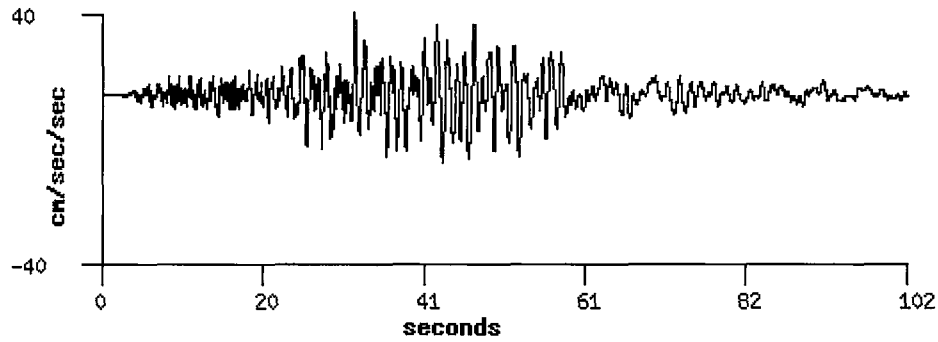
Duzce Earthquake – Marmara Ereğlisi Botas Station Acceleration Record (90)



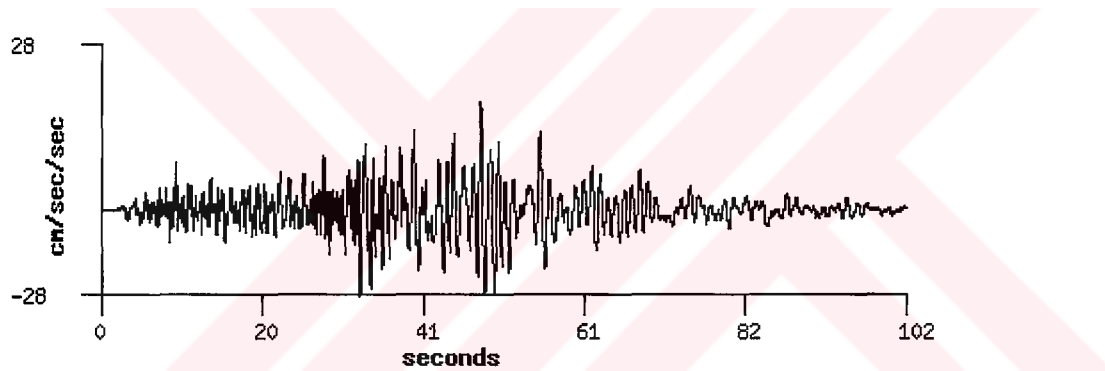
Duzce Earthquake – Marmara Ereğlisi Botas Station Acceleration Record (UP)



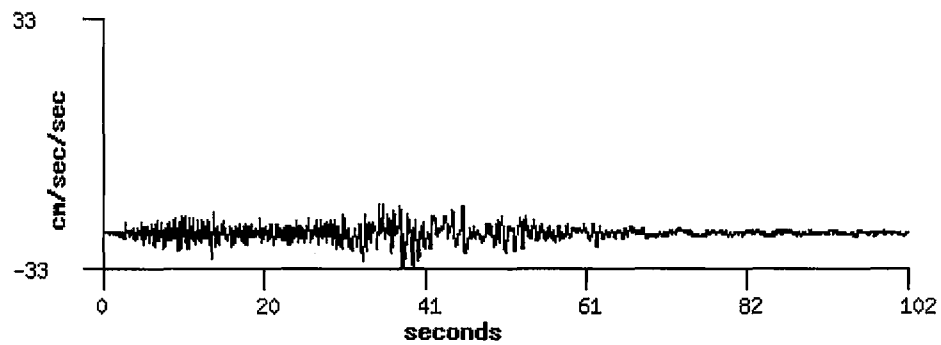
Duzce Earthquake – Yalova Ahmet Tas Residence Station Acceleration Record (0)



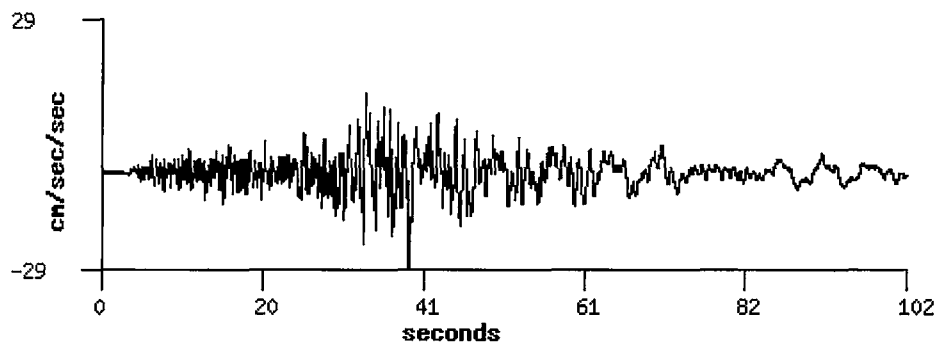
Duzce Earthquake – Yalova Ahmet Tas Residence Station Acceleration Record (90)



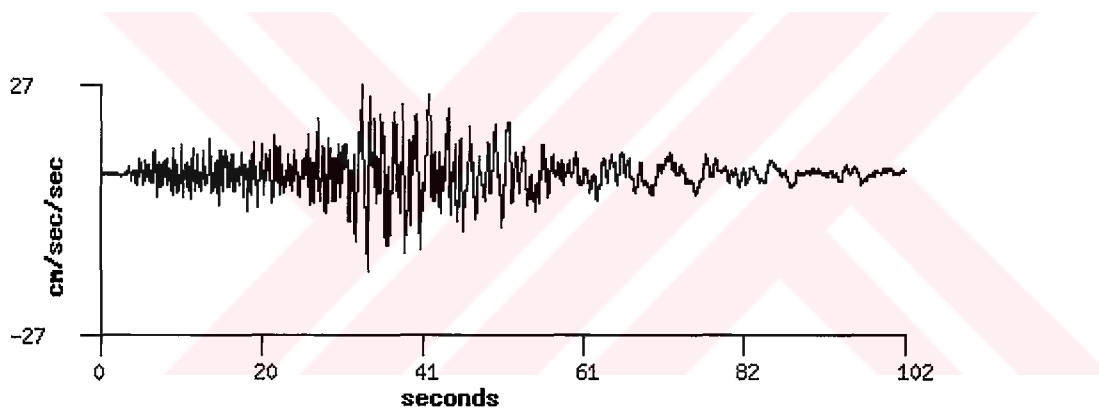
Duzce Earthquake – Yalova Ahmet Tas Residence Station Acceleration Record (UP)



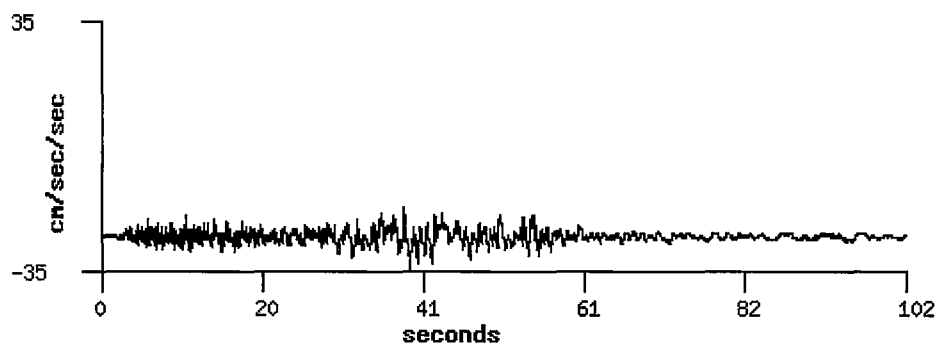
Duzce Earthquake – Yalova Baglaralti Station Acceleration Record (0)



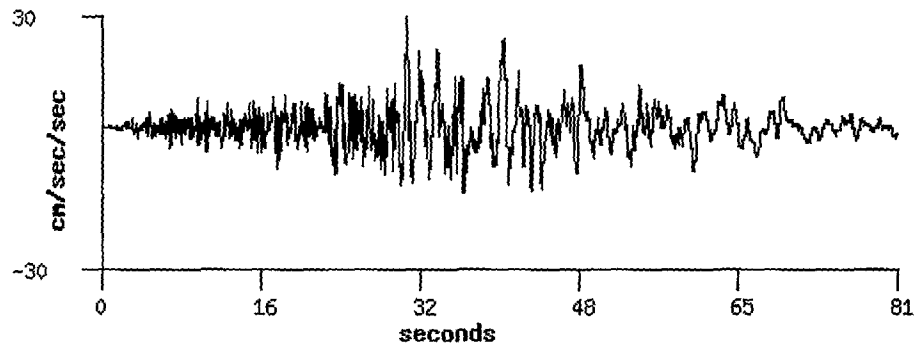
Duzce Earthquake – Yalova Baglaralti Station Acceleration Record (270)



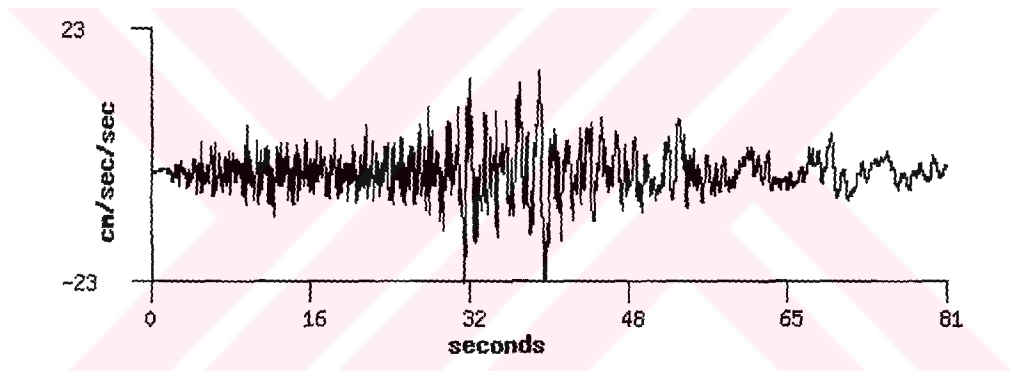
Duzce Earthquake – Yalova Baglaralti Station Acceleration Record (UP)



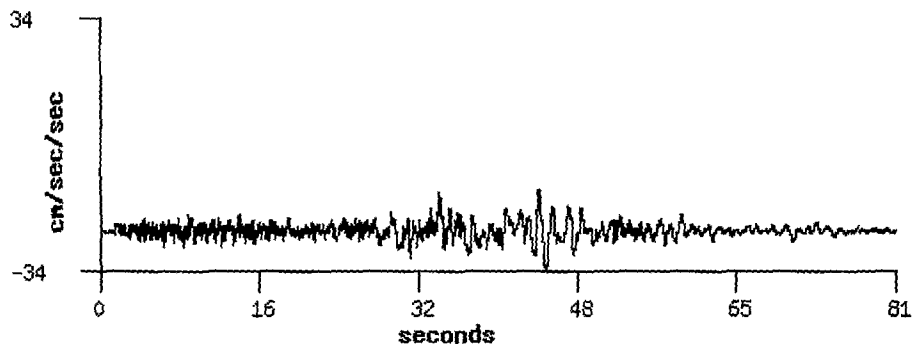
Duzce Earthquake – Yalova Bahcevan Station Acceleration Record (0)



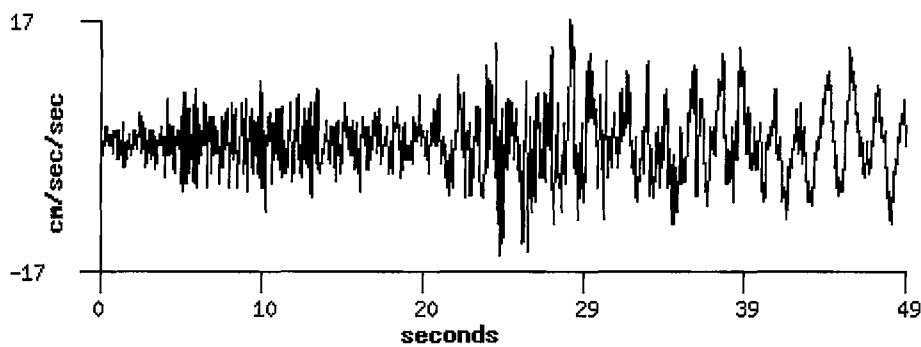
Duzce Earthquake – Yalova Bahcevan Station Acceleration Record (90)



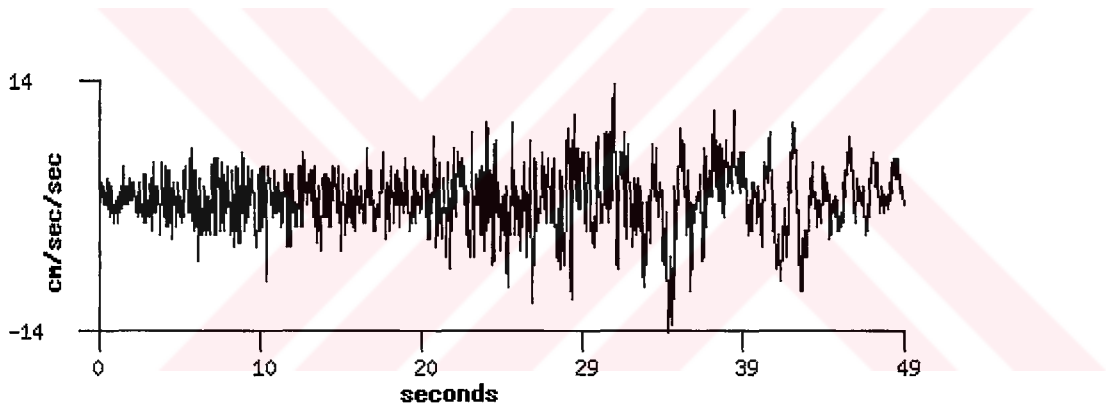
Duzce Earthquake – Yalova Bahcevan Station Acceleration Record (UP)



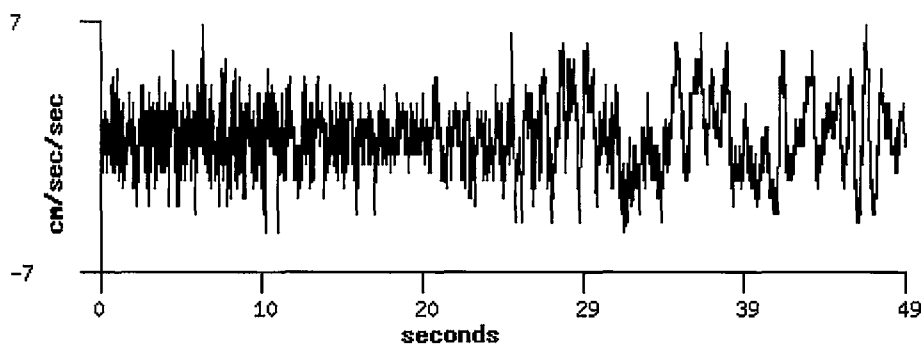
Duzce Earthquake – Yalova Gir Station Acceleration Record (0)



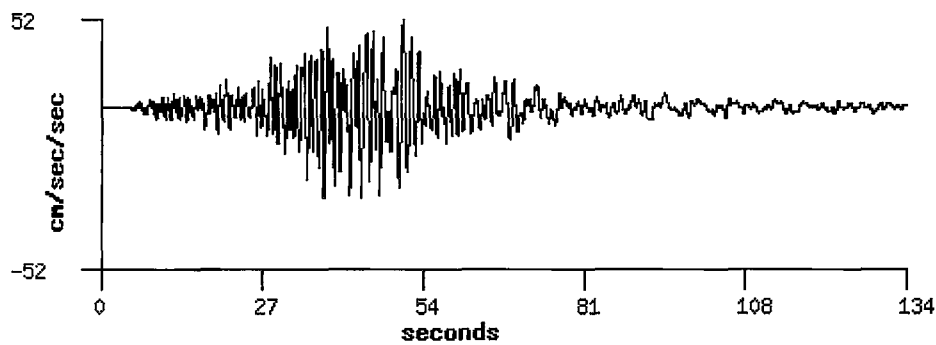
Duzce Earthquake – Yalova Gir Station Acceleration Record (270)



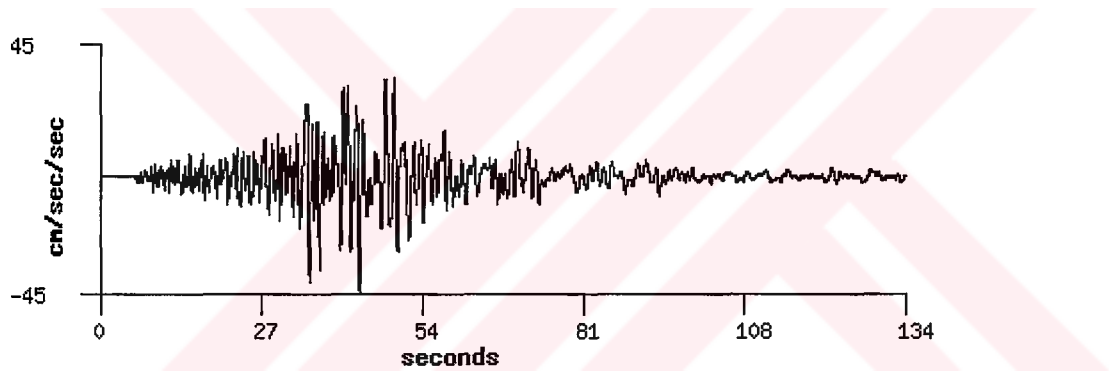
Duzce Earthquake – Yalova Gir Station Acceleration Record (UP)



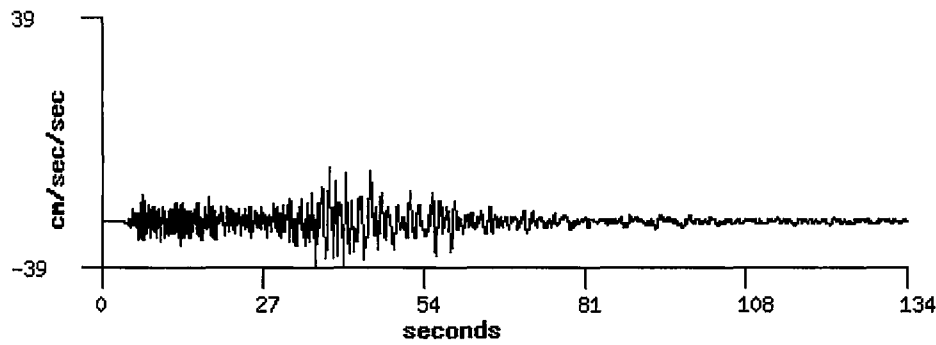
Duzce Earthquake – Yalova Hastane Station Acceleration Record (0)



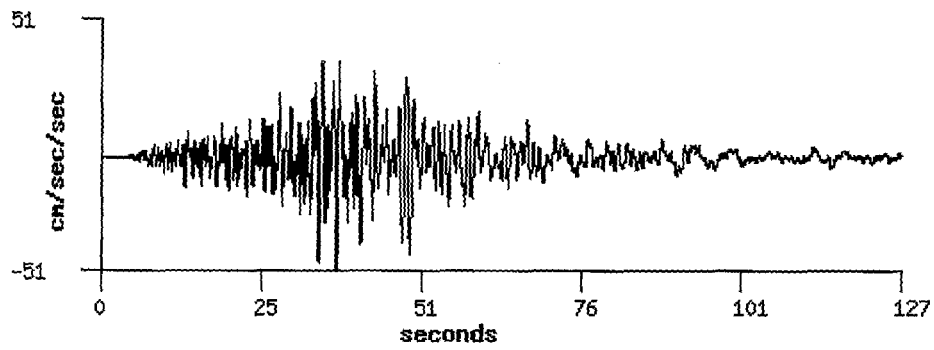
Duzce Earthquake – Yalova Hastane Station Acceleration Record (90)



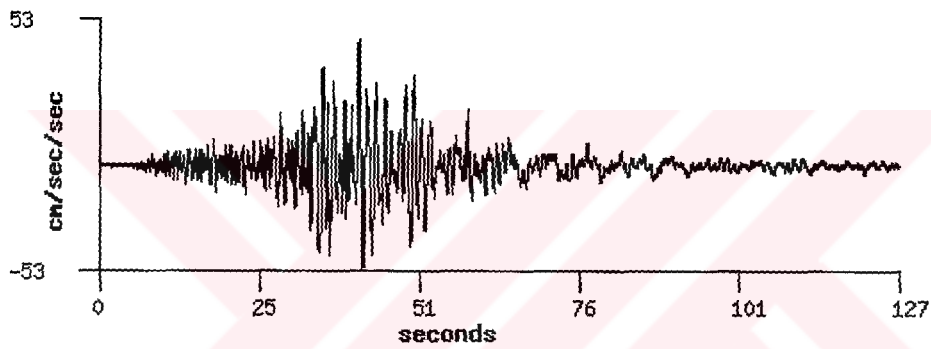
Duzce Earthquake – Yalova Hastane Station Acceleration Record (UP)



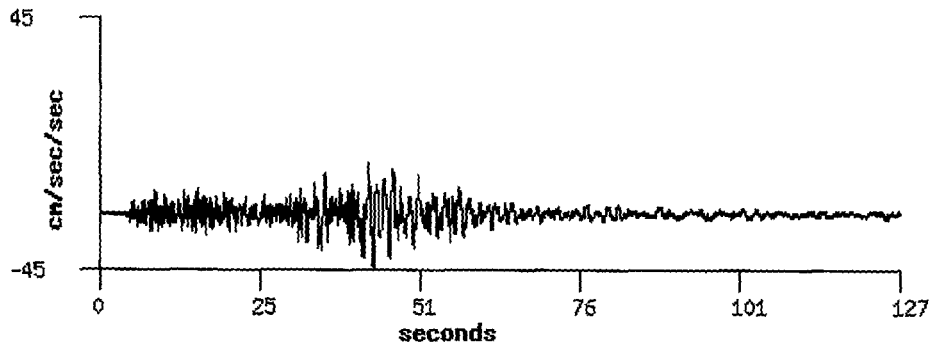
Duzce Earthquake – Yalova Hilal Station Acceleration Record (0)



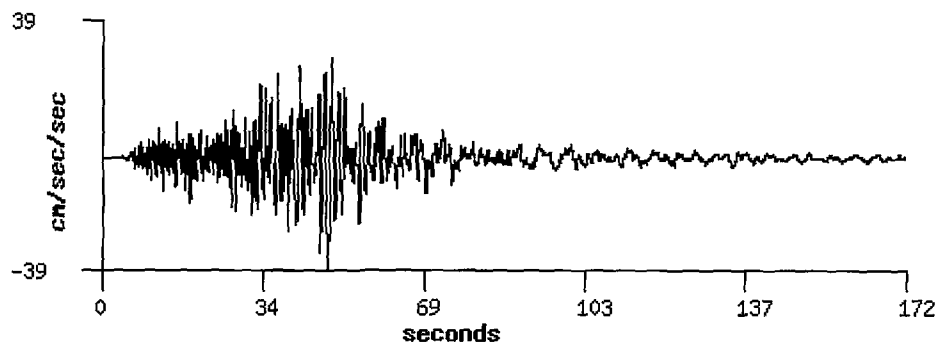
Duzce Earthquake – Yalova Hilal Station Acceleration Record (90)



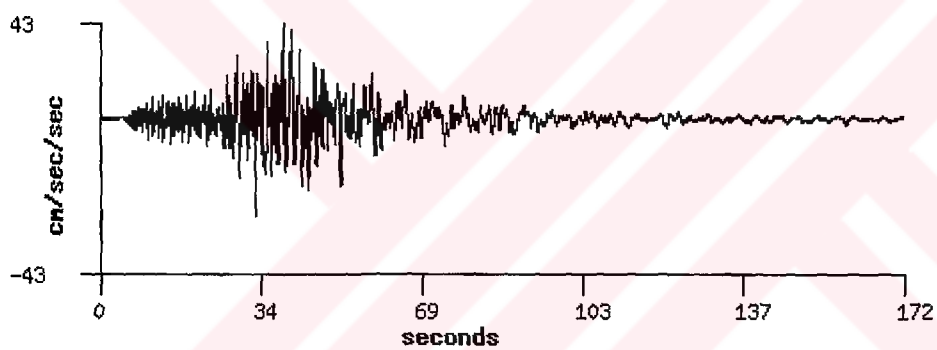
Duzce Earthquake – Yalova Hilal Station Acceleration Record (UP)



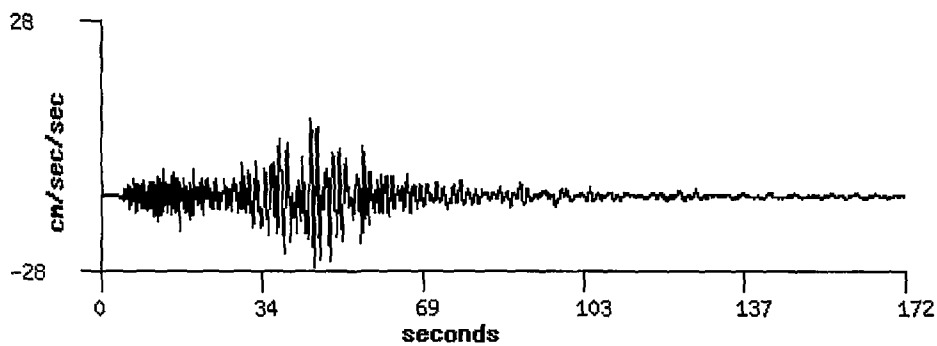
Duzce Earthquake – Yalova Ruzgar Station Acceleration Record (0)



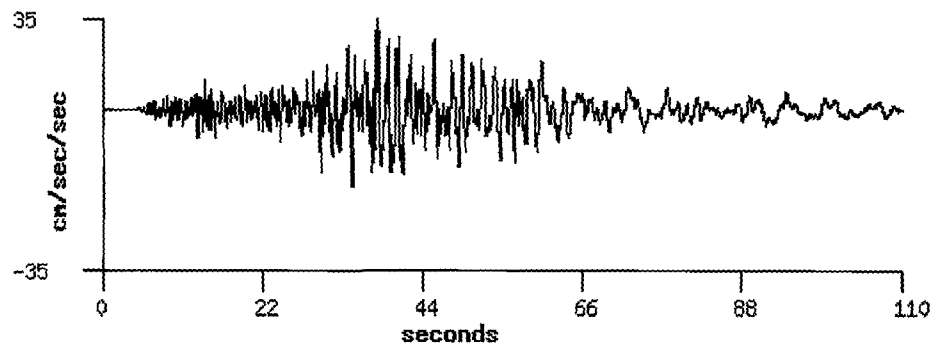
Duzce Earthquake – Yalova Ruzgar Station Acceleration Record (270)



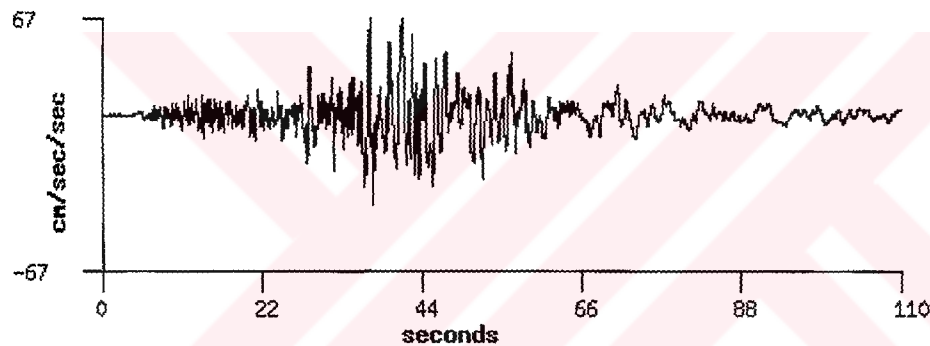
Duzce Earthquake – Yalova Ruzgar Station Acceleration Record (UP)



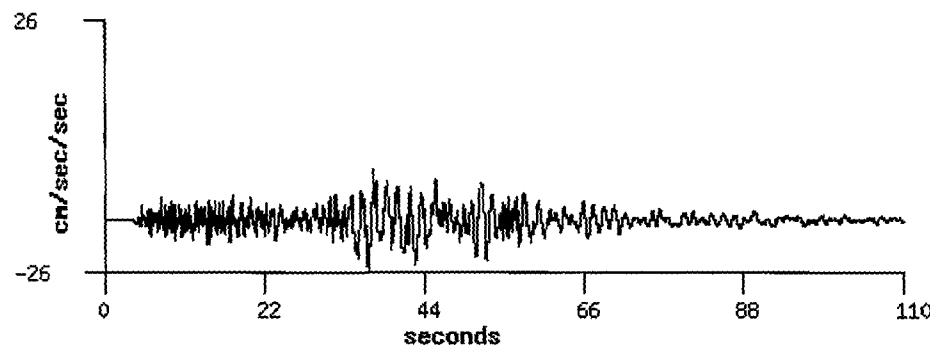
Duzce Earthquake – Yalova Tarim Directory Station Acceleration Record (0)



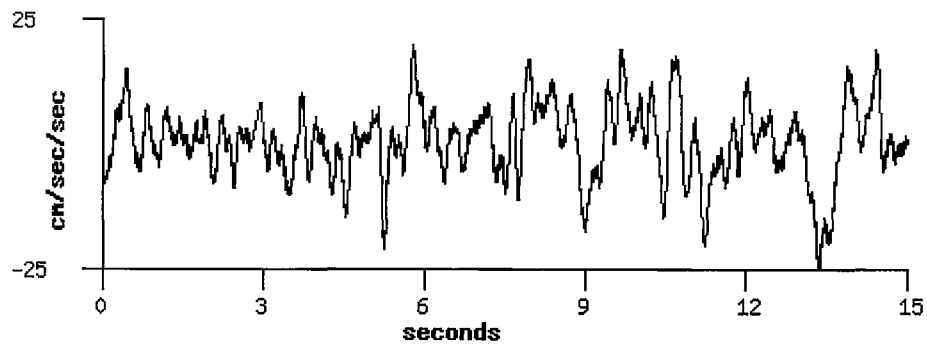
Duzce Earthquake – Yalova Tarim Directory Station Acceleration Record (90)



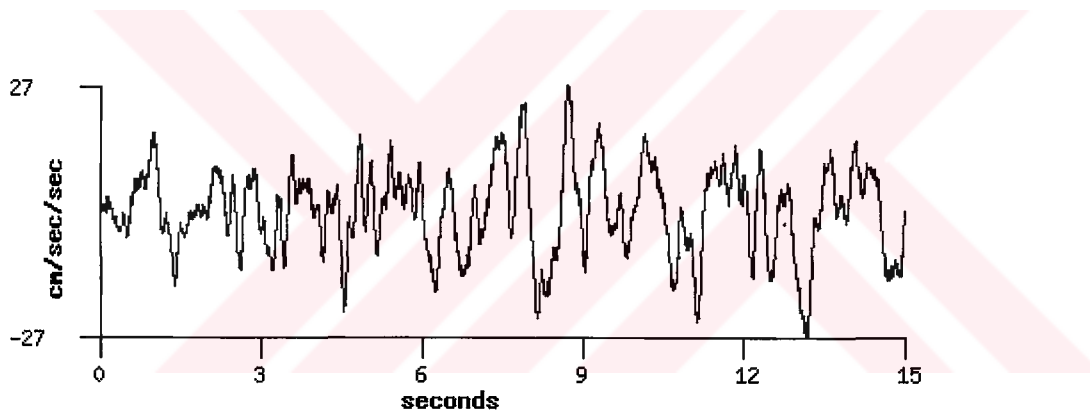
Duzce Earthquake – Yalova Tarim Directory Station Acceleration Record (UP)



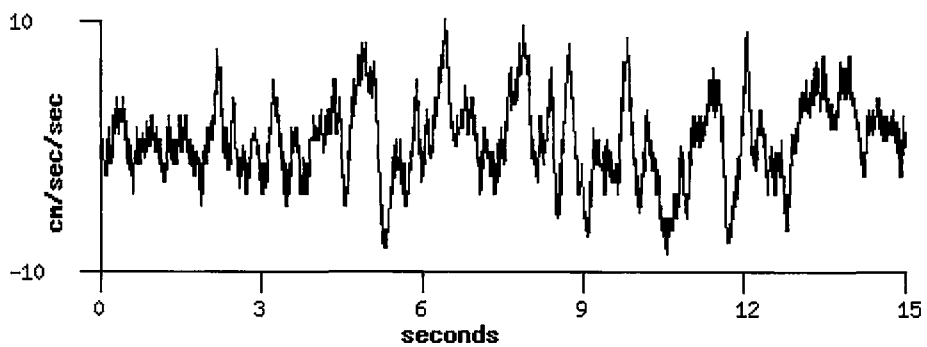
Duzce Earthquake – Yalova Station Acceleration Record (0)



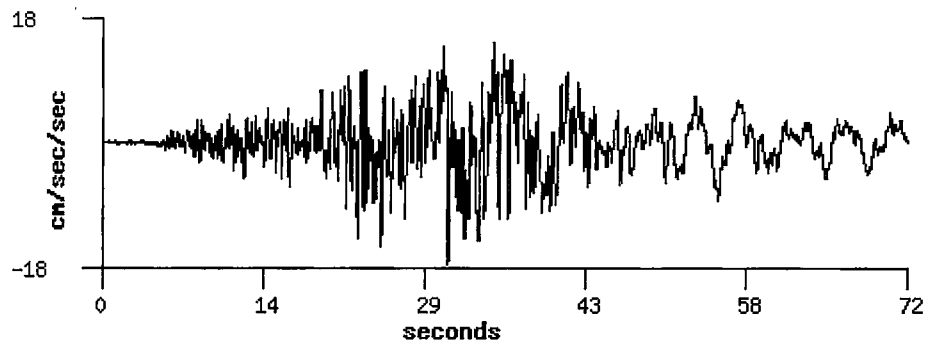
Duzce Earthquake – Yalova Station Acceleration Record (270)



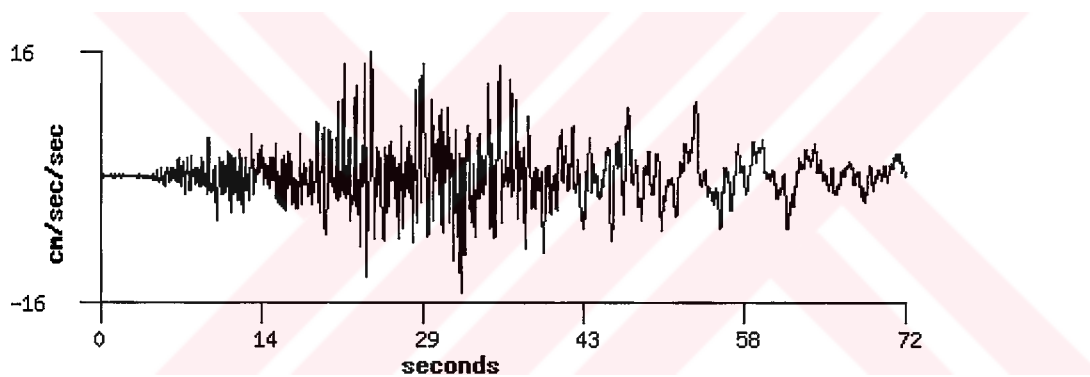
Duzce Earthquake – Yalova Station Acceleration Record (UP)



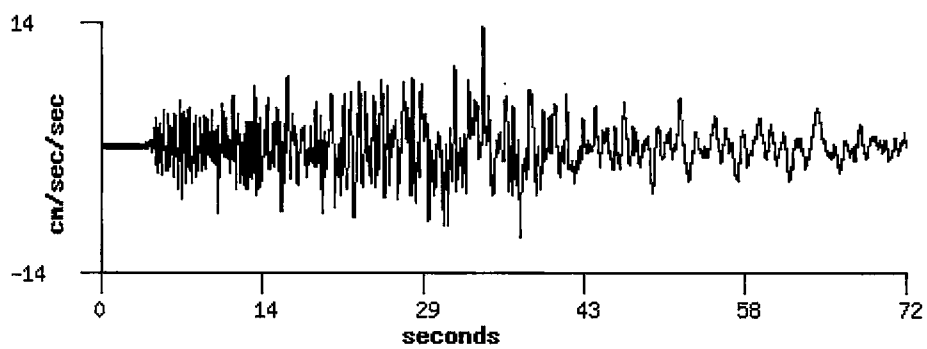
Duzce Earthquake – Yarimca Station Acceleration Record (0)



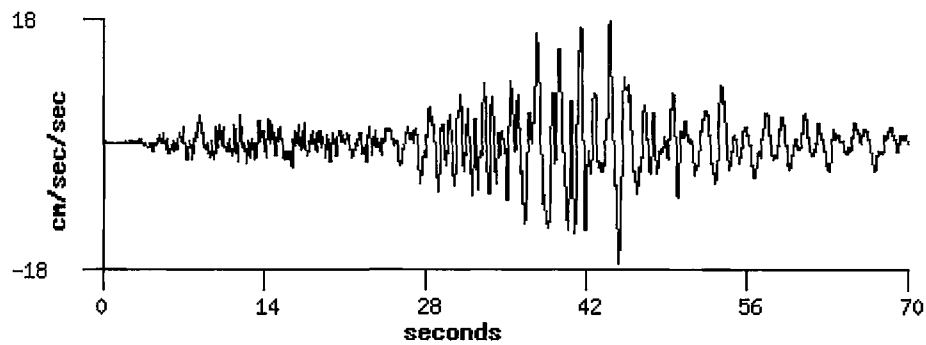
Duzce Earthquake – Yarimca Station Acceleration Record (270)



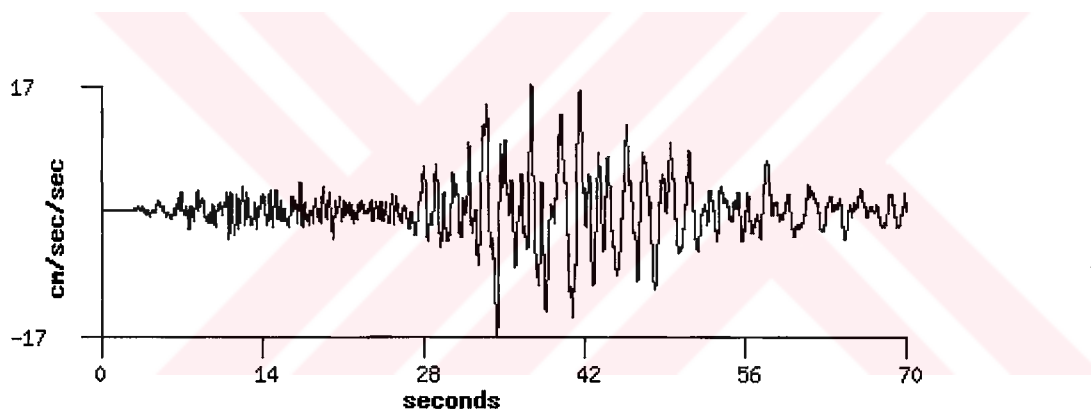
Duzce Earthquake – Yarimca Station Acceleration Record (UP)



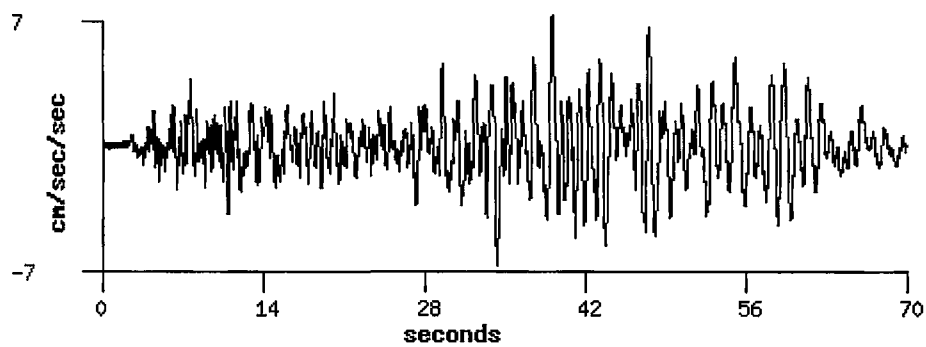
Duzce Earthquake – Yesilkoy Station Acceleration Record (90)



Duzce Earthquake – Yesilkoy Station Acceleration Record (180)



Duzce Earthquake – Yesilkoy Station Acceleration Record (DOWN)



CIRRUCULLUM VITAE

Mustafa Birkan Bayrak was born in November 29, 1979 in Istanbul. He completed his primary school in Nuri Ors Primary School in 1990, his secondary school in Orucgazi Junior High School in 1993, and his high school in Rifat Canayakin High School in 1997 in İstanbul. He started his BS degree at the Civil Engineering Department of the Istanbul Technical University and completed a four-year undergraduate education and graduated in 2002. He has been selected to be a research and teaching assistant in the Geotechnical Engineering Division of Civil Engineering Department at the Istanbul Technical University in 2002. At the same time, he started his MS education as a graduate student in the Soil Mechanics and Geotechnical Engineering Program at the Istanbul Technical University in 2002.

ÖZGEÇMİŞ

İnş. Müh. Mustafa Birkan Bayrak 29.11.1979'da İstanbul'da doğdu. İlkokulu 1990'da Nuri Örs İlkokulunda (İstanbul), ortaokulu 1993'de Oruçgazi İlköğretim Okulu'nda (İstanbul), liseyi de 1997'de Rıfat Canayakin Lisesi'nde (İstanbul) bitirdi. Lisans eğitimini İstanbul Teknik Üniversitesi İnşaat Mühendisliği Bölümü'nde tamamladıktan sonra 2002 yılında mezun oldu ve İTÜ İnşaat Fakültesi İnşaat Mühendisliği Geoteknik Anabilim Dalı'nda araştırma görevlisi olarak akademik hayatına başladı. Yine aynı yıl (2002) İTÜ Fen Bilimleri Enstitüsü Zemin Mekaniği ve Geoteknik Mühendisliği Yüksek Lisans Programına başladı.