AN ANALYSIS OF DEĞİRMENDERE SHORE LANDSLIDE DURING 17 AUGUST 1999 KOCAELİ EARTHQUAKE

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ABSTRACT

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In this study, the failure mechanism of the shore landslide which occured at Değirmendere coast region during 17 August 1999 Kocaeli (İzmit) - Turkey earthquake is analyzed. Geotechnical studies of the region are at hand, which reveal soil properties and geological formation of the region as well as the topography of the shore basin after deformations. The failure is analyzed as a landslide and permanent displacements are calculated by Newmark Method under 17 August 1999 İzmit record, scaled to a maximum acceleration of 0.4g. There are discussions on the main dominating mechanism of failure; landslide, liquefaction, fault rupture and lateral spreading. According to the studies, the failure mechanism is a seismically induced shore landslide also triggered by liquefaction and fault rupture, accompanied by the mechanism of lateral spreading by turbulence. A seismically induced landslide is discussed and modeled in this study. The finite element programs TELSTA and TELDYN are employed for static and dynamic analyses. Slope stability analyses are performed with the program SLOPE. The permanent displacements are calculated with Newmark Method, with the help of a MATLAB program, without considering the excess pore pressures.

Keywords: Earthquake, Finite Element Method, Dynamic Analysis,
Slope Stability, Newmark Method

ÖZ

17 AĞUSTOS 1999 KOCAELİ DEPREMİNDE MEYDANA GELEN DEĞİRMENDERE KIYI HEYELANININ İNCELENMESİ

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Bu çalışmada, 17 Ağustos 1999 Kocaeli (İzmit) - Türkiye depreminde Değirmendere sahil bölgesinde gerçekleşen kıyı heyelanının oluşma mekanizması tahlil edilmiştir. Eldeki geoteknik çalışmalar; bölgedeki zemin özellikleri ve jeolojik oluşumlar kadar kıyı çanağının depremden sonraki topografyasını da ortaya çıkarmaktadır. Göçme, bir heyelan olarak değerlendirilmiş ve 17 Ağustos 1999 İzmit istasyonu kaydının maksimum ivmesi 0.4g'ye ölçeklendirilerek Newmark Yöntemi ile kalıcı deplasmanlar hesap edilmiştir. Heyelanın oluşumunu kontrol eden ana mekanizma ile ilgili akademik tartışmalar dört konu üzerinde sürmektedir; heyelan, sıvılaşma, fay yırtılması ve yanal yayılma. Eldeki çalışmalara göre göçme mekanizması; türbülanslı yanal yayılmanın eşlik ettiği, sıvılaşma ve fay yırtılmasının tetiklemeye yardım ettiği, deprem kaynaklı bir kıyı heyelanıdır. Bu çalışmada deprem kaynaklı kıyı heyelanı üzerinde çalışılmış ve modelleme yapılmıştır. Statik ve dinamik analizler için, birer sonlu elemanlar programı olan TELSTA ve TELDYN kullanılmıştır. SLOPE programı ile şev stabilite tahlilleri yapılmıştır. Kalıcı deplasmanlar, bir MATLAB programı

yardımı ile, boşluk suyu basıncındaki artış göz önüne alınmadan Newmark Yöntemi kullanılarak hesap edilmiştir.

Anahtar Kelimeler: Deprem, Sonlu Elemanlar Yöntemi, Dinamik Analiz, Şev Stabilitesi, Newmark Yöntemi

To My Family

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CHAPTER 1

INTRODUCTION

1.1. General

An earthquake struck Marmara region of Turkey on August 17, 1999 at 3.02 am, named Kocaeli (İzmit) earthquake. Beside all the heavy damages that affected several provinces, a shore landslide occurred at Çınarlık shore of Değirmendere. 230 x 70 m area, accommodating some recreational facilities and a municipality hotel with residents was lost into the sea. The failure mechanism is of interest in this study, which is dominated by seismically induced landslide and accompanied by liquefaction, lateral spreading and fault rupture. For this purpose the slope is modeled by the finite element method. The finite element programs TELSTA and TELDYN are employed for static and dynamic analyses. Then permanent displacements are calculated by Newmark Method.

In Chapter 2, the theoretical background of slope stability is presented. There are two aspects in this part; the static slope stability analysis and the dynamic slope stability analysis. Each of them is examined in detail. Slope stability under static conditions is summarized with reference to limit equilibrium method and stress-deformation analysis. Dynamic slope stability under dynamic loads is addressed with reference to pseudo-static approach and permanent displacement analysis.

In Chapter 3, various aspects of August 17, 1999 earthquake, which caused Değirmendere landslide is described in several ways. First of all, the engineering parameters of Kocaeli earthquake are given. Secondly, seismicity of Marmara region and Kocaeli province are examined. Then the damages caused by earthquake are described in a large view. Lastly, Değirmendere landslide is examined in terms of location, soil conditions, mechanism of the failure, method of analysis and analysis results.

In Chapter 4, results of the studies and the conclusions are given.

1.2 Aim of the Study

The aim of this study is to analyze the shore landslide failure occurred during 17 August 1999 Kocaeli earthquake on the north nose of the coastline in Değirmendere subdistrict of Kocaeli with Permanent Displacement Method (Newmark Method). For this purpose a dynamic finite element program, TELDYN, is employed to get the average acceleration time history of the sliding mass.

CHAPTER 2

A REVIEW OF STABILITY OF SLOPES DURING EARTHQUAKES

2.1. Static Slope Stability Analysis

In the cases of seismically induced landslides, the governing factor of failure is the dynamic forces acting on the slope. However, static forces also affect the mechanism. Under static conditions, if the landslide-resisting shear forces are not high enough, the required slide-mobilizing dynamic forces will be low, and this leads to the failure of slope. Hence, failure is a result of both static and dynamic forces mobilizing slide of the slope. Also it is a fact that dynamic slope stability analysis has mainly generated from the static analysis methods. These two reasons make it necessary to examine static slope stability analysis at first.

2.1.1. Limit Equilibrium Method

Limit equilibrium method has been a technique used for decades of years on the world for the stability analyses in soil mechanics. This method consists in the analysis of equilibrium of a rigid body, such as the slope, on a potential slip surface of some assumed shape (straight line, arc of a circle, logarithmic spiral). From such equilibrium study, shear stress (τ) is calculated and compared to the available shear resistance (τ_f). From this comparison the first indication of stability is derived as the Factor of Safety;

$$F = \tau_f / \tau \qquad (2.1)$$

This method has two important assumptions; 1) the soil mass on failure surface is rigid 2) the shear strength act along the failure surface at the same amount and same time.

There are various equilibrium methods. Some of them consider the total equilibrium of the rigid body (Culmann Method), while others divide the body into slices for its non homogeneity and consider the equilibrium of each of them (Fellenius, Bishop, Morgenstern and Price, Spencer, Janbu, Sarma Methods). The Ordinary Method of Slices (Fellenius, 1927) and Bishop's Modified Method (Bishop, 1955) use a circular failure surface. If the surface is assumed to be non-circular, than methods of Morgenstern and Price (1965), Spencer (1967), Janbu (1968) can be used.

In the method of slices, the volume affected by slide is subdivided into a convenient number of slices (Figure 2.1). If the number of slices is n, the problem presents the following unknowns:

n values of normal forces acting on the base of slices (N)
n values of shear forces at the base of slices (S)
(n-1) normal forces acting on slice interface (E)
(n-1) tangential forces acting on slice interface (X)
n values of coordinate that identifies the application point of N
(n-1) values of coordinate that identifies the application point of X
an unknown safety factor F

The number of unknowns is 6n-2, while there are a total of 4n equations usable. The problem is statistically indeterminate to order i = (6n-2)-(4n) = 2n-2.

The degree of indeterminacy is further reduced when it is assumed that N is applied at the mid point of a slice, which is equivalent to assuming that total normal tensions are distributed uniformly. The various methods that are based on equilibrium theory differ in the way in which indeterminacy degrees are eliminated. The most common assumptions typically deal with the slice interface forces X and E.

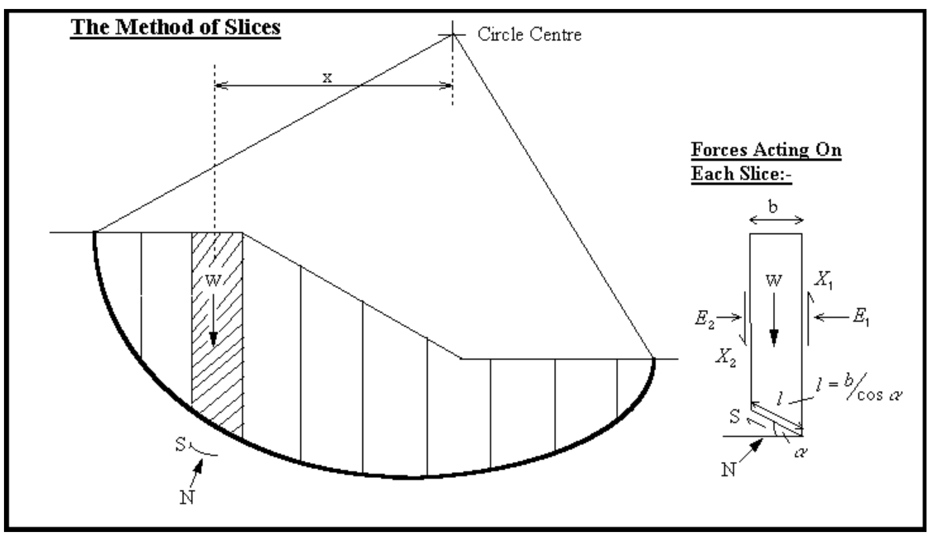

Figure 2.1 Forces acting on a slice in Method of Slices

To see the effect of the assumptions, the Ordinary Method of Slices (Fellenius, 1927) may be analyzed. This method assumes that the resultant of the side forces (X and E) acting on a slice act parallel to the base of the slice and they are ignored. Using this assumption, we have 2n+1 equations at hand and that much of unknowns;

n values of normal forces at base (N)
n values of shear forces at base (S)
Safety factor F

So the problem becomes determinate. But the moment equilibrium around the center of the circular slip surface is the only condition of equilibrium satisfied by this method.

Slope-stability problems are usually analyzed using a variety of limit equilibrium methods of slices. When evaluating the stability conditions of soil slopes of simple configuration, circular potential slip surfaces are usually assumed and the Ordinary Method (Fellenius, 1927) and the Simplified Bishop Method (Bishop, 1955) are commonly used, the latter being preferred due to its high precision. However, in many situations, the actual failure surfaces are found to deviate largely from circular shape or the potential slip surfaces are predefined by planes of weakness in rock slopes. In such cases, a number of methods of slices can be used to accommodate the non-circular shape of slip surfaces (Janbu, 1954; Lowe and Karafiath, 1960; Morgenstern and Price, 1965; Spencer, 1967; U.S. Army Corps of Engineers, 1967; and etc.). Among them, the Morgenstern-Price Method (Morgenstern and Price, 1965) is regarded as the most popular one, because it fully satisfies the equilibrium conditions and involves the least numerical difficulties. The basic assumption underlying the Morgenstern-Price method is that the ratio of normal to shear interslice forces across the sliding mass is represented by an interslice force function that is the product of a specified function f(x) and an unknown scaling factor λ. According to the vertical force equilibrium conditions for individual slices and the moment equilibrium condition for the whole sliding mass, two equilibrium equations are derived involving the two unknowns; the factor of safety FS and the scaling factor λ. Unfortunately, solving for FS and λ is very complex since the equilibrium equations are highly nonlinear and in rather complicated form. Some sophisticated iterative procedures (Morgenstern and Price, 1967; Fredlund and Krahn, 1977; Chen and Morgenstern, 1983; Zhu, 2001) have been developed for such purposes.

For the limit equilibrium methods, theoretically $FS \geq 1.0$ should be enough for a stable slope, but due to some uncertainties and the presence of assumptions made, FS values significantly greater than 1.0 are accepted to be safe in practice (Kramer, 1996). The minimum acceptable FS values for slope design are; 1.5 for normal long term loading conditions and 1.3 for temporary slopes or end-of construction conditions in permanent slopes.

One of the constraints of limit equilibrium methods is about strain-softening materials. As a result of the basic assumption of rigid-perfectly plastic material, it gives no idea about progressive failure, which is the case in reality. When a failure occurs in life, shear strength is not mobilized at the same time along the failure surface, which is against the second basic assumption. Instead, the shear resistance is mobilized at an arbitrary point on surface and when the peak strength is exceeded, the other points nearby are mobilized to reach their peak point of resistance while the resistance of the first point falls to the residual value. This is known as progressive failure. To avoid problems, residual values of shear strength should be used for limit equilibrium analyses of strain-softening materials (Kramer, 1996).

Another constraint of the limit equilibrium methods is their insufficiency about deformations. For the computation of deformations, another type of analysis may be used; Stress-Deformation Analysis.

2.1.2. Stress-Deformation Analysis

Finite-element method is the most commonly used type of analysis to compute stresses and deformations. It is important to see the intensity of stresses in a slope body, which gives idea about the potential failure surface. Finite element method not only gives the stresses and deformations in a static slope stability analysis, but also can simulate many features such as loading conditions, different material layers, various boundary conditions etc.

This method is highly affected by the input parameters to simulate the nature of soil. For more developed models, more number of parameters are needed which also increases the range of error. To overcome this problem, iterative techniques are developed and used in most of the finite element methods.

TELSTA is one of the computer programs designed for plane strain static finite-element analyses of soils, and it is used for the stress and deformation analyses of Değirmendere landslide during 1999 earthquake, to present required results for the program TELDYN, which is a dynamic finite element analysis program (TELSTA & TELDYN user's manuels).

2.2. Dynamic Slope Stability Analysis

A number of analytical techniques are available for dynamic slope stability analysis, based on both limit equilibrium and stress-deformation methods, as discussed in section 2.1. Introduction of the seismic effect makes the problem more complex, but the main problem is to decide how it affects the failure mechanism. Mainly the seismic force increases the slide-mobilizing stresses and decreases the resisting stresses. However there is another point; the seismic force may also influence the material properties and decrease the shear strength.

2.2.1. Pseudo-static Analysis

Over seventy years passed from the first time seismic safety of earth structures has been analyzed using the method of pseudo-static analysis. This method uses the same principle with limit equilibrium methods, where the only difference is addition of an earthquake by horizontal/vertical accelerations. The slide-mobilizing and resisting forces on the failure surface are calculated with the contribution of static earthquake force. Earthquake has both vertical and horizontal components, but as the effect of vertical component is negligible -this will be discussed below-, seismic force is represented only by a static horizontal force of

$$F_{eq} = k_h \cdot W \qquad (2.2)$$

where k_h is the seismic coefficient and W is the weight of the failure mass, as seen from Figure 2.2.

The factor of safety can be defined as the ratio resists rotation of a critical slip surface about the center of the sliding surface to the moment that is driving the rotation. For a circular sliding surface as seen in Figure 2.2, the factor of safety can be formulated as follows;

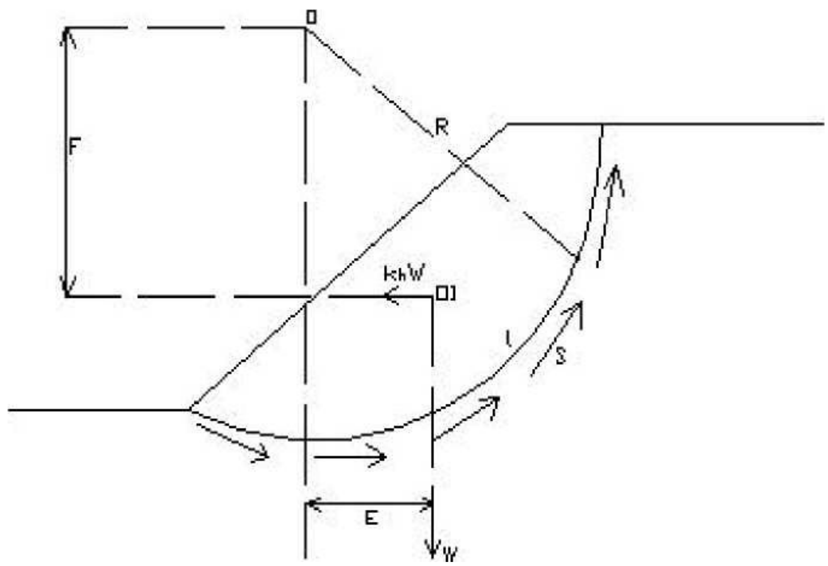

Figure 2.2 Forces acting on a sliding circular mass in Pseudo-static Method

$$FS = \frac{Resisting\ moments}{Overturning\ moments} = \frac{s.l.R}{E.W + k_h.F.W} \quad (2.3)$$

where s is the shear strength, W is weight, k_h is the seismic coefficient, E and F are the moment arms, R is the radius and l is the length of the sliding surface.

If a planar failure surface had been assumed as in Figure 2.3, then a force equilibrium would be considered along the surface and the formula for FS would be;

$$FS = \frac{Resisting\ forces}{Driving\ forces} = \frac{c.l_{ab} + [(W - F_v).\cos\beta - F_h.\sin\beta]\tan\phi}{(W - F_v).\sin\beta + F_h.\cos\beta} \quad (2.4)$$

where c and ϕ are the strength parameters, l_{ab} is the length of the failure plane.

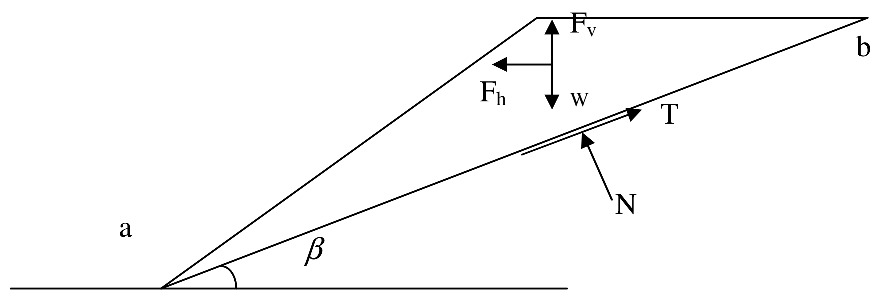

Figure 2.3 Forces acting on a sliding planar mass in Pseudostatic Method

As recognized from formula 2.4, the vertical component of earthquake F_v has the same effect on both resisting and driving forces. But the horizontal component F_h absolutely decreases the value of FS. So the vertical pseudo-static force has less influence on result and can be neglected. This leads to formula 2.2, horizontal component representing the whole pseudo-static force.

Pseudo-static analysis method uses a crude technique to add the seismic forces in calculation. Assuming the earthquake effect as a static force acting on the center of the body leads to inaccurate results, which was also stated by Terzaghi (1950). Another important difficulty of the method is selection of an appropriate seismic coefficient (k_h). There are several academic contributions to this problem, but at the end this requires engineering judgment, which is difficult to decide.

As a method based on the limit equilibrium method, pseudo-static analysis gives no idea about the deformations, which is another limitation. Because of this and the difficulties in the selection of seismic coefficients and in the evaluation of safety factor, use of pseudo-static method for seismic slope stability analyses has reduced much today.

2.2.2. Permanent Displacement Analysis

The insufficiency of Pseudo-static Method –disregarding the permanent deformations- is a problem for engineers, because without information about deformations serviceability can not be checked, which is essential to make necessary decisions. Newmark (1965) introduced a method to compute these seismically induced permanent deformations. In this approach, the mass of soil located above the critical failure surface is represented as a rigid block resting on an inclined plane as shown in Figure 2.4. When the block is subjected to acceleration caused by the ground motion which is greater than the yield acceleration, the driving forces may exceed the resisting forces. Thus, the block slides along the inclined plane. The resisting and the driving forces acting on the sliding block are illustrated in Figure 2.5.

Determination of the yield acceleration is the most critical step of the analysis. The yield acceleration a_y is the minimum pseudo-static acceleration required to cause the block to move relative to sliding plane. It can be obtained by using the following equation:

$$a_y = k_h \cdot g \qquad (2.5)$$

where k_h is the horizontal seismic coefficient calculated in pseudo-static analysis which is explained in Section 2.2.1.

When a block on an inclined plane is subjected to accelerations greater than the yield acceleration, the block will move relative to plane. Thus, the relative acceleration constituting the displacement can be written as follows:

$$a_{rel}(t) = a(t) - a_y \tag{2.6}$$

where a(t) is the acceleration of inclined plane.

Thus, by computing an acceleration at which the inertia forces become sufficiently high to cause yielding to begin and integrating the effective acceleration on the sliding mass in excess of this yield acceleration as a function of time (Figure 2.6), the velocities and ultimate displacements of the sliding mass can be evaluated (Seed et al.,1979).

The time history of acceleration of the inclined plane, a(t), can be considered as the average acceleration time history of the sliding mass. In order to determine the average time history of acceleration, a_{ave}, following steps should be carried out:

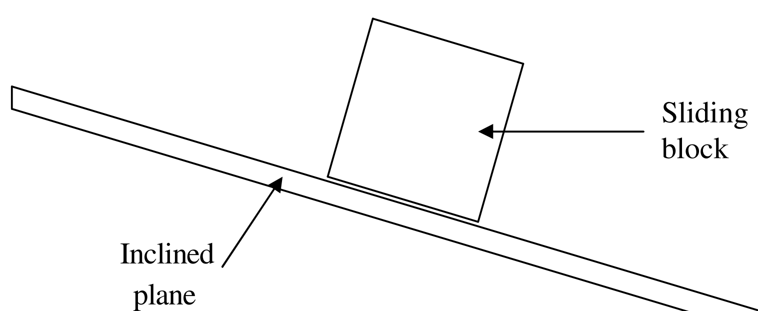

Figure 2.4 Sliding block resting on an inclined plane

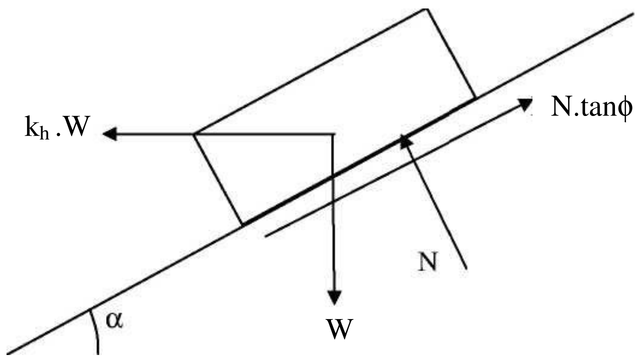

Figure 2.5 Forces acting on a sliding block

i) Sliding mass is divided into finite elements or finite strips.

ii) The average time history of acceleration is calculated for each element by using the dynamic finite element analysis.

iii) The time history of force on an element is obtained by multiplying the acceleration of each element with its mass:

$$F_e(t) = m_e \, . \, a_e(t) \qquad (2.7)$$

where m_e is the mass of an element and $a_e(t)$ is the time history of acceleration of an element.

iv) Total force acting on the sliding mass can be calculated by summing the forces acting on elements:

$$F(t) = \Sigma \, F_e(t) = \Sigma \, m_e \, . \, a_e(t) \qquad (2.8)$$

v) In the last step, the average time history acceleration of the sliding mass is determined by dividing total force by total mass of the sliding mass:

$$a_{ave} = \frac{F(t)}{m} = \frac{\Sigma m_e . a_e(t)}{\Sigma m_e} \tag{2.9}$$

Consequently, as explained before, by integrating twice the average time history of acceleration, permanent displacement of the slope can be calculated.

Makdisi and Seed (1978) developed the Newmark's permanent displacement method by using the sliding block analyses and average accelerations computed by the procedure of Chopra (1966). In this approach, knowing the fundamental period of embankment and the yield acceleration of the slope, simple charts can be used to estimate earthquake-induced permanent displacements. Furthermore, Lemos and Coelho (1991) and Tika Vassilikos et al. (1993) have both suggested methods that can incorporate a rate dependent friction angle into the Newmark analysis to account for time varying shear strengths due to earthquake loading. Although a number of modified permanent displacement methods have been proposed, today Newmark (1965) type of analysis is widely used by the geotechnical engineers.

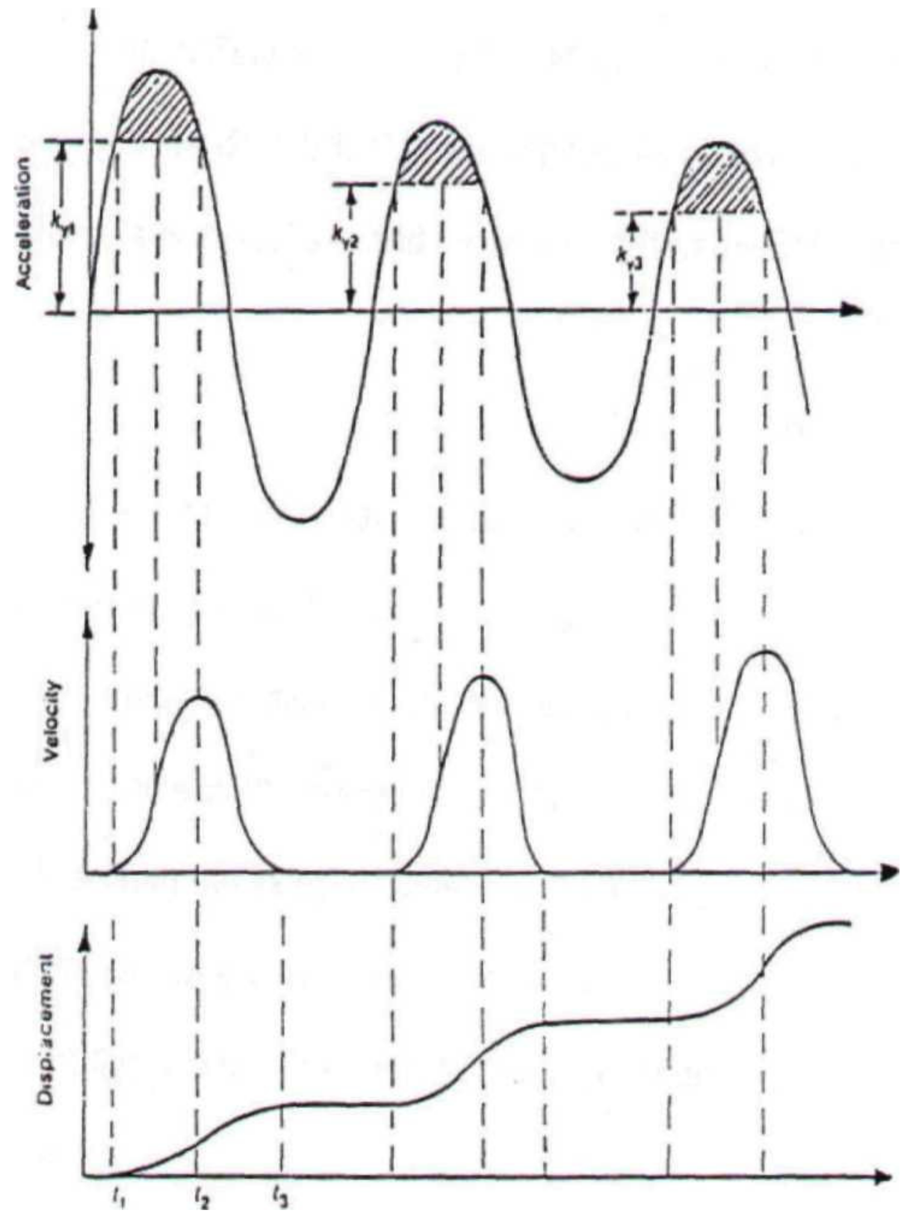

Figure 2.6 Twice integration of acceleration time-history to calculate displacements (Seed, H.B., 1979)

2.2.3. Finite Element Method

Finite element method treats a continuum as an assemblage of finite elements which are defined by nodal points and assumes that the response of the continuum is equivalent to the response of the nodal points. Elements are connected with each other at the nodal points and they simulate the material behavior of the zones. It is one of the most powerful methods for evaluating the response of slopes under earthquake loading. It is possible to obtain actual results by this method by considering the nonlinear stress-strain behavior of the construction materials. Comparing with the other methods, advantages of finite element method can be given as follows:

i) Time dependent stress-strain behavior of any element or region of the slope body can be evaluated.
ii) Effects of the slope-loading interaction and foundation characteristics can be simulated.
iii) Irregular geometry and complex boundary conditions can be taken into account.
iv) Nonlinear behavior of the soil can be analyzed and permanent dynamic deformations can be calculated.

In the case of a response analysis, it is necessary to solve the equation of motion which represents the dynamic equilibrium of all the elements. The equation of motion for dynamic finite element method can be given as:

$$[M]\{\ddot{U}\}+[C]\{\dot{U}\}+[K]\{U\}=-[M]\{\ddot{Y}\} \tag{2.10}$$

where U is the displacement vector and Y is the time history of the base motion, M is the mass matrix, C is the damping matrix and K is the stiffness matrix.

There are several methods used for the solution of the Equation 2.10. These methods can be written as:

i) Direct integration
ii) Modal superposition
iii) Fourier analysis

The most common method used for evaluating the behavior of non-linear systems under cyclic loading is the direct integration method. The other methods; modal superposition and Fourier analysis are only valid for the evaluation of the linear-elastic systems.

The finite element method can be used for the solution of the two dimensional and three dimensional dynamic response problems. In the case of earth structures, usually plane strain and two dimensional analysis of transverse (along the slope body, normal to slope surface) sections are used. There are several computer programs available involving the assumption of plain strain conditions. Among them, an effective one is TELDYN which uses equivalent linear method and provides compliant base.

CHAPTER 3

A CASE STUDY: DEĞİRMENDERE LANDSLIDE DURING 17 AUGUST 1999 KOCAELİ EARTHQUAKE

3.1. Engineering Parameters of Earthquake

An earthquake occurred in Marmara region of Turkey on August17, 1999 at 3.02 am on local time (00:01:39:80 GMT), named Kocaeli (İzmit) earthquake. Earthquake Research Department (ERD) of the General Directorate of Disaster Affairs reported the earthquake parameters as; epicenter 40.70N latitude 29.91E longitude, depth 15.9 kilometers, magnitude Mw=7.4 , Md=6.7 and maximum seismic intensity X (MSK scale). Geographical location of epicenter was about at 12 kilometers southeast of İzmit city center. The earthquake occurred on the western part of North Anatolian Fault Zone (NAFZ) with a 120 km surface rupture extending from southwest of Düzce in the east to near Karamürsel basin in the west. The movement was right-lateral strike slip type.

The earthquake parameters given by General Directorate of Disaster Affairs are emphasized in this study, but various institutes supplied different values, which are tabulated on Table 3.1. The locations of epicenter given by three different institutes are presented on Figure 3.1

Table 3.1 Earthquake parameters supplied by various institutes

Institute	Date	Latitude	Longitude	Depth	Mw	Md
Disaster Affairs of General Management Earthquake Research Department	17/08/1999 03:01:37 (L.T)	40.70N	29.91E	15.9	7.4	6.7
Boğaziçi University Kandilli Observatory	17/08/1999 03:01.37.6 (L.T)	40.76N	29.97	18		7.4
USGS	17/08/1999 00:01:39.80 (GMT)	40.702	29.987	17	7.4	

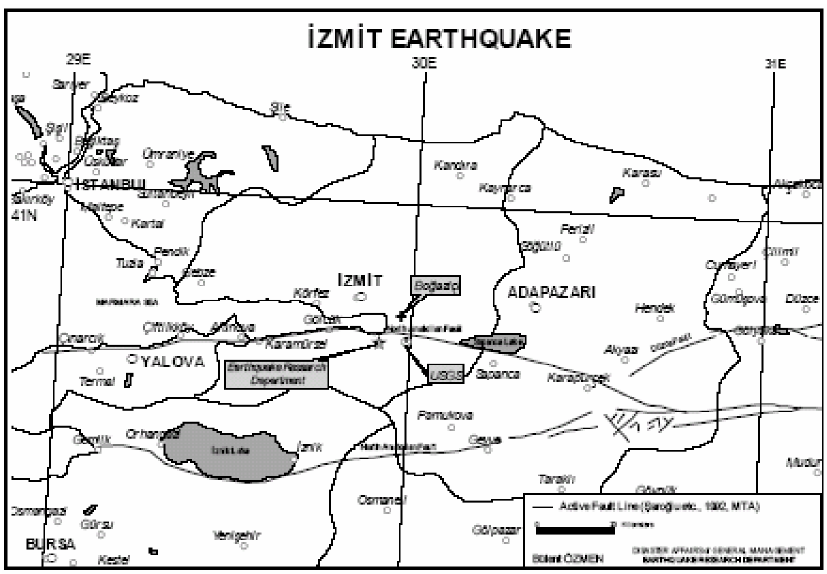

Figure 3.1 Epicenter locations by various institutes (Özmen, 2000.b)

General Directorate of Disaster Affairs recorded accelerations of Kocaeli earthquake at 24 stations. The stations are tabulated at Table 3.2 below. The maximum horizontal peak ground acceleration was recorded at Adapazarı station (42 km from epicenter) as 407 mG, while the horizontal peak ground acceleration recorded at the nearest station to epicenter (İzmit station, 12 km from epicenter) was 225 mG.

Table 3.2 Stations that recorded data of Kocaeli earthquake (L : north-south T : east-west , V : vertical max acceleration records)

Symbol of Station	Name of Station	Coordinates		L (mG)	T (mG)	V (mG)
		Latitude (N)	Longitude (E)			
TKT	TOKAT	40.33	36.55	0.8	1.2	0.4
KUT	KÜTAHYA	39.42	30.00	50	59.7	23.2
CYH	CEYHAN (ADANA)	37.02	35.81	2	3	1.5
AYD	AYDIN	37.84	27.84	5.9	5.2	3.3
KOY	KÖYCEĞİZ (MUĞLA)	36.97	28.69	1	2	1
DNZ	DENİZLİ	37.81	29.11	5.9	11.7	3.7
BRN	BORNOVA (İZMİR)	38.46	27.23	9.9	10.8	3.3
TOS	TOSYA (KASTAMONU)	41.01	34.04	11.7	8.9	4.4
CNK	ÇANAKKALE	40.14	26.40	24.6	28.6	7.9
USK	UŞAK	38.67	29.40	8.9	7.2	3.4
BLK	BALIKESİR	39.65	27.86	17.8	18.2	7.6
AFY	AFYON	38.79	30.56	13.5	15	5
MNS	MANİSA	38.58	27.45	12.5	6.5	4.5
BRS	BURSA	40.18	29.13	54.3	45.8	25.7
IST	İSTANBUL	41.08	29.09	60.7	42.7	36.2
SKR	SAKARYA	40.74	30.38		407	259
TKR	TEKİRDAĞ	40.98	27.52	32.2	33.5	10.2
SRK	ŞARKÖY (TEKİRDAĞ)	40.64	27.13	29.4	33.6	14.5
IZN	İZNİK (BURSA)	40.44	29.75	91.8	123.3	82.3
ERG	EREĞLİ (TEKİRDAĞ)	40.98	27.79	91.4	101.4	57
CEK	ÇEKMECE (İSTANBUL)	40.97	28.70	118	89.6	49.8
IZT	İZMİT	40.79	29.96	171.2	224.9	146.4
GBZ	GEBZE (İZMİT)	40.82	29.44	264.8	141.5	198.5
DZC	DÜZCE	40.85	31.17	373.7	314.8	479.9
GYN	GÖYNÜK (BOLU)	40.38	30.73	117.8	137.7	129.9

3.2. Seismicity of Marmara Region and Kocaeli (İzmit) Province

Turkey is on one of the main earthquake bands in the world, the Alps-Himalayas earthquake band, which extends from Azores to southeast Asia. The Anatolian plate is forced to move north and northwest by the Arabian and African plates, stopped at north by the Eurasian plate and at west by the Aegean plate. This causes accumulation of stress at the border zones of Anatolian plate where most of the earthquakes in Turkey occur. The zones are North Anatolian Fault Zone, East Anatolian Fault, Southeast Anatolian Overlap and Aegean Graben System (Şaroğlu et.al, 1992). North Anatolian Fault is studied by many researchers for its high effect on Turkey earthquakes (Alpar & Yaltırak, 2002; Gökaşan, E., et.al., 2001, Kuşçu, İ., et.al., 2002).

Anatolian plate has always been a region of destructive earthquakes in history. The active faults and epicenter locations of earthquakes with $Mw \geq 4$ during 1881-1998 on Anatolian Plate are presented in Figure 3.2. Examining the earthquake regions map, published by Ministry of Public Works and Settlement in 1996 (Appendix C), 66 % of Turkey's surface area is on the 1^{st} and 2^{nd} degree earthquake regions. North Anatolian Fault Zone is one of the four earthquake-generating systems in Turkey. This fault extends to Marmara region in west, causing earthquakes in this region, like 17 August 1999 Kocaeli earthquake.

Marmara region has a very active seismical history, which can be seen from the records. The historical earthquakes recorded in Marmara region without instruments from the year 427 B.C. up to 1900 A.D. are presented in Appendix D. The earthquakes in Marmara region between 27E – 32E longitudes and 39N – 42N latitudes recorded with instruments from 1881 up to 1998 and having a magnitude $Mw \geq 4$ are tabulated in Appendix E. Besides these instrumentally recorded 409 earthquakes are presented in Figure 3.3.

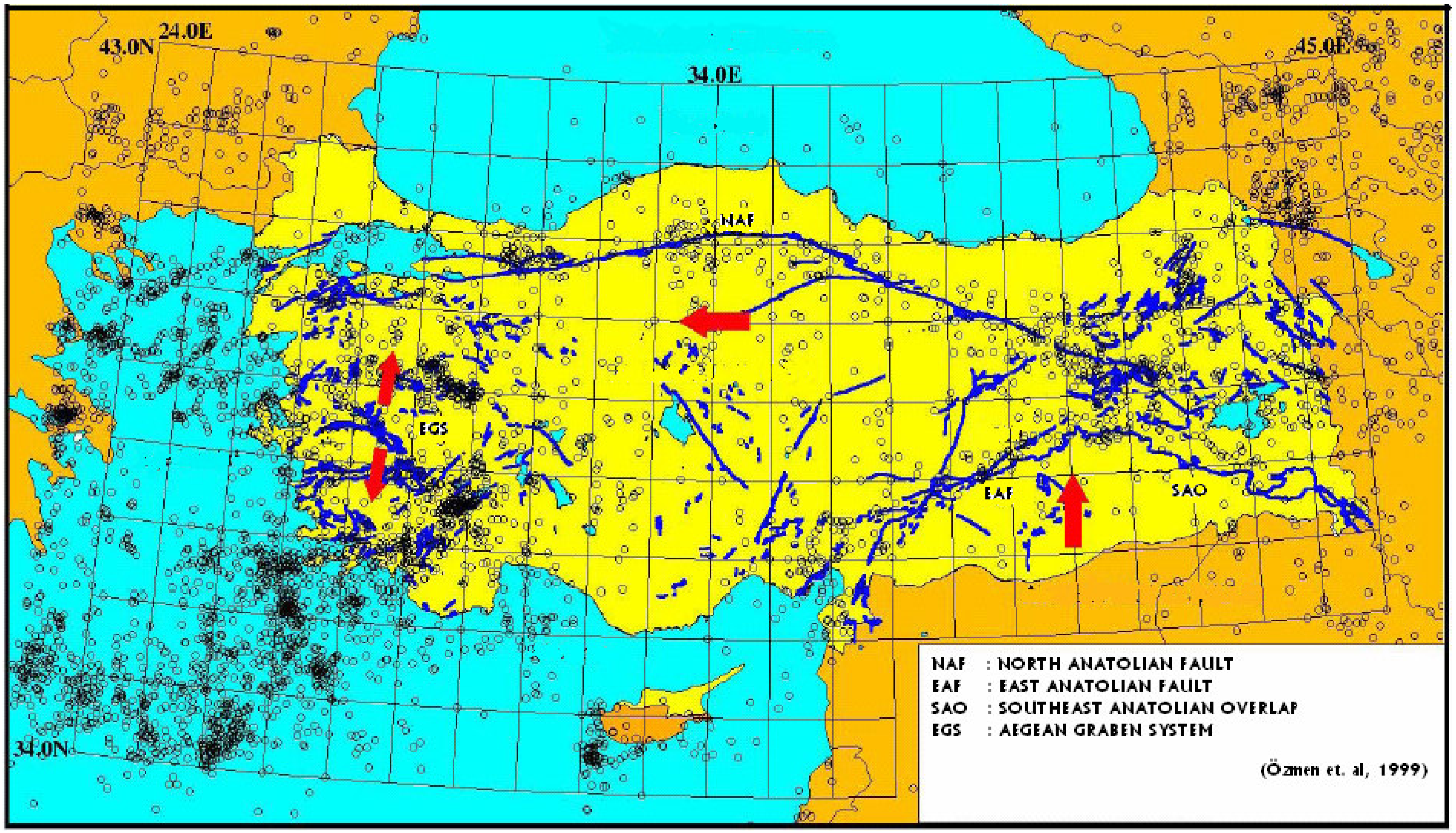

Figure 3.2 Active faults and epicenter locations (Mw≥4 erthquakes during 1881-1998) on Anatolian Plate (Özmen, 2000.a)

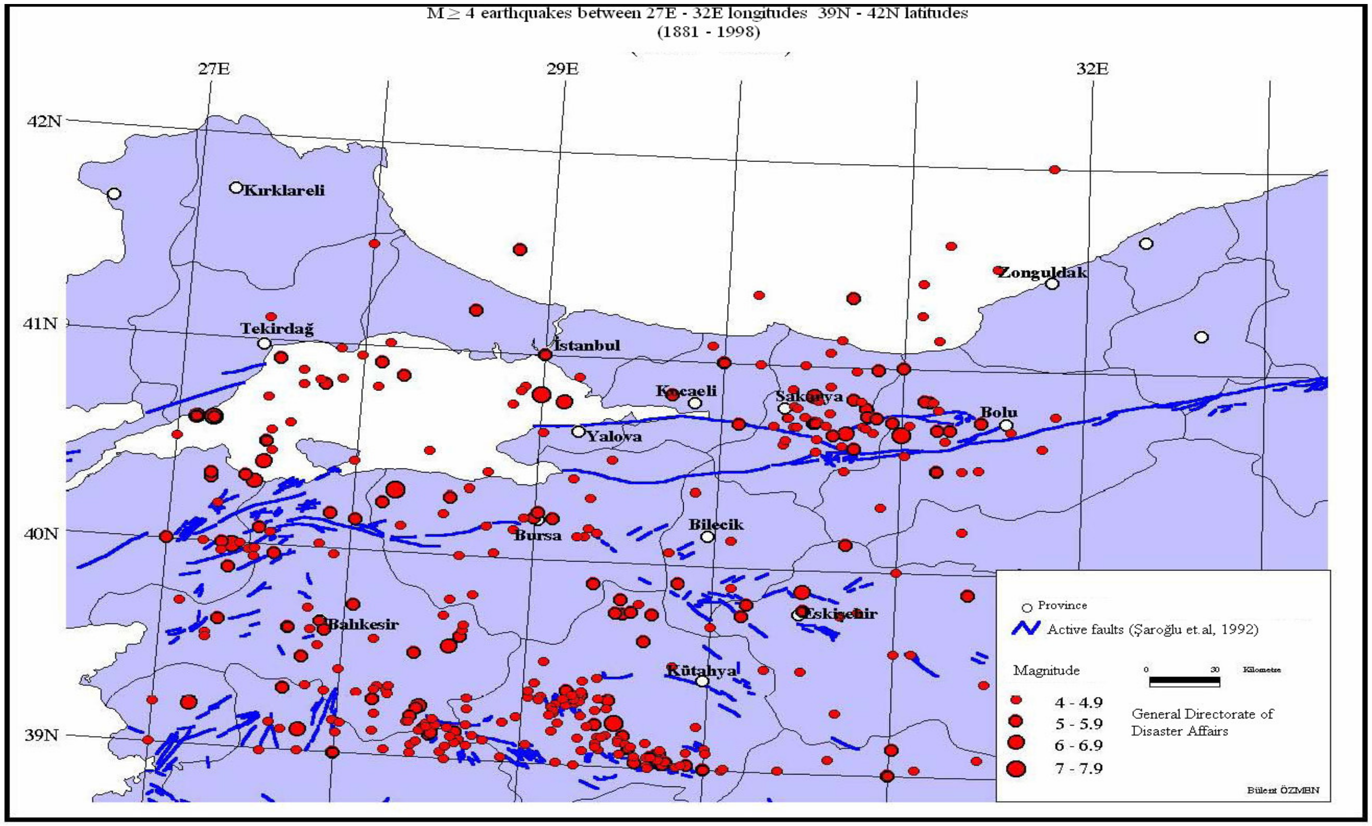

Figure 3.3 Earthquakes in Marmara region with Mw ≥ 4 in1881-1998 (Özmen, 2000.a)

Kocaeli (İzmit) province and its vicinity are mostly on the 1st degree earthquake region, according to the earthquake regions map published by Ministry of Public Works and Settlement (1996) and the book prepared by Gencoğlu et.al (1996) (Figure 3.4). Kocaeli has 3631 km^2 surface area, where 3255 km^2 (90 %) is on 1st degree earthquake region and 376 km^2 (10 %) is on 2nd degree earthquake region.

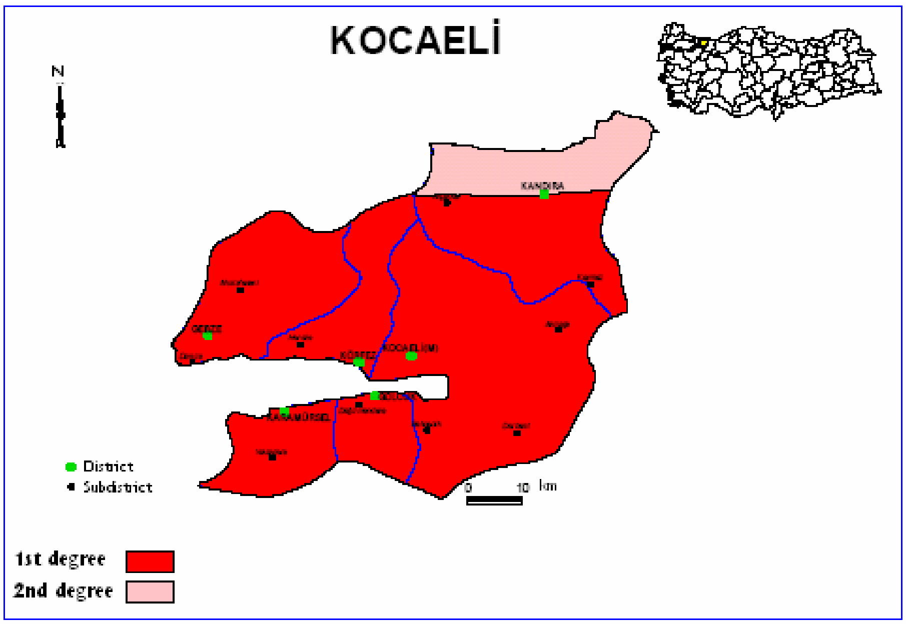

Figure 3.4 Earthquake regions, Kocaeli (İzmit) and its vicinity belong to

Değirmendere is a subdistrict of Gölcük district and as it is seen from Figure 3.4, it is also on the 1st degree earthquake region. Examining North Anatolian Fault on Figure 3.3, it is obvious that the north branch of the fault passes very close to Değirmendere, which will be discussed in section 3.4.

3.3. Damages Caused by Kocaeli Earthquake

Kocaeli earthquake is the second largest earthquake in Turkey in point of amount of human loss since 1939 Erzincan earthquake, which had caused loss of 32,962 lives with a magnitude of Mw=7.8. Kocaeli earthquake caused 17,479 death, injury of 43,953 people (Table 3.3); on the point of damages, collapse or heavy damage of 66,441 residences and 10,901 offices, moderate damage of 67,242 residences and 9,927 offices, slightly damage of 80,160 residences and 9,712 offices (Table 3.4). The provinces most affected by earthquake are Kocaeli (12 km from epicenter), Sakarya (39 km from epicenter) and Yalova (59 km from epicenter) in point of heavy damages and collapses. Forty-eight percent of heavy damages occurred in Kocaeli, twenty-nine percent in Sakarya and fourteen percent in Yalova. The other provinces affected are Bolu, İstanbul, Eskişehir and Bursa in order of descending heavy damage (Özmen, 2000.a; Rathje, E.M., et.al. 2004).

Table 3.3 Distribution of people died and injured according to provinces

PROVINCE	PEOPLE DIED	PEOPLE INJURED
KOCAELİ	9476	19447
SAKARYA	3890	7284
YALOVA	2504	6042
İSTANBUL	981	7204
BOLU	271	1165
BURSA	268	2375
ESKİŞEHİR	86	375
ZONGULDAK	3	26
TEKİRDAĞ	-	35
TOTAL	**17479**	**43953**

Table 3.4 Damage results of Kocaeli earthquake

CITY	DAMAGE RESULT					
	HEAVY		MODERATE		SLIGHT	
	HOUSE	SHOP	HOUSE	SHOP	HOUSE	SHOP
BOLU	3095	649	4180	1015	3303	482
BURSA	63	5	434	19	940	68
ESKİŞEHİR	80	19	96	8	314	22
İSTANBUL	3073	532	13339	1999	12455	1239
KOCAELİ	31625	4901	29076	3887	31751	4345
SAKARYA	19043	4068	12200	1963	18712	1675
YALOVA	9462	727	7917	1036	12685	1881
TOTAL	**66441**	**10901**	**67242**	**9927**	**80160**	**9712**

Kocaeli is the province most affected by the earthquake. Within the total damage caused by Kocaeli earthquake, 48% of the heavy damage, 43% of the moderate damage and 40% of slight damage occurred in Kocaeli. According to 1997 census, population of Kocaeli was 1,177,379. In districts of Kocaeli, Gölcük is the one with largest damage and most loss of life in percent. 35.7% of the residences in Gölcük (with subdistricts and villages) were heavily damaged, while this percentage is 14.19 in Karamürsel district, 12.75 in Körfez district and 10% in Kocaeli city center. The number of people died in Gölcük (with subdistricts and villages) was 5025, which is 6.84% of the population. This percentage is 1,76% in Kocaeli city center. The distance of Gölcük to epicenter is only 7.12 km. Değirmendere is a subdistrict of Gölcük and 35% of Gölcük's population were living in Değirmendere according to 1997 census. This subdistrict is on the shore between Karamürsel and Gölcük districts and is only 3 km. from Gölcük. The distance of Değirmendere shore to the fault is 350 m (Ishihara et.al, 2000). 41% of the heavily damaged residences of Gölcük are in Değirmendere.

An isoseismal map of Kocaeli earthquake was prepared by Özmen (2000.b) with the use of MSK (Medvedev-Sponhever-Karnik) Scale (Figure 3.5). There are four centers of damage with an intensity of X; Adapazarı city center, Çiftlikköy, Gölyaka and Gölcük. Among these regions, Gölcük is the one with largest vicinity area of intensity X as expected because of the closeness to epicenter. The total surface area on isoseismal map with intensity scale X is 294 km^2. The total number of people living on this area was 419,699 and total number of residences was 98,175. Totally 33% of these residences were heavily damaged.

As a result of the fact that Marmara region is the most developed and crowded part of Turkey, huge number of life losses and heavy damage occurred. Totally 15,816,476 people were affected by earthquake, which was about quarter of the Turkey's population in 1999.

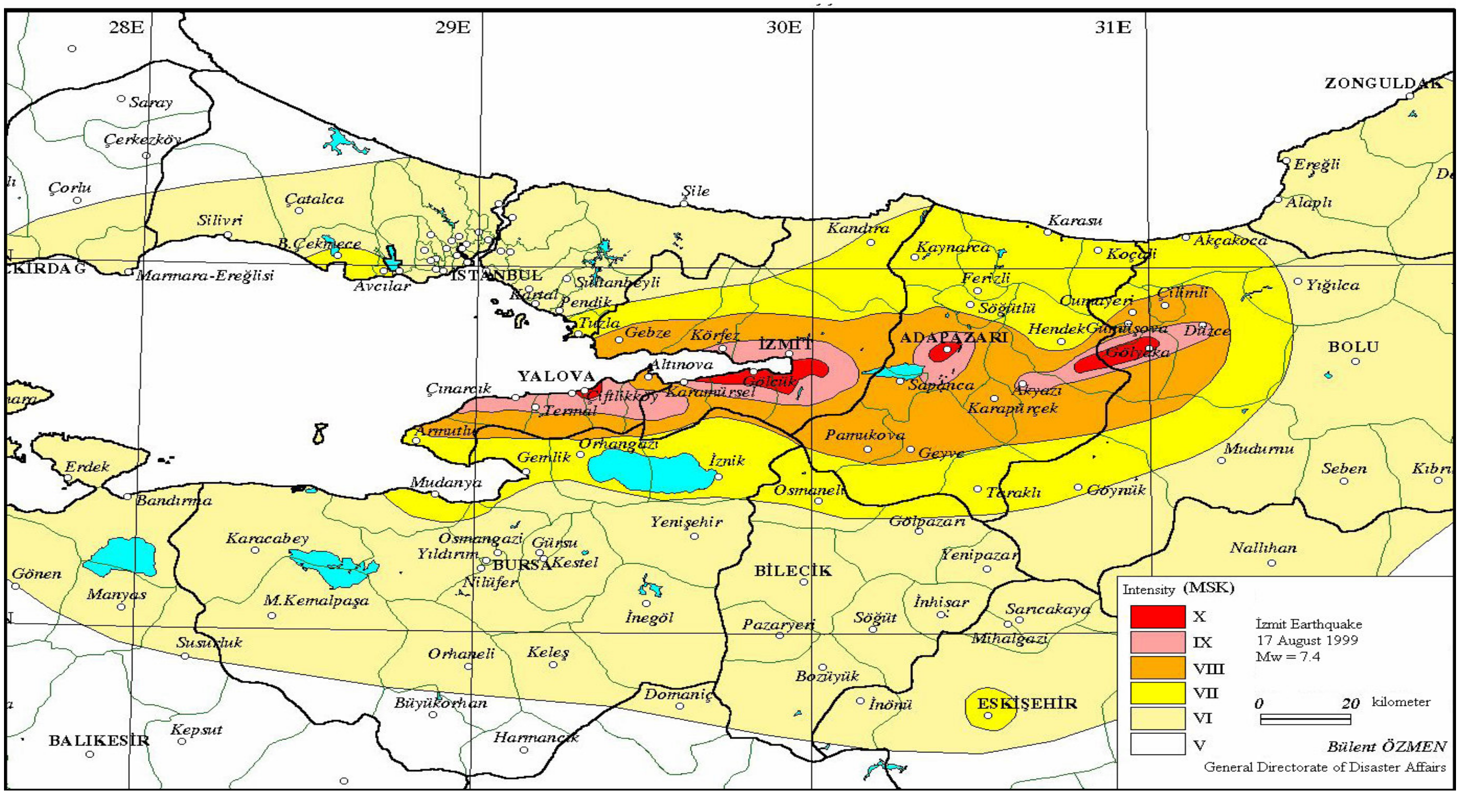

Figure 3.5 Isoseismal map of Kocaeli earthquake (Özmen, 2000.a)

3.4. Değirmendere Shore Landslide

3.4.1. Location and Soil Conditions

Değirmendere is a subdistrict of Gölcük district on the south coastline of İzmit bay. It is on the highway connecting Karamürsel and Gölcük districts in east-west direction, closer to Gölcük. The distance between Değirmendere and Gölcük is 3 km (Figure 3.6).

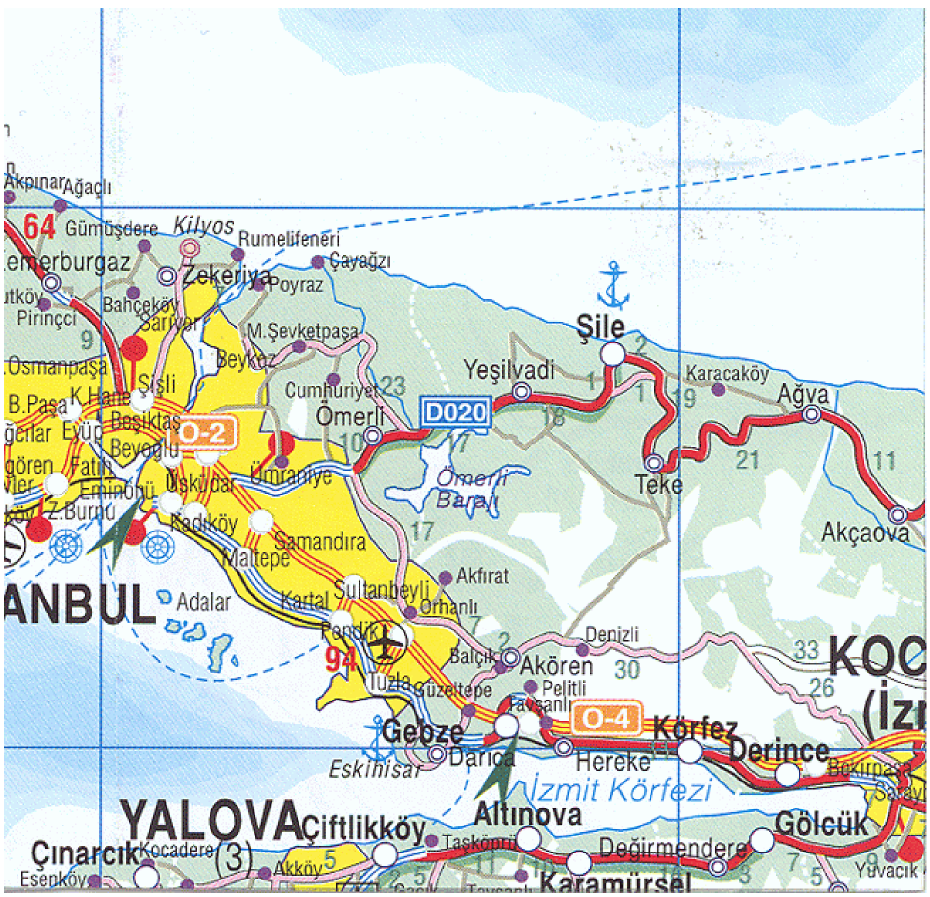

Figure 3.6 Road map around İzmit gulf

The active faults on Anatolian plate were studied by Şaroğlu et.al (1992, MTA). According to these studies it is exposed that the western part of North Anatolian Fault (NAF) is separated into two branches and the north branch dives into Marmara Sea at the beginning of İzmit bay (Figure 3.7). It passes along the south coastline going forward in the west. Between Gölcük and Altınova -where Değirmendere is also located-, the fault is in the sea but very close to the shore. The distance of NAF to Değirmendere shore is about 350 m (Ishihara et.al, 2000).

Figure 3.7 North Anatolian Fault passing close to Değirmendere shore

İzmit Bay is a tectonic subsidence basin, morphologically formed by North Anatolian Fault, separating the Miocene Erosion Surface (MES). This subsidence basin is also called Adapazarı Corridor. MES is the oldest geomorphologic unit in the region, which is seen as ridges at south boundary of Değirmendere today. At Değirmendere coastline, the main geomorphologic formation is the alluvial precipitates which are not indurated. These alluvial deposits formed in the Holocene Period during 8000 years (Arel &.Kiper, 2000.a).

Several borings very close to the failure edge are opened by Kiper & Arel (2000.b) at Çınarlık shore. Examining the results of these studies, the soil profile of Çınarlık shore at shallow depths (0 – 8 m) is principally formed by SM, GM, ML soil types. They constitute saturated layers with low density, which is susceptible to liquefaction. The deeper layers are in SW, GM, GW types in general, density increasing with depth. The soil is saturated and ground water level is about 1 m (Kiper & Arel, 2000.a).

3.4.2. Shore Landslide

A shore landslide occurred on Çınarlık shore of Değirmendere, sliding a huge soil mass into the sea. Çınarlık shore is a peninsular nose intrusion into İzmit Bay at north edge of Değirmendere. On the area slid, there existed a recreational area with facility establishments and a municipality hotel (Çınar Hotel) (Figures 3.8 and 3.9). The dimensions of the area slid into sea are 230 m long in east-west direction and 75 m wide in north-south direction. The volume of the soil slumped is predicted to be 200,000 – 300,000 m^3.

A bathymetry map is prepared by Kiper & Arel (2000.a) by ultrasonic method. Examining this map, the new basin has a uniform slope, without a sudden fall. There exists swelling on basin and this shows that the soil mass was exposed to lateral spreading by turbulences up to 300 – 350 m. It is important to remember here that the distance of North Anatolian Fault to the coastline is also 350 m, as emphasized in section 3.4.1. The information at hand leads us to decide that the failure mechanism is composed of several components;

- Effect of the fault, rupturing the toe of slope
- Seismic contribution to the slope instability
- Liquefaction of the alluvial deposits at shallow depths (0 – 8 m)
- Lateral spreading of slumped material by turbulences

Besides, tsunami is also studied by researchers (Rothaus, R.M., et.al., 2004; Tinti, S., et.al., 2006) but this is not the subject of this thesis. The question is, which of them controlled the failure. The failure mechanism is predicted by the author of this thesis as a seismically induced shore landslide also triggered by liquefaction and fault rupture, where lateral spreading by turbulence accompanies. The analyses performed have an aim of computing permanent displacements by this seismically induced landslide using Newmark Method.

Figure 3.8 Çınarlık shore before earthquake (Çetin et.al, 2004.a)

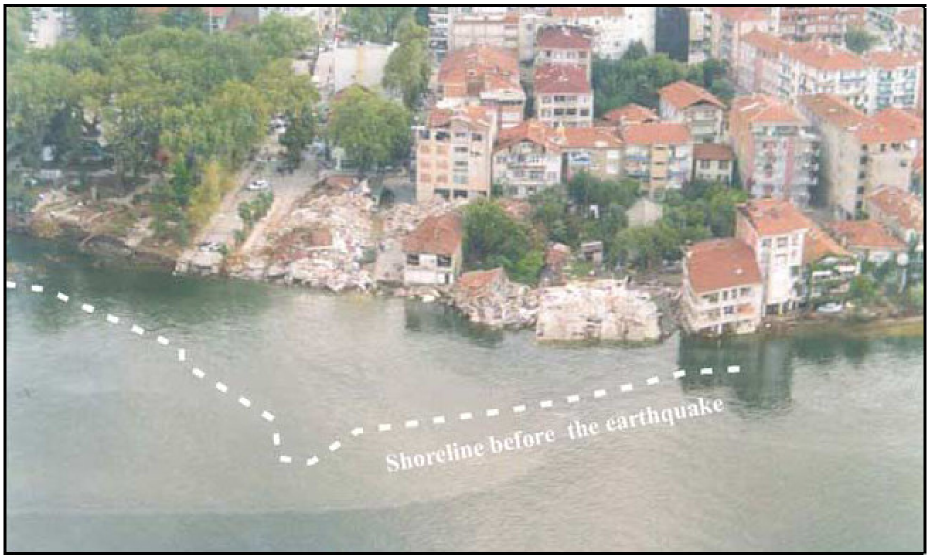

Figure 3.9 Çınarlık shore after earthquake (Çetin et.al, 2004.a)

3.4.3. Method of Analysis

The problem in the scope of this thesis can be subdivided into four stages;

1. Analysis of static situation (stresses) in the body
2. Finding the potential slip surface and seismic coefficient that generates landslide
3. Dynamic analysis of the body
4. Calculation of permanent displacements

Different computer programs are employed with actual field data in order to catch the behavior of Değirmendere landslide during Kocaeli earthquake. Finite element programs are the most robust tools to analyze this kind of problem. The geometry of the slope and physical properties of earth material are determined as the first step of analysis. The studies carried out by Arel &

Kiper (2000.b) and the bathymetric map prepared by the Department of Navigation, Hydrography and Oceanography helped in these determinations, as will be explained in section 3.4.4. The representative cross-section of slope is prepared for the whole slid mass, and it is converted to a finite element mesh. The mesh is composed of 223 elements and 256 nodal points.

To find the static stresses in the slope, the computer program TELSTA is used. It is a computer program designed for plane strain and axisymmetric static finite element analyses of soils and simple structures. The calculation proceeds in increments specified by the user. A successive incremental procedure is used to approximate the non-linear behavior of soil. In the procedure, the load is divided into a number of small increments and the soil behavior is assumed to be linear elastic within each element.

TELSTA uses the theories of strength, stress-strain and bulk modulus parameters for finite element analyses of stresses and movement in soil mass by J.M. Duncan, Peter Byrne, Kai S. Wong and Philip Molary. This describes the hyperbolic parameters and presents parameter values determined from drained and undrained tests on a number of soils. As described by Duncan et.al. (1980), the stress-strain relation is described with aid of equation below;

$$\sigma_1 - \sigma_3 = \frac{\varepsilon}{\frac{1}{E_i} + \frac{\varepsilon}{(\sigma_1 - \sigma_3)_{ult}}} \qquad (3.1)$$

An improvement made by this modeling is the variation of elastic modulus with confining pressure. Duncan introduced this formulation as;

$$E_i = K.P_a.(\frac{\sigma_3}{P_a})^n \qquad (3.2)$$

where K is the modulus number, n is the modulus exponent and P_a is the atmospheric pressure. Since Duncan suggested this theory up to failure point, TELSTA also uses a number to estimate the failure point.

$$(\sigma_1 - \sigma_3)_f = R_f . (\sigma_1 - \sigma_3)_{ult} \tag{3.3}$$

whereas R_f is in the range 0.5 – 0.9. Bulk modulus of the soil is calculated according to the equation;

$$B = K_b . P_a . (\frac{\sigma_3}{P_a})^n \tag{3.4}$$

TELSTA uses quadrilateral elements that can be reduced to triangles. The material constants are calculated according to Duncan & Chang hyperbolic model and Hardin & Drnevich hyperbolic model in order to define non-linear behavior of soil. Those parameters are assigned to the input file of TELSTA with the aid of test results obtained from borings which are opened by Arel & Kiper (2000.b).

TELSTA creates an output file to be used in the input file of the computer program TELDYN. In this output file, the data of nodal points and elements including mean effective stresses of elements are given in a format necessary for TELDYN. The boundary conditions of nodal points are also included. TELDYN is a computer program designed for equivalent linear, plane strain, dynamic finite element analysis of soils. The concept of equivalent linear seismic analysis involves conduct of several iterations in order to obtain shear moduli and damping ratios in each element that are compatible with the average level of shear strain induced by shaking. As introduced by Seed & Idriss (1969), the concept uses single values of shear modulus and damping ratio in each element throughout the entire period of shaking. However in TELDYN it is possible for the user to divide input acceleration history into segments.

The concept of equivalent linear dynamic finite element analysis involves conduct of several iterations in order to obtain single values for the shear modulus and damping ratio in each element that are compatible with average level of shear strain induced by shaking. Two steps are actually involved in this equivalencing;

1. Within each cycle of loading the shear stress-strain relationships for soils are non-linear and exhibit hysteretic damping. As the cyclic shear strain amplitude increases, the average modulus decreases hysteretic as indicated by the area enclosed by stress-strain curve increases. The average "equivalent linear" shear modulus can be represented by the secant modulus drawn through the end of the hysteresis loop.
2. The second step in equivalencing process involves choosing an appropriate average shear strain to use in the determination of the modulus and damping values to be used in the analyses. A typical shear strain history is irregular in nature. Conventionally the average shear strain is taken to be equal to 0.65 times the maximum shear strain.

Seed & Idriss proposed an equation for the assessment of the maximum shear stresses developed during an earthquake;

$$\tau_{\max} = \gamma.\frac{h}{g}.a_{\max}.r_d \tag{3.5}$$

where r_d is the stress reduction factor with depth and a_{max} is the maximum ground acceleration.

The actual time history of shear stress at any point in a soil deposit during an earthquake will have an irregular form. However, after experiencing a number of different cases it has been found that with a reasonable degree of accuracy the average equivalent uniform shear stress τ_{av} is about 65 % of τ_{max} ;

$$\tau_{av} = 0.65\ \gamma.\frac{h}{g}.a_{\max}.r_d \qquad (3.6)$$

In TELDYN a slightly different procedure is used in the second step of the equivalencing process. Division of the acceleration histories into segments is a convenient way to subsequently obtain the shear stress and shear strain histories in segments. TELDYN is then set up to iterate within each segment and to obtain strain compatible values of the shear moduli and damping ratios for use in that segment before proceeding to the next segment. However the user must specify initial estimates of shear modulus reduction factor and damping ratio to be used on the first iteration of the first segment.

Ideally, the value of shear modulus at small strains and the curves which define the variation of shear modulus and damping ratio with cyclic shear strain will be determined by appropriate field and laboratory tests for each material type involved. However some guidance on the selection of typical values is provided as default values with average Seed & Idriss curves for sand. For each material type user has option for specifying the shear modulus G_{max} at low strains.

$$G_{\max} = K_g.P_a.(\frac{\sigma'_m}{P_a})^{ng}.(OCR)^{nocr} \qquad (3.7)$$

where K_g is 22 times K_{2max} and ng is 0.5 according to Seed & Idriss, $\sigma m'$ is the initial mean effective stress computed in TELSTA.

Beside shear modulus, TELDYN needs Poisson's ratio for each material type. Equations of motion in TELDYN are solved using the Wilson stable step by step integration method.

Shear modulus reduction and damping ratio curves can be manually specified regarding the soil characteristics. The default curves of TELDYN may also be used. For saturated elements having the pore pressure curves as a default character of the program code, appropriate values of the number of cycles required to cause failure and the average shear stress as a function of confining pressure and initial shear stress ratios are obtained from the curves of DeAlba et.al. (1976). Calculation of average acceleration history is found for a potential sliding mass which is defined before as a potential slip surface having the minimum factor of safety. Having known the acceleration time history, the displacements of the sliding mass are computed using Newmark's family of methods. By integrating the acceleration time history twice, the displacements are computed.

3.4.4. Results of the Analysis

The analysis of failure at Değirmendere coastline is analyzed in four stages;

1. Static analysis of body with the computer program TELSTA
2. Static and pseudo-static slope stability analyses with computer program SLOPE
3. Dynamic analysis of body with the computer program TELDYN

4. Application of Newmark Method with the help of computer program MATLAB

In TELSTA analysis section, as emphasized above, a mesh with 223 elements and 256 nodal points is used which symbolizes a cross section of 487 m long and 120 m high (Figure 3.10).

The profile of the area including the slope subject to this study, prior to the earthquake, has been obtained by means of bathymetric measurements by Department of Navigation, Hydrography and Oceanography (connected to the Command of Turkish Armed Forces). The map has been prepared for Değirmendere subdistrict, including the topography of the slope under the coastline. Also Arel & Kiper (2000.b) prepared a drawing of the shore before earthquake, using both their own studies and this bathymetric map. Regarding these studies, the shore slope is introduced into the cross section with an inclination of 27^0. The ground level is lightly inclined down to the sea at Çınarlık shore and this is also reflected to the cross section.

The mesh is composed of 9 types of cohesionless materials. All of them are not different types of materials but as the depth increases, physical material properties change and for this reason different layers are utilized as different materials. Several borings were opened at Çınarlık shore by Kiper & Arel (2000.b). The samples has been investigated by triaxial tests, consolidation tests and unconfined compression tests. Also grain size curves and boring logs has been prepared by the researchers, which include SPT results. These studies helped determining material parameters. The 9 types of soil materials which are used in the analyses are shown in the limits of mesh on Figure 3.11.

The static analysis with TELSTA produced a file that gives element and nodal point data. The file includes initial mean effective stress values at each element at static situation. Also boundary conditions for nodal points are given. This data is integrated into the TELDYN input file.

The program TELDYN is used to find the acceleration time history of the mass slid into sea. The average acceleration history of mass can not be directly found. Instead, the cross section of the slid mass is divided into areas, the acceleration histories of nodal points at corners of the areas are computed with TELDYN, and the average acceleration history of mass is found using ratios of these areas to the whole slid area. For this process, first of all the slip surface of the landslide had to be studied. The computer program SLOPE is employed for this aim.

SLOPE is a computer program to make slope stability analyses and find the slip surface with the least factor of safety. It can make both static and pseudo-static analyses. So the studies with SLOPE progressed in two stages;

1. Static slope stability analysis
2. Pseudo-static slope stability analysis

In the first stage, static slope stability analyses of the body were performed to find the potential slip surface within many alternative slip surfaces. SLOPE does not use a mesh. Instead, layers of soil materials are introduced using x and y coordinates (Figure 3.12). The cross section is simplified in terms of length and the material types outside the potential failure section for the sake of simplicity. Ground water condition information is also entered into SLOPE input file. The sea level is entered as the level of ground water and is taken as 1 m below the shore line before failure (Kiper & Arel, 2000.a). An important advantage of SLOPE is the common point entrance for the potential slip surfaces to pass. At hand we have such information: the failure edge. The shore line before and after the earthquake are known and for our cross section the failure edge is at 70 m back of the original shore line (Figure 3.12). The failure edge point on cross section symbolizes the common point of potential slip surfaces for SLOPE. Having known this information, a grid of slip surface circle centers is assigned. At this stage seismic forces are taken as zero. Among the potential slip surfaces, the one with minimum factor of safety is given by SLOPE as;

- Center of circle: 200 , 295
- Radius of circle: 225.36 m
- Factor of safety: 1.926

and this circle is drawn on Figure 3.12. This potential slip surface is logical and consistent with our guess.

In the second stage of SLOPE analyses, seismic coefficient k_h is also included for the pseudo-static analysis method, which was explained in section 2.2.1. The slip surface found in first stage is used as the default circle. The other parameters are not changed, but only earthquake acceleration factor is entered in terms of 'g'. There are two components for acceleration: vertical and horizontal. Vertical component is entered zero because in TELDYN analysis only the horizontal component of the earthquake record, which is the greater one, is used. The horizontal component is increased step by step to decrease the factor of safety (FS) to 1. Several trials are made to reach FS = 1 and to examine the effect of increasing horizontal seismic coefficient k_h on FS (Table 3.5). A graph is drawn to observe the sensitivity of FS to seismic coefficient (Figure 3.13). FS = 1.003 is reached for the default circle with the horizontal seismic coefficient $k_h = 0.133$.

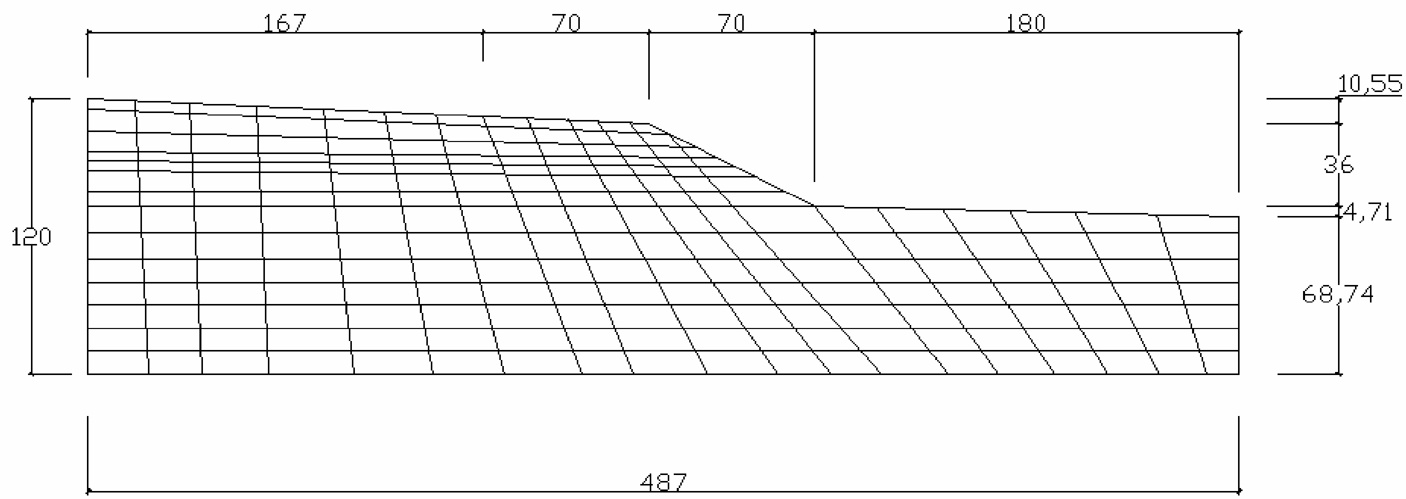

Figure 3.10 Mesh of cross section used in TELSTA and TELDYN analyses

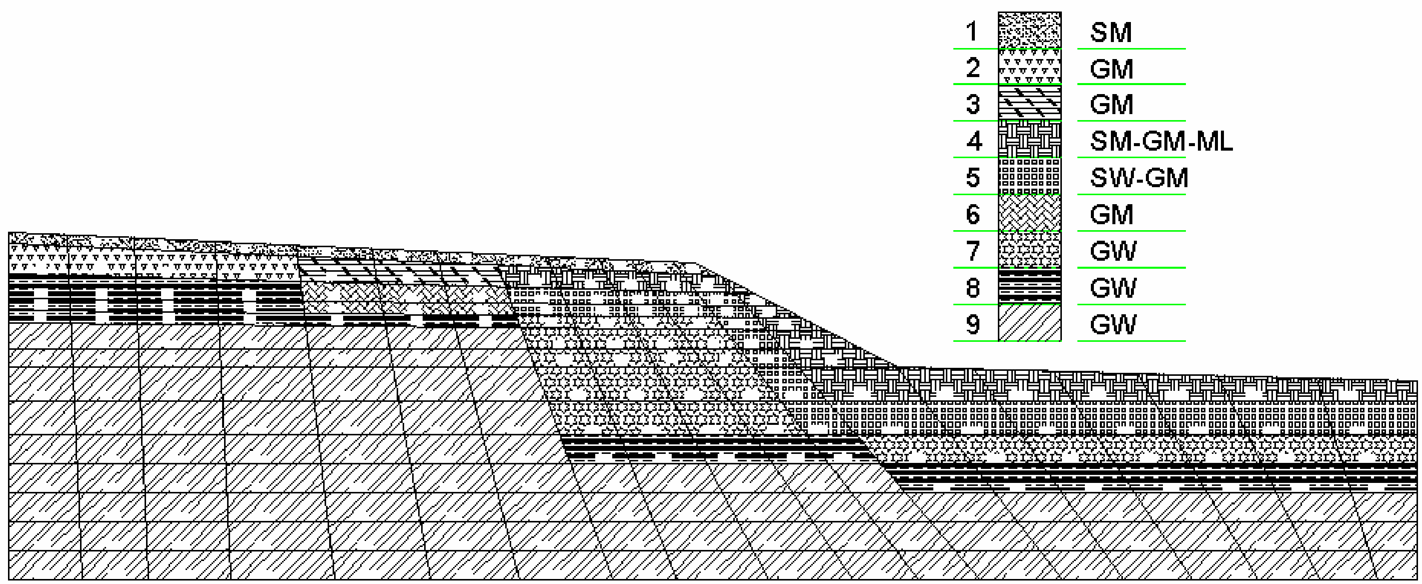

Figure 3.11 Cross section of the slope indicating the soil types

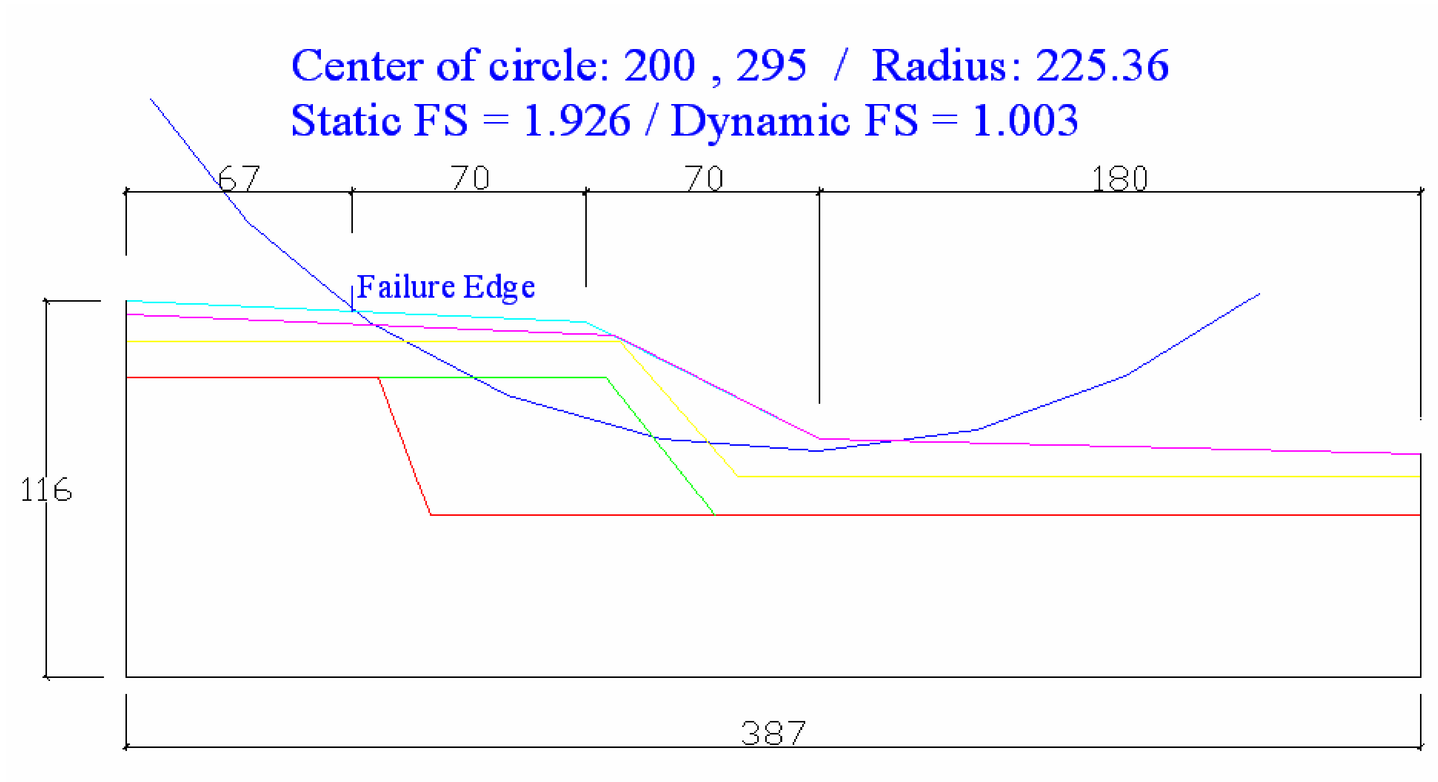

Figure 3.12 Cross section used in SLOPE analyses

Table 3.5 Seismic coefficient versus Factor of safety results of pseudo-static analysis with SLOPE

Seismic coefficient (k_h)	Static Factor of safety (FS)
0.000	1.926
0.010	1.807
0.020	1.702
0.030	1.607
0.040	1.522
0.050	1.444
0.060	1.374
0.070	1.309
0.080	1.250
0.090	1.195
0.100	1.145
0.110	1.098
0.120	1.055
0.130	1.014
0.140	0.977
0.150	0.941
0.133	1.003

These SLOPE analyses mean that, Çınarlık shore slope was stable before Kocaeli earthquake with a static FS of 1.926, and a seismic force was needed to fail it. The seismic acceleration needed to cause the landslide was 0.133g. İzmit station record of earthquake has a maximum acceleration of 0.225g in east-west direction and 0.171g in north-south direction, which is the earthquake input motion data used in this study.

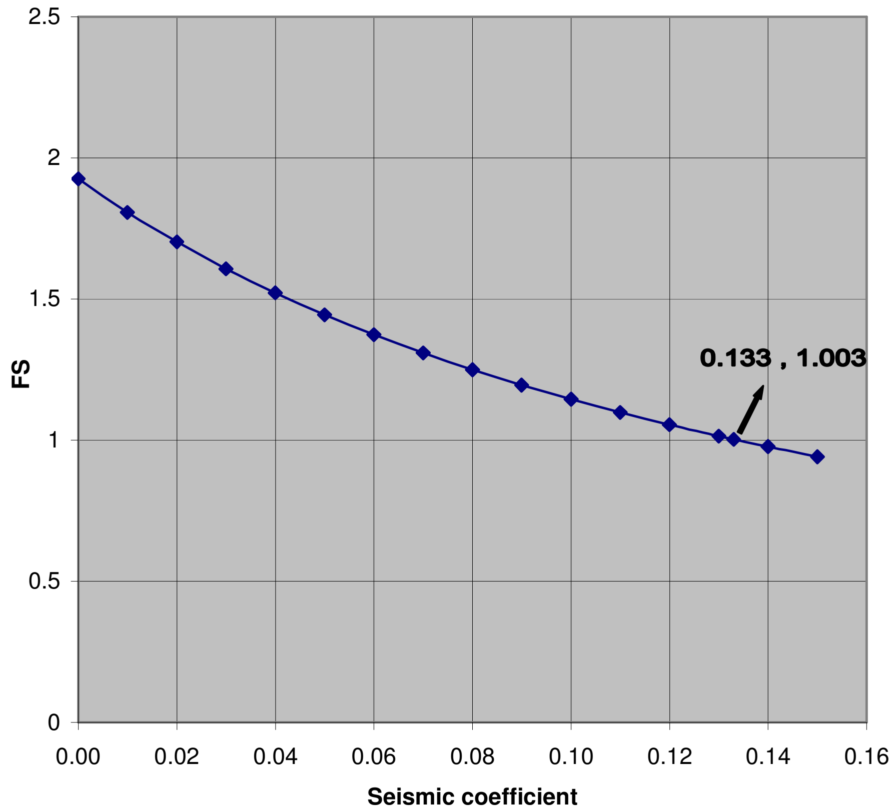

Figure 3.13 Sensitivity of FS to seismic coefficient

At this point, the dynamic analyses of the body with TELDYN could be started. The main goal of these analyses was, as emphasized before, getting the acceleration time histories of the necessary nodal points in the failed section. With the information of slip surface, the nodal points in the area of failure are decided.

For the formation of TELDYN input file, first of all the output file from TELSTA analysis is integrated, which gives nodal point and element data.

Earthquake input motion data is needed for the dynamic analyses. The most logical way to get this data is to use the real earthquake records.
İzmit (Meteorology station) record is taken as the earthquake input motion data, which is 13 km to Değirmendere. İzmit station is on rock site (Gülkan & Kalkan, 2002). This record data was taken from the official web site of General Directorate of Disaster Affairs (www.deprem.gov.tr). Dynamic analyses are performed using both the east-west component and the north-south component of İzmit station record. The E-W and N-S components of earthquake record generated peak values which are close to each other for most of the records (Table 3.2). Some N-S records have larger peak values than the E-W records, although this was a strike-slip type earthquake in E-W direction. So the two components are comparable with each other in terms of peak acceleration values, but both of them are used in the analyses to examine their effects and difference in results.

There is a critical point about the earthquake data, which is the maximum acceleration desired. The İzmit station record has a maximum acceleration value of 0.225g in E-W direction and 0.171g in N-S direction, which can not reflect the reality for Değirmendere. The distance of a region to the fault highly affects the peak ground acceleration (PGA) that occurs at that region. About this problem, Gülkan & Kalkan (2002) studied with many earthquake data dominated with 1999 Kocaeli and Düzce earthquakes. They generated curves for estimation of PGA in terms of the closest distance of a region to the fault (Figure 3.14). The maximum horizontal acceleration value in terms of 'g' is entered as 0.400 to TELDYN input file with the use of these curves. This value is comparable with the Sakarya record obtained on rock, 3.2 km away from the fault, which has a maximum acceleration value of 0.407g.

The failed area on our cross section has a lower boundary drawn by the slip surface. This failed area is divided into small areas in accordance with the mesh. The small areas are surrounded with nodal points at corners. Acceleration histories of these nodal points are generated with TELDYN. Firstly the average acceleration histories of the small areas are formed with the use of surrounding nodal points of each. Then weighted average acceleration history of the failed mass is generated using the ratios of small areas to the total failed area on cross section. This single average acceleration history is used to apply Newmark method for the purpose of finding permanent displacements.

As explained in section 2.2.2, Newmark method uses twice integration of the acceleration history, regarding the acceleration values larger than the yield acceleration. The yield acceleration a_y is the minimum pseudostatic acceleration required to cause the mass to move;

$$a_y = k_h \, . \, g \qquad (3.8)$$

where k_h is the horizontal seismic coefficient, which was calculated in pseudo-static analysis with the computer program SLOPE as 0.133.

When a mass is subjected to accelerations greater than the yield acceleration, the mass will move relative to its base. Thus, the relative acceleration constituting the displacement can be written as follows, where a(t) is the acceleration of mass:

$$a_{rel}(t) = a(t) - a_y \qquad (3.9)$$

Thus, by computing an acceleration at which the inertia forces become sufficiently high to cause yielding to begin and integrating the effective acceleration on the sliding mass in excess of this yield acceleration as a function of time, the velocities and permanent displacements of the sliding mass can be evaluated (Seed, H.B.,1979). For this complex procedure, the computer program MATLAB was used. Acceleration time history and the yield acceleration are entered into the input file. Both are multiplied with the gravitational acceleration g (9.81 m/s^2), so the yield acceleration is:

$$a_y = 0.133 \times 9.81 = 1.3 \text{ m/s}^2 \quad (3.9)$$

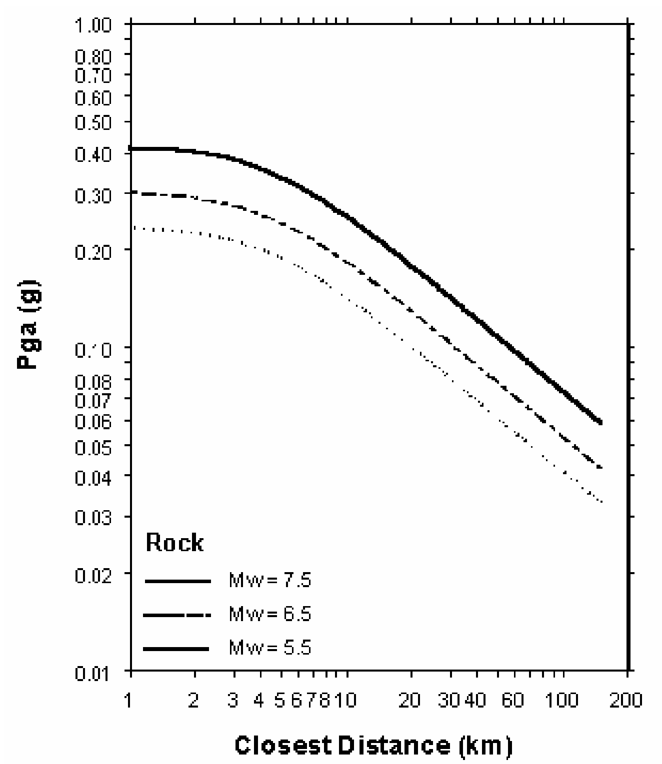

Figure 3.14 Curves of peak acceleration versus distance at rock sites (Gülkan & Kalkan, 2002)

Firstly, the TELDYN analyses are performed using N-S component of İzmit station record, since the failure occurred in north-south direction. This component has a peak acceleration value of 0.171g. The average acceleration time history of the failed mass is generated by the weighted average technique, as explained above. This average acceleration time history is introduced into MATLAB to calculate the permanent displacements by Newmark Method. MATLAB generated three graphs: acceleration, velocity and displacement graphs versus time. The yield acceleration line is drawn on the acceleration graph to supply examination of effective acceleration. These graphs are presented in Figures 15, 16, 17.

The displacement-time graph of sliding mass gives the permanent displacement that occurred for mass. At the end of earthquake, average permanent displacement is calculated as 73 cm for the whole failed mass.

Secondly, the E-W component of İzmit station record is entered into the TELDYN input file as earthquake input motion data. The same procedure is applied again to obtain firstly the average acceleration time history and finally the average permanent displacement of the failed mass. The acceleration, velocity and displacement graphs versus time are generated by METLAB, which are presented in Figures 18, 19, 20.

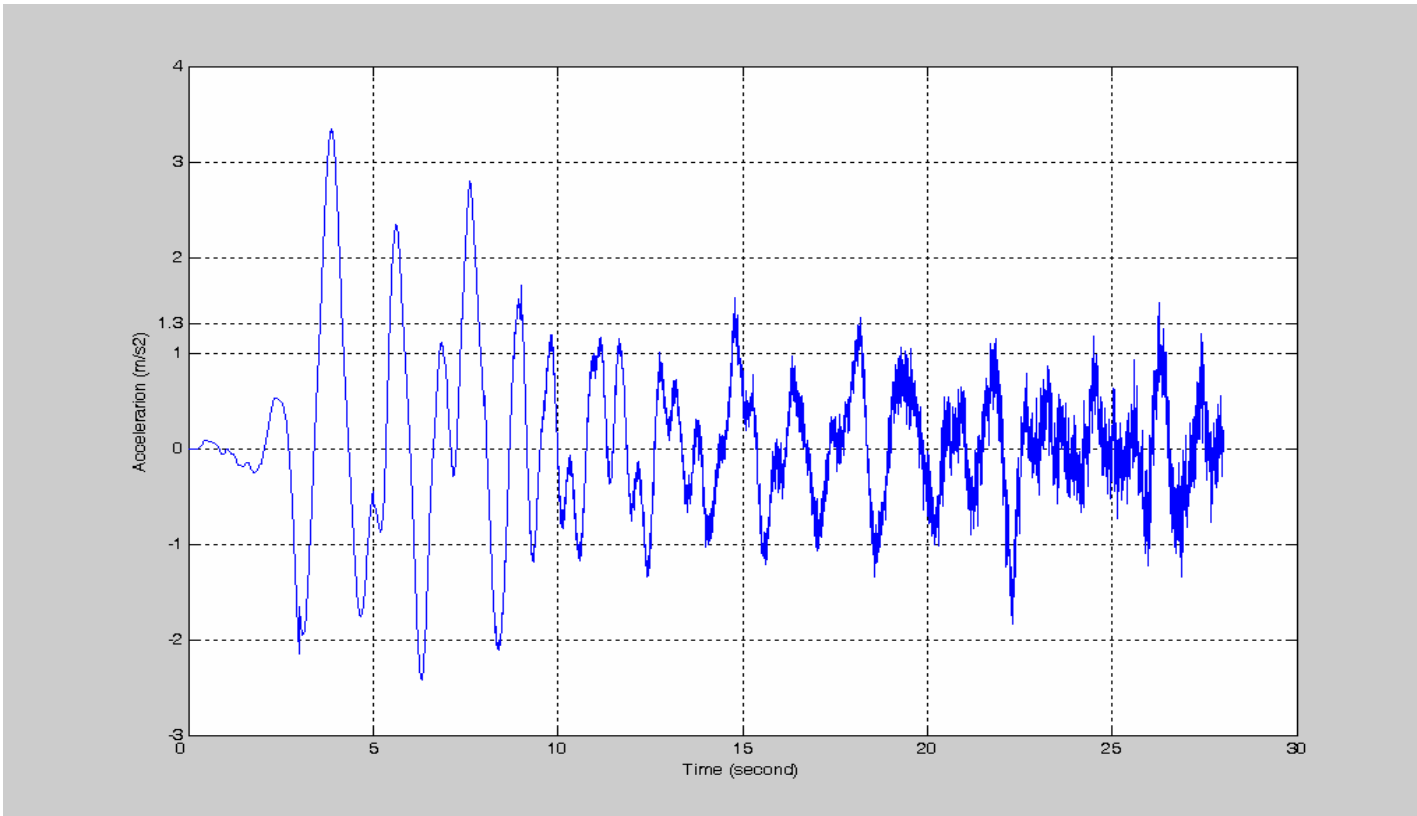

Figure 3.15 Acceleration-time graph of the sliding mass (with N-S eq. data)

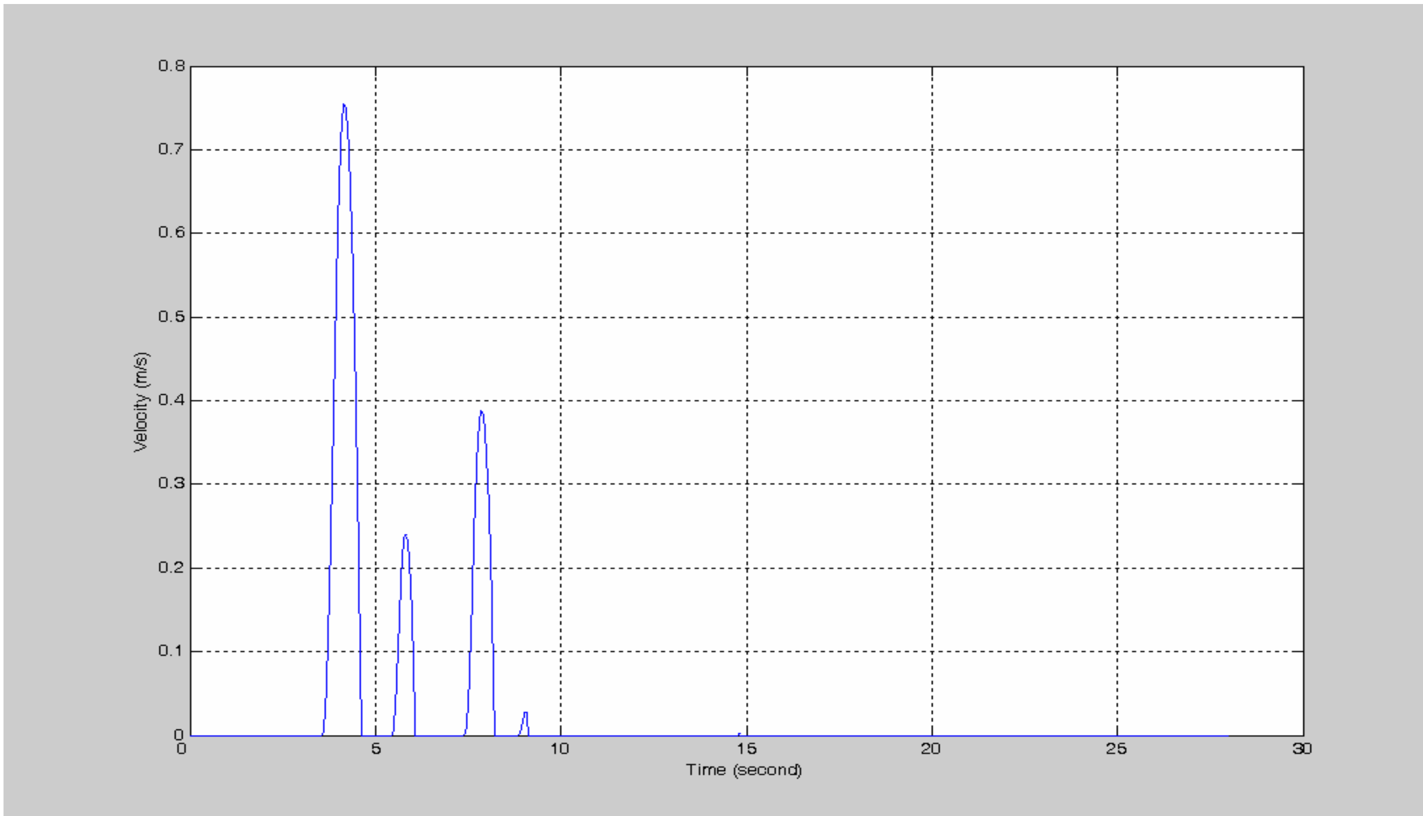

Figure 3.16 Velocity-time graph of the sliding mass (with N-S eq. data)

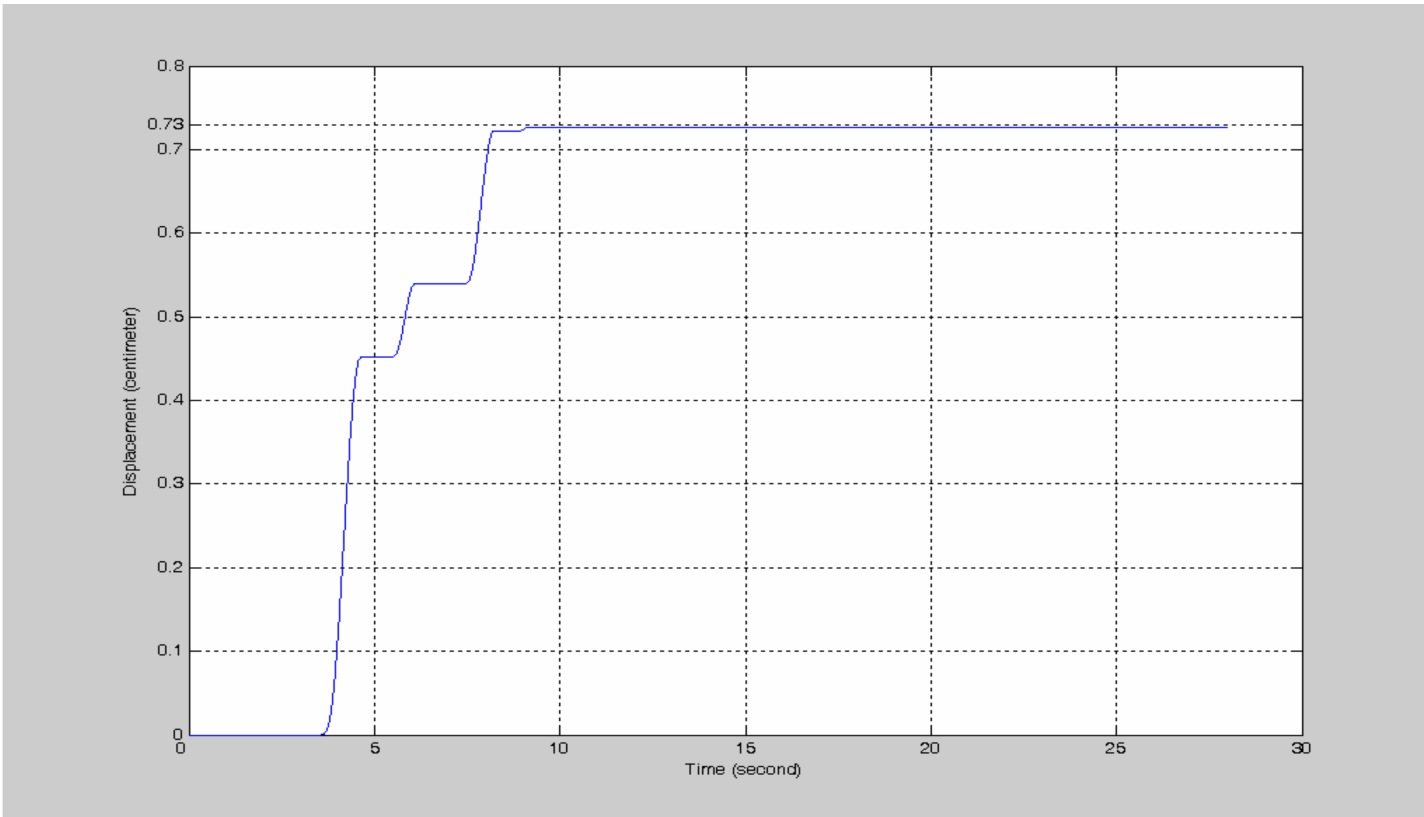

Figure 3.17 Displacement-time graph of the sliding mass (with N-S eq. data)

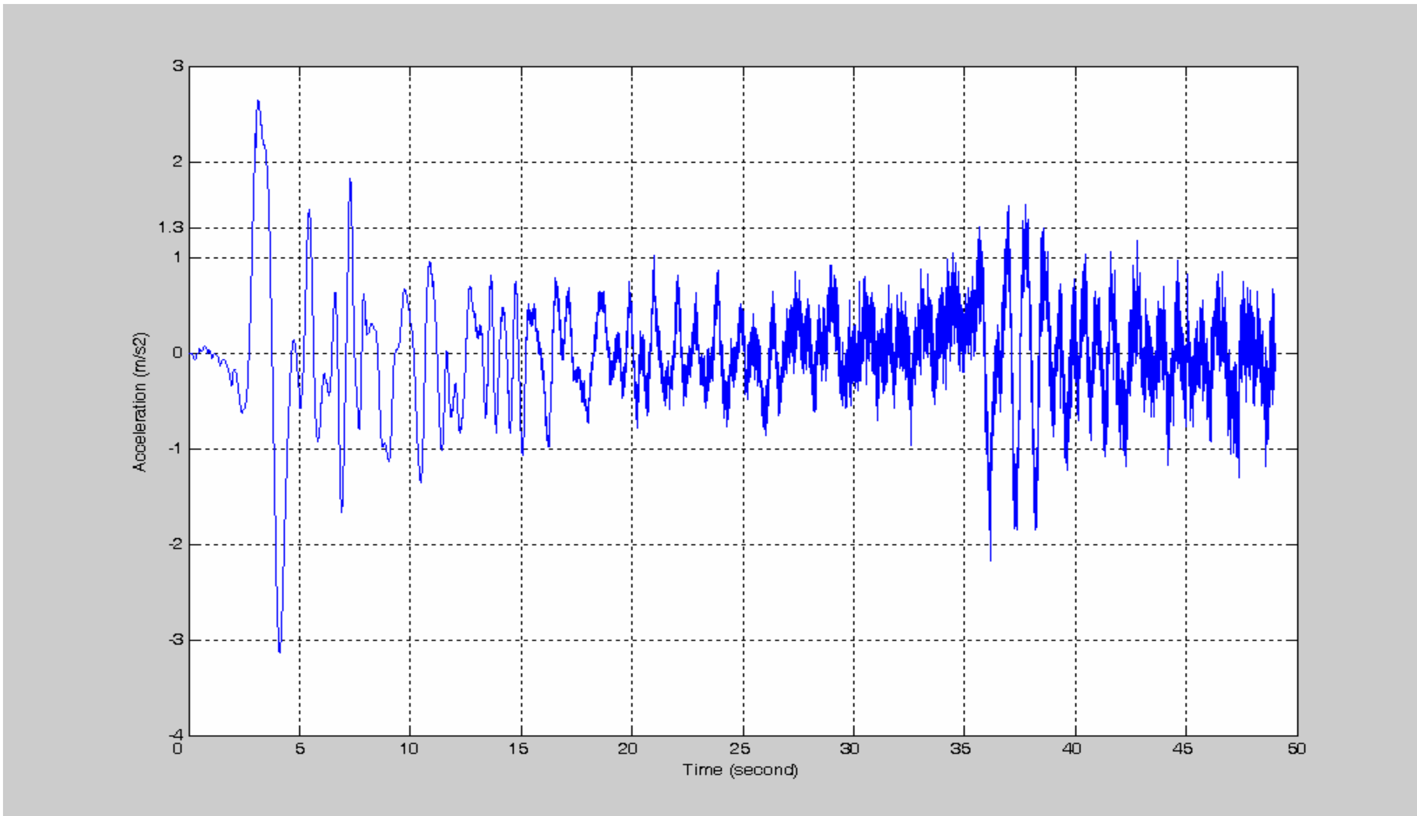

Figure 3.18 Acceleration-time graph of the sliding mass (with E-W eq. data)

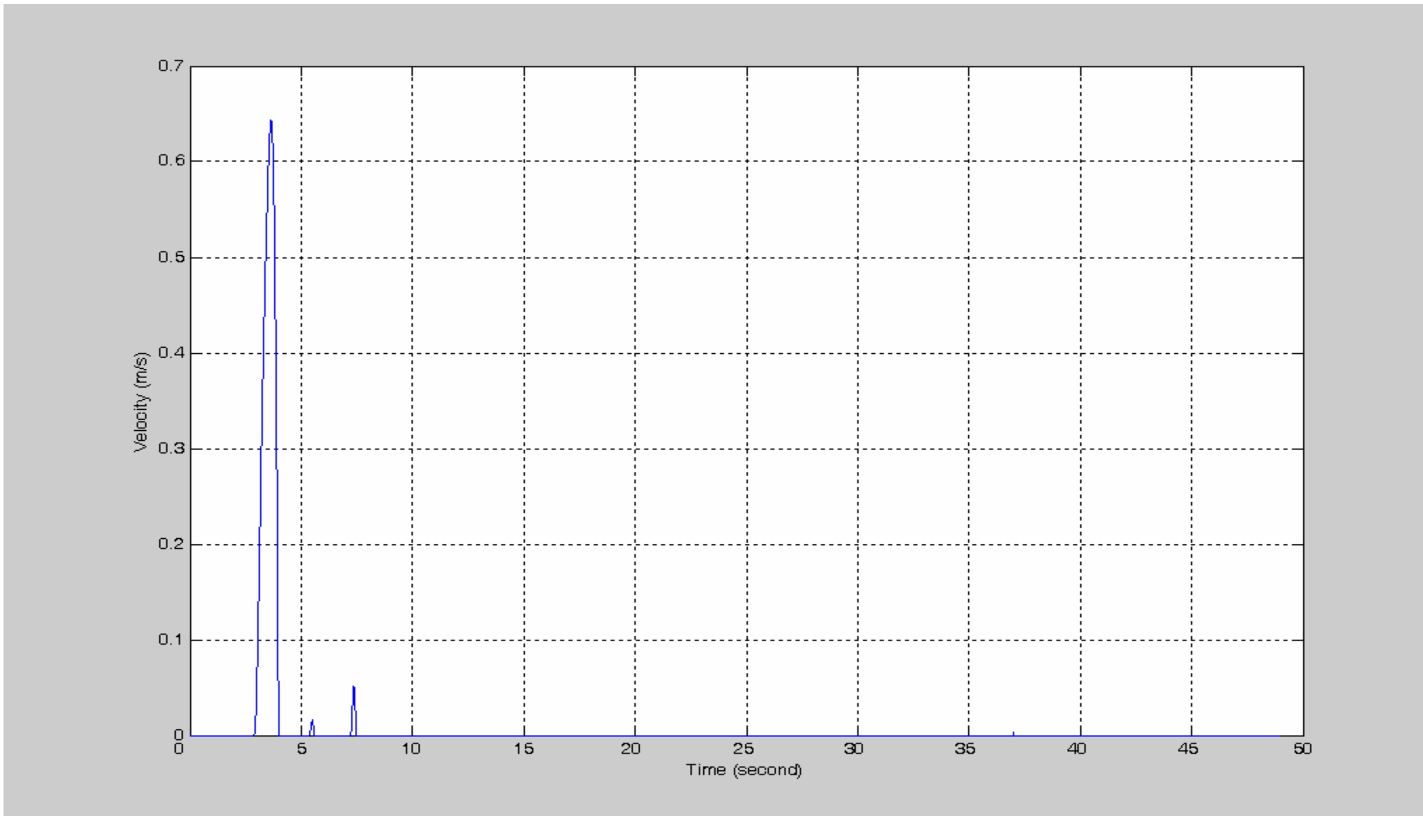

Figure 3.19 Velocity-time graph of the sliding mass (with E-W eq. data)

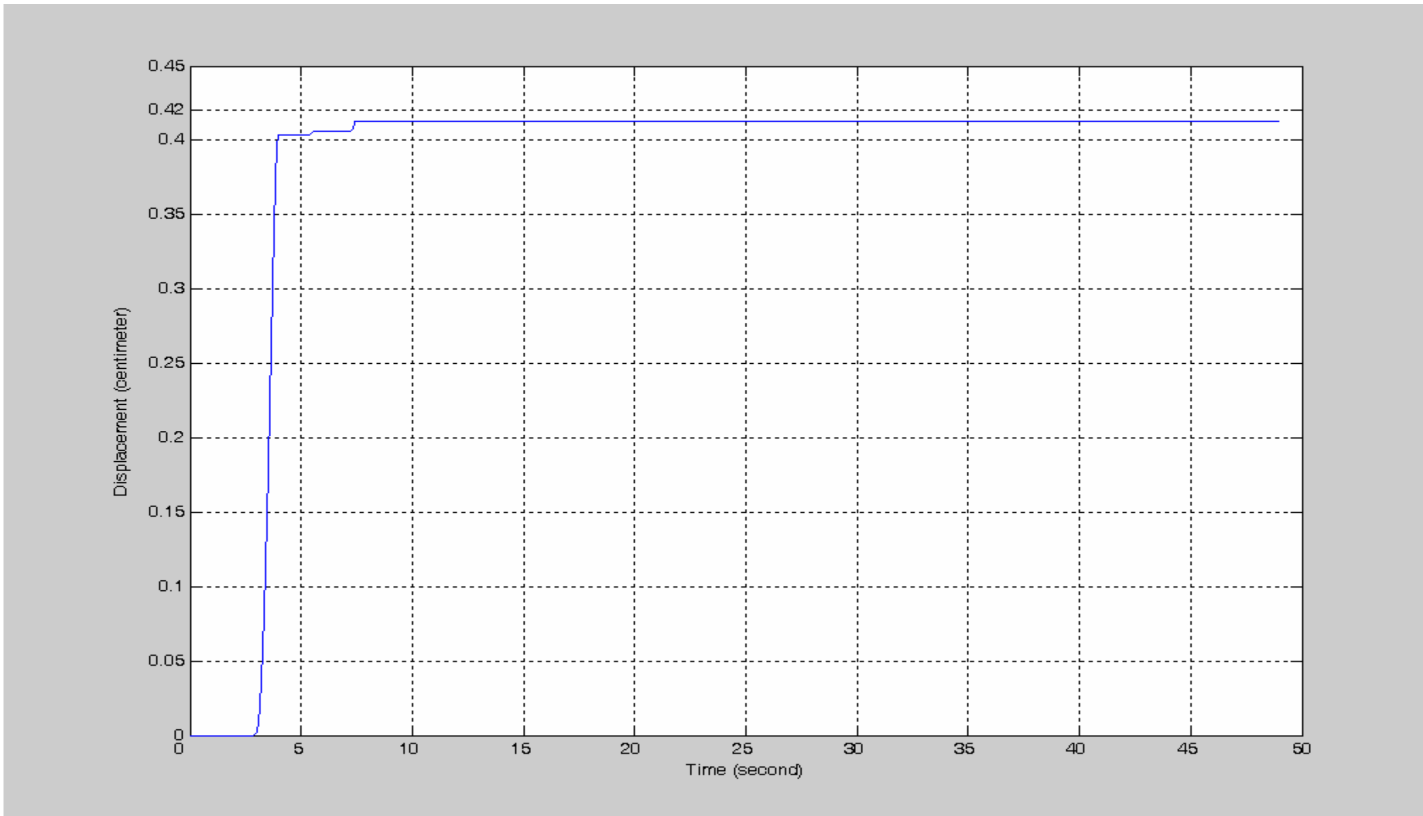

Figure 3.20 Displacement-time graph of the sliding mass (with E-W eq. data)

During the process applied and explained above, a tricky point has to be known. While the average acceleration histories of the mesh elements are calculated, it is observed that the average acceleration history filters out the maximum acceleration values obtained at the nodal points. For example, while an element with 3 nodal points have PGA values of 0.425, 0.420 and 0.435 at the nodes, the average acceleration history of the element is found to have a PGA value of 0.273. For this reason, an alternative way of calculating the average permanent displacement of mass is planned and applied to see the effect of this phenomenon.

In this procedure taking average of nodal points' acceleration histories is not applied. Instead, the displacements are calculated for each nodal point separately. Then the average displacement of small area in interest is calculated by taking the average of permanent displacement values of surrounding nodal points. At the end, weighted average method is applied to find the average permanent displacement of the mass, with the use of ratios of small areas to the total area.

Alternatively, this procedure is applied using the E-W component of İzmit earthquake record.. Using this alternative procedure, the average permanent displacement of the whole failed mass is calculated as 47 cm, whereas average permanent displacement was obtained as 42 cm by utilizing the average acceleration time history of the whole sliding mass. The average displacement is found to increase by 12 % with the alternative procedure.

CHAPTER 4

RESULTS AND CONCLUSION

In this study, the shore landslide occurred at Değirmendere coastline during 17 August 1999 Kocaeli earthquake is examined. The morphological structure of this failure is not clear as opposed to those that are generated on land. The reason for this uncertainty is that, the earth material is carried away by turbulence as a result of shock waves under water.

The analysis of shore landslide at Değirmendere is examined in four stages as explained in section 3.4.4. The first stage, the TELSTA analyses generated stresses in the body enclosed by cross section limits. Slope stability analyses are performed with the program SLOPE to reach two answers; to determine the slip surface on which the landslide occurred during Kocaeli earthquake and to assess a seismic coefficient which triggered the landslide. Then dynamic analyses are performed with TELDYN and the average acceleration time history of the failed mass is obtained. Using this acceleration time history, permanent displacements are calculated with Newmark Method using a program prepared by with the help of MATLAB.

Four points of discussion are mentioned in the academic studies concerning the mechanism of failure; seismically induced landslide, liquefaction in the first 10 m depth, fault rupture on the toe of failure basin, lateral spreading by turbulence as a result of wave attacks. Among them, the dominating mechanism is considered to be a landslide which is seismically induced by earthquake and the analyses in this study are performed to calculate the permanent displacements with Newmark Method.

The fault rupture is about 250 m far from the basin limit of landslide (350 m from the old coastline), which is considered to cause large accelerations.

Lateral spreading by turbulence may be a factor that continues the flow of earth material for a long time after the failure started. Spreading accompanies the failure but it is not probably more effective than the other three reasons to start failure. Examining the bathymetry map (Arel & Kiper, 2000.a), the new basin has a uniform slope, without a sudden fall. Rising of basin shows that the soil mass was exposed to lateral spreading by turbulences up to 300 – 350 m, remembering that the distance of North Anatolian Fault to the old coastline is also 350 m as mentioned above (Kiper & Arel, 2000.a).

Liquefaction might have been the most significant triggering mechanism after seismically induced landslide. There are studies on liquefaction of slope material at Değirmendere shore. Liquefaction analysis is performed by Çetin et.al. (2004.a). According to their conclusion, liquefaction of the soil layer below 8 m depth might have played a major role in the observed instability. "The soil layer at depth range of 8-11 m has small margin of safety against liquefaction triggering and is believed to have suffered from significant shear strength loss due to pore pressure generation. Remembering the fact that the site investigations were done on actually nonfailed soils, after the earthquake, it is believed that the soils slid into the bay as a result of slope instability are more prone to liquefaction and likely to exhibit less SPT blowcounts if site investigation studies had been performed on these soils before the landslide." (Çetin et.al., 2004.a). Soil at depths of 4-8 m is composed of relatively loose silt with low plasticity and sand (SM, GM, ML). Kiper & Arel (2000.a) suggest that there is a liquefaction possibility between depths of 4 m and 8 m. They suggest the dominating mechanism of failure as seismically induced landslide, rather than liquefaction.

The failure is analyzed as a seismically induced shore landslide. The permanent displacements are calculated by Newmark Method. The average permanent displacements of the sliding body calculated by this method using two components (north-south and east-west) of scaled İzmit station record of 1999 Kocaeli earthquake to a PGA of 0.4g, are tabulated below (Table 4.1). The maximum average permanent displacement of the slope is calculated to be significantly large, i.e., 73 cm.

Table 4.1 Average permanent displacements calculated for the failed mass

Displacements Calculated with Newmark Method (İzmit Station Record)	The N-S component of record is used for earthquake input motion data	The E-W component of record is used for earthquake input motion data
Average permanent displacement	73 cm	42 cm

As a matter of fact, the displacements should be larger than the calculated ones. The reason for this argument is that, the shear strength decrease as a result of excess pore pressure build up is not taken into account in this study. Build up of excess pore pressures during the cyclic loading of earthquake should have resulted in a decrease of shear strength which would have aggravated the slope movement, finally increasing the permanent displacements. This can be examined in the future studies.

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APPENDIX A

DESCRIPTION OF THE COMPUTER PROGRAM TELDYN

TELDYN is a computer program specifically designed for analysis of the response of soils to vertically propagating motions caused by earthquakes. An equivalent linear procedure is used to account for the nonlinearity of the soil. Furthermore, it is possible for the user to divide the input acceleration history into segments and the shear moduli and the damping ratios are then set to be compatible with the average shear strains within each segment.

Here the basic steps of input and output of the program are given:

A. Input Data
1) Nodes
2) Elements
3) Boundary Conditions
    a) Compliant boundary
    b) Viscous boundary
    c) Mixed boundary
4) Material Properties
    a) Modulus Reduction Curves of Construction Materials
    b) Damping Curves of Construction Materials
    c) Pore Pressure Generation Curves

d) Specific Values of Material Parameters

e) Saturated Elements

5) Input Motion

a) Data about Horizontal Input Motion

b) Data about Vertical Input Motion

B. Output Options

1) Print Options

2) Restart Options

APPENDIX B

REPRESENTATIVE TELDYN INPUT FILE

```
DEGIRMENDERE 1999 EARTHQUAKE
TELDYN INPUT
C GENERAL INPUT DATA
C No.Els No.Nodes No.nlhb No.nrhb No.ncb No.ess No.acc No.surf Plots?
  223     256      0      0        41    0       10      0      0
C Nummat No.usmrc No.usdc No.satel No.uswc No.usppc Damping Patm
  9      1        1      208    0      0       2    101.3
C RunOpt AvStrain Maxiter Maxdiff InitG InitD Hertz SFactor Dfactor
   1      1         3     0.10  1     0.0024   0.    1.       1.
C INPUT MOTION DATA
C Npim  Code Totseg  Nowseg  DT     Hamax Vamax
 10391  1     52      52    0.005  0.400   0
 1.0
 1.0
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 0.65
C MATERIAL PROPERTY DATA
C No. Unitw Mrcno. Dcno. GmaxCode E2Code
  1   17     0      0     2       4
C  Kg  ng
  750  0.25
C  Poisson's ratio
  0.30
  2   18     1      1     2       4
```

```
  850  0.4
  0.25
  3   18     1      1     2       4
  900  0.4
  0.25
  4   17     1      1     2       4
  1050  0.25
  0.30
  5   19     1      1     2       4
  950  0.4
  0.33
  6   20     1      1     2       4
  900  0.4
  0.28
  7   21     1      1     2       4
  950  0.4
  0.33
  8   21     1      1     2       4
  900  0.4
  0.37
  9   22     1      1     2       4
  900  0.5
  0.40
C DEGRADATION CURVES
C GRAVEL
  1.0  0.97 0.73   0.37   0.1     0.08
C DAMPING CURVES
C GRAVEL
  0.0053  0.016  0.0533 0.16  0.256  0.30
C COMPLIANT BASE DATA
C Unitw Pwvel Swvel
10000 10000000 90000000
C NODAL POINT DATA
C   No.      X      Y    Code5   Code6
1         0                  120.000          0          4
2         20.100             119.100          0          0
3         43.200             118.100          0          0
4         71.300             116.800          0          0
5         99.500             115.600          0          0
6         125.200            114.400          0          0
7         147.300            113.500          0          0
8         167.300            112.600          0          0
9         186.100            111.700          0          0
10        203.500            111.000          0          0
11        215.300            110.400          0          0
```

12	229.200	109.800	0	0
13	237.200	109.500	0	0
14	0	116.000	0	4
15	20.300	115.100	0	0
16	43.400	114.100	0	0
17	71.500	112.800	0	0
18	99.900	111.600	0	0
19	125.900	110.400	0	0
20	148.300	109.400	0	0
21	168.800	108.500	0	0
22	187.700	107.700	0	0
23	205.700	106.900	0	0
24	218.100	106.300	0	0
25	232.400	105.700	0	0
26	245.700	105.100	0	0
27	0	105.900	0	4
28	20.700	105.300	0	0
29	43.800	104.700	0	0
30	71.900	103.900	0	0
31	100.900	103.100	0	0
32	127.300	102.400	0	0
33	150.300	101.800	0	0
34	171.500	101.200	0	0
35	190.500	100.700	0	0
36	209.200	100.200	0	0
37	222.600	99.900	0	0
38	237.300	99.500	0	0
39	250.800	99.100	0	0
40	257.700	98.900	0	0
41	0	97.200	0	4
42	21.100	97.000	0	0
43	44.100	96.800	0	0
44	72.200	96.500	0	0
45	101.700	96.200	0	0
46	128.500	95.900	0	0
47	151.800	95.700	0	0
48	173.600	95.500	0	0
49	192.700	95.300	0	0
50	211.900	95.100	0	0
51	226.000	95.000	0	0
52	240.900	94.900	0	0
53	254.500	94.700	0	0
54	266.000	94.600	0	0
55	0	93.100	0	4
56	21.300	92.900	0	0

57	44.300	92.700	0	0
58	72.400	92.400	0	0
59	102.200	92.100	0	0
60	129.300	91.800	0	0
61	152.900	91.600	0	0
62	175.100	91.400	0	0
63	194.300	91.200	0	0
64	214.100	91.000	0	0
65	228.800	90.900	0	0
66	244.100	90.700	0	0
67	258.100	90.600	0	0
68	274.100	90.500	0	0
69	0	88.900	0	4
70	21.400	88.700	0	0
71	44.500	88.500	0	0
72	72.600	88.200	0	0
73	102.600	88.000	0	0
74	130.000	87.700	0	0
75	153.900	87.500	0	0
76	176.700	87.300	0	0
77	196.000	87.100	0	0
78	216.300	86.900	0	0
79	231.700	86.700	0	0
80	247.300	86.600	0	0
81	261.600	86.400	0	0
82	282.300	86.200	0	0
83	0	79.600	0	4
84	21.800	79.600	0	0
85	44.900	79.600	0	0
86	73.000	79.600	0	0
87	103.600	79.600	0	0
88	131.500	79.600	0	0
89	156.000	79.600	0	0
90	179.500	79.600	0	0
91	199.000	79.600	0	0
92	220.200	79.600	0	0
93	236.700	79.600	0	0
94	252.800	79.600	0	0
95	267.500	79.600	0	0
96	295.300	79.600	0	0
97	0	73.500	0	4
98	22.100	73.500	0	0
99	45.100	73.500	0	0
100	73.200	73.500	0	0
101	104.300	73.500	0	0

102	132.600	73.500	0	0
103	157.600	73.500	0	0
104	181.800	73.500	0	0
105	201.400	73.500	0	0
106	223.500	73.500	0	0
107	240.900	73.500	0	0
108	257.600	73.500	0	0
109	272.700	73.500	0	0
110	307.200	73.500	0	0
111	333.500	72.800	0	0
112	361.200	72.000	0	0
113	390.000	71.300	0	0
114	417.700	70.600	0	0
115	452.000	69.700	0	0
116	487.100	68.800	0	4
117	0	62.000	0	4
118	22.600	62.000	0	0
119	45.600	62.000	0	0
120	73.700	62.000	0	0
121	105.600	62.000	0	0
122	134.600	62.000	0	0
123	160.500	62.000	0	0
124	186.000	62.000	0	0
125	206.000	62.000	0	0
126	229.600	62.000	0	0
127	248.900	62.000	0	0
128	266.500	62.000	0	0
129	282.500	62.000	0	0
130	316.100	62.000	0	0
131	341.200	62.000	0	0
132	367.900	62.000	0	0
133	395.500	62.000	0	0
134	422.000	62.000	0	0
135	454.400	62.000	0	0
136	487.100	62.000	0	4
137	0	50.000	0	4
138	23.100	50.000	0	0
139	46.100	50.000	0	0
140	74.200	50.000	0	0
141	107.000	50.000	0	0
142	136.800	50.000	0	0
143	163.600	50.000	0	0
144	190.400	50.000	0	0
145	210.800	50.000	0	0
146	236.000	50.000	0	0

147	257.200	50.000	0	0
148	275.800	50.000	0	0
149	292.800	50.000	0	0
150	325.400	50.000	0	0
151	349.800	50.000	0	0
152	375.900	50.000	0	0
153	402.500	50.000	0	0
154	428.000	50.000	0	0
155	458.000	50.000	0	0
156	487.100	50.000	0	4
157	0	40.000	0	4
158	23.600	40.000	0	0
159	46.600	40.000	0	0
160	74.700	40.000	0	0
161	108.100	40.000	0	0
162	138.600	40.000	0	0
163	166.100	40.000	0	0
164	194.100	40.000	0	0
165	214.900	40.000	0	0
166	241.300	40.000	0	0
167	264.100	40.000	0	0
168	283.600	40.000	0	0
169	301.300	40.000	0	0
170	333.200	40.000	0	0
171	356.900	40.000	0	0
172	382.500	40.000	0	0
173	408.400	40.000	0	0
174	433.100	40.000	0	0
175	461.100	40.000	0	0
176	487.100	40.000	0	4
177	0	30.000	0	4
178	24.000	30.000	0	0
179	47.000	30.000	0	0
180	75.100	30.000	0	0
181	109.300	30.000	0	0
182	140.400	30.000	0	0
183	168.700	30.000	0	0
184	197.800	30.000	0	0
185	218.900	30.000	0	0
186	246.600	30.000	0	0
187	271.100	30.000	0	0
188	291.400	30.000	0	0
189	309.800	30.000	0	0
190	341.000	30.000	0	0
191	364.000	30.000	0	0

192	389.100	30.000	0	0
193	414.200	30.000	0	0
194	438.100	30.000	0	0
195	464.200	30.000	0	0
196	487.100	30.000	0	4
197	0	20.000	0	4
198	24.400	20.000	0	0
199	47.500	20.000	0	0
200	75.500	20.000	0	0
201	110.400	20.000	0	0
202	142.200	20.000	0	0
203	171.300	20.000	0	0
204	201.500	20.000	0	0
205	222.900	20.000	0	0
206	252.000	20.000	0	0
207	278.000	20.000	0	0
208	299.200	20.000	0	0
209	318.400	20.000	0	0
210	348.800	20.000	0	0
211	371.200	20.000	0	0
212	395.700	20.000	0	0
213	420.100	20.000	0	0
214	443.100	20.000	0	0
215	467.200	20.000	0	0
216	487.100	20.000	0	4
217	0	10.000	0	4
218	24.900	10.000	0	0
219	47.900	10.000	0	0
220	76.000	10.000	0	0
221	111.600	10.000	0	0
222	144.000	10.000	0	0
223	173.800	10.000	0	0
224	205.200	10.000	0	0
225	226.900	10.000	0	0
226	257.300	10.000	0	0
227	285.000	10.000	0	0
228	307.000	10.000	0	0
229	326.900	10.000	0	0
230	356.500	10.000	0	0
231	378.300	10.000	0	0
232	402.400	10.000	0	0
233	426.000	10.000	0	0
234	448.200	10.000	0	0
235	470.300	10.000	0	0
236	487.100	10.000	0	4

237	0	0	2	4
238	25.300	0	2	4
239	48.300	0	2	4
240	76.400	0	2	4
241	112.700	0	2	4
242	145.800	0	2	4
243	176.400	0	2	4
244	208.900	0	2	4
245	230.900	0	2	4
246	262.600	0	2	4
247	291.900	0	2	4
248	314.800	0	2	4
249	335.500	0	2	4
250	364.300	0	2	4
251	385.500	0	2	4
252	409.000	0	2	4
253	431.900	0	2	4
254	453.200	0	2	4
255	473.400	0	2	4
256	487.100	0	2	4

C ELEMENT DATA

C No.	I	J	K	L	MTYPE	SIGMN	SIGMN	OCR
1	1	14	15	2	1	-8.	-8.	1.
2	2	15	16	3	1	10.	10.	1.
3	3	16	17	4	1	-4.	-4.	1.
4	4	17	18	5	1	-11.	-11.	1.
5	5	18	19	6	1	22.	22.	1.
6	6	19	20	7	1	23.	23.	1.
7	7	20	21	8	1	38.	38.	1.
8	8	21	22	9	1	16.	16.	1.
9	9	22	23	10	1	45.	45.	1.
10	10	23	24	11	1	49.	49.	1.
11	11	24	25	12	1	50.	50.	1.
12	12	25	26	13	1	21.	21.	1.
13	14	27	28	15	2	113.	113.	1.
14	15	28	29	16	2	120.	120.	1.
15	16	29	30	17	2	118.	118.	1.
16	17	30	31	18	2	136.	136.	1.
17	18	31	32	19	3	117.	117.	1.
18	19	32	33	20	3	109.	109.	1.
19	20	33	34	21	3	92.	92.	1.
20	21	34	35	22	4	114.	114.	1.
21	22	35	36	23	4	117.	117.	1.
22	23	36	37	24	4	103.	103.	1.
23	24	37	38	25	4	100.	100.	1.

24	25	38	39	26	4	84.	84.	1.
25	26	39	40	40	4	34.	34.	1.
26	27	41	42	28	8	226.	226.	1.
27	28	42	43	29	8	234.	234.	1.
28	29	43	44	30	8	215.	215.	1.
29	30	44	45	31	8	190.	190.	1.
30	31	45	46	32	6	170.	170.	1.
31	32	46	47	33	6	196.	196.	1.
32	33	47	48	34	6	171.	171.	1.
33	34	48	49	35	5	166.	166.	1.
34	35	49	50	36	5	149.	149.	1.
35	36	50	51	37	5	154.	154.	1.
36	37	51	52	38	5	133.	133.	1.
37	38	52	53	39	5	108.	108.	1.
38	39	53	54	40	4	107.	107.	1.
39	41	55	56	42	8	351.	351.	1.
40	42	56	57	43	8	344.	344.	1.
41	43	57	58	44	8	328.	328.	1.
42	44	58	59	45	8	304.	304.	1.
43	45	59	60	46	6	258.	258.	1.
44	46	60	61	47	6	235.	235.	1.
45	47	61	62	48	6	205.	205.	1.
46	48	62	63	49	5	207.	207.	1.
47	49	63	64	50	5	206.	206.	1.
48	50	64	65	51	5	193.	193.	1.
49	51	65	66	52	5	169.	169.	1.
50	52	66	67	53	5	149.	149.	1.
51	53	67	68	54	4	127.	127.	1.
52	55	69	70	56	8	427.	427.	1.
53	56	70	71	57	8	421.	421.	1.
54	57	71	72	58	8	408.	408.	1.
55	58	72	73	59	8	378.	378.	1.
56	59	73	74	60	8	361.	361.	1.
57	60	74	75	61	8	329.	329.	1.
58	61	75	76	62	8	303.	303.	1.
59	62	76	77	63	7	339.	339.	1.
60	63	77	78	64	7	315.	315.	1.
61	64	78	79	65	7	292.	292.	1.
62	65	79	80	66	7	254.	254.	1.
63	66	80	81	67	5	173.	173.	1.
64	67	81	82	68	4	155.	155.	1.
65	69	83	84	70	9	562.	562.	1.
66	70	84	85	71	9	556.	556.	1.
67	71	85	86	72	9	539.	539.	1.
68	72	86	87	73	9	513.	513.	1.

69	73	87	88	74	9	490.	490.	1.
70	74	88	89	75	9	460.	460.	1.
71	75	89	90	76	9	452.	452.	1.
72	76	90	91	77	7	424.	424.	1.
73	77	91	92	78	7	410.	410.	1.
74	78	92	93	79	7	370.	370.	1.
75	79	93	94	80	7	316.	316.	1.
76	80	94	95	81	5	226.	226.	1.
77	81	95	96	82	4	196.	196.	1.
78	83	97	98	84	9	708.	708.	1.
79	84	98	99	85	9	701.	701.	1.
80	85	99	100	86	9	685.	685.	1.
81	86	100	101	87	9	660.	660.	1.
82	87	101	102	88	9	635.	635.	1.
83	88	102	103	89	9	610.	610.	1.
84	89	103	104	90	9	585.	585.	1.
85	90	104	105	91	7	547.	547.	1.
86	91	105	106	92	7	514.	514.	1.
87	92	106	107	93	7	460.	460.	1.
88	93	107	108	94	7	396.	396.	1.
89	94	108	109	95	5	293.	293.	1.
90	95	109	110	96	4	240.	240.	1.
91	97	117	118	98	9	879.	879.	1.
92	98	118	119	99	9	872.	872.	1.
93	99	119	120	100	9	858.	858.	1.
94	100	120	121	101	9	836.	836.	1.
95	101	121	122	102	9	813.	813.	1.
96	102	122	123	103	9	790.	790.	1.
97	103	123	124	104	9	756.	756.	1.
98	104	124	125	105	7	704.	704.	1.
99	105	125	126	106	7	652.	652.	1.
100	106	126	127	107	7	589.	589.	1.
101	107	127	128	108	7	506.	506.	1.
102	108	128	129	109	5	388.	388.	1.
103	109	129	130	110	4	302.	302.	1.
104	110	130	131	111	4	213.	213.	1.
105	111	131	132	112	4	144.	144.	1.
106	112	132	133	113	4	125.	125.	1.
107	113	133	134	114	4	108.	108.	1.
108	114	134	135	115	4	93.	93.	1.
109	115	135	136	116	4	84.	84.	1.
110	117	137	138	118	9	1106.	1106.	1.
111	118	138	139	119	9	1101.	1101.	1.
112	119	139	140	120	9	1088.	1088.	1.
113	120	140	141	121	9	1069.	1069.	1.

114	121	141	142	122	9	1045.	1045.	1.
115	122	142	143	123	9	1025.	1025.	1.
116	123	143	144	124	9	987.	987.	1.
117	124	144	145	125	7	893.	893.	1.
118	125	145	146	126	7	836.	836.	1.
119	126	146	147	127	7	756.	756.	1.
120	127	147	148	128	7	681.	681.	1.
121	128	148	149	129	5	515.	515.	1.
122	129	149	150	130	5	419.	419.	1.
123	130	150	151	131	5	361.	361.	1.
124	131	151	152	132	5	302.	302.	1.
125	132	152	153	133	5	261.	261.	1.
126	133	153	154	134	5	241.	241.	1.
127	134	154	155	135	5	224.	224.	1.
128	135	155	156	136	5	212.	212.	1.
129	137	157	158	138	9	1320.	1320.	1.
130	138	158	159	139	9	1315.	1315.	1.
131	139	159	160	140	9	1304.	1304.	1.
132	140	160	161	141	9	1286.	1286.	1.
133	141	161	162	142	9	1263.	1263.	1.
134	142	162	163	143	9	1231.	1231.	1.
135	143	163	164	144	9	1206.	1206.	1.
136	144	164	165	145	8	1085.	1085.	1.
137	145	165	166	146	8	1036.	1036.	1.
138	146	166	167	147	8	937.	937.	1.
139	147	167	168	148	8	814.	814.	1.
140	148	168	169	149	8	746.	746.	1.
141	149	169	170	150	7	614.	614.	1.
142	150	170	171	151	7	555.	555.	1.
143	151	171	172	152	7	501.	501.	1.
144	152	172	173	153	7	471.	471.	1.
145	153	173	174	154	7	446.	446.	1.
146	154	174	175	155	7	430.	430.	1.
147	155	175	176	156	7	421.	421.	1.
148	157	177	178	158	9	1516.	1516.	1.
149	158	178	179	159	9	1511.	1511.	1.
150	159	179	180	160	9	1501.	1501.	1.
151	160	180	181	161	9	1484.	1484.	1.
152	161	181	182	162	9	1460.	1460.	1.
153	162	182	183	163	9	1429.	1429.	1.
154	163	183	184	164	9	1355.	1355.	1.
155	164	184	185	165	9	1339.	1339.	1.
156	165	185	186	166	9	1214.	1214.	1.
157	166	186	187	167	9	1104.	1104.	1.
158	167	187	188	168	9	1007.	1007.	1.

159	168	188	189	169	9	945.	945.	1.
160	169	189	190	170	8	764.	764.	1.
161	170	190	191	171	8	720.	720.	1.
162	171	191	192	172	8	682.	682.	1.
163	172	192	193	173	8	651.	651.	1.
164	173	193	194	174	8	631.	631.	1.
165	174	194	195	175	8	617.	617.	1.
166	175	195	196	176	8	609.	609.	1.
167	177	197	198	178	9	1714.	1714.	1.
168	178	198	199	179	9	1709.	1709.	1.
169	179	199	200	180	9	1699.	1699.	1.
170	180	200	201	181	9	1681.	1681.	1.
171	181	201	202	182	9	1657.	1657.	1.
172	182	202	203	183	9	1616.	1616.	1.
173	183	203	204	184	9	1565.	1565.	1.
174	184	204	205	185	9	1493.	1493.	1.
175	185	205	206	186	9	1395.	1395.	1.
176	186	206	207	187	9	1265.	1265.	1.
177	187	207	208	188	9	1172.	1172.	1.
178	188	208	209	189	9	1043.	1043.	1.
179	189	209	210	190	9	995.	995.	1.
180	190	210	211	191	9	915.	915.	1.
181	191	211	212	192	9	885.	885.	1.
182	192	212	213	193	9	856.	856.	1.
183	193	213	214	194	9	835.	835.	1.
184	194	214	215	195	9	822.	822.	1.
185	195	215	216	196	9	817.	817.	1.
186	197	217	218	198	9	1914.	1914.	1.
187	198	218	219	199	9	1908.	1908.	1.
188	199	219	220	200	9	1897.	1897.	1.
189	200	220	221	201	9	1878.	1878.	1.
190	201	221	222	202	9	1851.	1851.	1.
191	202	222	223	203	9	1812.	1812.	1.
192	203	223	224	204	9	1752.	1752.	1.
193	204	224	225	205	9	1673.	1673.	1.
194	205	225	226	206	9	1564.	1564.	1.
195	206	226	227	207	9	1433.	1433.	1.
196	207	227	228	208	9	1307.	1307.	1.
197	208	228	229	209	9	1219.	1219.	1.
198	209	229	230	210	9	1137.	1137.	1.
199	210	230	231	211	9	1091.	1091.	1.
200	211	231	232	212	9	1061.	1061.	1.
201	212	232	233	213	9	1040.	1040.	1.
202	213	233	234	214	9	1022.	1022.	1.
203	214	234	235	215	9	1012.	1012.	1.

204	215	235	236	216	9	1007.	1007.	1.
205	217	237	238	218	9	2118.	2118.	1.
206	218	238	239	219	9	2111.	2111.	1.
207	219	239	240	220	9	2097.	2097.	1.
208	220	240	241	221	9	2074.	2074.	1.
209	221	241	242	222	9	2043.	2043.	1.
210	222	242	243	223	9	2001.	2001.	1.
211	223	243	244	224	9	1936.	1936.	1.
212	224	244	245	225	9	1852.	1852.	1.
213	225	245	246	226	9	1741.	1741.	1.
214	226	246	247	227	9	1592.	1592.	1.
215	227	247	248	228	9	1458.	1458.	1.
216	228	248	249	229	9	1366.	1366.	1.
217	229	249	250	230	9	1301.	1301.	1.
218	230	250	251	231	9	1263.	1263.	1.
219	231	251	252	232	9	1245.	1245.	1.
220	232	252	253	233	9	1226.	1226.	1.
221	233	253	254	234	9	1211.	1211.	1.
222	234	254	255	235	9	1202.	1202.	1.
223	235	255	256	236	9	1199.	1199.	1.

C SATURATED ELEMENTS

C no	wcn	ppgcn	nofc	av.ssr
11	0	0	5	0.65
12	0	0	5	0.65
18	0	0	5	0.65
19	0	0	5	0.65
20	0	0	5	0.65
21	0	0	5	0.65
22	0	0	5	0.65
23	0	0	5	0.65
24	0	0	5	0.65
25	0	0	5	0.65
26	0	0	5	0.65
27	0	0	5	0.65
28	0	0	5	0.65
29	0	0	5	0.65
30	0	0	5	0.65
31	0	0	5	0.65
32	0	0	5	0.65
33	0	0	5	0.65
34	0	0	5	0.65
35	0	0	5	0.65
36	0	0	5	0.65
37	0	0	5	0.65
38	0	0	5	0.65

39	0	0	5	0.65
40	0	0	5	0.65
41	0	0	5	0.65
42	0	0	5	0.65
43	0	0	5	0.65
44	0	0	5	0.65
45	0	0	5	0.65
46	0	0	5	0.65
47	0	0	5	0.65
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59	0	0	5	0.65
60	0	0	5	0.65
61	0	0	5	0.65
62	0	0	5	0.65
63	0	0	5	0.65
64	0	0	5	0.65
65	0	0	5	0.65
66	0	0	5	0.65
67	0	0	5	0.65
68	0	0	5	0.65
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77	0	0	5	0.65
78	0	0	5	0.65
79	0	0	5	0.65
80	0	0	5	0.65
81	0	0	5	0.65
82	0	0	5	0.65
83	0	0	5	0.65

84	0	0	5	0.65
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C OUTPUT OPTIONS
C PrtOpt RestartOpt
   0       1
C ACCELERATION HISTORIES FOR NODALS
C Np.  Hst.code
  8    1
  9    1
  10   1
  11   1
  12   1
  13   1
  38   1
  40   1
  49   1
  50   1
C EARTHQUAKE DATA
  the 'itt2755a.izt' eq record; direction e-w , max 0.2249g
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  0.00000  0.00606  0.00325  0.00255  0.00323  0.00323  0.00323  0.00417
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 -0.00313 -0.00288 -0.00181  0.00000  0.00107  0.00252  0.00379  0.00218
  0.00206  0.00000  0.00000 -0.00232  0.00000 -0.00166 -0.00169 -0.00169
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(the data continues..)
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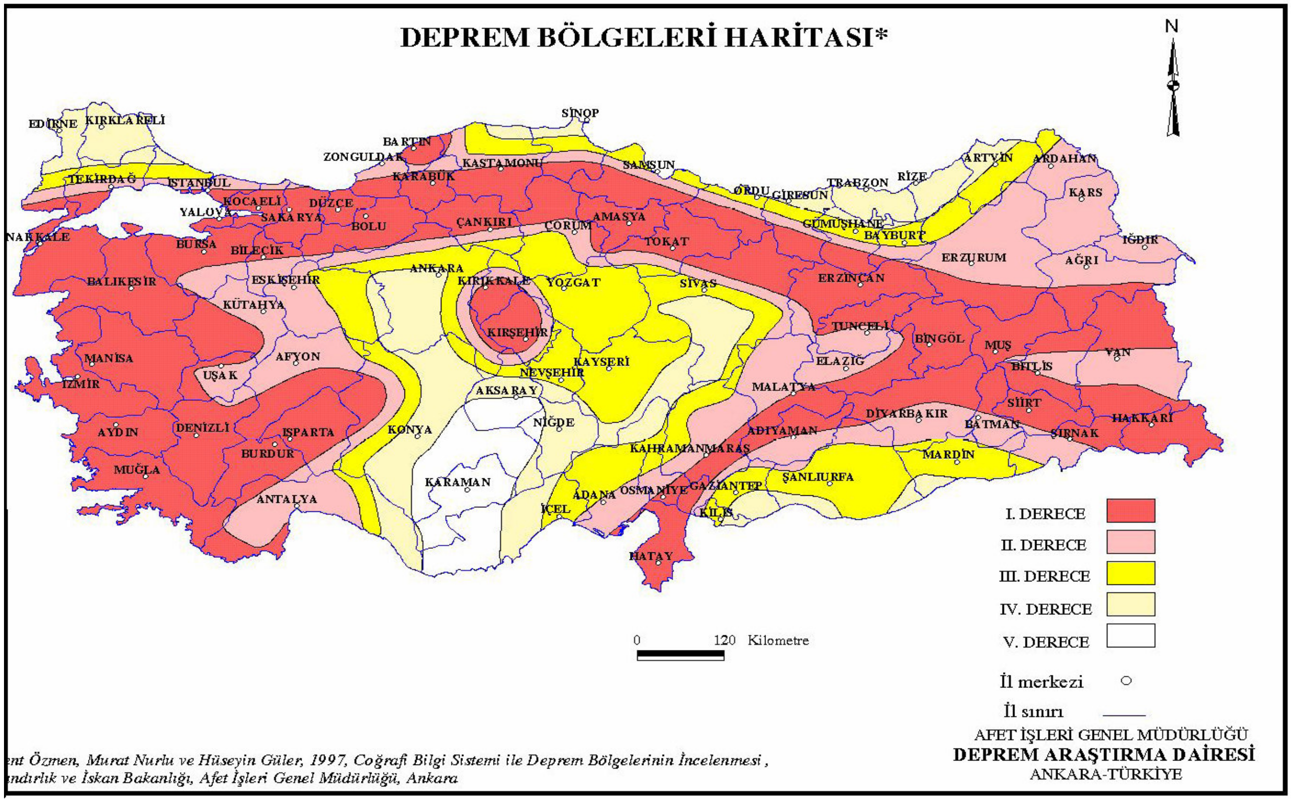

Figure B.1 Earthquake regions map of Turkey, 1996

APPENDIX D

Table D.1 Earthquakes recorded in history without instruments between 25E – 33E longitudes and 39N – 42N latitudes (Marmara Region)

Date	*Time*	*Lat. (N)*	*Long. (E)*	*Affected Region or Epicenter*	*Intensity*
M.Ö. 427		41.2	31.4	Zonguldak Ereğlisi	V
M.Ö. 360		41.2	31.4	Zonguldak Ereğlisi	
M.Ö. 330		40.1	25.25	Limni Adasının Kuzeydoğusu	IX
M.Ö. 282		40.5	26.7	Bolayır,Gelibolu	VIII
24.11.29		40.4	29.7	İznik,İzmit	IX
33		40.4	29.7	İznik,Kocaeli-Bursa Yöresi	VIII
02.01.69		40.4	29.7	İznik,İzmit	VII
93		40.6	27	Gelibolu Y.Ad.kuzeyi,Trakya	VIII
10.11.117		40.4	27.8	Erdek, Kapıdağ Y.Adası	VII
120		40.4	29.7	İznik,İzmit	VIII
129		40.4	29.4	İznik,Zeytinbağ(Mudanya'nın batısı	VIII
138		40.15	26.4	Çanakkale,Bandırma	VIII
155		40.3	28	Bandırma ve Yöresi	VIII
03.05.170		40.1	28	Bandırma,Erdek,Gemlik çuk.	IX
170		40.8	29.9	İzmit ve yöresi	VIII
212		41	29	İstanbul	VII
253		39.1	27.15	Bergama ve yöresi	IX
268		40.8	29.9	İzmit ve yöresi	VIII
325		41	29	İstanbul	IX
?.10.350		40.8	30	İzmit,İznik	VIII
356		41	29	İstanbul	VII
24.08.358		40.75	29.9	Kocaeli,İznik,İstanbul	IX
?.11.359		40.75	29.6	İzmit	VIII
02.12.362		40.75	29.6	İznik,İzmit,İstanbul	VIII
01.02.363		41	29	İstanbul	VIII
11.10.368		40.4	29.7	İznik	VII
376		41	29	İstanbul	VIII
378		40.4	29.7	İznik	VI
382		41	29	İstanbul ve yöresi	VIII
394		41	29	İstanbul	VIII
396		41	29	İstanbul	VIII
398		41	29	İstanbul	VII
?.02.402		41	29	İstanbul	VIII

Table D.1 continued

403		41	29	İstanbul	V
05.07.408		41	29	İstanbul	VII
412		41	29	İstanbul	VII
07.04.422		41	29	İstanbul ve yöresi	VI
427		41	29	İstanbul ve yöresi	IX
430		41	29	İstanbul ve yöresi	VIII
434		41	29	İstanbul ve yöresi	VII
438		41	28.9	İstanbul ve yöresi	VIII
26.10.440		41	28.9	İstanbul ve yöresi	VII
26.01.446		40.7	29.3	İzmit Körf.,İstanbul,İzmit	(VIII)
08.12.447		40.8	29.6	İzmit Körf.,İstanbul,İzmit,İznik	IX
26.01.450		41	29	İstanbul ve yöresi	VIII
464		40.4	27.85	Erdek,Bandırma	VII
467		40.8	29.9	İzmit	VI
470		41	29	İstanbul	VII
25.09.478		40.8	29	İstanbul ve geniş yöresi	IX
26.09.488		41	29	İstanbul	VI
488		40.8	29.6	İzmit,Karamürsal	VIII
496		41	29	İstanbul	
500		40.8	29.9	İzmit	VIII
517		41	29	İstanbul	VII
04.10.525		41	29	İstanbul	VI
526		41	29	İstanbul	VII
527		41	29	İstanbul	VII
?.11.533		41	29	İstanbul	VII
16.08.541		41	29	İstanbul	VIII
06.09.543		40.35	27.8	Erdek,Bandırma	IX
?.11.545		41	29	İstanbul	VI
546		41	29	İstanbul	VII
547		41	29	İstanbul	V
?.02.548		41	29	İstanbul	V
549		41	29	İstanbul	V
550		41	29	İstanbul	V
15.08.553		40.75	29.1	İstanbul,Kocaeli	X
02.04.557	night	41	29	İstanbul	VIII
16.10.557		41	29	İstanbul	VIII
14.12.557	night	41	29	İstanbul ve yöresi	VIII
559		41	29	İstanbul	VI
560		41	29	İstanbul	VI
26.10.580		41	29	İstanbul	VI
582		41	29	İstanbul	VI
10.05.583		41	29	İstanbul	VII
20.04.601		41	29	İstanbul	VII
611		41	29	İstanbul	VII
677		41	29	İstanbul	VI

Table D.1 continued

715		40.4	29.7	İznik, İstanbul	IX
732		41	29	İstanbul ve yöresi	VIII
26.10.740	8	40.8	29	İstanbul,İzmit,İznik	VIII
08.02.789		41	29	İstanbul	VIII
04.05.796		41	29	İstanbul	VIII
840		41	29	İstanbul	VI
23.05.860		41	29	İstanbul	VII
?.08.861		41	29	İstanbul	VI
16.05.865		41	29	İstanbul	IX
09.01.867		41	29	İstanbul	VIII
10.01.870		41	29	İstanbul	VIII
915		41	29	İstanbul	VII
945		41	29	İstanbul	
960		41	29	İstanbul	VIII
02.09.968		41	29	İstanbul	VIII
23.09.985		40.4	28.9	İznik,Bandırma,Erdek	VIII
26.10.986		41	29	İstanbul ve yöresi, Trakya	IX
?.01.1010		41	29	İstanbul ve yöresi	VIII
09.03.1010		41	29	İstanbul	VII
13.08.1032		41	29	İstanbul	VIII
06.03.1033		41	29	İstanbul	VII
?.05.1035		41	29	İstanbul ve yöresi	VII
20.12.1037		41	29	İstanbul ve yöresi	VIII
06.09.1038		41	29	İstanbul	VI
10.01.1041		41	29	İstanbul	
10.06.1041		41	29	İstanbul ve geniş yöresi	VIII
19.02.1063		41	29	İstanbul	VI
23.09.1064		40.4	28.9	İznik,Bandırma,Mürefte,İstanbul	IX
1070		41	29	İstanbul	
06.12.1082		41	29	İstanbul ve yöresi	VIII
1086		41	29	İstanbul	VII
01.06.1296		41	29	İstanbul	VIII
1305		41	29	İstanbul	VII
1323		41	29	İstanbul	VIII
12.02.1332		41	29	İstanbul	VII
23.09.1344		41	29	Istanbul	IX
1346		41	29	Istanbul	VII
?.03.1354		40.7	27	Gelibolu,Bolayir,Malkara	IX
06.08.1383		39.25	26.25	Midilli	VIII
1401		39.25	26.25	Midilli	
1417		40.2	29.1	Bursa	VII
1443		41	29	Istanbul	VIII
1462		41	29	Istanbul	IX
06.01.1489		41	29	Istanbul	VIII
1507		41.04	28.98	Istanbul	VIII

Table D.1 continued

1508		41	29	Istanbul	VI
14.09.1509		40.75	29	Istanbul,Edirne	IX
16.11.1510		41.7	26.6	Edirne ve genis yöresi,Istanbul	VIII
1532		41	29	Istanbul	VII
12.06.1542		41	29	Istanbul	VI
10.05.1556		41	29	Istanbul	VIII
30.04.1557		41	29	Istanbul	VIII
14.12.1569		41	29	Istanbul	VI
05.03.1571		41	29	Istanbul	VII
1592		41	29	Istanbul	VII
30.07.1633		41	29	Istanbul	VI
?.05.1641		41	29	Istanbul	VI
19.08.1642		41	29	Istanbul	VIII
?.04.1646		41	29	Istanbul	VII
28.06.1648	afternoon	41	29	Istanbul	VIII
06.02.1659		41	29	Istanbul ve yöresi	IX
03.07.1668		40.7	31.6	Bolu,Kastamonu	VIII
?.04.1672		40	26	Bozcaada Kuzeyi-Ege D.	VIII
25.05.1672		40.7	29.9	Izmit,Istanbul	VIII
1674		40.2	29.1	Bursa	VII
10.09.1688		39.15	26.5	Midilli, Sakiz,Santorin	VIII
11.07.1690	afternoon	41	29	Istanbul	VII
1698		41	29	Istanbul	V
1700		39.4	29.9	Kütahya	VI
05.05.1718		41	29	Istanbul	VIII
06.03.1719		41	29	Istanbul	VI
25.05.1719	noon	40.7	29.5	Istanbul, Izmit, Karamürsel	IX
22.06.1720		41	29	Istanbul	VI
1725		41	29	Istanbul	VI
1729		41	29	Istanbul	VI
1737		41	29	Istanbul	VIII
26.05.1752		41	29	Istanbul,Edirne	VII
18.07.1752		40.8	26.3	Kesan ve yöresi	VIII
29.07.1752	20	41.7	26.5	Edirne,Havsa	IX
02.09.1754	21.45	40.8	29.4	Izmit Körf.,Istanbul,Izmit	IX
20.01.1755		41	29	Istanbul	VI
?.02.1755		39.25	26.25	Midilli ve komsu adalar	
20.01.1757		41	29	Istanbul	VI
04.12.1757		41	29	Istanbul	VI
02.11.1762		40.15	26.4	Çanakkale	VII
03.09.1763		41	29	Istanbul	VIII
23.04.1766		40.8	28.2	Çorlu,Büyükçekmece,Edirne	VII
22.05.1766	5.3	41	29	Istanbul	IX
13.11.1766		41	29	Istanbul	VII
05.10.1768		41	29	Istanbul	VII

Table D.1 continued

20.02.1769		41	29	Istanbul	VI
14.08.1770		41	29	Istanbul	V
30.04.1772		41	29	Istanbul	V
15.08.1778		41	29	Istanbul	
16.04.1779		41	29	Istanbul	
01.06.1783		41	29	Istanbul	VI
26.10.1784		41	25.5	Gümülcüne-Dedeağaç yör.	VIII
16,06,1794		41	29	Istanbul	VI
15.08.1803		41	29	Istanbul	VI
19.05.1811		41	29	Istanbul	V
05.08.1819		41	29	Istanbul	VI
08.02.1826	20.3	39.5	28	Balikesir	VIII
12.05.1826		39.1	26.5	Midilli,Izmir	VI
23.05.1829		41	29	Istanbul,Gelibolu	VII
25.09.1834		41	29	Istanbul	V
30.08.1835		41	29	Istanbul	VI
25.11.1835		40.15	26.6	Çanakkale yöresi	VI
06.10.1841	2.3	41	29	Istanbul	VII
09.02.1845		39.25	26.5	Midlli Adasi	V
09.10.1845		39.3	26.3	Midilli Adasi	VII
12.10.1845		39.1	26.2	Midilli Adasi	X
01.12.1845		39.1	26.5	Midilli Ad., Sakiz Ad., Karaburun-izmir	VIII
19.09.1846		40.4	26.65	Gelibolu	VI
04.07.1847		40.4	26.65	Gelibolu	VI
10.07.1850	4.45	41	29	Istanbul	VI
21.04.1851	21	40	28.4	M.Kemalpasa-Bursa	VIII
23.08.1851	4.5	40	28.4	M.Kemalpasa-Bursa	VII
24.01.1855	3	41	29	Istanbul	VI
28.02.1855	19.4	40.2	29	Bursa,Kemalpasa	IX
11.04.1855	21.3	40.2	29.1	Bursa	X
15.12.1855		40.2	29.1	Bursa,Istanbul	VI
19.04.1858		40.2	29	Bursa	VI
27.04.1858		41	29	Istanbul	VI
21.08.1859	2	40.25	25.9	Imroz ve genis yöresi-Ege D.	IX
04.06.1860		40.2	29.1	Bursa yöresi	VII
06.08.1860		40.5	25.5	Samothraki Ad.-Ege D.	VII
02.12.1860	4	39.4	29.95	Kütahya,Manisa,Izmir	VI
07.10.1862		41	29	Istanbul	VI
?.10.1862		40	30.1	Sögüt, Bilecik	VII
23.02.1865		39.3	26.2	Midilli Ad.,Çanakkale	VIII
23.07.1865	21.3	39.4	26.2	Midilli Ad.,Çanakkale,Gelibolu	IX
14.02.1866	3.15	40.2	29.1	Bursa yöresi	VI
07.03.1867	6	39.1	26.5	Midilli ve Genis yöresi	IX
10.03.1867	9	39.3	26.2	Midilli Adasi-Ege D.	VII

Table D.1 continued

11.04.1867		39.3	26.5	Midilli Ad.,Edremit,Ayvalik	VII
22.07.1867	3	39.3	26.2	Midilli Ad., Izmir	VIII
23.04.1868		39.3	26.4	Midilli Ad. Ve Çanakkale	VI
17.05.1868		39.3	26.4	Midilli Ad. Ve Çanakkale	
03.01.1870		40.5	26.5	Saros Körfezi çevresi	VI
11.07.1870	3.3	39.25	26.5	Midilli Adasi	VI
14.07.1870		41.7	26.6	Edirne yöresi	VI
10.08.1870	11.1	39.9	27.3	Balikesir, Çanakkale	VII
10.12.1870		41	29	Istanbul	V
24.02.1871	1	40.2	29.1	Bursa yöresi	VI
11.10.1871		40.4	26.7	Gelibolu ve yöresi	VII
13.01.1872	10.15	40.4	27.8	Erdek	VI
17.01.1872		40.2	29	Bursa	VI
13.12.1872		40.4	26.7	Gelibolu, Çanakkale	VI
13.01.1873	10.3	40.4	26.7	Gelibolu,Çanakkale,Tekirdag,Imroz veSamothraki Adal	VI
26.06.1873		41	29	Istanbul	VI
09.11.1873		40.5	25.6	Semadirek Adasi-Ege D.	VII
05.07.1874		39.2	26.3	Midilli Adasi-Ege D.	VII
18.08.1874	evening	40.2	26.4	Çanakkale yöresi,Edremit,Balikesir	VI
18.11.1874	5	39.1	26.9	Dikili-Izmir, ve Midilli Ad.	VII
05.03.1875		40.2	26.4	Çanakkale	VII
?.10.1875	4	40.2	26.4	Çanakkale yöresi	IX
23.12.1875		40.2	26.4	Çanakkale,Ezine	VI
17.04.1876	4	40.2	29.1	Bursa yöresi	VI
25.10.1876		40.2	26.4	Çanakkale yöresi	V
13.10.1877	8.35	40.6	27.6	Marmara Adalari-Marmara D.	VIII
01.11.1877		40.6	27.6	Marmara Adalari-Marmara D.	VI
?.03.1878	9	41	29	Istanbul	V
19.04.1878		40.7	29.3	Izmit,Istanbul,Bursa,Sapanca	VIII
?.10.1880		41	29	Istanbul	VI
?.12.1880		39.2	26.5	Midilli Adasi-Ege D.	V
04.10.1881		40.4	26.7	Gelibolu ve Edirne	VI
30.12.1881		40.2	29.1	Bursa yöresi	V
23.01.1884		39.8	26.3	Ezine-Çanakkale	VI
01.02.1884		40.2	29.1	Bursa yöresi	VI
13.05.1884		40.4	27.8	Bandirma ve Erdek-Balikesir	VII
?.08.1886		41	29	Istanbul	VI
04.09.1886		39.25	26.5	Midilli Adasi-Ege D.	VII
06.10.1886		39.55	28.9	Gökçedag-Balikesir,Tavsanli-Kütahya	VIII
14.05.1887	5.3	40	25.5	Limni ve Mythilini Adalari-Ege D.	VIII

Table D.1 continued

?.09.1887		40.2	29.1	Bursa yöresi	VI
25.10.1889	23.2	39.3	26.3	Midilli adası , izmir sakız adası çanakkale tekirdağ	IX
03.11.1889		39.3	26.3	Midilli Ad.-Ege D.	VIII
25.04.1890		39.3	26.3	Midilli Ad.-Ege D.	VI
05.05.1890		39.3	26.3	Midilli Ad.-Ege D.	
28.01.1893	18	40.5	25.5	Samothraki,Imroz,Midilli ve Sakiz Adaları ve Ege D.	IX
24.07.1893		41.4	26.4	Dimetoka-Yunanistan ve Edirne	VIII
10.07.1894	12.3	40.8	29	Istanbul , Prens Adalari-Marmara D.,karamürsel Adap	X
03.08.1894		40.2	26.4	Çanakkale,Biga,Lapseki,Edirne	V
21.01.1895		40.4	29.7	Iznik	V
14.03.1895		40.4	26.7	Gelibolu ve Edirne	V
14.11.1895		39.1	27.1	Bergama-Izmir	VIII
16.04.1896	9.45	39.3	29.2	Emet ve genis yöresi	VIII
07.02.1897	12.2	39.75	31.1	Beylikahir-Eskisehir	V
14.03.1897	9.3	40.4	29.1	Gemlik yöresi-Bursa	V
?.12.1897		39.6	27.9	Balikesir ve yöresi	VIII
26.12.1897	7.05	40.1	30	Bilecik,Osmaneli	V
28.02.1898		39.6	27.9	Balikesir	VIII
?.05.1899		40.2	29.1	Bursa yöresi	VI

APPENDIX E

Table E.1 Earthquakes instrumentally recorded in history between 27E – 32E longitudes and 39N – 42N latitudes (Marmara Region) with M ≥ 4 in years 1881 - 1998

Day	Month	Year	Hour	Minute	Second	Lat.(N)	Long.(E)	Depth (km)	Magn. (M)
10	7	1894	12	30		40.8	29		7.3
	3	1901				41	29	0	5.7
12	5	1901	12	32		39.8	30.5	15	5
	10	1902				40.7	31.6	0	4.9
4	4	1903				39	28	20	5.5
11	1	1905	17	32	1	39.6	27.9	15	5
15	4	1905	5	36	4	40.2	29	6	5.6
30	4	1905	16	13		39.8	30.5	22	5.4
1	5	1905	19			39.9	30.1	0	4.9
22	10	1905	3	42	23	41	31	27	5.2
22	1	1907	2	41		41	29	12	4.5
21	8	1907				40.7	30.1	15	5.5
	7	1912				40.2	29.1	15	5
9	8	1912	1	29	40	40.6	27.2	16	7.3
10	8	1912	9	23	30	40.6	27.1	15	6.3
10	8	1912	18	30	30	40.6	27.1	15	5.3
11	8	1912	7	20	20	40.6	27.1	15	4.4
11	8	1912	8	19	44	40.6	27.2	0	5
21	10	1912	9	31	30	40.5	27	15	4.5
21	10	1912	23	40	30	40.5	27	15	4.8
26	4	1916	15	56	30	39.2	27	10	4.3
10	4	1917	19	40	18	40.6	27.1	15	5.3
8	8	1917	3	41	10	39	27	15	4.5
13	6	1918	18	13	55	39	27	0	4.9
19	6	1918	21	12	8	39	27	0	4.5
27	5	1919	10	35	15	39.13	31.02	10	5.3
13	10	1919	7	54	10	41.5	28	12	4.5
27	11	1919				39.2	27.2	30	6
2	8	1921	3	17	40	39	27	0	4.8
29	5	1923	11	34	20	41	30	25	5.5
26	10	1923	12	13	16	41.2	28.6	24	5
22	1	1924	11	5	44	39.51	28.4	80	5.3
14	4	1924				39	27.8	15	4.7

Table E.1 continued

	9	1924				40.9	29.2	15	4.3
22	12	1924	17	49	42	39.6	27.7	15	5.4
29	4	1925	20	3	40	39.6	27.7	15	4.6
10	6	1925	4	45	40	41	29	8	4.4
24	6	1925	0	0	35	40.88	30.39	10	4.6
14	9	1925	9	6	45	39	31	0	4.9
20	9	1925	18	6	52	39	31	0	4.9
5	4	1926				39	30	0	4.3
16	12	1926	17	54	5	40.13	30.72	10	5.7
20	12	1926	10	31	6	39	31	0	4.9
	12	1926				40.8	30.4	0	4.5
4	1	1927	4	49		39.5	29.8	15	4.2
7	1	1927				40.8	30.8	0	5
	1	1927				40.8	30.4	0	4.9
7	2	1927	6	4	36	39	31	15	5.2
24	1	1928	7	36	12	40.99	30.86	10	5.3
6	5	1928	18			39.8	30.5	12	5
5	4	1929	8	26	55	41.61	31.23	10	4.8
5	4	1929	23	18	15	41.5	31.5	0	4.8
27	4	1929	22	18	6	40.51	31.43	70	4.8
10	10	1929	23	0	55	41.11	27.46	0	4.5
		1929				39.46	31.5	0	4.5
15	10	1932	22	19	54	40.9	30.6	15	4.5
5	2	1933	5	30		41.5	31.5	0	4.4
15	5	1933	3	21	6	41.26	31.09	60	4.7
4	1	1935	14	41	30	40.4	27.49	30	6.4
4	1	1935	15	18	57	40.5	27.5	5	4.6
4	1	1935	15	19	24	40.5	27.5	5	4.5
4	1	1935	16	20	5	40.3	27.45	20	6.3
22	10	1935	7	29	43	40.31	27.21	10	5.2
22	11	1935				40	27.2	0	4.3
		1935				40.77	30.6	0	4.6
2	7	1938	12	26	46	40.17	27.88	10	5
5	7	1939	3	40	29	39.75	29.52	50	5.2
31	7	1939	13	32	48	39.8	29.6	10	4.8
2	8	1939	13	6	17	39.75	29.48	50	5.3
3	8	1939	12	32	55	39.75	29.68	50	5.5
9	8	1939	23	43	51	39.91	29.81	60	5.1
15	9	1939	23	16	31	39.76	29.56	20	5.7
19	10	1939	21	32	48	39.82	29.5	10	5.3
25	12	1939	6	34		40	27	15	5.2
13	6	1940	11	2	0	41.34	30.17	30	4.6
19	8	1940	20	43	42	40.13	30.09	40	4.5
9	2	1941	9	23	19	40.13	28.27	0	4.6
16	6	1942	5	42	34	40.8	27.8	20	5.6

Table E.1 continued

12	8	1942	20	38	46	39.13	27.64	50	4.8
12	8	1942	21	52	46	39.1	27.7	17	4.8
28	10	1942	0	31	52	39.27	28.19	10	5.4
28	10	1942	2	22	53	39.1	27.8	50	6
28	10	1942	2	41	53	39.46	27.79	10	5.5
15	11	1942	17	1	23	39.55	28.58	10	6.1
8	1	1943	23	56	43	40.92	28.1	0	5
14	4	1943	8	15	41	39.62	29.64	40	5
20	6	1943	15	32	54	40.85	30.51	10	6.6
20	6	1943	16	47	57	40.84	30.73	10	5.5
6	9	1943	16	32	47	40.21	31.35	10	4.9
8	9	1943	5	35	0	40.7	30.4	0	4.9
19	9	1943	21	1	0	40.7	31.6	0	4.3
6	12	1943	18	17	0	40.7	31.6	0	4.3
23	1	1944	19	50	0	39.2	28.2	0	4.3
1	2	1944	6	8	52	40.7	31.27	10	5
2	2	1944	3	33	17	40.74	31.44	40	5.1
15	2	1944				40.84	31.15	0	5.8
20	2	1944	21	55	0	40.7	31.6	0	4.3
5	4	1944	4	40	43	40.84	31.12	10	5.5
15	4	1944	4	40		40.5	31.2	0	5.6
15	11	1944	22	55	0	40.7	31.6	0	4.3
18	11	1944	13	30	0	40.7	31.6	0	4.3
8	2	1945	6	24	0	40.7	31.6	0	4.9
9	2	1945	2	28		40.5	31.2	0	4.9
24	3	1945	20	51	0	40.7	31.6	0	4.3
15	5	1945	0	57	0	40.8	31.2	0	4.3
20	11	1945	6	28	0	39.9	31.4	0	5.5
15	3	1947	0	57	0	40.7	31.6	0	4.3
3	5	1947	4	14	18	39	30	15	5.3
19	5	1947	18	25	0	40.7	31.6	0	4.6
28	5	1947	4	58	0	40.7	31.6	0	4.3
5	3	1948	8	10	0	40.7	31.6	0	4.3
14	6	1948	7	55	0	39.8	30.5	0	4.9
13	11	1948	4	44	50	40.23	29.02	60	5.6
24	12	1948	1	27	0	40.5	31.2	0	4.3
5	2	1949	0	28	22	39.89	29.35	40	5
8	11	1949	15	48	0	40.7	31.6	0	4.3
28	11	1949	18	47	18	40.98	30.74	10	4.7
28	11	1950	17	53	24	39.73	28.05	40	5.1
12	3	1951	8	56	32	42	31.8	0	4.7
15	9	1951	22	52	13	40.15	28.02	40	5
13	3	1952	6	30	2	41.02	28.14	11	4.9
19	3	1952	1	27	29	39.6	28.64	40	5.4
22	3	1952	23	22		40.8	31.2	0	4.3

Table E.1 continued

18	3	1953	19	6	16	39.99	27.36	10	7.2
18	3	1953	20	20	35	39.97	27.92	10	4.2
18	3	1953	20	34	56	40.02	27.83	10	4.6
18	3	1953	21	18	10	39.96	27.59	30	5.4
18	3	1953	22	28	0	40	27.4	30	4.8
18	3	1953	23	28	55	40	27.4	0	4.5
19	3	1953	12	53		40	27.4	0	4.8
19	3	1953	21	13	58	39.88	27.35	10	5
22	3	1953	13	17		40	27.4	0	4.6
23	3	1953				40	27.3	0	5.5
24	3	1953	20	20		40	27.4	0	4.9
26	3	1953	15	10	30	39.94	27.48	10	4.7
31	3	1953	18	24		40	27.4	0	4.5
1	4	1953	1	47	39	39.97	27.45	20	4.9
3	6	1953	16	5	31	40.28	28.53	20	5.3
9	6	1953	16	28	25	39.34	28.21	20	4.6
22	7	1953	15	9	38	39.24	28.43	10	5.2
23	3	1954	12	58	46	40.5	27.5	0	5
24	10	1954	23	37	19	40.46	27.53	10	4.8
26	10	1954	10	34	29	40.56	27.52	10	4.6
6	1	1956	14	52	59	41	30.2	10	4.9
20	2	1956	20	31	44	39.89	30.49	40	6.4
23	2	1956	6	4	37	39.76	30.17	60	5.2
25	2	1956	6	20	0	39.8	30.8	0	4.3
24	5	1956	9	20	0	39.8	30.5	0	4.3
14	7	1956	19	1	7	40.32	30.9	40	4.6
18	7	1956	9	46	53	39.96	27.3	60	4.5
28	8	1956	1	29	51	41.08	29.93	80	4.6
28	3	1957	22	26	0	39.3	27.7	17	5.1
26	5	1957	6	33	35	40.67	31	10	7.1
26	5	1957	8	54	51	40.6	30.74	40	5.4
26	5	1957	9	14	0	41.34	30.7	100	5.1
26	5	1957	9	16	41	41.42	31.09	10	4.9
26	5	1957	9	36	39	40.76	30.81	10	5.9
27	5	1957	6	20	37	41.14	31.19	80	4.2
27	5	1957	7	5	15	40.84	31.17	80	4.7
27	5	1957	8	24	25	41.13	30.65	70	4.6
27	5	1957	11	1	35	40.73	30.95	50	5.8
28	5	1957	0	9	54	40.58	30.53	50	4.8
28	5	1957	5	33	49	40.57	31.02	40	4.7
29	5	1957	8	47	53	40.72	31.04	20	4.7
29	5	1957	10	17	48	40.83	30.77	20	4.9
30	5	1957	13	7	56	40.62	31.78	10	4.2
30	5	1957	14	29	51	40.65	31.24	10	4.2
1	6	1957	5	27	0	40.75	30.86	50	5

Table E.1 continued

2	6	1957	1	12	1	40.71	30.78	10	4.8
17	6	1957	0	14	0	40.7	31.2	0	5.1
11	8	1957	15	34	36	39.2	29.2	0	4.2
11	10	1957	7	33	5	39.32	28.19	10	4.9
24	10	1957	2	33	15	40.06	29.75	10	4.7
26	12	1957	15	1	45	40.83	29.72	10	5.2
22	7	1958	1	55	0	39.8	30.5	0	4.3
23	11	1958	13	7	38	40.49	30.69	10	4.4
2	4	1959	4	34	29	40.5	29.41	20	4.6
26	7	1959	17	7	6	40.91	27.54	10	5.4
28	3	1961	0	44	12	39.82	30.19	10	5
24	8	1961	13	29	33	39.41	27.99	10	4.3
19	4	1962	8	22	18	40.75	28.84	10	4.3
14	9	1962	0	33	26	39.57	28.17	40	4.5
28	4	1963	0	41	52	39.32	27.82	30	4.7
14	6	1963	6	54	0	40.4	29.2	0	4.3
18	9	1963	16	58	15	40.77	29.12	40	6.3
24	9	1963	2	10	44	40.84	28.9	10	4.8
6	10	1964	14	29	58	40.24	28.16	23	5.1
6	10	1964	14	31	23	40.3	28.23	34	7
20	10	1964	8	47	56	40	28.6	0	4.8
15	12	1964	21	3	16	40.02	28.79	26	4.6
2	9	1965	5	29	27	39.7	27.1	0	4.4
25	3	1966	23	17	36	39	29.3	43	4.7
5	6	1966	9	14	6	39.07	29.34	36	4.4
28	6	1966	17	1	4	39	27	49	4.5
21	8	1966	1	30	44	40.33	27.4	12	5.5
29	1	1967	19	47	52	38.99	27.6	0	4.5
7	4	1967	17	40	7	40	31	0	4.3
13	6	1967	12	54	7	39.03	31.14	2	4.6
22	7	1967	16	56	58	40.67	30.69	33	6.8
22	7	1967	17	14	10	40.7	30.8	6	4.6
22	7	1967	17	18	54	40.7	30.8	0	4.2
22	7	1967	17	30	7	40.73	30.53	0	4.8
22	7	1967	17	48	7	40.66	30.62	26	5.1
22	7	1967	18	7	21	41	30	0	4.7
22	7	1967	18	8	54	40.7	30.8	0	4.2
22	7	1967	18	9	55	40.72	30.51	35	5
22	7	1967	18	13	36	40.7	30.8	0	4.5
22	7	1967	18	14	0	40.7	30.8	0	4.2
22	7	1967	19	47	31	41.07	30.59	59	4.6
22	7	1967	20	35	40	40.79	30.42	4	4.7
22	7	1967	21	21	41	41	30.45	49	4.6
22	7	1967	23	42	0	40.64	30.53	30	4.7
23	7	1967	4	3	40	40.61	30.35	21	4.5

Table E.1 continued

26	7	1967	9	16	6	40.61	30.67	21	4.4
30	7	1967	1	19	31	40.71	30.58	23	4.6
30	7	1967	1	31	2	40.72	30.52	18	5.6
30	7	1967	18	58	46	40.75	30.46	27	4.5
31	7	1967	7	12	5	40.6	27.62	4	4.4
1	8	1967	0	13	34	40.72	30.52	26	4.6
14	8	1967	20	9	25	40.74	30.37	25	4.9
18	3	1968	5	40	1	40.83	30.53	39	4.5
28	3	1968	17	12	20	40.5	31.34	6	4.5
6	5	1968	9	38	47	40.33	28.63	4	4.2
12	2	1969	8	43	5	40.7	30.29	30	4.4
3	3	1969	0	59	11	40.08	27.5	6	5.7
5	3	1969	14	41	16	40.06	27.56	33	4.7
22	3	1969	18	0	55	39.1	28.67	28	4.7
23	3	1969	21	8	42	39.14	28.48	9	5.9
24	3	1969	1	59	34	39.11	28.51	30	5
24	3	1969	2	58	49	39.15	28.6	4	4.5
24	3	1969	8	13	5	39.02	28.41	43	4.7
24	3	1969	11	34	34	39.17	28.7	37	4.6
24	3	1969	12	13	17	39.08	28.65	20	4.5
25	3	1969	13	21	12	39.06	28.41	28	4.9
25	3	1969	13	21	34	39.25	28.44	37	6
25	3	1969	13	37	53	39	28	0	4.2
25	3	1969	14	18	52	39.17	28.49	34	4.8
25	3	1969	14	40	27	39.02	28.9	25	4.4
25	3	1969	16	13	30	39.08	28.44	42	4.7
26	3	1969	3	31	27	39.03	28.27	37	4.6
26	3	1969	9	0	11	39.3	28.1	52	4.4
27	3	1969	18	7	3	39.12	28.2	51	4.5
28	3	1969	10	2	17	39.13	28.45	37	4.9
17	4	1969	12	23	28	39.11	28.62	0	4.2
30	4	1969	20	20	32	39.12	28.52	8	5.2
1	5	1969	1	14	46	39.1	28	0	4.3
3	5	1969	16	7	59	39	28.6	25	4.2
6	5	1969	6	36	6	39.3	28.1	0	4.2
13	5	1969	17	48	2	39.03	28.57	35	4.6
14	5	1969	23	57	36	39.15	28.49	36	4.6
27	6	1969	10	40	25	39.3	28.7	0	4.2
14	8	1969	21	51	5	39.52	27.87	21	4.7
19	8	1969	21	55	57	39.7	27.8	0	4.4
7	10	1969	5	9	12	39.2	28.4	13	5.1
7	10	1969	18	49	3	39.16	28.54	49	4.5
13	10	1969	3	24	26	39.17	28.38	9	4.3
24	12	1969	8	41	32	40.5	28.4	0	4.5
23	3	1970	7	56	8	39.2	28.2	26	4.2

Table E.1 continued

28	3	1970	21	2	24	39.21	29.51	18	7.2
28	3	1970	21	12	10	39.5	30.3	0	4.2
28	3	1970	21	13	24	39.3	30.7	0	4.6
28	3	1970	21	19	20	39.5	30.5	0	4.3
28	3	1970	31	41	20	39.13	29.53	42	4.5
28	3	1970	21	59	11	39.28	29.46	17	4.8
28	3	1970	23	12	43	39.15	29.56	31	5.2
28	3	1970	23	44	0	39.07	29.76	32	5.2
29	3	1970	2	5	28	39.29	29.18	38	4.6
29	3	1970	2	31	11	39.01	30.4	33	4.6
29	3	1970	2	54	52	39.12	29.53	22	4.6
29	3	1970	6	56	24	39.06	29.74	29	5.4
29	3	1970	7	40	42	39.6	31	0	4.2
29	3	1970	19	11	43	39.14	29.42	22	4.7
29	3	1970	22	12	43	39.2	29.2	0	4.6
30	3	1970	6	46	25	39.09	29.03	23	4.5
30	3	1970	6	49	5	39.43	29.4	33	4.8
30	3	1970	7	59	22	39.34	29.26	16	5.3
30	3	1970	8	35	18	39.29	29.24	36	4.7
30	3	1970	16	32	37	39.09	29.59	30	5.2
30	3	1970	20	38	5	39.05	29.62	28	4.6
30	3	1970	20	59	31	39.3	29.29	33	4.6
31	3	1970	0	51	36	39.33	29.41	18	4.6
31	3	1970	1	7	55	39.41	29.32	25	4.4
31	3	1970	3	38	15	39.1	30	0	4.5
31	3	1970	3	46	51	39.03	29.79	35	4.8
31	3	1970	4	10	5	39.01	29.2	9	4.6
31	3	1970	4	47	17	39	30.1	15	4.3
31	3	1970	5	21	14	39.6	31.1	0	4.2
1	4	1970	15	56	5	39.32	29.27	35	4.8
1	4	1970	17	55	14	39.01	29.69	41	4.3
2	4	1970	0	28	32	39.11	29.57	28	4.3
2	4	1970	20	35	9	39.05	29.72	35	4.6
4	4	1970	3	52	26	39.7	30	0	4.5
5	4	1970	19	48	48	39.2	31.7	0	4.4
7	4	1970	4	12	34	39.32	29.09	33	4.5
7	4	1970	10	55	2	39	27.8	48	4.2
7	4	1970	17	5	12	39.34	29.32	33	5.2
7	4	1970	22	58	55	39.01	30.11	21	4.3
9	4	1970	10	12	30	39.11	29.41	34	4.7
10	4	1970	1	14	40	39.13	29.31	22	4.2
11	4	1970	8	36	38	39.1	28.8	49	4.4
11	4	1970	17	24	25	39.09	29.76	22	4.6
13	4	1970	5	16	0	39.32	29.03	15	4.5
15	4	1970	16	29	58	39.34	29.3	28	4.8

Table E.1 continued

30	4	1970	23	59	9	39.09	29.59	29	4.5
11	5	1970	9	58	47	39.36	29.32	0	4.3
1	6	1970	6	43	13	39	29.7	54	4.2
10	6	1970	5	17	16	39.15	29.46	43	4.5
14	6	1970	0	58	26	39.25	29.17	23	4.2
7	8	1970	4	53	24	39.08	30.01	41	4.5
6	9	1970	17	39	10	40.2	28.5	0	4.2
14	9	1970	7	10	13	39.24	29.32	37	4.6
15	9	1970	6	28	48	39.7	28.54	10	4.2
15	11	1970	3	14	56	39.32	29.28	0	4.2
13	12	1970	20	18	46	39.1	29.6	0	4.2
17	12	1970	2	17	5	39.27	29.4	26	4.5
20	12	1970	11	1	47	39.36	29.24	26	5.5
21	12	1970	0	22	25	39.09	29.41	27	4.2
8	2	1971	8	19	53	39.2	29.4	0	5.3
15	2	1971	8	19	57	39.19	29.36	32	4.9
23	2	1971	19	41	23	39.62	27.32	10	5.1
13	4	1971	12	59	39	39.03	29.8	41	5.2
30	4	1971	16	44	4	39.19	28.52	5	4.3
1	5	1971	13	45	27	40.95	27.99	13	4.6
6	5	1971	4	24	36	39.04	29.75	34	4.7
25	5	1971	5	43	26	39.05	29.71	16	5.9
25	5	1971	5	53	28	39.05	29.69	13	4.8
10	6	1971	9	31	54	39.02	29.63	33	5.1
6	11	1971	19	43	48	39.02	29.78	16	5.1
18	12	1971	0	43	8	39.5	29.1	0	4.3
6	3	1972	2	50	15	39.09	31.48	28	4.2
14	3	1972	14	5	47	39.32	29.47	38	5.2
18	6	1972	22	32	50	39.02	29.88	34	4.4
23	6	1972	4	25	30	39.19	28.9	42	4.3
23	6	1972	17	16	3	39.16	29.17	20	4.2
3	9	1972	8	38	46	39.16	27.98	30	4.6
23	9	1972	3	32	49	39.78	28.57	0	4.3
4	10	1972	6	14	26	39.14	29.44	34	4.6
10	11	1972	7	40	41	40.41	28.73	0	4.3
8	2	1973	14	33	14	39.25	28.7	38	4.2
8	4	1973	9	52	47	39.17	28.39	7	4.2
11	6	1973	0	29	33	40.31	29.3	26	4.2
27	6	1973	11	50	23	40.72	27.49	5	4.2
22	11	1973	14	54	53	40.36	29.88	8	4.2
21	1	1975	17	50	25	39.07	30.67	23	4.5
8	5	1976	23	25	8	39.33	29.1	33	4.9
21	5	1976	9	37	2	39.28	29.16	24	4.5
25	5	1976	18	43	28	39.31	29.09	14	4.6
28	5	1976	23	2	20	39.26	29.17	8	4.5

Table E.1 continued

9	6	1976	10	2	33	39.24	29.15	12	4.7
14	6	1976	6	52	37	39.34	29.27	23	4.7
22	8	1976	13	28	51	39.35	29.03	23	4.9
23	3	1977	11	55	54	39.63	28.65	23	4.6
15	6	1978	0	26	45	40.79	27.68	28	4.6
28	6	1979	21	22	9	40.78	31.85	0	4.7
18	7	1979	13	12	2	39.66	28.65	7	4.9
4	5	1980	9	22	13	39.22	28.97	22	4.5
12	3	1981	4	6	0	40.8	28.09	12	4.5
26	12	1981	17	53	35	40.15	28.74	0	4.9
28	12	1981	14	53	35	39.39	29.06	10	4.5
9	6	1982	4	13	36	40.14	28.89	10	4.4
9	9	1982	5	47	10	40.98	27.87	10	4.4
26	12	1982	17	48	1	39.32	28.26	5	4.9
27	12	1982	11	2	44	39.34	28.27	10	4.8
1	2	1983	13	54	11	40.2	28.94	3	4.8
15	2	1983	2	21	45	39.07	28.71	7	4.6
5	7	1983	12	1	27	40.33	27.21	7	5.8
21	10	1983	20	34	49	40.14	29.35	12	4.9
27	10	1983	8	40	10	40.16	29.3	18	4.3
15	11	1983	10	59	11	40.12	29.28	7	4.4
29	3	1984	0	6	1	39.64	27.87	12	4.6
25	4	1987	22	11	0	39.3	27.92	3	4.2
1	1	1988	12	21	51.5	40.12	29.24	10	4.5
24	4	1988	20	49	33.6	40.86	28.23	16	5.3
4	1	1989	14	55	1	39.78	30.7	5	4.2
15	2	1989	4	1	16.9	39.05	29.71	23	4.3
17	12	1989	21	22	33.1	39.3	28.27	10	4.1
24	5	1990	5	49	6.4	39.98	27.48	28	4
12	2	1991	9	54	58.3	40.82	28.88	10	4.6
3	3	1991	8	39	26.4	40.62	29.02	21	4.5
8	3	1991	9	23	13.1	40.83	27.89	11	4.5
26	6	1991	11	0	36.9	39.6	27.82	11	4
18	3	1993	7	51	38.1	40.43	27.99	10	4.2
31	3	1993	18	20	44.1	39.15	28.02	13	4.2
2	9	1993	21	3	41.5	40.19	27.26	14	4.1
6	12	1993	16	25	34.6	39.21	29.95	10	4
12	12	1993	17	21	26.2	41.51	28.82	28	5
8	2	1995	21	24	53.5	40.82	27.77	23	4.5
13	4	1995	4	8	1.6	40.86	27.67	24	4.8
18	10	1997	9	18	53.3	39.81	28.69	17	4
21	10	1997	10	49	33.5	40.7	30.42	11	4.1
5	3	1998	1	45	8.9	39.55	27.25	7	4.4
5	3	1998	1	55	26.7	39.53	27.25	5	4.3