NEURAL NETWORK PREDICTION OF TSUNAMI PARAMETERS IN THE AEGEAN AND MARMARA SEAS

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Approval of the Graduate School of Natural and Applied Sciences

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ABSTRACT

NEURAL NETWORK PREDICTION OF TSUNAMI PARAMETERS IN THE AEGEAN AND MARMARA SEAS

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Tsunamis are characterized as shallow water waves, with long periods and wavelengths. They occur by a sudden water volume displacement. Earthquake is one of the main reasons of a tsunami development. Historical data for an observation period of 3500 years starting from 1500 B.C. indicates that approximately 100 tsunamis occurred in the seas neighboring Turkey.

Historical earthquake and tsunami data were collected and used to develop two artificial neural network models to forecast tsunami characteristics for future occurrences and to estimate the tsunami return period. Artificial Neural Network (ANN) is a system simulating the human brain learning and thinking behavior by experiencing measured or observed data.

A set of artificial neural network is used to estimate the future earthquakes that may create a tsunami and their magnitudes. A second set is designed for the estimation of tsunami inundation with relation with the tsunami intensity, the earthquake depth and the earthquake magnitude that are predicted by the first set of neural networks.

In the case study, Marmara and Aegean regions are taken into consideration for the estimation process. Return periods including the last occurred earthquake in the Turkish seas, which was the İzmit (Kocaeli) Earthquake in 1999, were utilized together with the average earthquake depths calculated for Marmara and Aegean regions for the prediction of the earthquake magnitude that may create a tsunami in the stated regions for various return periods of 1-100 years starting from the year of 2004. The obtained earthquake magnitudes were used together with tsunami intensities and earthquake depth to forecast tsunami wave height at the coast.

It is concluded that, Neural Networks predictions were a satisfactory first step to implement earthquake parameters such as depth and magnitude, for the average tsunami height on the shore calculations.

Keywords: Tsunami, earthquake, artificial neural network, forecast, prediction, tsunami wave height, tsunami intensity, tsunami occurrence period, Marmara Sea, Aegean Sea.

ÖZ

EGE VE MARMARA DENİZLERİNDE YAPAY SİNİR AĞLARI İLE TSUNAMİ PARAMETRELERİNİN TAHMİNİ

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Tsunami, uzun dalga periodu ve dalga boyu özellikleri gösteren sığ su dalgaları olarak tanımlanır. Su hacminde oluşan ani değişmelerden kaynaklanmaktadır. İ.Ö. 1.500 yılından itibaren 3.500 senelik bir gözlem süresi için tarihsel veriler, Türkiye kıyılarında yaklaşık 100 tsunami oluşumu göstermektedir.

Gelecek oluşumlar için tsunami özelliklerini belirlemek ve tsunami geri oluşum süresini tahmin etmek gayesiyle tarihsel veriler toplanmış ve yapay bir sinir ağı modeli kurulmasında kullanılmıştır. Yapay sinir ağları (YSS), ölçülmüş ve gözlemlenmiş verileri tecrübe ederek, insan beyninin düşünme ve öğrenme davranışlarını modelleyen bir sistemdir.

İki yapay sinir ağı yapısı oluşturulmuştur. Oluşturulan birinci yapay sinir ağı yapısı, gelecekte tsunami oluşturabilecek depremlerin ve deprem şiddetlerinin tahmininde kullanılmıştır. İkinci ağ yapısı, tsunami büyüklüğü, deprem derinliği ve ilk yapay sinir ağı yapısı ile öngörülmüş deprem şiddetlerini ilişkilendirerek tsunaminin kıyıdaki yükselmesini tahmini için oluşturulmuştur.

Örnek çalışmada, Marmara ve Ege bölgeleri için tahminler yapılmıştır. Türkiye kıyılarında 1999 yılında oluşan ve son deprem olan Izmit (Kocaeli) depremini de kapsayan tarihsel tsunamilerin geri oluşum süreleri çıkartılmış, Marmara ve Ege bölgeleri için ortalama deprem oluşma derinliği hesaplanmış ve bunlar, bahsi geçen bölgelerde 2004 yılından itibaren 1-100 yılları arasında çeşitli geri oluşum süreleri için tsunami oluşturabilecek deprem şiddetlerinin hesaplanmasında kullanılmıştır. Elde edilen deprem şiddetleri, tsunami büyüklüğü ve deprem derinliği ile birlikte kıyıda oluşacak tsunami dalga yüksekliği tahmininde kullanılmıştır.

Yapay sinir ağları tahmininin, kıyıda oluşacak tsunami dalga yüksekliği hesaplarına derinlik ve şiddet gibi deprem parametrelerinin katıldığı bir ilk adım olarak uygun sonuçlar verdiği sonucuna varılmıştır.

Anahtar Kelimeler: Tsunami, deprem, yapay sinir ağları, tahmin, öngörü, tsunami dalga yüksekliği, tsunami büyüklüğü, tsunami oluşma süresi, Marmara Denizi, Ege Denizi.

To my beloved family and
To my love,

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CHAPTER 1

INTRODUCTION

1. 1 Description of the Problem

In the history, the "Acts of God" has always created many problems to the human communities. A natural disaster is terrifying as we can not predict when and where it would occur. Thus no precaution can be taken against an unexpected natural disaster.

Tsunami, also a natural event caused by various natural phenomena, is a very important aspect for many seas and oceans, which are located in a faulty zone. Tsunamis are shallow-water waves, with long periods and wavelengths. A tsunami is triggered by a sudden displacement of a large amount of water mass from its equilibrium position which may be caused by an earthquake, a submarine landslide or a volcanic eruption.

Contrary to the fact that the location, time and the violence of an occurrence of a tsunami may not be known exactly, one may have an idea about all these according to the past experiences.

During the past 3500 years, Turkey, which is located in a faulty zone, has encountered about 100 tsunamis in its neighboring seas. Those may serve as a light to foresee tsunami characteristics for future occurrences as well as the probable occurrence period.

In this study, in the guidance of the light and the suitability of the data collected from various references, we concentrated on two major aims. The first is the “Neural Network based estimation of the magnitudes of the future earthquakes which may create tsunamis in three Turkish coast regions, Marmara Sea, Eagean Sea and Mediterranean Sea”, and the second is “Neural Network based estimation of the wave height at the coast of the tsunami, which occurred in the past or might occur in the future in regard to the predicted earthquake magnitude”.

Artificial Neural Network is a system simulating the human brain learning and thinking behavior by experiencing some received data. It is widely used and is a good alternative for problems which are difficult to be solved by conventional mathematical methods.

The prediction of the tsunami characteristics by means of “Neural Network” is executed for the first time in the literatures and academic researches in Turkey as well as in the World. These predictions are done by the “Multi-layer feed-forward network” which is briefly described in the following pages.

Following the “Introduction” chapter, relevant studies are mentioned in the Chapter 2. In Chapter 3, Tsunami is presented and the Tsunamis occurred in the Turkish coasts are presented. The Chapter 4 describes what an “Artificial Neural Network” is and the methodology used to build the neural network structure. A case study for Marmara and Aegean Seas is performed and the results are presented in the Chapter 5. Finally the conclusion of the study is mentioned in the Chapter 6.

CHAPTER 2

LITERATURE SURVEY

2. 1 Relevant Studies

The Literature Survey is carried out through the Engineering Village 2 Data Base, which provides access to the Compendex®, Inspec®, NTIS, Referex Engineering, ENGnetBASE, Patents from USPTO and esp@cenet, GlobalSpec, Scirus, EEVL and LexisNexis News and through the Science Citation Index (SCI®) records.

Among 76.005 “neural network” records in the Engineering Village 2, there are 335 records in which the “neural network” has been used in the “ocean engineering” field and 72 records in which it has been used in the “coastal engineering” field. The Science Citation Index (SCI®) provides information on 24.599 “neural network” records from which 110 records are on “neural network” and “ocean engineering” and 45 records are on “neural network” and “coastal engineering”.

In the Engineering Village 2 and the SCI®, there is no record in which the “neural network” is used for a “tsunami” research.

Most researches about the neural networks in the ocean and coastal engineering dealt with the geological, environmental and marine areas such as the predictions related to phytoplankton, chlorophylls, ocean bottom parameters, ocean color, temperature and coastal formations.

Deo, M.C. and Naidu, C. Sridhar (1999), forecasted waves by using neural networks with lead times varying from 3 to 24h, based on the observation of waves at site and compared the results with those of the numerical models dealing with complex differential equations and calling very large amount of meteorological and oceanographic data.

Tsai, Ching-Piao and Lee, Tsong-Lin (1999), used the artificial neural networks with back-propagation for the forecast of tidal-level variations. Tsai, Ching-Piao and Lee, Tsong-Lin concluded that the hourly tidal levels over a long duration can be efficiently predicted using only a very short-term hourly tidal record.

Deo, M.C.; Jha, A.; Chaphekar, A.S. and Ravikant, K. (2001) created simple 3-layered feed forward type network to obtain the output of significant wave heights and the average wave periods from the input of generating wind speeds as an alternatives to the existing deterministic models. Deo, M.C.; Jha, A.; Chaphekar, A.S. and Ravikant, K. concluded that an appropriately trained network can provide satisfactory results in open wider areas, in deep water and also when the sampling and prediction interval is large, such as a week.

Tsai, Ching-Piao; Lin, Chang and Shen, Jia-N (2002), attempted to forecast the waves by learning the characteristics of observed waves, rather than using the wind information which has so many uncertainties due to the influence of the geometric configurations in the coastal and harbor areas. The research resulted in the Artificial Neural Network model performed accurately for wave forecasting when using a short-term observed wave data.

Lee, T.L. and Jeng, D.S. (2002), presented an artificial neural network model for forecasting the tidal-level using the short term measuring data. The comparison of the results of this model with those of the harmonic analysis using the “least squares method” indicates that the hourly tidal levels over a long duration can be predicted using a short-term hourly tidal record.

Supharatid, Seree (2003), presented an application of the neural network model for forecasting and filtering problems by using the Levenberg-Marquardt algorithm. Seree first constructed a multilayer feed forward network to forecast the tidal-level variations at the Chao Phraya river mouth in Thailand and found that the lead time of 1 to 24 hourly tidal levels could be successfully predicted using only a short-time hourly learning data. Secondly, he used the network to establish a stage-discharge relationship for tidal river and concluded that the NN model modeled the transfer function with a higher accuracy than multiple regression analysis.

Lee, Tsong-Lin (2004), predicted long-term tidal levels with back-propagation neural network using short term measuring data. The network was tested by the on site tidal level data at Taichung Harbor in Taiwan. The long-term tidal wave predictions were compared with the ones of conventional harmonic methods and the efficiency of the neural network method was observed.

Makarynskyy, O. (2004) attempted to improve wave short-term forecasts based on artificial neural networks. He used the networks created by the wave data from two sites offshore the Atlantic and the Irish Sea coasts of Ireland to correct the predictions solely by using the initial simulations of the wave parameters with leading times from 1 to 24 h and merging the measurements and initial forecasts.

Beside the Neural Network related research, the Engineering Village 2 contains 804 records on “tsunami”, from which 112 records are on “tsunami and tsunami characteristics prediction” and 19 are on “tsunami and tsunami characteristics forecast”. Among the 985 “tsunami” records, the SCI® provides access to 5 “tsunami prediction” records and to 1 “tsunami forecast” record.

Adams M., (1970) investigated the prediction of the tsunami inundation from the seismic data available to the Pacific Tsunami Warning System during a tsunami alert. Adams derived the procedure from a synthesis of existing theories for the generation, propagation, and run up of tsunamis. In this research, the relationships were determined by the theories and the coefficients from empirical fits to historical data. A tsunami index related to the size of the tsunami and values of the earthquake parameters was defined. Adams prepared expected tsunami inundation charts in accordance with the derived relationships from the populated coastlines of Hawaii.

Hatori, Tokutaro (1982), studied the magnitudes of the Kurile-Kamchatka tsunamis during the period from 1904 to 1980. Tokutaro drew the refraction diagrams of two imaginary sources to predict the travel times of tsunami along the Kurile and Japanese coasts.

Crawford, Peter L. (1987) predicted the tsunami and tide elevations along the southern coast of Alaska. Crawford created a synthetic tsunami record and calculated the probability of their occurrence by using little historical data. He used numerical methods to combine the effects of astronomical tides and tsunamis to determine the combined tsunami and tide elevations of the 100- and 500-year events.

Abe, Katsuyuki; (1989) developed a method to estimate tsunami run-up heights from earthquake magnitudes by considering the definition of the tsunami magnitude (Mt) and the scaling relation of earthquake fault parameters. Katsuyuki drew a simple diagram which is convenient for the rapid estimate of tsunami run-up heights from earthquake magnitudes.

Demetracopoulos, A.C.; Hadjitheodorou, C. and Antonopoulos, J.A. (1994) studied the tsunami occurrences in the Greek Seas and in the Mediterranean Sea and made a statistical analysis to simulate the expected wave heights in the vicinity of the Rion-Antirrion Straits, for various probabilities of occurrence of a seismic event.

Wei, Y.; Cheung, K.F.; Curtis, G.D. and McCreery, C (2001), developed a methodology to forecast tsunami height, based on real-time water-level data near the source. They worked for Aleutian-Alaska source region and its potential threat to Hawaii. They verified the algorithm and the database using actual water-level data of past tsunami events.

Grilli, Stephan T.; Vogelmann, Sylvia and Watts, Philip (2001) simulated tsunami generation by underwater landslides in a three-dimensional Numerical Wave Tank by solving fully nonlinear potential flow equations.

Cho, Yong-Sik; Park, Koo-Yong and Lin, Tae-Hoon (2004), developed a numerical model based on the quad tree grids in order to study the run-up heights of near shore tsunamis in the vicinity of a circular island. They used the nonlinear shallow-water equations as the governing equations of the model and compared the numerical results with the available laboratory measurements.

CHAPTER 3

TSUNAMI

3. 1 General Descriptions

The word “Tsunami” took its place in the world languages by the Japanese help signals after the Big Meiji Tsunami dated 15 June 1896 which killed 21,000 people. “Tsunami” (pronounced tsoo-nah-mee) is a Japanese word with the English translation, "harbor wave" which is represented by two characters “tsu” meaning harbor and “nami” meaning wave.

Japanese scientists were the firsts to study the phenomenon of tsunami. The greatest tsunami events in the world took place in the eastern coast of Japan which explains why the Japanese word is used internationally. The term tsunami was adopted for general use in 1963 by an international scientific conference (http://asc-india.org/info/howtsu.htm).

In the past, tsunamis were referred as "tidal waves" by the general public and as "seismic sea waves" by the scientific community. As tides are results of the gravitational influences of the moon, sun and planets, "tidal wave" is a misnomer. Tsunamis have no relation with tides, although, when a tsunami strikes a coastal zone, this is mainly influenced by the tidal level of that area at the time of impact. The term "seismic sea wave" is also misleading. "Seismic" implies an earthquake-related generation mechanism, but a tsunami can also be caused by an event that is not seismic, such as an explosion, a submarine landslide, a volcanic eruption or a large meteorite impact.

3. 2 What is Tsunami?

Tsunamis differ from wind-generated waves in a way that their source is sea bottom instead of water surface, and they are characterized as shallow-water waves, with long periods and wavelengths. Tsunamis may be distinguished from ordinary waves by their great length between their wave crests, which can be more than 100 km, and by the time between these crest passages that is in the order of one hour. The long wavelengths of the tsunamis force them to behave as shallow-water waves. A wave becomes a shallow-water wave, when the ratio between the water depth and its wavelength is very small ($d/L_o \leq 0.0156$). Table-3.1 shows differences between a wind wave and a tsunami.

Table-3.1. Differences of Ordinary Wave and Tsunami (adopted from Kaynak, U., (2002),)

	Wind Wave	**Tsunami**
Velocity	25-30 km/h	600-900 km/h
Max. Wave Length at Open Sea	~ 100 m	~ 100.000 m
Max. Wave Height at Open Sea	~ 12 m	~ 0,1-1,0 m

Shallow-water waves move at a velocity that is equal to the square root of the product of the acceleration of gravity and the water depth (Eq. (3.1.));

$$v = \sqrt{g.d} \qquad \text{Eq. (3.1.)}$$

where v is speed in m/s, g is acceleration due to gravity (9.8 m/s^2) and d is the depth of the water in m.

As the rate at which a wave loses its energy is inversely related to its wavelength, tsunamis not only propagate at high speeds, but they also travel large distances with limited energy losses. (http://www.geophys.washington.edu/tsunami/general/physics/characteristics.html)

In deep water, tsunami propagates at a speed exceeding 800 kilometers per hour, and at a wave height of only a few tens of centimeters or less. This is the reason why it is very difficult to predict the occurrence of a tsunami in deep water. It can not be felt by ships and can not be seen by airplanes.

As the tsunami enters the shoaling water of coastlines, its velocity decreases and its height increases causing an inundation as seen in Figures 3.1.a and 3.1.b.

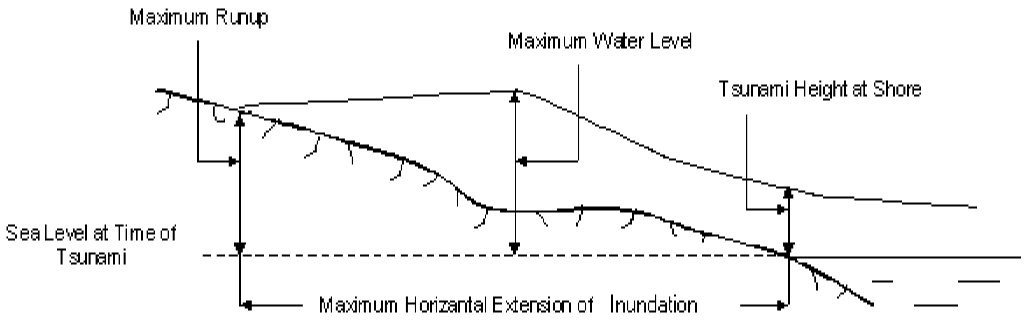

Figure-3.1.a Maximum horizontal extension of the inundation produced by the tsunami (Farreras, 2000).

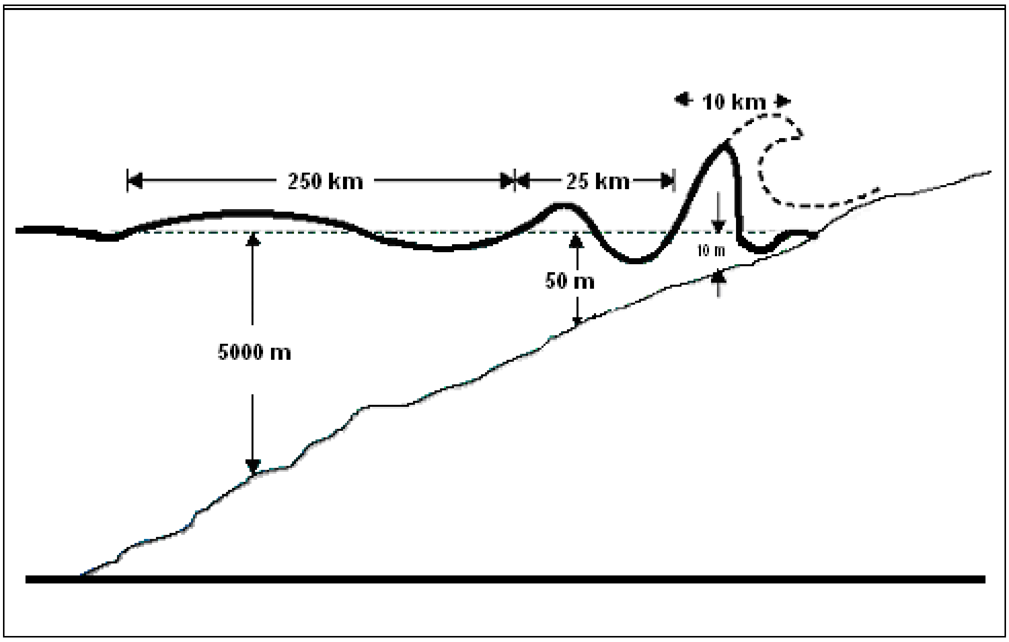

Figure-3.1.b Tsunami in shoaling waters (adopted from Brochure, Tsunami - The Great Waves, 2002)

In the open sea, tsunami has about 10 centimeter height at the surface, but its wave height increases rapidly as it reaches shallow water. Tsunami wave energy extends from the surface to the bottom. While entering the shallow water, as the tsunami attacks the coastline, the wave energy is compressed because of the shorter distance and shallower depth which creates destructive waves which may pile up more than 10 meters of height. Large tsunamis are known to reach a height of 30 meters.

3. 3 Shallow Water Equation

When the product limit is as $kh < \pi / 10$ for waves propagating in shallow water, these are called long waves or shallow water waves. The notation ***k*** is the wave number obtained by the Eq. (3.2.) and ***h*** is the water depth;

$$k = \frac{2\pi}{L} \qquad \text{Eq. (3.2.)}$$

where ***L*** is the wave length in meter.

As may be seen from the Eq. (3.2.), when ***L*** increase, the wave number ***k*** will decrease, thus the ***kh*** product will diminish which will lead to shallow water equation. Tsunamis with long wavelengths are considered to behave like shallow water waves.

The motion of the long waves derived from the three-dimensional conservation of mass equation for an incompressible fluid is;

$$\frac{\partial \eta}{\partial t} + \frac{\partial [U(h+\eta)]}{\partial x} + \frac{\partial [V(h+\eta)]}{\partial y} = 0 \qquad \text{Eq. (3.3.)}$$

where;	x, y	: Cartesian coordinates
	t	: time
	h	: still water depth
	η	: water surface elevation above still water level
	U, V	: vertically averaged velocity components (in that we assume velocities in the x and y direction constant over the depth)

3. 4 Development of Tsunami

There are mainly three causes of a tsunami: earthquakes, submarine landslides, volcanic eruption and/or crater collapse. As mentioned before, a tsunami is generated by a sudden displacement of a large amount of water mass from its equilibrium position. Waves are formed as the displaced water mass, which acts under the influence of gravity, attempts to regain its equilibrium. This generates a sea wave, called tsunami.

The initial size of a tsunami wave is determined mainly due to the amount of vertical sea floor deformation, which is related to earthquake magnitude, depth and fault characteristics. There are other parameters that influence the formation of tsunami, such as the velocity of the sea floor deformation, bathymetric configuration, shoreline configuration, water depth at the source of the event and the energy efficiency, which is the energy transferred from the crust to the water column.

Regardless of the origin of the source of a tsunami, the tsunami develops through three physical processes; generation, propagation and inundation which are characterized in the Figure-3.2.

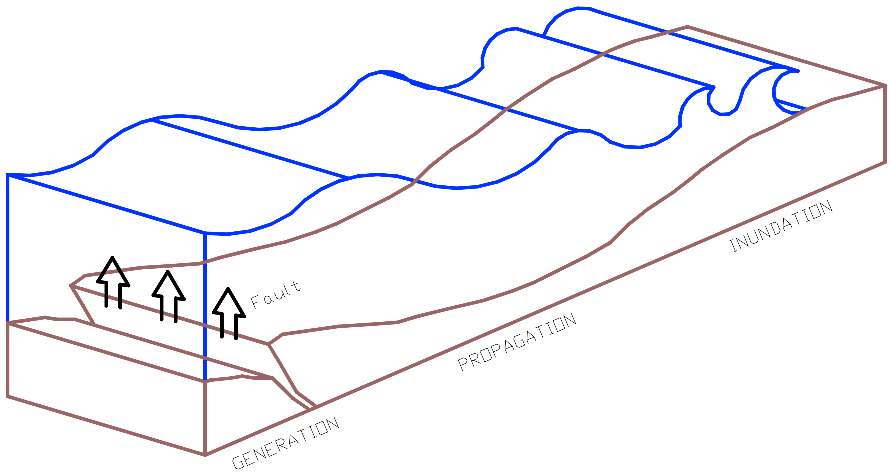

Figure-3.2. Three Physical Process of Tsunami
(adopted from Lorca, E. and Recabarren, M.)

The generation process begins by sudden disturbance of the water column and the movement of the vertical sea floor from its equilibrium position which triggers the tsunami. The triggering action may be an earthquake, a submarine landslide, a submarine volcanic eruption or a large meteorite impact which is a very few possibility.

The second phase of propagation, is the transfer of generated tsunami from deep water near the source to shallow water area. In this process, the tsunami wave transports the seismic energy that is collected, through the undulations of the water.

When the wave enters shallow water region, the phenomenon called shoaling which is due to decreased depth and refraction which is due to the velocity difference of the wave on different bottom contours, occur. As a consequence, different parts of the waves travel at different velocities, a situation which causes the waves to bend (refraction) and to begin to overtake one another increasing the volume of water (shoaling) as seen in the Figure-3.3.

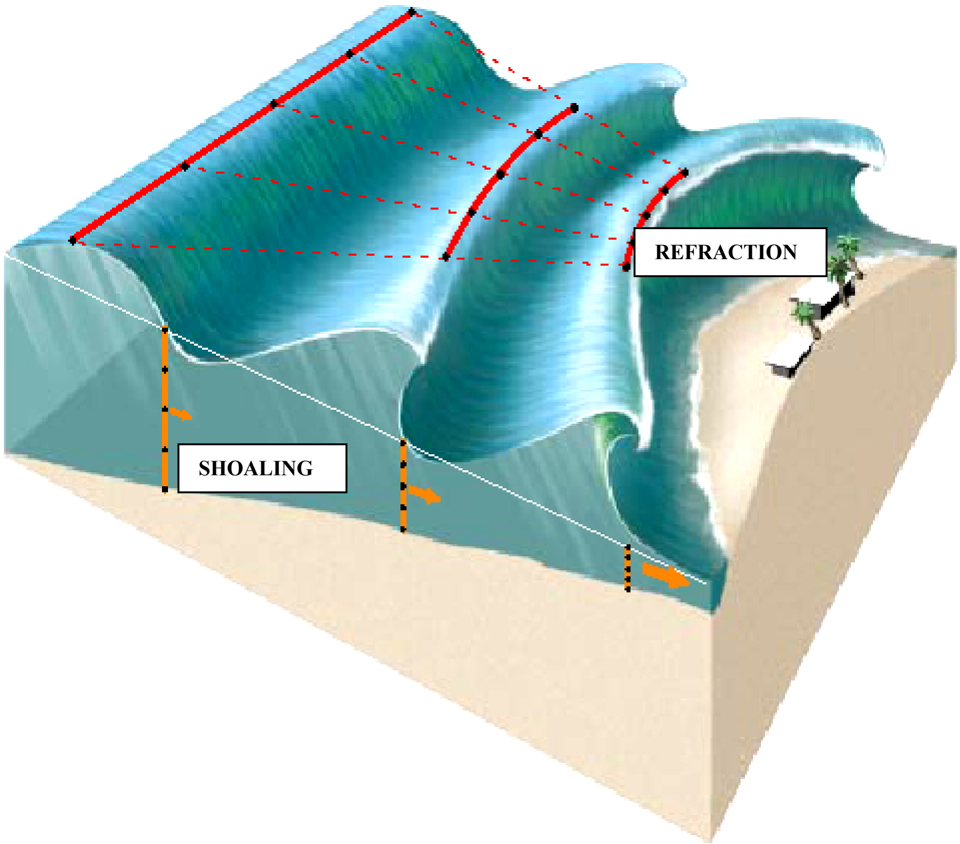

Figure-3.3 Shoaling and Refraction

(Gonzales F. I., Scientific American, May 1999)

The amount of seismic energy transported by the tsunami is squeezed to small water volumes as a result of shoaling and refraction. This creates higher waves and faster currents.

Inundation and run-up, the last stages of tsunami, occur as tsunami attacks or hits the coastline as breaking waves, a wave wall or just a flood. Tsunamis do not break frequently, but if it moves from the deep water to a shallow river or bay, it may form a bore which has a steep breaking front. Flooding may extend inland up to 350 m. Flooding of tsunami tends to take the people and the destroyed objects in itself when it retreats. Tsunamis may reach a run-up height, which is the vertical height of water above the sea level, of 30 meters.

The inundation and run-up characteristics of tsunamis differ from one tsunami to another due to the physical characteristics of the coastline. One tsunami may flood onshore with leaving debris up to 150 meters inland in one place of the coastline but may hit by a water wall of 3-meter height in another place.

3. 5 Tsunamis in Turkey

Science is not able to predict when an earthquake will occur yet, thus the scientists can not determine when a tsunami would occur exactly. However, with the aid of historical records of tsunamis and some computer tools such as numerical models, scientists may have an idea where they are most likely to be generated. Tsunami height measurements and computer tools help to forecast future tsunami impact at the coastal areas, that is the reason why it is important to collect data from the past tsunami records.

According to the study carried out by the Washington University, about 62% of all tsunamis have occurred in the Pacific Ocean, 20% in the Indian Ocean, 9%

in the Mediterranean Sea and 9% in the Atlantic Ocean. Tsunamis occurred in the Mediterranean Sea, which also includes the Aegean and the Marmara Seas, were not as violent as those occurred in the Pacific Ocean but they are quite important for Turkey which is located in a seismic zone.

Turkey lies on the Mediterranean region of the Alpine-Himalayan acrogenic belt. It is located in a seismic region where 3 active faults, North Anatolian Fault (NAF), East Anatolian Fault (EAF) and the Hellenic Arc, are present.
As one of the main factors creating tsunamis is the earthquake, Turkey, being located in the faulty region, will probably encounter tsunamis caused by seismic motions in the future as it happened in the past.

According to the studies of Altınok and Ersoy (2000), the historical records show that there occurred approximately 100 tsunamis in the seas neighboring Turkey, the Mediterranean, the Aegean, the Black and the Marmara Seas for an observation period of around 3500 years starting from 1500 B.C. The last tsunami was recorded in 17 August 1999, Izmit Earthquake which caused severe damage and killed a lot of people.

The Marmara, a small inland sea when compared to the other seas surrounding Turkey, has significant risk of occurrence of Tsunami, as it experienced more than 40 tsunamis in the past.

The spatial distribution of the observed earthquakes may be seen in Figure-3.4., and the chronological distribution in Figure-3.5.

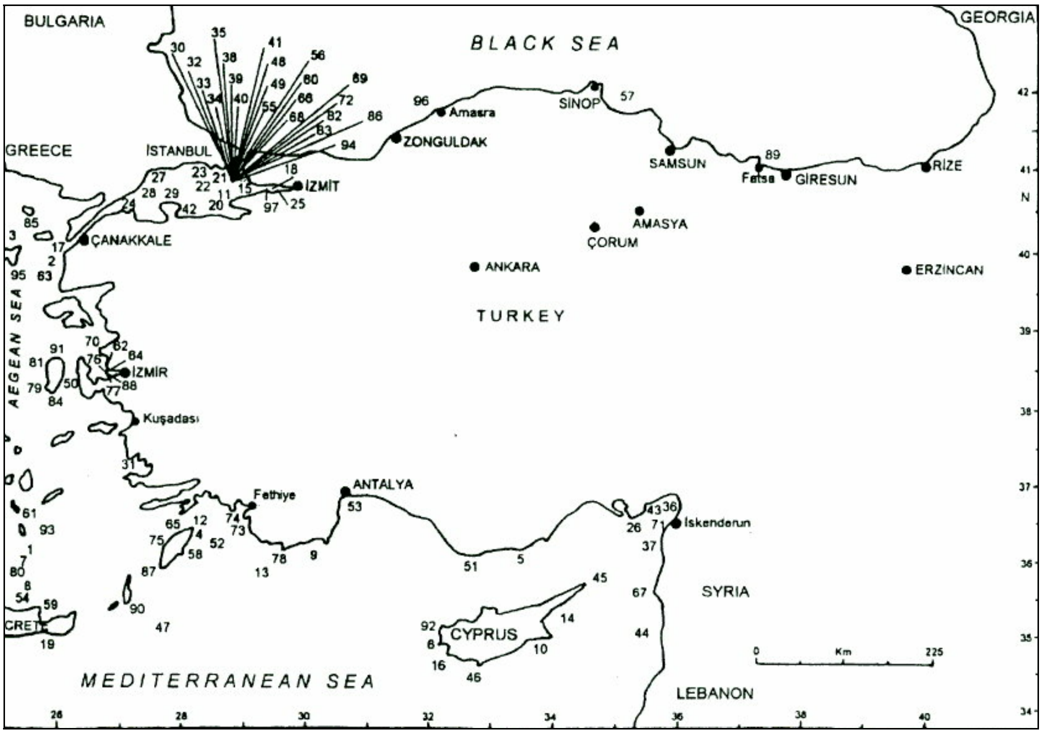

Figure-3.4 The spatial distribution of the observed earthquakes
(Altınok and Ersoy, 2000)

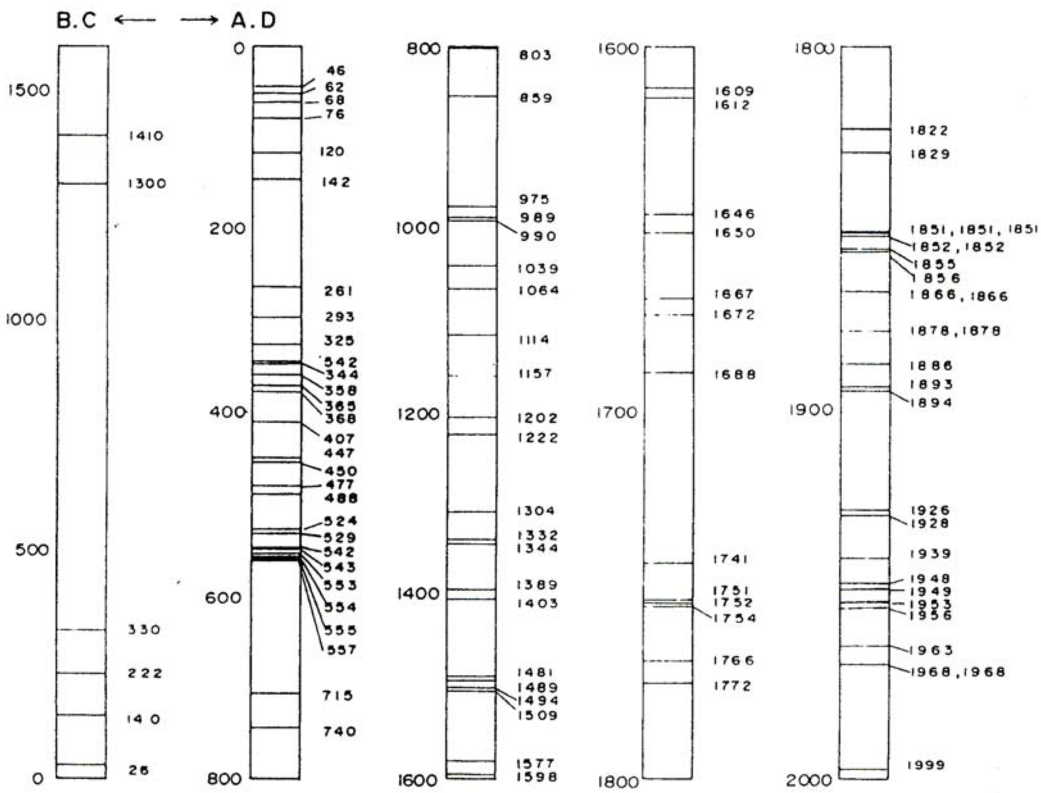

Figure-3.5 The chronological distribution of the observed earthquakes (Altınok and Ersoy, 2000)

As observed from the Figure-3.4, the areas where the tsunamis are concentrated are Izmit Bay, Istanbul Coasts, Gemlik Bay, Kapıdağ Peninsula and the Gelibolu Coasts (Altınok and Ersoy, 2000).

The actual number of tsunamis may be higher than what is known today as there may be some missing historical data. According to the study of Altınok and Ersoy, 2000 and Altınok et al., 2001, some of the major tsunamis which occurred in the Turkish coasts are as follows:

1) The earthquake in the year 120 or 128 which affected the Iznik and Izmit regions created a tsunami along the Kapıdağ Peninsula coast.
2) On 24 August 358, a tsunami triggered by earthquake was observed in the Marmara Sea.
3) Tsunamis triggered by an earthquake on 24/25/26 September 477/480 occurred in Istanbul, and had significant impact on the shoreline. The earthquakes were felt in Istanbul, Çanakkale, Izmit, Bozcaada and Gelibolu regions.
4) Many people were killed on August 545 by a tsunami occurred in Bosphorus. On 15 August 553, Izmit and Istanbul coasts faced with an inundation length of about 2 km.
5) On 14 December 557, an earthquake affecting Istanbul and Izmit Bays created tsunami which caused an inundation length of about 3 km.
6) An earthquake on 14 October 1314, which affected almost all Marmara shoreline created tsunami with an inundation length of about 2 km.
7) The earthquake occurred on 10 September 1509 in Istanbul triggered a tsunami in Marmara Sea which passed over the Istanbul city walls. It had a run-up more than 6 meters. The walls on the shore of Izmir castle were damaged severely; the quay walls of the shipyard collapsed and the wave flooded the lower regions of the city.
8) The earthquake on 1598 in Amasya and Çorum, generated a tsunami in the Black Sea. The sea receded and drove back and killed about 1000 people. The wave height was about 1 m.
9) On 22 May 1766, a tsunami triggered by earthquake resulted in severe damage in the Bosphorus and along Mudanya shoreline.
10) The Erzincan earthquake, happened on 26/27 December 1939, was one of the heaviest earthquakes which the earth has ever experienced. About 40000 people were killed and thousands of houses were damaged. The sea receded up to between 50-100 m in the shoreline. When the sea drove back, the edge of the coast rose up to 20 m. The

tsunami effect was felt in Ünye, Giresun, Ordu, Fatsa and in some parts of the Russian coasts.

11) The earthquake of Bartın happened on 3 September 1968. It was felt in Istanbul, Ankara, Bursa and Samsun. The coastline uplifted between Amasra and Çakraz. The sea receded 12 to 15 m and never reached its original level. The sea inundated the land twice, first 100 m, and second 50-60 m.
12) The earthquake of Izmit on 17 August 1999, caused many deaths and injuries and tremendous damage to the Izmit Gulf. The sea first receded and drove back with a run-up of more than 2.5 m. The water rise exceeded 10 m in some places, such as Değirmendere.

In most of the Tsunami cases in Turkey, the sea first recedes and then drives back at varying heights. Some of them cause people to drown and destroy the coastline and make floods.

Altınok and Ersoy (2000) collected the observed tsunamis on and near the Turkish coast, as given in Table-3.2.

Table-3.2 demonstrates the date and the location of the tsunamis occurred as well as their intensities ***i***. Tsunami intensity ***i***, is a value of six-grade scale which is based on the description of tsunami macroscopic effects such as damage. It is does not deal with the measurement or estimation of a physical parameter such as the tsunami height. Tsunami Intensity Scale was first presented by Sieberg (1927) and modified by Ambraseys (1962) and was published as Modified Sieberg Sea-Wave Intensity Scale. This scale is given in Appendix B. Tsunami intensity may be different for each affected area depending on the shore type and characteristics, bathymetry, construction method of the coastline located structures etc… A better solution may be to scale the tsunami intensities in relation with its physical characteristics. e.g. tsunami wave height, inundation and velocity

Table-3.2. Observed Tsunamis on and near the Turkish Coast

Date	**Place**	**Tsunami Intensity**
1410±100 B.C.	North east of Crete	i=6
1300	Çanakkale Region (Dardanelles), Troy	i=6
330	North east of Limnos Islands.	
222	Rhodes, Cyprus, Corinth	
140	Acre, Tyr-Syria	i=4 (6)
26	Paphos-Cyprus	i=3 (6)
46 A.D.	North east of Crete, Santoroni Island	
53/62/66	Cnossos-Crete, Leben	i=3
68	Demre, Patara-Lycia	
76-78	Larnaca, Paphos, Salamis-Cyprus	
120/128	Kapıdağ Peninsula (Cyzicus), Iznik, Izmit	
142	Fethiye Gulf, Rhodes, Kos, Seriphos, Syme Islands	i=3-4
261-262	South coasts of Anatolia	i=4
293-306	Salamis-Cyprus	
325	Izmit Gulf	
342	Paphos, Famagusta, Cyprus	
344	Çanakkale Region, Thracian coasts	i=3-4
24.08.358	Izmit Gulf, Iznik, Istanbul	i=4
21.07.365	East Meditterranean, Crete, Greece, Adriatic coasts, Alexandria, West Anatolia	i=3-6
11.10.368	Iznik and its surrounding	
01.04.407	Istanbul	
08.11.447	Marmara Sea, Istanbul, Izmit Gulf, Marmara Islands	i=4-6
26.01.450	Marmara Sea, Istanbul	i=3

Table-3.2. Observed Tsunamis on and near the Turkish Coast (Continued)

Date	**Place**	**Tsunami Intensity**
24/25/26.09.477/480	Gelibolu, Çanakkale, Istanbul, Izmit, Bozcaada	
26.09.488	Izmit Gulf	
524/525	South coasts of Anatolia, Anazarba-Adana	
529	Thracian coasts of Marmara	
542	West coasts of Thracia, Bandırma Gulf	i=4
06.09.543	Kapıdağ Peninsula, Erdek, Bandırma	
15.08.553	Istanbul, Izmit Gulf	
15/16.08.554	South west coasts of Anatolia, Kos Isl., Mandalya Gulf	i=4-6
15/16.08.555	Istanbul, Izmit Gulf	
14.12.557	Istanbul, Izmit Gulf	
715	Istanbul, Izmit Gulf	
26.10.740	Marmara sea, Istanbul, Izmit, Iznik Lake	i=3-4
19.12.803	Iskenderun Gulf	i=3
11.859	Syrian coasts, near Samandağ	i=3
26.10.975	Istanbul, Thracian coasts of Marmara	i=3
989	Istanbul, Marmara coasts	
990	Istanbul, Marmara coasts	
02.02.1039	Istanbul, Marmara coasts	
23.09.1064	Iznik, Bandırma, Mürefte, Istanbul	
10.08.1114	Ceyhan, Antakya, Maraş	
15.07.1157	Hama-Homs, Chaizar Region	
22.05.1202	Cyprus, Syrian coasts, Egypt	i=3-5
05.1222	Paphos, Limasol-Cyprus	i=4
08.08.1304	East Meditterranean, Rhodes, Crete, Peloponnesus	i=4-5
12.02.1332	Marmara sea, Istanbul	i=3
14.10.1344	Marmara sea, Istanbul, Thracian coasts, Gelibolu	i=4
20.03.1389	Izmir, Chios and Lesvos Islands	i=3-4
16.11.1403	South coasts of Anatolia, Syrian coasts	i=3
03.05.1481	Rhodes, South west coasts of Anatolia, Crete	i=3

Table-3.2. Observed Tsunamis on and near the Turkish Coast (Continued)

Date	**Place**	**Tsunami Intensity**
1489	South coast of Anatolia, Antalya	i=3
01.07.1494	Herakleion-Crete	i=2-3
10.09.1509	Istanbul, Marmara coasts	i=3
17.07.1577	Istanbul	
1598	Amasya, Çorum	
04.1609	Rhodes, East Mediterranean	
08.12.1612	North of Crete	i=5
05.04.1646	Istanbul	i=3-4
29.09.1650	Santorini, Patmos, Sikinos Isls. Northen Crete	i=4-6
30.11.1667	Izmir Gulf	i=2
14.02.1672	Bozcaada, Kos Isl.	
10.07.1688	Izmir Gulf	i=3
31.01.1741	Rhodes	
15.08.1751	Istanbul	
21.071752	Syrian coasts	i=3
02.09.1754	Izmit Gulf, Istanbul	
22.05.1766	Istanbul, Marmara Sea	i=2
24.11.1772	Chios Isl., Foça	
13.08.1822	Antakya, Iskenderun, Kilis	
23.05.1829	Istanbul, Gelibolu	i=3
28.02.1851	Fethiye, Kaya-Muğla, Rhodes	i=3
03.04.1851	Fethiye Gulf	i=3
23.05.1851	Rhodes, Dodecanese, Chalki	i=2
12.05.1852	Izmir	i=3
08.09.1852	Izmir	i=3
13.02.1855	Fethiye Gulf	i=3
13.11.1856	Chios Isl.	i=3
31.01.1866	Santorini Isl.	i=3-4
02.02.1866	Chios Isl.	i=3

Table-3.2. Observed Tsunamis on and near the Turkish Coast (Continued)

Date	**Place**	**Tsunami Intensity**
19.04.1878	Izmit, Istanbul, Marmara Sea	i=3
10.05.1878	Izmit, Istanbul, Bursa	
27.08.1886	Southern Peloponnesus, Pylos, Izmir	i=2-3
09.02.1893	Northern Aegean Sea, Samothrace Isl., Thracian coasts, Alexandroupolis	i=3
10.07.1894	Istanbul	i=3
26.06.1926	Rhodes, South west of Turkey, Archangelo, Fethiye, Karpathos, Herakleion	
31.03.1928	Izmir	i=2
26-27.12.1939	Fatsa-Black Sea	i=4
09.02.1948	Karpathos - Dodocanese	i=4
23.07.1949	East Aegean Sea, North Chios Isl.	i=2
10.09.1953	South coasts of Turkey	
09.07.1956	Greek Archipelago, Amorgos, Astypalaca Isls.	i=5-6
18.09.1963	Eastern Marmara, Yalova, Karamürsel, Kılıç, Armutlu, Mudanya, Gemlik Gulf	
19.02.1968	North Aegean Sea	i=2
03.09.1968	Amasra-Black Sea	i=3
17.08.1999	Izmit Gulf	i=3

Beside the collection of Altınok and Ersoy (2000), in his thesis "A Study on the Coastal Amplification near Southwestern Turkey", B. Haboğlu has developed synthetic tsunamis created by landslides for various regions of Turkey. In this study, two mathematical models "Tsunami-N2" and "Two-Layer" modeled tsunamis, which were developed in Tohoku University and

METU. The obtained synthetic tsunami parameters can be found in Appendix C.

CHAPTER 4

NEURAL NETWORKS

4. 1 Methodology of Artificial Neural Networks

Artificial Neural Network (ANN) is a system which uses some models imitating the network characteristics of a human neuron. The human brain learns by experiencing events. This is the proof of that some problems which go beyond the scope of current computers programs dealing with strict rules, are indeed solvable by small brain simulating ones.

ANN is an attempt to simulate the multiple layers of simple processing elements called neurons with special software and codes. Each neuron is linked to certain of its neighbors with varying coefficients of connectivity which represent the strengths of these connections. Learning is accomplished by adjusting these strengths to cause the overall network to output appropriate results.

Nowadays, artificial neural network is widely used in the fields of economy, medicine, industry engineering, computer engineering, electronics and for other intelligence problems. Neural network systems are used in engineering applications since they are good alternatives for the problems which are difficult to be solved by conventional mathematical methods.

The applications of neural networks may be classified as 5 main categories,

- Classification
- Prediction
- Data association
- Data conceptual
- Data filtering

In this study, as the available data are insufficient and there is not a known relation between, prediction with conventional statistical methods is hard to be achieved. Artificial Neural Network, which creates the interrelation of the data to estimate the expected output in the learning phase, is a better solution for tsunami characteristics prediction.

4. 2 The Biological Neuron

The human neural system comprises neural cells called neurons. In the human brain, there are between 10 billion to 100 billion of neurons, which are closely connected with each other in different levels. The power of the brain comes from the number of the neurons and multiple connections among them. A model of a biological neuron can be found in the Figure-4.1

A neuron can communicate with its neighbors by means of impulses. These impulses or signals are transmitted to the impacting membrane. A neuron is formed of a body, a nucleus within the body and two extensions by the two sides. The extension which is shorter and branches receives the input information called dendrites and the other extension which is longer and unique that transmits the output information to the other neuron is called axon.

The body part, which the nucleus is in, is called soma. Soma is the part in which inputs are processed.

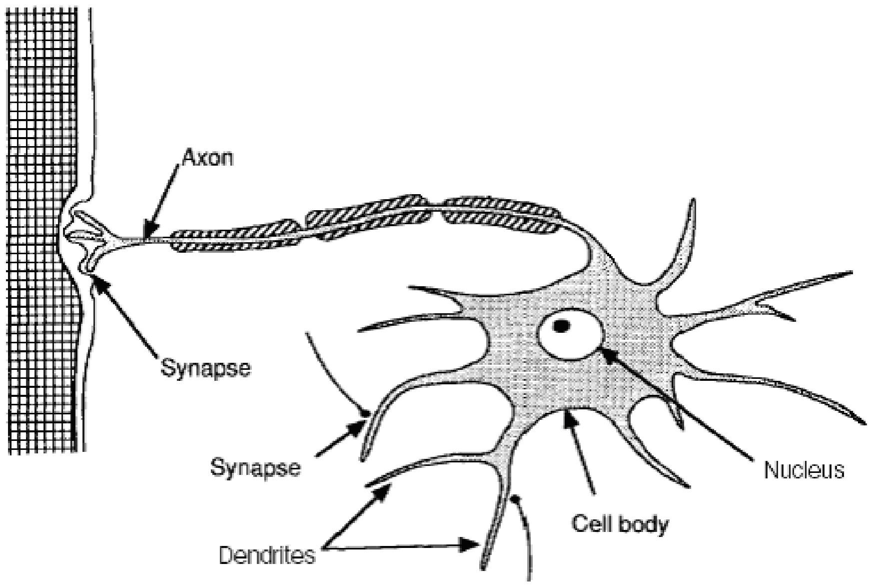

Figure-4.1. Biological Neuron (Freeman, J. A., Skapura, D. M., Neural Networks Algorithms, Applications, and Programming Techniques, 1991)

The body part, which the nucleus is in, is called soma. Soma is the part in which inputs are processed.

Despite the fact that the axon has a diameter of one percent of 1mm; its length may reach various meters. Membranes called synapses establish the interconnection between dendrites and axon.

A neuron collects and juxtaposes the signals it receives from other neurons by means of its dendrites (Figure-4.2.). If the signal group is strong enough, the neuron produces an output signal. This signal is transmitted to the receiver neurons by being passed through the axons.

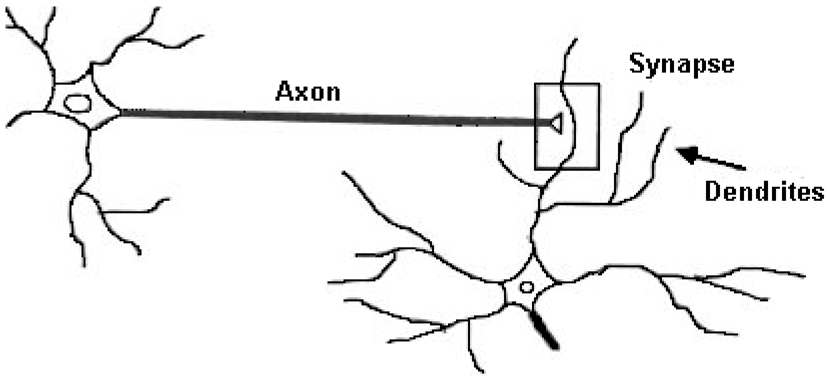

Figure-4.2. Transmission of an impulse (Neural Networks, Stergiou, C., Siganos, D., 1996)

4. 3 The Artificial Neuron

An artificial neuron is an artificially created element which imitates biological neuron behavior. It simulates the four basic functions of natural neurons, the acceptance of inputs (dendrites), the process of inputs (soma), the transformation of inputs to outputs (axon) and the electromechanical transmission among neurons (synapses). An artificial neuron presentation is given in the Figure-4.3.

The inputs of network are represented by the symbols x_k which are multiplied by a connection weight, represented by w_{jk}, before entering into the processing element (node) which simulates the cell body with its nucleon of the natural neuron.

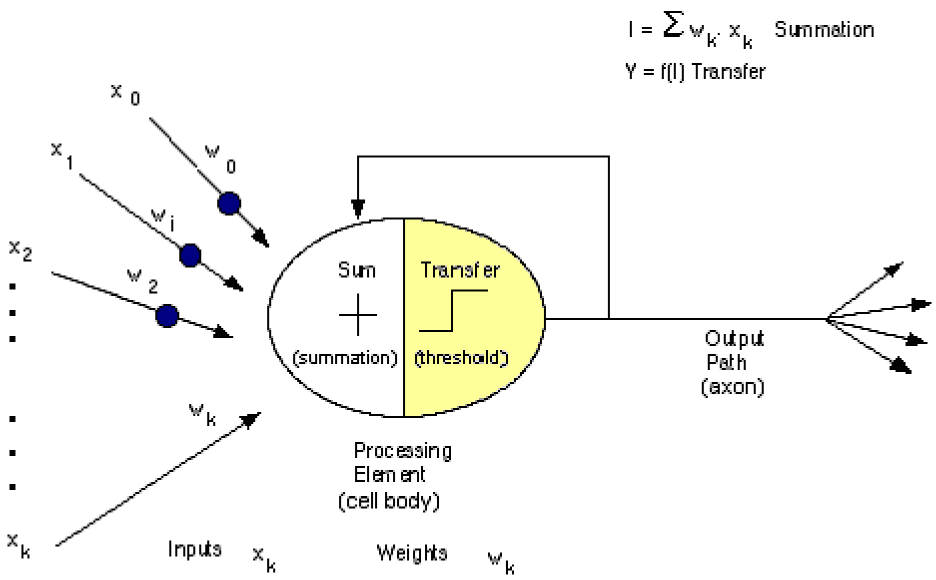

Figure-4.3. The Artificial Neuron

(http://www.dacs.dtic.mil/techs/neural/neural_ToC.html)

As it will be described later, the input x(n) is sent to the neuron on its incoming weights w(n). The product x(n).w(n) is processed by a propagating function which simply sums the values of all incoming weights. The obtained result is compared with a threshold value by the neuron's activation function.

If the neuron is activated, it sends an output to be transmitted to the weights to all connected neurons and so on.

4. 4 Designing a Neural Network

The design of a neural network is performed by a series of trial and error processes. The major steps which the neural network system designers should follow are as follows; (Klerfors, D., 1998)

- Arranging neurons in various layers,
- Deciding the type of connections among the neurons for different layers, as well as among the neurons with a layer.
- Deciding the way a neuron receives inputs and produces output.
- Determining the strength of connection within the network by allowing the network to learn appropriate values of connection weights by using a training data set.

The design of neural network is not an easy and short step. The adequate network can only be obtained after a series of iterative processes.

4. 5 Layers

The artificial networks simulate the complex natural network by clustering the artificial neurons. In every neuron system, there must be some input nodes as well as some output nodes. Some of the neurons interface the real world to receive the inputs and some other neurons provide the real world with the outputs of the network. The rest of the neurons are hidden layers whose number depends on the problem to be solved.

The input layer is the layer which takes the input values x(n) from outside. All the nodes of the input layer form the input of the neural net. The output layer is the layer in which all the nodes send the output values y(n) to the user's external environment. All the other iterative calculations and weight adjustments to design the network and the calculations after the design are carried out by the hidden layers (Figure-4.4).

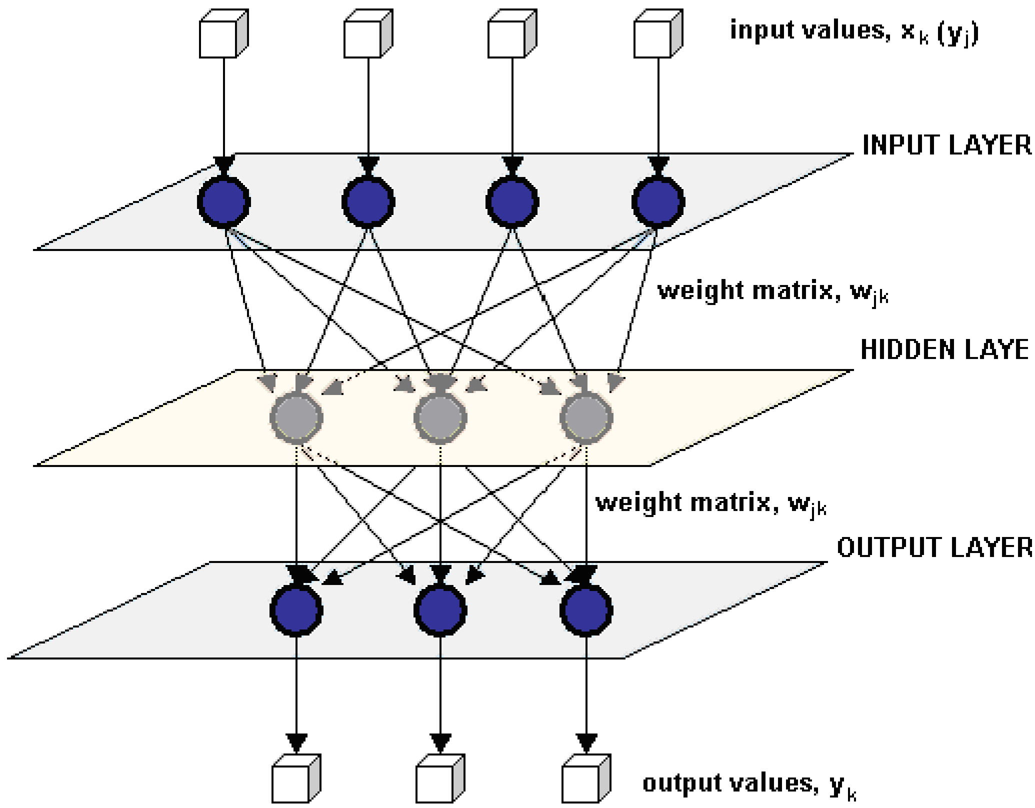

Figure-4.4. Layers

As the input layer receives the input, its neurons (nodes) produce output which is an input for the following layers of the net. This process continues until the output layer which releases its result to the output environment.

All the nodes in the hidden layer are in full relation with the others. This means that all things which are learned in the hidden nodes are based on the evaluation of the whole inputs values. The hidden layers are the places where the solidarity of the model is established.

The hidden layers are the heart of the network system. The weights are adjusted in accordance with the input and output values in the hidden layer entrances and exits. They try to obtain the expected output values.

The number of processing hidden layers among the input and output layers is determined by trial and error processes. The hidden layers should fit to an optimum value. If the number of hidden layers is higher than it should be, there will be an over fit problem, in which the training set of data is memorized and the network will be useless for new data sets. Contrary, if the number of the hidden layer is lower, the network will not be able to learn adequately and to form a healthy network.

The number of the hidden layers influences the performance of the network up to 5 digits. Thus, the best result can be obtained by changing the other network parameters before changing the hidden layer number.

4. 6 The Working Process of the Network

The working process of the network is as follows;

1 – Obtaining and analyzing data and describing the problem,
2 – Selection of the learning (training) and test data,

3 – Selection of the suitable network type,

4 – Selection of the appropriate parameters,

5 – Normalization of the data

6 – Learning (training) process

7 – Testing Process

8 – Use of the network for new entries

As described above, the network type should be decided according to the problem. There are various network type grouped below the titles "inter-layer connections" in which the neurons communicate among layers and "intra-layer connections" in which the neurons communicate within layers. Some of the networks types are; fully connected network, partially connected network, feed forward network as inter-layer connections and recurrent network as intra-layer connections.

The learning process is the most important point in the system as the net develops through learning. There are mainly three types of learning methods: 1) "unsupervised learning" in which the hidden neurons should organize itself without any exterior help such as expected outputs, 2) "supervised learning" in which the connections among hidden layers are from outside and are arranged randomly in the beginning and rearranged according to the output results, 3) "back propagation" which is developed by supervised learning in which the information about errors is filtered back through the system to obtain the expected output and is used to adjust the connections between the layers without any exterior intervention.

4. 7 Processing Element

The processing element receives inputs $\boldsymbol{x_k}$ (also called y_j) from neighbors or external sources and uses them to compute an output signal y_k as well as to adjust the weights during the process of learning. The input elements x_k (y_j), which are multiplied by the weights w_{jk}, are transmitted to the processing elements. The output y_k of the processing element is also called the "activation" of the following unit. A model of a processing unit can be found in Figure-4.5.

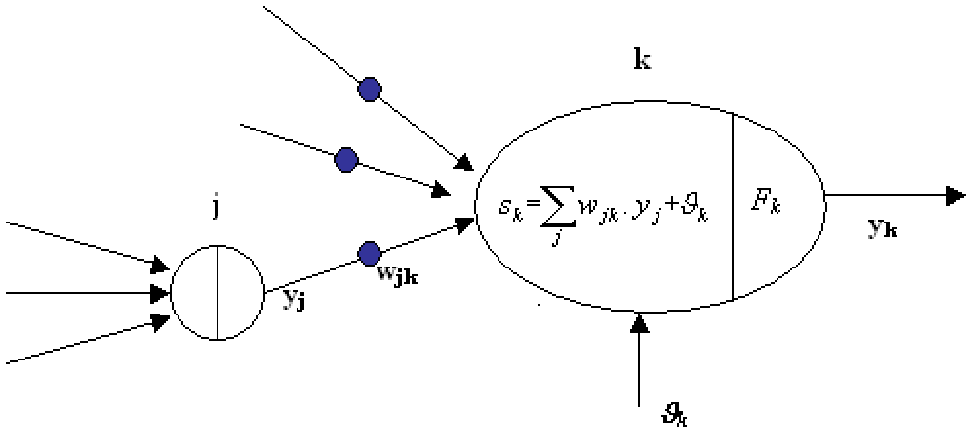

Figure-4.5. Processing unit

The total input to the processing element of unit k is;

$$S_k(t) = \sum_j w_{jk}(t) \; . y_j(t) + \vartheta_k(t) \qquad \text{Eq. (4.1.)}$$

Letters such as ***j*** and ***k*** names all the processing units. The notation w_{jk} means from the unit ***j*** through unit ***k***. The contribution for positive w_{jk} is considered as an excitation and for negative w_{jk} is as inhibition. S_k is the effective input of a processing element that is related to the propagation rule, the input and weight values. The activation function F_k determines the new level of activation based on the effective input S_k and the current activation y_k. The external input ϑ_k is a real number which is called bias or offset term; when it is added to the weighted sum of the input values or threshold value; when it is subtracted from the weighted sum. The bias contributes to the net-input value to the unit, and it participates in the learning process like any other weight.

The addition of the bias is optional but it mostly helps to the convergence of the weights to an acceptable solution. It is perhaps thought as an extra degree of freedom, and its use is largely a matter of experimentation with the specific application (Freeman, J. A. and Skapura, D. M., Neural Networks Algorithms, Applications, and Programming Techniques, 1991).

The product of the input and the weights are summed in the processing unit where the potential level of the neuron is calculated. The product of the inputs is transmitted to an activation function (transfer function/threshold function) F_k in which the summation total is compared with a certain threshold value to determine the neural output. If the effective inputs are greater than the threshold value, the neuron will create an output signal, if it is less, no signal will be generalized.

4. 8 The Activation Function

The activation function (transfer function/threshold function) is proportional to the effective inputs S_k and to the current activation y_k of the neuron.

$$y_k(t+1) = F_k\left(y_k(t)\ .s_k(t)\right) \qquad \text{Eq. (4.2.)}$$

There are many threshold functions which are used as activation function such as; step (hard limiter), linear, semi-linear, ramping, and sigmoid functions (Figure-4.6.). The choice is mostly a non-linear function as linear functions are limited since the outputs are proportional to inputs. The output of the activation functions may be 0 and 1, 1 and –1, and other mathematical combinations.

In our problem, bipolar sigmoid activation function is used for the hidden layers units and linear activation function is used for the output layer calculations.

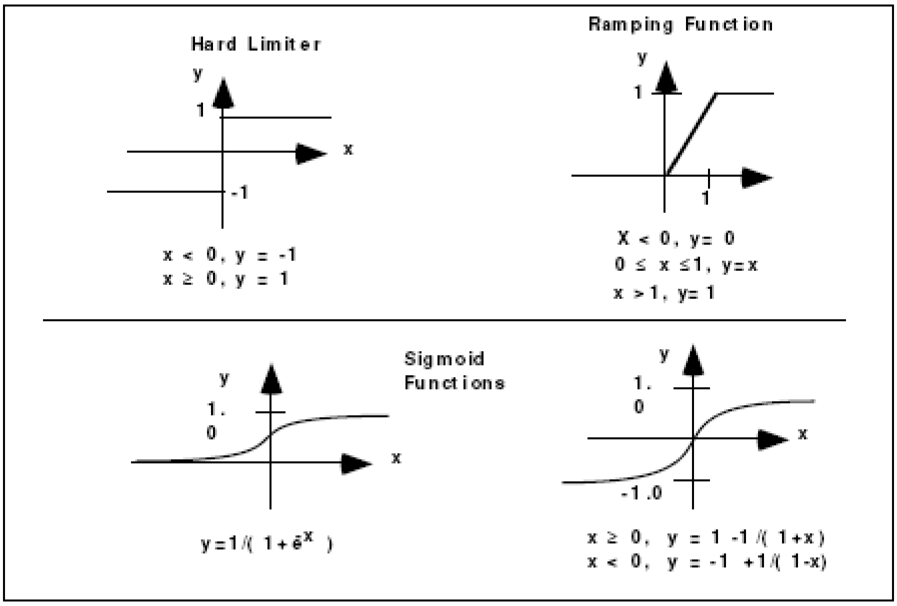

Figure-4.6. Activation functions (Anderson, D., McNeil, G., Neural Networks Technologies, 1992)

The linear activation function is (Figure-4.7.);

$$F_k = S_k = \sum_j w_{jk} \cdot y_j + \vartheta_k \qquad \text{Eq. (4.3.)}$$

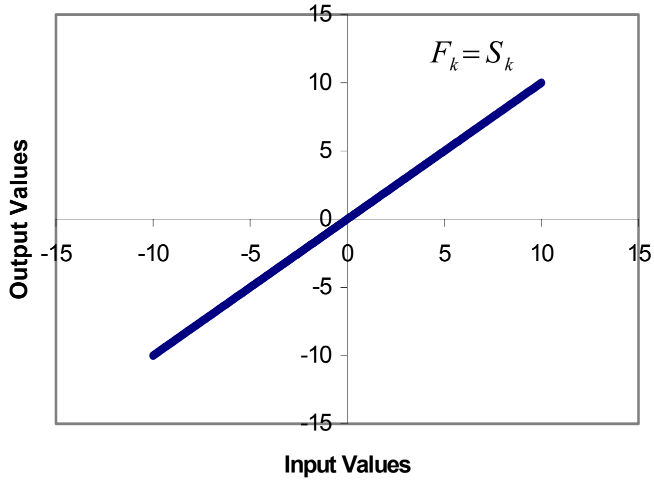

Figure-4.7. Linear Transfer Function

The bipolar and polar sigmoid functions are the most frequently used activation functions. The characteristic of them is that they are monotonically increasing, continuous and differentiable everywhere. The bipolar sigmoid function approaches minimum and maximum values at the asymptotes, which ranges between 1 and -1. (Figure-4.8.)

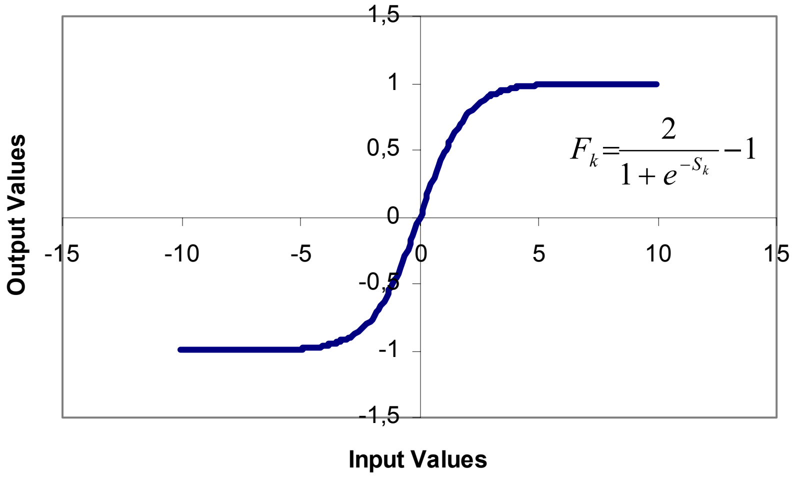

Figure-4.8. Bipolar Sigmoid Transfer Function

The S-shaped bipolar sigmoid function is as follows;

$$F_k = \frac{2}{1+e^{-S_k}} - 1 \qquad \text{Eq. (4.4.)}$$

Thus,

$$F_k = \frac{2}{1+e^{-\sum_j w_{jk}(t)\,.\,y_i(t)+\vartheta_k(t)}} - 1 \qquad \text{Eq. (4.5.)}$$

4. 9 Training (Learning)

The power of the neural network comes from the way which the weights are set. This is done by the learning procedures. There are mainly three learning methods, unsupervised training, supervised training and back-propagation, even though the back-propagation is not considered to be a separate learning method.

In unsupervised training, the inputs are provided to the network but the desired outputs are not presented. The network system should organize itself, a situation which is not very useful nowadays but is the basis of robotic self-learning. The supervised training is also referred to as self-organization or adaptation.

The vast majority of the neural networks are trained by supervised training. In the supervised training process, the inputs and outputs are presented to the network, which are also called the training set. Initially, the weights are randomly selected and examples are fed through the neural net. Then, the outputs are compared with the expected outputs and the weights are rearranged by exterior.

In the back propagation, which is a developed supervised training, the output values are subtracted from the expected outputs, thus the errors are calculated. These are feed back to the network and the weights are adjusted without any exterior contribution. In this way, the neural net "learns" what the desired output is and the signals are back propagated until reaching an acceptable level of errors.

The training phase is a very important process to create a suitable network system, but it can consume time. This training is considered to be complete when the neural network reaches a user defined performance level. This level signifies that the network has achieved the desired statistical accuracy as it produces the required outputs for a given sequence of inputs.
(http://www.dacs.dtic.mil/techs/neural/neural_ToC.html)

The back propagation method is applied to the network systems in the problem of this study, as it is well known from previous research and studies that it is the best network type for prediction problems.

4. 10 Learning Laws

The weight is adjusted by means of some modification rules in the training process. Mostly, this adjustment is due to an error, which is related to the output of the system and to the expected output values.

There are four main training (learning) laws, which are the Hebb's Rule, Hopfield Law, Delta Rule and Kohonen's Law.

The Hebb's law is the basis of the Hopfield and Delta rules and first appeared in the Hebb's book "The Organization of Behavior" in 1949. The basic rule is: if a neuron receives an input from another neuron, and if both are highly active, the weight between the neurons should be strengthened.

In addition the Hebb's rule, the Hopfield Law states the magnitude of the strengthening or weakening. The processing neuron with the biggest output is declared winner in the Kohonen's Law. This neuron has the right to inhibit or excite its neighbors. Only the winner and the excited neighbors will adjust their weights.

The Delta rule, which is also called the Least Mean Square (LMS) Learning Law, is the most commonly used learning Rule. This rule is based on the weight adjustment according to the error calculated in proportion to the current output and expected output values.

The weight adjustment related to the Delta rule for the linear activation function is as follows;

$$\Delta w_{jk} = \gamma . y_j . (d_k - y_k) \qquad \text{Eq. (4.6.)}$$

where; γ is a positive constant called as the learning rate and d_k is the desired output provided by the exterior.

The basis of the derivation of the Eq. (4.6.) is as it is described for the Generalized Delta Rule (Gradient Descend) in the following pages with using the linear activation function.

4. 11 The Generalized Delta Rule (Gradient Descend)

The generalized delta rule (gradient descend), which is the most frequently used rule, is used for the learning processes to predict the earthquake magnitude which may trigger a tsunami in near future and the related tsunami height at the coast.

This rule is based on the idea of continuously modifying the strengths of input connections to reduce the difference (the delta) between the desired output value and the actual output of a neuron. This rule changes the connection weights in a way that minimizes the mean squared error of the network (Klerfors, D., 1998).

When training the network, for every input pattern vector $\boldsymbol{p}$, the difference of the current output $\boldsymbol{y^p}$ and the expected output $\boldsymbol{d^p}$ is the error of this pattern. The rule uses an error function based on this difference to adjust the weights.

As its name implies; Least Mean Square (LMS), the error function is the summed squared error of each neurons;

$$E=\frac{1}{2}\sum_p (d^p-y^p)^2 \qquad \text{Eq. (4.7.)}$$

where the index ***p*** ranges over the set of input patterns.

The values of the weights that minimize the error function is found by making a change in the weight proportional to the negative, which means of opposite direction in terms of vector notation, of the derivative of the error of each pattern with respect to each weight which is called the gradient descend;

$$\Delta_p w_{jk} = -\gamma \frac{\partial E^p}{\partial w_{jk}} \qquad \text{Eq. (4.8.)}$$

The derivative can be written as;

$$\frac{\partial E^p}{\partial w_{jk}} = \frac{\partial E^p}{\partial s_k^p} \frac{\partial s_k^p}{\partial w_{jk}} \qquad \text{Eq. (4.9.)}$$

Knowing that the effective sum of the inputs is;

$$S_k^p = \sum_j w_{jk} \cdot y_j^p + \vartheta_k \qquad \text{Eq. (4.10.)}$$

Taking its derivative to obtain the second term of the Eq. (4.9.);

$$\frac{\partial s_k^p}{\partial w_{jk}} = y_j^p \qquad \text{Eq. (4.11.)}$$

Defining the error signal δ_k^p as the gradients descend;

$$\delta_k^p = -\frac{\partial E^p}{\partial s_k^p} \qquad \text{Eq. (4.12.)}$$

The equation Eq. (4.8.) can be written as;

$$\Delta_p w_{jk} = \gamma \cdot \delta_k^p \cdot y_j^p \qquad \text{Eq. (4.13.)}$$

The chain rule of the derivative may be used to calculate the error signal causing the gradient descends.

$$\delta_k^p = -\frac{\partial E^p}{\partial s_k^p} = \frac{\partial E^p}{\partial y_k^p}\frac{\partial y_k^p}{\partial s_k^p} \qquad \text{Eq. (4.14.)}$$

It is known that the activation is a differentiable function of the total input;

$$y_k^p = F(s_k^p) \qquad \text{Eq. (4.15.)}$$

The derivative of the Eq. (4.15.) shall be;

$$\frac{\partial y_k^p}{\partial s_k^p} = F'(s_k^p) \qquad \text{Eq. (4.16.)}$$

There are two cases for the calculation of the first term of the Eq. (4.13.). The first case is when the ***kth*** term is an output unit of the network (k=o). The derivative of the Eq. (4.7) shall be;

$$\frac{\partial E^p}{\partial y_o} = -(d_o^p - y_o^p) \qquad \text{Eq. (4.17.)}$$

Therefore, the error signal shall be;

$$\delta_o^p = (d_o^p - y_o^p).F_o'(s_o^p) \qquad \text{Eq. (4.18.)}$$

The second case is when the ***kth*** term is a hidden unit of the network (k=h). The error measure shall be written as a function of the net inputs from the hidden layers up to the output layers, using the chain rule;

$$\frac{\partial E^p}{\partial y_h^p} = \sum_{o=1}^{No}\frac{\partial E^p}{\partial s_o^p}\frac{\partial s_o^p}{\partial y_h^p} = \sum_{o=1}^{No}\frac{\partial E^p}{\partial s_o^p}\frac{\partial}{\partial y_h^p}\sum_{j=1}^{Nh} w_{ko}\, y_j^p =$$
$$\sum_{o=1}^{No}\frac{\partial E^p}{\partial s_o^p} w_{ho} = -\sum_{o=1}^{No}\delta_o^p\, w_{ho} \qquad \text{Eq. (4.19.)}$$

Thus, the Eq. (4.14.) shall be;

$$\delta_h^p = F'(s_h^p)\sum_{o=1}^{No}\delta_o^p\, w_{ho} \qquad \text{Eq. (4.20.)}$$

As an input ***x*** enters the network, the calculated activation (output) values y_o^p are transmitted through the output units. The actual output values are then compared with the expected output values $\boldsymbol{d_o}$ and their difference is called the error δ_o^p.

This error tries to diverge to zero value by the network. For this purpose, in the delta rule, the network makes changes in the weights.

The Delta Rule, which is the learning algorithm of the network, is the basis of the back propagation method as the error is back propagated into previous layers, each layer at once. The process of back-propagating the network errors continues until the first layer is reached. Distributing the error of an output unit to all hidden units that are connected changes the weights.

4. 12 Weight Adjustment

From Eq. (4.13.) we know that the weight is adjusted by the product of the learning rate γ, the error that is also called the local gradient δ_k^p and the input signal from the node ***j*** to ***k***, y_j^p.

$$\Delta_p w_{jk} = \gamma . \delta_k^p . y_j^p \qquad \text{Eq. (4.21.)}$$

No matter what the $\boldsymbol{k^{th}}$ term is, an output unit or a hidden unit, the derivative of the activation function $F(s_k^p)$ is calculated for the calculation of the error signal δ_k^p.

The Bipolar Sigmoid Function is selected as the activation function in this thesis. Its derivative shall be;

$$F'(s^p) = \frac{\partial}{\partial s^p}\left(\frac{2}{1+e^{-s^p}} - 1\right) = \frac{2}{(1+e^{-s^p})^2}(-e^{-s^p}) = \frac{2}{(1+e^{-s^p})}\frac{e^{-s^p}}{(1+e^{-s^p})}$$

$$= 2y^p(1-y^p) \qquad \text{Eq. (4.22.)}$$

Thus, the error signals for an output unit shall be;

$$\delta_o^p = (d_o^p - y_o^p)2.y_o^p(1-y_o^p) \qquad \text{Eq. (4.23.)}$$

and for the hidden unit;

$$\delta_h^p = 2y_h^p(1-y_h^p)\sum_{o=1}^{No}\delta_o^p w_{ho} \qquad \text{Eq. (4.24.)}$$

Therefore, the weight adjustments for an output unit and hidden unit shall be respectively;

$$\Delta_p w_{jk} = \gamma.(d_o^p - y_o^p)\,2\,y_o^p(1-y_o^p).y_j^p \qquad \text{Eq. (4.25.)}$$

$$\Delta_p w_{jk} = \gamma.2.y_h^p(1-y_h^p)\sum_{o=1}^{No}\delta_o^p w_{ho}.y_j^p \qquad \text{Eq. (4.26.)}$$

The learning (training) procedures are accomplished by the weight setting from the outputs through the hidden layers to the inputs. The learning rate that is by definition, the proportion of modification of the weights of the global errors in the feed forward networks, is chosen between $0 < \gamma < 1$.

If the learning rate γ is chosen a small value, the algorithm will proceed slowly, but will follow accurately the path of steepest descent in weight space. Depending of the problem, the process may take weeks or months for old computers. If γ is taken a big value, the algorithm may oscillate, that may constitute local minimum points and prevent reaching the global minimums.

Thus the learning rate should be chosen the biggest value that will not lead an oscillation. To avoid the oscillation, there is a simple method that increases the learning rate by modifying the delta rule by including a momentum term α. The Eq. (4.21.) becomes;

$$\Delta w_{jk}(t+1) = \gamma . \delta_k^p . y_j^p + \alpha \Delta w_{jk}(t) \qquad \text{Eq. (4.27.)}$$

The momentum term α is a positive constant between $0<\alpha<1$, which will prevent the algorithm to hang on a local minimum.

4. 13 Multi-layer Feed-forward Networks

The network type, which is used for the prediction purposes, is multi-layer feed forward network. The multi layer feed forward network is a layered network in which each layer posses units that receives inputs from the preceding layers and send its outputs to the following layer. There are no connections within a layer (Figure-4.9.).

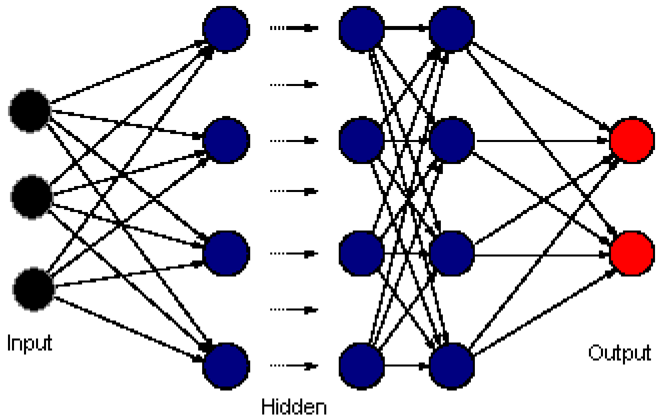

Figure-4.9. Feed-forward Network

CHAPTER 5

CASE STUDY

This case study is performed to predict the future earthquake magnitudes which may create tsunamis in the Turkish coasts and to estimate the related tsunami wave height. In the Case Study, the earthquake magnitudes which may create a tsunami for the return periods of 1, 2, 3, 4, 5, 10, 50 and 100 years were predicted for the Aegean and the Marmara region. These magnitudes were used with the tsunami intensities ranging from 1 to 6 to predict the tsunami height at the coast.

5. 1 Collection of the Data

A research was carried through the historical data to collect various earthquake and tsunamis records (Table-5.1). The data in Table-5.1 were used to feed the artificial neural networks.

In Table-5.1, "Earthquake Intensity" is a parameter characterized by the shaking of ground by an earthquake at one particular location. It is not a physical parameter and is based on the eyewitness descriptions. The Mercalli scale (1902) is an earthquake intensity classification method and is based on damage description. H.O. Wood and F. Neumann modified this parameter in 1931. The Modified Mercalli Intensity scale is given in Appendix D. The magnitude of an earthquake "Ms – The surface wave magnitude" is a measure of its size. It is calculated from the ground motion recorded by a seismograph and corrected for distance from the earthquake epicenter to the seismograph. The earthquake depth is the distance in km from the hypocenter (focus) to the surface (epicenter).

Table 5.1. The Major Earthquakes and Tsunamis in the Turkish Coast

Date	Place	Earthquake Intensity	Magnitude (Ms)	Earthquake Depth (km)	Tsunami Observation	Tsunami Intensity	H_{av}	H_{real}	Reference
BC 1410±100	North east of Crete	**X**	**7,4**		Yes	i=6	31,1		P, T
BC 1300	Çanakkale Region (Dardanelles), Troy				Yes	i=6	31,1		P
BC 330	North east of Limnos Islands.	**IX**	**6,8**		Yes		0,49		P, T
BC 222	Rhodes, Cyprus, Corinth	**X**	**7,4**		Yes		0,49		P, K, T
BC 185	Rhodes, Cyprus	**IX**	**6,8**		No	-	-		K, T
BC 140	Acre, Tyr-Syria	**VIII**	**6,2**		Yes	i=4	7,78		P, T
BC 69	Antakya, Syria	**IX**	**6,8**		No	-	-		K, T
BC 26	Paphos-Cyprus	**IX**	**6,8**		Yes	i=3	3,89		P, K, T
BC 17	Manisa - Aydın	**IX**	**6,8**		No	-	-		K
24.11.29	Iznik, Izmit	**IX**	**6,8**		No	-	-		K, T
46	North east of Crete, Santoroni Island	**VIII**	**6,2**		Yes		0,49		P, T
53/62/66	Cnossos-Crete, Leben	**VIII**	**6,2**		Yes	i=3	3,89		P, T
68	Demre, Patara-Lycia				Yes		0,49		P
76-78	Larnaca, Paphos, Salamis-Cyprus	**IX**	**6,8**		Yes		0,49		P, T
105	Candarli Bay-Greece	**IX**	**6,8**		No	-	-		K, T
110	Izmir, Ephesus	**IX**	**6,8**		No	-	-		K, T
120/128	Kapıdağ Peninsula (Cyzicus), Iznik, Izmit	**VII**	**5,6**		Yes		0,49		P, T
142	Fethiye Gulf, Rhodes, Kos, Seriphos, Syme Islands				Yes	i=3-4	5,5		P
155	Rodos, Mugla, Fethiye	**X**	**7,4**		No	-	-		K, T

Table 5.1. The Major Earthquakes and Tsunamis in the Turkish Coast (Continued)

Date	Place	Earthquake Intensity	Magnitude (Ms)	Earthquake Depth (km)	Tsunami Observation	Tsunami Intensity	H_{av}	H_{real}	Reference
177	Izmir, Sakiz, Sisam	**X**	**7,4**		No	-	-		K, T
212	Istanbul	**VII**	**5,6**		No	-	-		AYM, T
261-262	South coasts of Anatolia	**IX**	**6,8**		Yes	i=4	7,78		P, T
293-306	Salamis-Cyprus				Yes		0,49		P
325	Izmit Gulf	**IX**	**6,8**		Yes		0,49		P, K, AYM, T
342	Paphos, Famagusta, Cyprus	**IX**	**6,8**		Yes		0,49		P, T
344	Çanakkale Region, Thracian coasts	**VIII**	**6,2**		Yes	i=3-4	5,5		P, T
24.08.358	Izmit Gulf, Iznik, Istanbul	**IX**	**6,8**		Yes	i=4	7,78		P, K, T
21.07.365	East Meditterranean, Crete, Greece, Adriatic coasts, Alexandria, West Anatolia	**X**	**7,4**		Yes	i=3-6	11		P, T
11.10.368	Iznik and its surrounding	**VII**	**5,6**		Yes		0,49		P, T
376	Istanbul	**VIII**	**6,2**		No	-	-		AYM, T
382	Istanbul	**VIII**	**6,2**		No	-	-		AYM, T
402	Istanbul	**VIII**	**6,2**		No	-	-		AYM, T
01.04.407	Istanbul				Yes		0,49		P
408	Istanbul	**VII**	**5,6**		Yes		0,49		P, AYM, T
412	Istanbul	**VII**	**5,6**		No		-		AYM, T
427	Istanbul, Izmit, Iznik	**IX**	**6,8**		No	-	-		K, AYM, T
08.11.447	Marmara Sea, Istanbul, Izmit Gulf, Marmara Islands, Marmara and Çanakkale coasts	**IX**	**6,8**		Yes	i=4-6	15,6		P, K, AYM, T

Table 5.1. The Major Earthquakes and Tsunamis in the Turkish Coast (Continued)

Date	Place	Earthquake Intensity	Magnitude (Ms)	Earthquake Depth (km)	Tsunami Observation	Tsunami Intensity	H_{av}	H_{real}	Reference
26.01.450	Marmara Sea, Istanbul	**VIII**	**6,2**		Yes	i=3	3,89		P, T
478	Gelibolu, Çanakkale, Istanbul, Izmit, Bozcaada	**IX**	**6,8**		Yes		0,49		P, K, AYM, T
26.09.488	Izmit Gulf	**VIII**	**6,2**		Yes		0,49		P, T
524/525	South coasts of Anatolia, Anazarba-Adana	**VIII**	**6,2**		Yes		0,49		P, T
529	Thracian coasts of Marmara				Yes		0,49		P
06.09.543	Kapıdağ Peninsula, Erdek, Bandırma	**IX**	**6,8**		Yes	i=4	7,78		P, K, T
15.08.553	Istanbul, Izmit Gulf	**X**	**7,4**		Yes		0,49		P, K, AYM, T
15/16.08.554	South west coasts of Anatolia, Kos Isl., Mandalya Gulf	**VIII**	**6,2**		Yes	i=4-6	15,6		P, T
15/16.08.555	Istanbul, Izmit Gulf	**VIII**	**6,2**		Yes		0,49		P, AYM
14.12.557	Istanbul, Izmit Gulf	**VIII**	**6,2**		Yes		0,49		P, T
688	Izmir	**IX**	**6,8**		No	-	-		K, T
715	Istanbul, Izmit Gulf	**IX**	**6,8**		Yes		0,49		P, K, AYM, T
26.10.740	Marmara sea, Istanbul, Izmit, Iznik Lake	**VIII**	**6,2**		Yes	i=3-4	5,5		P, AYM, T
803	Iskenderun Gulf				Yes	i=3	3,89		P
840	Istanbul	**VI**	**5,0**		Yes		0,49		P, AYM, T
859	Syrian coasts, near Samandağ	**IX**	**6,8**		Yes	i=3	3,89		P, T
16.05.865	Istanbul	**IX**	**6,8**		No	-	-		K, T
885	Istanbul, Girit	**IX**	**6,8**		No	-	-		AYM
26.10.975	Istanbul, Thracian coasts of Marmara				Yes	i=3	3,89		P

Table 5.1. The Major Earthquakes and Tsunamis in the Turkish Coast (Continued)

Date	Place	Earthquake Intensity	Magnitude (Ms)	Earthquake Depth (km)	Tsunami Observation	Tsunami Intensity	H_{av}	H	Reference
26.10.986	Istanbul, Marmara coasts	**IX**	**6,8**		Yes		0,49		P, K, T
990	Istanbul, Marmara coasts				Yes		0,49		P
1010	Istanbul	**VII**	**5,6**		No	-	-		AYM, T
1033	Istanbul	**VII**	**5,6**		No	-	-		AYM, T
1037	Istanbul	**VIII**	**6,2**		No	-	-		AYM, T
1038	Istanbul	**VI**	**5,0**		No	-	-		AYM, T
02.02.1039	Istanbul, Marmara coasts				Yes		0,49		P
1041	Istanbul	**VIII**	**6,2**		No	-	-		AYM, T
1063	Istanbul	**VII**	**5,6**		No	-	-		AYM, T
23.09.1064	Iznik, Bandırma, Mürefte, Istanbul	**IX**	**6,8**		Yes		0,49		P, K, T
10.08.1114	Ceyhan, Antakya, Maraş	**IX**	**6,8**		Yes		0,49		P, K, T
15.07.1157	Hama-Homs, Chaizar Region	**IX**	**6,8**		Yes		0,49		P, T
22.05.1202	Cyprus, Syrian coasts, Egypt	**VIII**	**6,2**		Yes	i=3-5	7,78		P, T
05.1222	Paphos, Limasol-Cyprus	**IX**	**6,8**		Yes	i=4	7,78		P, T
1296	Istanbul	**VIII**	**6,2**		No	-	-		AYM, T
08.08.1304	East Meditterranean, Rhodes, Crete, Peloponnesus	**X**	**7,4**		Yes	i=4-5	11		P, K, T
12.02.1332	Marmara sea, Istanbul	**VII**	**5,6**		Yes	i=3	3,89		P, AYM, T
14.10.1344	Marmara sea, Istanbul, Thracian coasts, Gelibolu	**IX**	**6,8**		Yes	i=4	7,78		P, K, AYM, T
20.03.1389	Izmir, Chios and Lesvos Islands	**IX**	**6,8**		Yes	i=3-4	5,5		P, K, T

Table 5.1. The Major Earthquakes and Tsunamis in the Turkish Coast (Continued)

Date	Place	Earthquake Intensity	Magnitude (Ms)	Earthquake Depth (km)	Tsunami Observation	Tsunami Intensity	H_{av}	H_{real}	Reference
16.11.1403	South coasts of Anatolia, Syrian coasts	**VIII**	**6,2**		Yes	i=3	3,89		P, T
1430	Istanbul	**VII**	**5,6**		No	-	-		AYM, T
1462	Istanbul	**IX**	**6,8**		No	-	-		K, T
03.05.1481	Rhodes, South west coasts of Anatolia, Crete	**IX**	**6,8**		Yes	i=3	3,89	1,8	P, K, T
1489	South coast of Anatolia, Antalya	**VIII**	**6,2**		Yes	i=3	3,89		P, AYM, T
18/08/1493	Istankoy Island	**IX**	**6,8**		No	-	-		K, T
01.07.1494	Herakleion-Crete	**VIII**	**6,2**		Yes	i=2-3	2,75		P, T
10.09.1509	Istanbul, Marmara coasts	**IX**	**7,6**		Yes	i=3	3,89		P, K, AYM, NPE, T
1512	Istanbul	**VII**	**5,6**		No	-	-		AYM
1532	Istanbul	**VII**	**5,6**		No	-	-		AYM
10.05.1556	Istanbul	**VIII**	**6,2**		No	-	-		AYM, T
17.07.1577	Istanbul	**VIII**	**6,2**		Yes		0,49		P, T
1598	Amasya, Çorum	**IX**	**6,8**		Yes		0,49	1	P, T
1609	Rhodes, East Mediterranean				Yes		0,49		P
08.12.1612	North of Crete	**VIII**	**6,2**		Yes	i=5	15,6		P, T
05.04.1646	Istanbul	**VII**	**5,6**		Yes	i=3-4	5,5		P, NPE, T
29.09.1650	Santorini, Patmos, Sikinos Isls. Northen Crete				Yes	i=4-6	15,6	18-30	P
1653	Aydın	**IX**	**6,8**		No	-	-		K, T
1659	Istanbul	**IX**	**6,8**		No	-	-		K, T

Table 5.1. The Major Earthquakes and Tsunamis in the Turkish Coast (Continued)

Date	Place	Earthquake Intensity	Magnitude (Ms)	Earthquake Depth (km)	Tsunami Observation	Tsunami Intensity	H_{av}	H_{real}	Reference
30.11.1667	Izmir Gulf	**VIII**	**6,2**		Yes	i=2	1,95		P, T
14.02.1672	Bozcaada, Kos Isl.	**VIII**	**6,2**		Yes		0,49		P, T
10.07.1688	Izmir Gulf	**X**	**7,4**		Yes	i=3	3,89		P, K, T
1690	Istanbul	**VII**	**5,6**		No	-	-		AYM, T
25.05.1719	Istanbul, Izmit, Karamursel	**IX**	**7,6**		No	-	-		K, AYM, NPE
04.04.1739	Izmir	**IX**	**6,8**		No	-	-		K, T
31.01.1741	Rhodes				Yes		0,49		P
07.06.1751	Sisam Island, Aegean Sea	**X**	**7,4**		No	-	-		K, T
15.08.1751	Istanbul				Yes		0,49		P
21.07.1752	Syrian coasts	**IX**	**6,8**		Yes	i=3	3,89		P, T
02.09.1754	Izmit Gulf, Istanbul	**IX**	**7,0**		Yes		0,49		P, K, NPE, T
22.05.1766	Istanbul, Marmara Sea	**IX**	**7,0**		Yes	i=2	1,95		P, K, AYM, NPE, T
24.11.1772	Chios Isl., Foça				Yes		0,49		P
13.08.1822	Antakya, Iskenderun, Kilis	**X**	**7,4**		Yes		0,49		P, K, T
23.05.1829	Istanbul, Gelibolu	**VII**	**5,6**		Yes	i=3	3,89		P, T
1841	Istanbul	**VII**	**5,6**		No	-	-		AYM, T
18.10.1843	Rhodes, Aegean Sea	**IX**	**6,8**		No	-	-		K, T
12.10.1845	Midilli Island	**X**	**7,4**		No	-	-		K, T
21.06.1846	Sisam Island, Soke	**IX**	**6,8**		No	-	-		K, T

Table 5.1. The Major Earthquakes and Tsunamis in the Turkish Coast (Continued)

Date	Place	Earthquake Intensity	Magnitude (Ms)	Earthquake Depth (km)	Tsunami Observation	Tsunami Intensity	H_{av}	H_{real}	Reference
28.02.1851	Fethiye, Kaya-Muğla, Rhodes	**IX**	**6,8**		Yes	i=3	3,89	0,6	P, K, T
28.02.1851	Fethiye Gulf	**IX**	**6,8**		Yes	i=3	3,89	1,8	P, K, T
23.05.1851	Rhodes, Dodecanese, Chalki				Yes	i=2	1,95		P
12.05.1852	Izmir				Yes	i=3	3,89		P
08.09.1852	Izmir				Yes	i=3	3,89		P
18.08.1853	Tep and Genis Region - Greece	**IX**	**6,8**		Yes		0,49		T
02.03.1855	Fethiye Gulf	**VII**	**5,6**		Yes	i=3	3,89		P, T
12.10.1856	Rhodos, Karpatos, Girit	**X**	**7,4**		Yes		0,49		P, K, T
13.11.1856	Chios Isl., Rhodos, Aegean Sea	**IX**	**6,8**		Yes	i=3	3,89		P, K, T
03.11.1862	Turgutlu, Manisa	**IX**	**6,8**		No	-	-		K, T
22.04.1863	Rhodos	**IX**	**6,8**		No	-	-		K, T
23.07.1865	Midilli Island, Çanakkale, Gelipoli	**IX**	**6,8**		No	-	-		K
31.01.1866	Santorini Isl.	**VII**	**5,6**		Yes	i=3-4	5,5		P, T
02.02.1866	Chios Isl.	**VIII**	**6,2**		Yes	i=3	3,89		P, T
07.03.1867	Midilli Island	**IX**	**6,8**		No	-	-		K, T
02.04.1872	Antakya, Samandag	**IX**	**6,8**		No	-	-		K, T
01.02.1873	Sisam Island, Izmir, Aydin	**IX**	**6,8**		No	-	-		K, T
01.10.1875	Canakkale	**IX**	**6,8**		No	-	-		K
19.04.1878	Izmit, Istanbul, Marmara Sea	**VIII**	**6,2**		Yes	i=3	3,89		P, T
10.05.1878	Izmit, Istanbul, Bursa	**VIII**	**6,2**		Yes		0,49		P, T

Table 5.1. The Major Earthquakes and Tsunamis in the Turkish Coast (Continued)

Date	Place	Earthquake Intensity	Magnitude (Ms)	Earthquake Depth (km)	Tsunami Observation	Tsunami Intensity	H_{av}	H_{real}	Reference
29.07.1880	Menemen, Emiralem, Izmir	**IX**	**6,8**		No	-	-		K, T
03.04.1881	Khios Island, Aegean Sea	**X**	**7,4**		No	-	-		K, T
15.10.1883	Cesme, Aegean Sea	**IX**	**6,8**		No	-	-		K, T
29.02.1885	Aegean Sea	**IX**	**6,8**		No	-	-		K
27.11.1886	Southern Peloponnesus, Pylos, Izmir	**VII**	**5,6**		Yes	i=2-3	2,75		P, T
25.10.1889	Midilli, Sakiz, Izmir	**IX**	**6,8**		No	-	-		K, T
12.03.1893	Northern Aegean Sea, Samothrace Isl., Thracian coasts, Alexandroupolis	**VII**	**5,6**		Yes	i=3	3,89	0,9	P, T
10.07.1894	Istanbul	**X**	**7,4**		Yes	i=3	3,89		P, AYM, NPE, T
19.08.1895	Aydin	**IX**	**6,8**		No	-	-		K, T
19.01.1909	Foca	**IX**	**6,0**	**60**	No	-	-		NPE
09.08.1912	Mürefte	**X**	**7,3**	**16**	No	-	-		CEV
26.06.1926	Rhodes, South west of Turkey, Archangelo, Fethiye, Karpathos, Herakleion	**VII**	**5,6**	**15**	Yes		0,49		P
31.03.1928	Izmir	**X**	**7,3**	**10**	Yes	i=2	1,95		P, CEV
04.01.1935	Erdek	**IX**	**6,7**	**5**	No	-	-		CEV, NPE
22.09.1939	Izmir, Dikili	**X**	**7,1**	**10**	No	-	-		CEV
26-27.12.1939	Fatsa-Black Sea	**XI**	**7,9**	**50**	Yes	i=4	7,78		P
23.05.1941	Muğla	**VIII**	**6,0**	**40**	No	-	-		CEV, NPE
13.11.1941	Muğla	**VIII**	**5,7**	**70**	No	-	-		CEV, NPE

Table 5.1. The Major Earthquakes and Tsunamis in the Turkish Coast (Continued)

Date	Place	Earthquake Intensity	Magnitude (Ms)	Earthquake Depth (km)	Tsunami Observation	Tsunami Intensity	H_{av}	H_{real}	Reference
06.09.1944	Edremit	**IX**	**7,0**	**70**	No	-	-		CEV, NPE
09.02.1948	Karpathos - Dodocanese	**X**	**7,2**	**30**	Yes	i=4	7,78		P
23.07.1949	East Aegean Sea, North Chios Isl.	**IX**	**6,9**	**10**	Yes	i=2	1,95	0,7 or 2	P, ET
23.07.1949	Karaburun	**IX**	**7,0**	**10**	No	-	-		CEV, NPE
02.05.1953	Karaburun	**VIII**	**5,1**	**60**	No	-	-		CEV, NPE
10.09.1953	South coasts of Turkey	**VIII**	**6,3**		Yes		0,49		P
16.07.1955	Aydın, Söke	**IX**	**7,0**	**40**	No	-	-		CEV, NPE
09.07.1956	Greek Archipelago, Amorgos, Astypalaca Isls. (Amorgos)	**X**	**7,4**	**10**	Yes	i=6	31,1	20-30	P
09.07.1956	Greek Archipelago, Amorgos, Astypalaca Isls. (Astypalaca)	**X**	**7,4**	**10**	Yes	i=6	31,1	20	P
09.07.1956	Greek Archipelago, Amorgos, Astypalaca Isls. (Pholegandros)	**X**	**7,4**	**10**	Yes	i=5	15,6	10	P
25.04.1957	Fethiye	**IX**	**7,1**	**80**	No	-	-		CEV, NPE
23.05.1961	Marmaris	**IX**	**6,5**	**70**	No	-	-		CEV
18.09.1963	Eastern Marmara, Yalova, Karamürsel, Kılıç, Armutlu, Mudanya, Gemlik Gulf	**VIII**	**6,3**	**40**	Yes		0,49		P, CEV
19.02.1968	North Aegean Sea	**X**	**7,2**	**7**	Yes	i=2	1,95	1,2	P
03.09.1968	Amasra-Black Sea	**VII**	**5,6**	**5**	Yes	i=3	3,89	3	P, AYM
14.01.1969	Fethiye	**VIII**	**6,2**	**22**	No	-	-		CEV, NPE

Table 5.1. The Major Earthquakes and Tsunamis in the Turkish Coast (Continued)

Date	Place	Earthquake Intensity	Magnitude (Ms)	Earthquake Depth (km)	Tsunami Observation	Tsunami Intensity	H_{av}	H_{real}	Reference
03.03.1969	Gönen	**VII**	**5,7**	**6**	No	-	-		CEV
06.04.1969	Karaburun	**VIII**	**5,6**	**16**	No	-	-		CEV, NPE
26.04.1972	Ezine	**VI**	**5,0**	**18**	No	-	-		NPE
01.02.1974	Izmir	**VI**	**5,2**	**24**	No	-	-		NPE
09.12.1977	Izmir	**VI**	**4,8**	**27**	No	-	-		CEV
16.12.1977	Izmir	**VI**	**5,3**	**24**	No	-	-		CEV
14.06.1979	Foca	**VIII**	**5,9**	**15**	No	-	-		CEV
05.07.1983	Biga	**VI**	**4,9**	**4**	No	-	-		CEV
17.08.1999	Izmit Gulf	**X**	**7,4**	**17**	Yes	i=3	3,89		P, K, AYM, CEV, NPE

The first 5 columns of the Table-5.1 show the date, location of an earthquake and its intensity, magnitude and depth. The blanks mean that there is no available data collected.

The missing parameters in the earthquake intensity $\boldsymbol{I_0}$ or magnitude $\boldsymbol{M_s}$ were completed by using the relation proposed by Kalafat (2002);

$$M_s = 1{,}39 + (0{,}60\, x\, I_o) \qquad \text{Eq. (5.1.)}$$

The 6th column states whether there was a tsunami occurrence related to this earthquake, and the 7th column gives the tsunami intensity.

The parameter $\boldsymbol{H_{av}}$, average wave height at the coast, is given in the 8th column and calculated in relation with intensities, from the formula proposed by Soloviev (1990) (Eq. 5.2.);

$$i = \log_2 \sqrt{2}\left(H_{av}\right) \qquad \text{Eq. (5.2.)}$$

The 9th column gives the available real tsunami height records and the last column names the references which lead to the creation of the Table-5.1.

The letters in the "Reference" column, in which the data was collected, are;

A : Altınok, Y. and Ersoy, Ş., (2000), "Tsunamis Observed on and Near the Turkish Coast"

AYM : Disaster Management Center web site, "Türkiye'de Önemli Depremler"

CEV : Ministry of Environment Internet Site, "Afetler"

K : Kandilli Observatory and Earthquake Research Institute Kalafat, D. Et al, , "Türkiye ve Dolayları Deprem Kataloğu

(1998-2002; M≥4.0)" and "Türkiye ve Dolayları Deprem Kataloğu (1981-1997, M≥4.0)" Ayhan "Türkiye ve Dolayları Deprem Kataloğu 1881-1980"

NPE : Erdem, N. P. and Lahn, E., (2001), "Türkiye Depremleri İzahlı Kataloğu"

T : Soysal, H., Sipahioğlu, S., Koçak, D. and Altınok, Y., (1981), TÜBİTAK, "Türkiye ve Çevresinin Tarihsel Deprem Kataloğu (M.Ö. 2100 - M.S. 1900)

5. 2 Design of the Neural Network

Two artificial neural networks were designed for the predicting purposes.

The adaptive learning rate γ, the momentum value α, the hidden layer number $\boldsymbol{H}$, and the iteration number $\boldsymbol{It}$, were selected following a trial error process to reach a suitable correlation value $\boldsymbol{R}$.

The numbers taken from the Table-5.1 were normalized for an easier neural network design. This was done as follows;

$$\text{Normalized Value} = \frac{x - \min.X}{\max.X - \min.X} \qquad \text{Eq. (5.2.)}$$

where;

x : value to be normalized

min. X : the minimum value between the data

max. X : the maximum value between the data

The first artificial neural network; "Network-1"is obtained for the earthquake magnitude estimation which may create a tsunami in the following years. The data in the Table-5.1 is divided into three occurrence regions, which are the Marmara, the Aegean and the Mediterranean regions. The return period of two successive tsunamis is calculated for each region to be used as an input in the network.

The inputs and outputs of the "Network-1" are given in the Table-5.2 and the data range in Table-5.3.

Table-5.2. Inputs and Outputs of Network-1

INPUTS			**OUTPUT**
Region Code 1 (Marmara) 2 (Aegean) 3 (Mediterranean)	Earthquake Depth (d)	Return Period (R_p)	Earthquake Magnitude (M_s)

Table-5.3. The Data Range Used in the Network-1

Variable	d	R_p	M_s
Maximum	80	970	7.6
Minimum	10	1	4.9

The total number of the data used in the Network-1 is 110 in which about 60% is used in the training phase. The obtained network parameters are given in the Table-5.4.

Table-5.4 Network-1 parameters

It	70.000
R	0,965
x-y-z	3-50-1
γ	0,001
α	0,5
MSE	0,00985293

Where;

It : Iteration number

R : Correlation Value

x : number of node in the input layer

y : number of node in the hidden layer

z : number of node in the output layer

γ : adaptive learning rate

α : momentum rate

MSE : mean square error

The number of iteration is determined by trial and error process to obtain the best correlation value and acceptable mean square error. The Figure-5.1 below shows the relation of the iteration number with the mean square error value for 70.000 iteration for the Network-1.

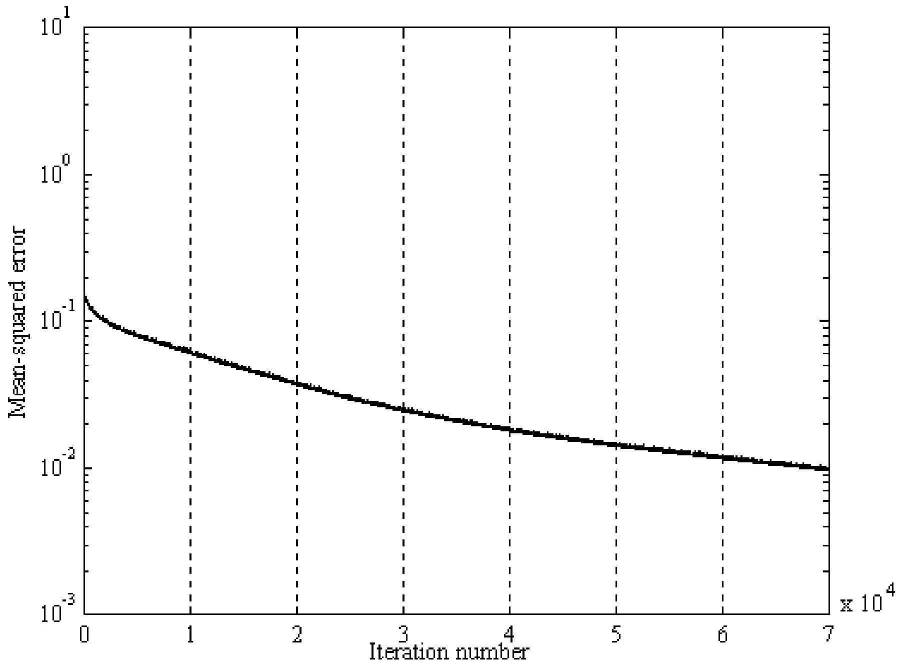

Fig 5.1. Iteration Number –Mean Square Error Relation for Network-1

The obtained correlation diagram for the Network-1 can be found in the Figure-5.2.

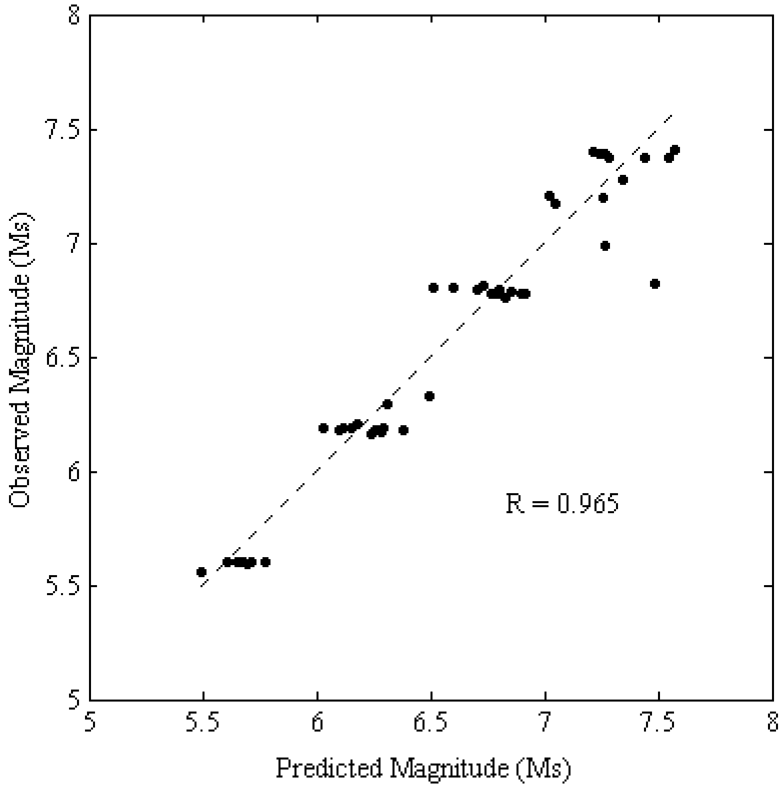

Fig-5.2. Correlation Diagram of the Network-1

The second artificial neural network; “Network-2“is obtained for the tsunami height estimation. The data used for “the Network-2” from Table-5.1 as input and outputs is given in the Table-5.5 and the data range is illustrated in Table-5.6.

Table-5.5. Inputs and Outputs of the Network-2

INPUTS			**OUTPUT**
Earthquake Magnitude (M_s)	Earthquake Depth (d)	Tsunami Intensity (i)	Average Tsunami Wave Height at the Coast (H_{av})

Table-5.6. The Data Range Used in the Network-2

Variable	M_s	d	i
Maximum	7.9	80	6
Minimum	4.8	4.0	0

The total number of the data used in the Network-2 is 31 in which about 61% is used in the training phase. The obtained network parameters are given in the Table-5.7.

Table-5.7 Network-2 parameters

It	5.000
R	0,972
x-y-z	3-10-1
γ	0,001
α	0,5
MSE	0,000034

Where;

It	: Iteration number
R	: Correlation Value
x	: number of node in the input layer
y	: number of node in the hidden layer
z	: number of node in the output layer
γ	: adaptive learning rate
α	: momentum rate
MSE	: mean square error

The Figure-5.3 below shows the relation of the iteration number with the mean square error value for 5.000 iteration for the Network-2.

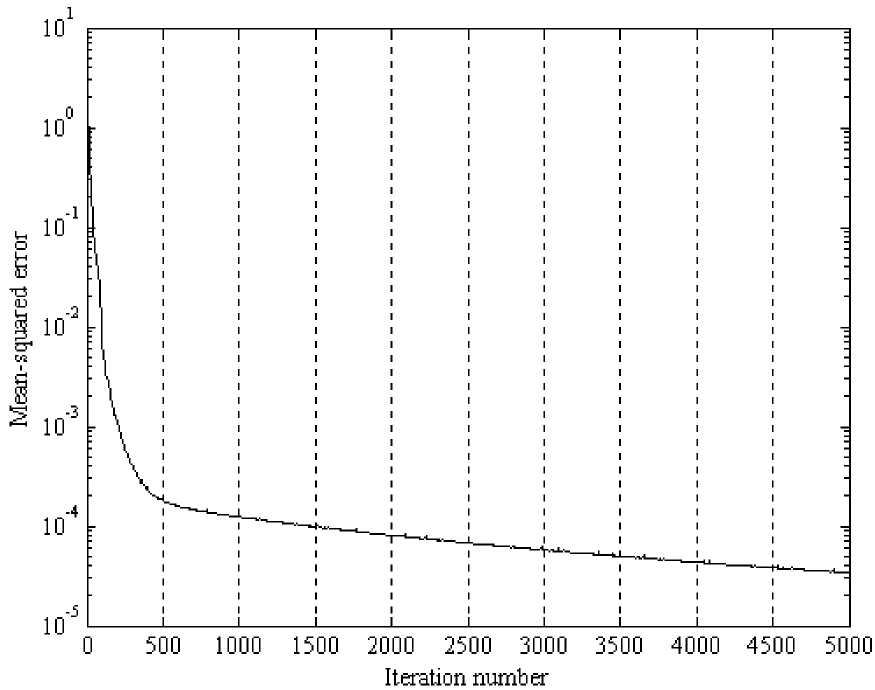

Fig 5.3. Iteration Number –Mean Square Error Relation for Network-1

The correlation diagram for Network-2 is given in Figure-5.4.

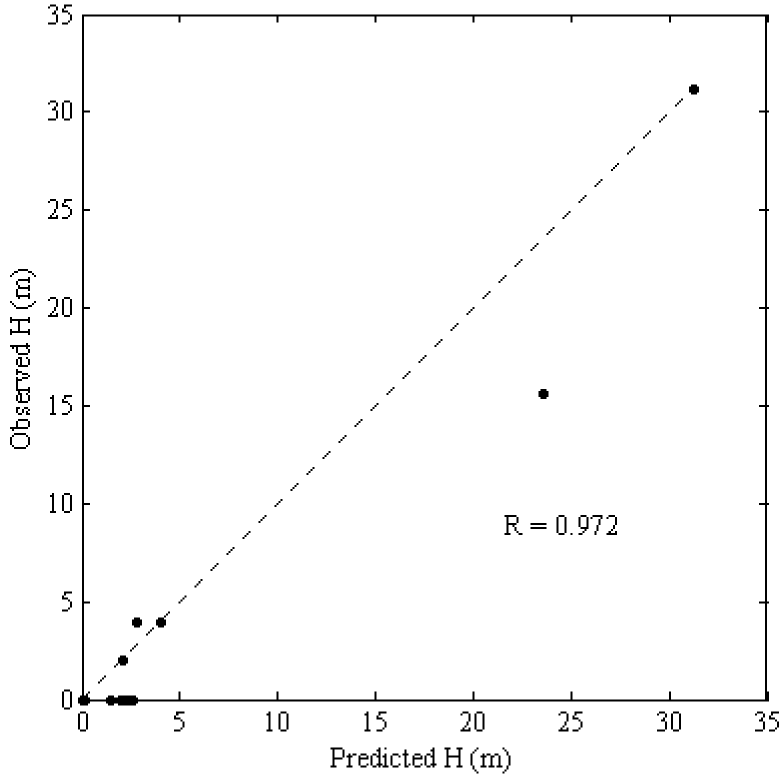

Fig 5.4. Correlation Diagram of the Network-2

5. 3 Prediction of Networks

The average earthquake depths for the Marmara and Aegean regions were used as constants for the prediction purposes.

The Region Code was taken as "1" to define Marmara region. The average earthquake depth was calculated to be 29 for this region, which would be used as a constant for the prediction problems. The return periods from the last earthquake which created a tsunami, the Izmit Golf earthquake in 1999, were used to calculate the earthquake magnitude that may create a tsunami for 1, 2, 3, 4, 5, 10, 50 and 100 years from 2004. The results of this prediction may be seen in the Table-5.8.

Table-5.8. The Predicted Earthquake Magnitudes for the Marmara Sea

Region Code :	**Year**	R_p	M_s
1 (Marmara)	2005 (1 year from 2004)	6	6,5787
Earthquake depth :	2006 (2 year from 2004)	7	6,5687
29 km	2007 (3 year from 2004)	8	6,5585
	2008 (4 year from 2004)	9	6,5480
	2009 (5 year from 2004)	10	6,5373
	2014 (10 year from 2004)	15	6,4806
	2054 (50 year from 2004)	55	5,9233
	3004 (100 year from 2004)	105	5,5192

The Aegean Sea Region is defined by the Region Code “2”. The average earthquake depth is 12. The results obtained for the Aegean Sea for the same return periods with Marmara are given in the Table-5.9.

Table-5.9. The Predicted Earthquake Magnitudes for the Aegean Sea

Region Code :	**Year**	**R_p**	**M_s**
2 (Aegean)	2005 (1 year from 2004)	6	6,8491
Earthquake depth :	2006 (2 year from 2004)	7	6,8454
12 km	2007 (3 year from 2004)	8	6,8415
	2008 (4 year from 2004)	9	6,8376
	2009 (5 year from 2004)	10	6,8335
	2014 (10 year from 2004)	15	6,8116
	2054 (50 year from 2004)	55	6,5758
	3004 (100 year from 2004)	105	6,3233

The average wave heights at the coast of the tsunamis triggered by the predicted earthquakes are estimated for intensities ranging from 1 to 6 by the Network-2 and the results are shown in the Table-5.10 and Table-5.11 for the Marmara and the Aegean seas.

Table-5.10. The Predicted H_{av} for the Marmara Sea

Region : Marmara **Earthquake depth :** 29 km	**Earthquake Magnitude (M_s)**	**Tsunami Intensity (i)**	**Tsunami Wave Height (H_{av}) (meter)**
	6,5787	1	0,4357
		2	2,3422
		3	5,8026
		4	8,5683
		5	10,6530
		6	13,0451
	6,5687	1	0,4637
		2	2,3861
		3	5,8523
		4	8,6027
		5	10,6542
		6	12,9747
	6,5585	1	0,4922
		2	2,4307
		3	5,9031
		4	8,6384
		5	10,6560
		6	12,9033
	6,5480	1	0,5213
		2	2,4765
		3	5,9555
		4	8,6757
		5	10,6585
		6	12,8304
	6,5373	1	0,5509
		2	2,5230
		3	6,0092
		4	8,7142
		5	10,6616
		6	12,7566
	6,4806	1	0,7055
		2	2,7661
		3	6,2962
		4	8,9280
		5	10,6875
		6	12,3725
	5,9233	1	2,0296
		2	4,8037
		3	9,0952
		4	11,4251
		5	10,8508
		6	8,2325
	5,5192	1	2,7422
		2	5,8068
		3	10,6186
		4	12,5873
		5	9,5427
		6	4,9024

Table-5.11. The Predicted H_{av} for the Aegean Sea

Region : Eagean **Earthquake depth :** 12 km	**Earthquake Magnitude (M_s)**	**Tsunami Intensity (i)**	**Tsunami Wave Height (H_{av})**
	6,8491	1	0,7963
		2	2,0411
		3	4,2618
		4	8,8759
		5	15,9151
		6	23,1957
	6,8454	1	0,8048
		2	2,0475
		3	4,2615
		4	8,8620
		5	15,8762
		6	23,1339
	6,8415	1	0,8138
		2	2,0543
		3	4,2612
		4	8,8476
		5	15,8355
		6	23,0688
	6,8376	1	0,8228
		2	2,0611
		3	4,2609
		4	8,8334
		5	15,7950
		6	23,0037
	6,8335	1	0,8323
		2	2,0683
		3	4,2607
		4	8,8186
		5	15,7527
		6	22,9352
	6,8116	1	0,8835
		2	2,1066
		3	4,2606
		4	8,7428
		5	15,5312
		6	22,5688
	6,5758	1	1,4459
		2	2,4972
		3	4,3271
		4	8,2156
		5	13,6251
		6	18,6889
	6,3233	1	1,9769
		2	2,8207
		3	4,4432
		4	8,0118
		5	12,3617
		6	14,9319

5. 4 Discussion of the Case Study Results

Two neural networks were developed and applied in order to forecast the earthquake magnitude that may create a tsunami in the future years and to estimate the probable tsunami height that may occur at the coast of Aegean and Marmara Seas.

Region codes were defined to separate Marmara, Aegean and Mediterranean Seas and they were used as input for the Network-1 with the earthquake depth and the return period to forecast the earthquake magnitude $\boldsymbol{M_s}$. Network-1 structure was developed in the form of $x_3y_{50}z_1$ which designates that, three nodes are existing in the input layer, 50 nodes are available in the hidden layer and one node is present in the output layer. The gradient descend algorithm was used with an optimum momentum rate of 0,5 and an adaptive learning rate of 0,001. A sigmoid bipolar function was utilized in hidden layers and a linear function was used in output layers. The Network was developed by an iterative approach that uses trial and error procedures. At a number of iteration equal to 70.000, a satisfactory correlation value of R = 0,965 was obtained with a mean square error equal to MSE=0,00985293.

From the first network model, it can be anticipated that the Marmara Sea has a high tsunami occurrence probability for earthquakes having magnitudes that exceed 5,5 for a return period of 100 years predicted from the year of 2004. It can also be observed that as the return period increase, the magnitude of earthquake that may create a tsunami decrease. As a result, tsunami occurrence risks increase, as lower magnitude earthquakes can also create a tsunami. Similarly for the Aegean Sea, the tsunami occurrence risk increases as the return period increase. Tsunami will occur for earthquakes having magnitudes that exceed 6,3 for a return period of 100 years predicted from the year of 2004.

This implies that, considering the earthquakes and tsunamis occurred in the past, there is a high probability of occurrence of a tsunami in 100 years beginning from the year of 2004 for Marmara Sea, but the return period of tsunamis are exceeding this return period value for the Aegean Sea. It is also seen in Tables 5.10 and 11 that, as the return period of tsunami increases to T_r=100 years, the prediction ability of neural networks decreases due to limited number of data. Increasing the earthquake and tsunami data for the training of artificial neural networks can solve this problem.

Tsunami intensity, earthquake magnitude and depth were used as input values for Network-2 to predict tsunami wave height at the coast of Marmara and Aegean Seas. Similar to Network-1, this network was developed by trial and error procedures to obtain the optimum adaptive learning rate considering the database. Network-2 structure was developed in the form of $x_3y_{10}z_1$ which designates that, three nodes exists in the input layer, 10 nodes are available in the hidden layer and one node is present in the output layer. The momentum rate and the adaptive learning rates were determined as 0,5 and 0,001, respectively. A satisfactory correlation value of R=0,972 was obtained for an iteration number of 5.000 and the Mean Square Error of predictions were determined as MSE=0,000034, at the testing stage. The gradient descend algorithm was used with bipolar sigmoid function in the hidden layers and linear activation function in the output layer.

It may be forecasted that, for the period of 2004-2009, earthquakes with a depth value of 29 km may create tsunami heights at the Marmara coast varying from 40 cm to 13 m depending on the tsunami intensity. Since the probability of having an earthquake is high for the same period in Istanbul, a tsunami having a Modified Seaberg Intensity Scale of i=4 can be expected to have a maximum average height of 8,5 m on the shore of Marmara. For Aegean and Marmara Seas the occurrence probability of a tsunami having intensity greater than 4 is very low.

Tsunami height characteristics differed in Aegean and Marmara Seas, since it is forecasted that, for the period of 2004-2009, earthquakes with a depth value of 12 km may create tsunami heights at the Aegean coast varying from 70 cm to 23 m depending on the tsunami intensity.

Results are compared with the intensity-wave height relation proposed by Soloviev (1990) (Papadopoulos, G. A. and Imamura, F., (2001)) in Table-5.12; and it is observed that Network-2 has predicted the average tsunami height on the shore within these limits given in Table-5.12.

Table-5.12. Intensity-Tsunami Height Relation proposed by Soloviev (1990)

i	H_{av}
1	0,97
2	1,95
3	3,89
4	7,78
5	15,57
6	31,13

As a result, Network-1 results demonstrated that, Marmara Sea has a higher tsunami occurrence risk compared to Aegean Sea, which may also be deducted from the historical records. Furthermore, Network-2 is a satisfactory first step to implement earthquake parameters such as depth and magnitude, for the average tsunami height on the shore (H_{av}) calculations.

CHAPTER 6

CONCLUSION AND RECOMMANDATIONS

1) This study is based on the reliability of the available past data, collected from various references based on historical documents. The past tsunami data depends upon observation of the effects of past tsunamis on the shore. More information and data can be collected by more coastal surveys and paleotsunami studies. Nowadays, better techniques can be applied and valuable information on the inundation distance and runup height of some historical tsunamis can be obtained. (Yalçıner et al., (2002), Minoura et al., (2000), Yalçıner et al., (TUBITAK-INTAG-827), Yalçıner et al. (TUBITAK-YDABCAG-60)). As such studies are conducted for Aegean and Marmara coasts, more reliable information can be obtained and the input of the neural network can be revised to increase the reliability of model predictions.

2) During the observation period of approximately 3500 years starting from 1500 B.C., the historical records show that there are around 100 tsunamis in the seas neighboring Turkey.

3) Tsunamis are different from wind-generated waves in the way that their source is the sea bottom instead of water surface, and they are characterized as shallow-water waves, with long periods and

wavelengths. In this thesis, tsunami characteristics of future occurrences and their probable occurrence periods were forecasted by using artificial intelligence techniques.

4) Artificial Neural Network (ANN) is a system simulating the human brain learning and thinking behavior by experiencing measured or observed data. It is widely used for problems, which are difficult to be solved by conventional mathematical methods.

5) Historical earthquake and tsunami data were collected and their occurrence relations were investigated to interrelate these natural events. The parameters of earthquake intensity and magnitude were interrelated to the average tsunami height at the coast.

6) A set of artificial neural networks was designed to estimate future earthquakes that may create tsunamis in three Turkish coastal regions, which are Marmara, Aegean Sea and Mediterranean Sea. The total number of the data used in the Network-1 was 110 in which about 60% is used in the training phase.

7) A second set of artificial neural networks was designed to estimate future tsunami inundations by considering the earthquake magnitudes predicted by the first set of neural networks. The total number of the data used in Network-2 was 31 in which about 61% is used in the training phase.

8) Two sets of neural networks were trained and tested by the historical earthquake and tsunami data collected for Turkish coasts. The statistical correlation parameters were found to be satisfactory

for the testing stages of these two network sets, i.e. r_1=0.965 and r_2=0.972 for Network-1 and Network-2, respectively.

9) In the case study carried out in this thesis, return periods including the last earthquake that created a tsunami, the İzmit (Kocaeli) Earthquake in 1999, were used to calculate the earthquake magnitude that may create tsunami for various return periods of 1-100 years from the year of 2004. The average earthquake depths were calculated as 29 and 12 for Marmara and Aegean regions respectively. These magnitudes were utilized together with tsunami intensities in order to predict the tsunami height at the coast.

10) It may be forecasted that, for the period of 2004-2009, earthquakes with a depth value of 29 km may create tsunami heights at the Marmara coast (inundation) varying from 40 cm to 13 m depending on the tsunami intensity. Since the probability of having an earthquake is high for the same period in Istanbul, a tsunami having a Modified Seaberg Intensity Scale of i=4 can be expected to have a maximum average height of 8,5 m on the shore of Marmara.

11) From the first network model, it can be anticipated that the Marmara Sea has a high tsunami occurrence probability for earthquakes having magnitudes that exceed 5,5 for a return period of 100 years predicted from the year of 2004. It can also be observed that as the return period increase, the magnitude of earthquake that may create a tsunami decrease. As a result, tsunami occurrence risks increase, as lower magnitude earthquakes can also create a tsunami.

12) For the Aegean Sea, the tsunami occurrence risk increases as the return period increase. Tsunami will occur for earthquakes having

magnitudes that exceed 6,3 for a return period of 100 years predicted from the year of 2004.

13) Tsunami height characteristics differed in Aegean and Marmara Seas, since it is forecasted that, for the period of 2004-2009, earthquakes with a depth value of 12 km may create tsunami heights at the Aegean coast (inundation) varying from 70 cm to 23 m depending on the tsunami intensity.

14) Network-2 is a satisfactory first step to implement earthquake parameters such as depth and magnitude, for the average tsunami height on the shore ($\boldsymbol{H_{av}}$) calculations.

15) The number of available data may be increased by new research and their reliabilities may be investigated for future studies.

16) New earthquake and tsunami parameters may be introduced for the tsunami prediction problems.

17) The obtained results from this study can be a first step to introduce the tsunami parameters as an input to the Reliability Risk Models in the design phase.

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APPENDIX A

DERIVATION OF LONG WAVE EQUATION

(R. G. Dean, R. A. Dalrymple, Water Wave Mechanics For Engineers And Scientists, 1998)

The three- dimensional concervation of mass equation for an incompressible fluid is;

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1.1}$$

This is true everywhere in th fluid. Integrating over depth;

$$\int_{-h}^{\eta}\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)dz= \tag{1.2}$$

$$=\int_{-h}^{\eta}\frac{\partial u}{\partial x}dz+\int_{-h}^{\eta}\frac{\partial v}{\partial y}dz+w(x,y,\eta)-w(x,y,-h)=0$$

The Leibniz rule of integration is used to integrate terms such asthe first two on the right-hand side of this expression. In general, it is stated as;

$$\frac{\partial}{\partial x}\int_{\alpha(x)}^{\beta(x)}Q(x,y)\,dy \tag{1.3}$$

$$=\int_{\alpha(x)}^{\beta(x)}\frac{\partial}{\partial x}Q(x,y)\,dy+Q(x,\beta(x))\frac{\partial\beta(x)}{\partial x}-Q(x,\alpha(x))\frac{\partial\alpha(x)}{\partial x}$$

Integrating the continuity equation;

$$\frac{\partial}{\partial x}\int_{-h}^{\eta}u\,dz-u(x,y,\eta)\frac{\partial\eta}{\partial x}-u(x,y,-h)\frac{\partial h}{\partial x}+w(x,y,\eta)-w(x,y,-h) \tag{1.4}$$

$$+\frac{\partial}{\partial y}\int_{-h}^{\eta} v\,dz - v(x,y,\eta)\frac{\partial \eta}{\partial y} - v(x,y,-h)\frac{\partial h}{\partial y} = 0$$

Defining

$$U = \frac{1}{h+\eta}\int_{-h}^{\eta} u\,dz \qquad \text{and} \qquad V = \frac{1}{h+\eta}\int_{-h}^{\eta} v\,dz$$

through the use of the mathematical definition of an average (Assuming that *u* and *v* are constants over the depth, *U* and *V*.

The continuity equation can be written as;

$$\frac{\partial}{\partial x}\left[U(h+\eta)\right] + \frac{\partial}{\partial y}\left[V(h+\eta)\right] - v(x,y,\eta)\frac{\partial \eta}{\partial y} - v(x,y,-h)\frac{\partial h}{\partial y} \tag{1.5}$$

$$-u(x,y,\eta)\frac{\partial \eta}{\partial x} - u(x,y,-h)\frac{\partial h}{\partial x} + w(x,y,\eta) - w(x,y,-h) = 0$$

The kinematic free surface boundary condition is, in three dimensions;

$$\frac{\partial \eta}{\partial t} + u(x,y,\eta)\frac{\partial \eta}{\partial x} + v(x,y,\eta)\frac{\partial \eta}{\partial y} = w(x,y,\eta) \tag{1.6}$$

The bottom boundary condition for a fixed (with time) surface is;

$$w(x,y,-h) = -u(x,y,-h)\frac{\partial h}{\partial x} - v(x,y,-h)\frac{\partial h}{\partial y} \tag{1.6}$$

Substituing these conditions into the vertically integrated continuity equation yields the final form of the continuity equation;

$$\frac{\partial[U(h+\eta)]}{\partial x} + \frac{\partial[V(h+\eta)]}{\partial y} - \frac{\partial \eta}{\partial t} \tag{1.6}$$

APPENDIX B

MODIFIED SIEBERG SEA-WAVE INTENSITY SCALE

i=1	Very light	Wave so weak as to be perceptible only on tide-gauge records
i=2	Light	Wave noticed by those living along the shore and familiar with the sea. On very flat shores generally noticed.
i=3	Rather strong	Generally noticed. Flooding of gently sloping coasts. Light sailing vessels carried away on shore. Slight damage to light structures situated near the coasts. In estuaries reversal of the river flow some distance upstream.
i=4	Strong	Flooding of the shore to some depth. Light scouring on man-made ground. Embankments and dikes damaged. Light structures near the coasts damaged. Solid structures on the coast injured. Bid sailing vessels and small ships drifted inland or carried out to sea. Coasts littered
i=5	Very strong	General flooding of the shore to some depth. Quay-walls and solid structures near the sea damaged. Light structures destroyed. Severe scouring of cultivated land and littering of the coast with floating items and sea animals. With the exception of big ships all other type of vessels carried inland or out to sea. Big bores in estuary rivers. Harbor works damaged. People drowned. Wave accompanied by strong roar.
i=6	Disastrous	Partial or complete destruction of manmade structures for some distance from the shore. Flooding of coasts to great depths. Big ships severely damaged. Trees uprooted or broken. Many casualties. with floating debris.

APPENDIX C

SYNTHETIC TSUNAMI CHARACTERISTICS (B. Haboğlu, 2002)

Place	H_{max} (m)	H_{avg} (m)
İç Island	4,94	1,23
Akar Bay	1,46	0,28
Akar River	2,64	0,88
Ulu Cape	6,17	2,01
Kaş Harbor	3,18	1,17
Meis Island	4,97	1,66
Ince Cape	5,88	2,12
Zeytin Cape	4,81	1,58
Kalkamak Cape	8,66	3,18
Kötü Cape	6,21	2,19
Kızılcakaya Beach	3,47	1,12
Belceğiz Bay	4,14	1,14
Kayaköy Beach (Gemile Bay)	3,56	1,25
Belen Mountain Coast	3,94	1,26
Göcek-1	3,40	0,96
Göcek-2	3,50	0,92
Kurtoğlu Cape-1	5,78	1,45
Kurtoğlu Cape-2	4,71	1,50
Akça Cape	4,42	1,72
Karaburun-1 (Dalaman)	1,98	0,79
Karaburun-2 (Dalaman)	3,52	1,46
Dişbilemez Cape	2,39	0,87
Köyceğiz Dalyan	3,63	1,36
Büyükkaraağaç	2,16	0,56
Turnalı Cape-1 (Marmaris)	1,99	0,56
Turnalı Cape-2 (Marmaris)	2,58	0,76

SYNTHETIC TSUNAMI CHARACTERISTICS (B. Haboğlu, 2002)

(Continued)

Place	H_{max} (m)	H_{avg} (m)
Kadırga Cape (Marmaris)	2,78	0,85
Akçaan Cape (Marmaris)	2,95	0,94
Kumlu Cape (Bozburun)	3,33	1,17
Çömlek Cape (Bozburun)	2,48	0,96
Kale Cape (Bozburun)	5,82	1,91
Kızılada (Bozburun)	2,86	0,79
Kara Cape (Bozburun)	1,78	0,43
Kızıl Cape (Bozburun)	1,23	0,36
Nis. Trampeta (Simi Island)	1,41	0,32
Nes. Diavetes (Simi Island)	1,26	0,25
Tilas Adası-Episkapı Ak.	0,51	0,18
Tilas Adası-Ak. Orfos	0,58	0,13
Ak. Zonar (Rhodes)	4,44	1,66
Ak. Ladiko (Rhodes)	3,65	1,68
Ak. Vagya (Rhodes)	3,68	1,24
Ak. Ay. Emilyanos (Rhodes)	8,14	3,01
Ak. Lakanya(Rhodes)	3,36	0,93
Ak. Nisos (Rhodes)	6,84	1,72
Ak. Drasonisi (Rhodes)	7,98	1,81
Nisis Sanya (Karpathos Isl.)	1,92	0,64
Ak. Mapriya (Karpathos Isl.)	3,01	0,93
Ak. Vrontos (Karpathos Isln)	2,20	0,77
Om. Amorfos (Karpathos Isl.)	3,05	1,15
Ak. Kastello (Karpathos Isl.)	5,23	1,48

APPENDIX D

MERCALLI INTENSITY SCALE, ABRIDGED, MODIFIED

Level	Descriptor
I	Not felt except in unusual circumstances.
II	Felt only by persons at rest indoors
III	Felt quite noticeably indoors.
IV	Felt indoors by many, outdoors by few. Some awaken. Dishes rattle. Like a heavy truck striking the building.
V	Felt by nearly everyone, many awakened. Some dishes and windows broken. Cracked plaster. Unstable objects overturned.
VI	Felt by all. Many frightened and run outdoors. Some heavy furniture moved. Some chimneys damaged. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design. Some chimneys broken. Noticed by persons driving cars.
VIII	Damage slight in specially designed structures, great in poorly designed structures. Panel walls thrown out of frame structures. Fall of chimneys, stacks, columns, monuments. Heavy furniture overturned. Changes in well water.
IX	Damage considerable in specially designed structures. Well designed frame structures thrown out of plumb. Partial collapse. Buildings shifted off foundations. Ground conspicuously cracked. Underground pipes broken.
X	Some well built frame structures destroyed. Most masonry and frame structures destroyed with foundations. Ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed over banks.
XI	Few if any masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps. Rails bent.
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

APPENDIX E

NEURAL NETWORK AND TSUNAMI REFERENCES

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