CALIBRATION OF VARIOUS MAGNITUDE SCALES IN TURKEY USING BROADBAND DATA

by

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ABSTRACT

The local magnitude, M_L, for earthquakes of Western Turkey and surrounding regions are determined using synthetic Wood-Anderson seismograms derived from newly available broadband recording from the Boğaziçi University Kandilli Observatory and Earthquake Research Institute (BU KOERI). Seismograms obtained from various types of broadband instruments are transformed to Wood-Anderson type using SAC (Seismic Analysis Code) routines and script files that are developed for this purpose. Wood-Anderson peak amplitudes are measured on 1560 three-component, obtained from 200 earthquakes in the distance range of 8 to 785 km. The earthquakes ranged from M_L = 1.0 to 6.4 and were recorded at about 7 stations in the region. M_L magnitudes can be obtained from the horizontal and vertical component. Scattering of each M_L magnitude in each station is analyzed and their dependence on magnitude and distance are discussed. The station magnitude correction values are found. Some improvements are proposed for the magnitude determination procedures that are actually used at BU KOERI Seismological Laboratory. Finally we have compared our M_L computations with the one obtained by other studies using different approaches or different waveform data. We have noted that our results agree well with M_L magnitude determinations done at TUBITAK MRC, but deviates significantly from the M_D calculations of BU KOERI Seismological Laboratory.

ÖZET

Boğaziçi Üniversitesi Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü (BÜ KRDAE) tarafından işletilen yeni tip geniş bandlı istasyonların kaydettiği Batı Türkiye ve çevresindeki depremlerin yerel büyüklükleri, M_L, Wood-Anderson sentetik sismografına çevrilmek suretiyle hesaplanmıştır. Değişik türdeki geniş bandlı istasyonlar, bu iş için geliştirilmiş SAC (Seismic Analysis Code) rutinleri ve kabuk programları vasıtasıyla Wood-Anderson sismometresine çevrilmiştir. Uzaklıkları 8 ile 785 km olan 200 depremin 1560 tane en büyük genliği Wood-Anderson sentetik sismografından okunmuştur. Bu depremler bölgedeki 7 istasyondan kaydedilmiş olup ve yerel büyüklükleri M_L = 1.0 ile 6.4 arasında değişmektedir. M_L büyüklüğü yatay ve düşey bileşenlerden elde edilmektedir. Herbir M_L büyüklüğünün herbir istasyondaki saçılma oranı analiz edilmiş ve bu saçılmanın büyüklük ve uzaklığa bağlı olup olmadığı tartışılmıştır. İstasyon büyüklük düzeltme değerleri bulunmuştur. BÜ KRDAE tarafından kullanılan büyüklük hesaplamaları için bazı iyileştirme önerileri sunulmuştur. Sonuç olarak hesapladığımız M_L değerlerini, farklı yaklaşımları kullanan farklı dalga formlarından hesaplanan diğer çalışmalardaki M_L değerleriyle karşılaştırdık. Şunu da belirtmek gerekirse, bizim sonuçlarımız TÜBİTAK Marmara Araştırma Merkezi (MAM) tarafından bulunan değerlerle örtüşmektedir. Diğer taraftan, BÜ KRDAE Sismoloji Laboratuvarı tarafından bulunan süreye bağlı büyüklük değerleriyle önemli ölçüde sapmalar görülmüştür.

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LIST OF SYMBOLS

M_L	Local Magnitude ....
M_D	Duration Magnitude..
T_s	Natural Period..........................
D_s	Damping Factor
V_{max}	Maximum Magnification...
A_{max}	Maximum Ground Amplitude
$-\log A_0$	Correction Factor According to Distance....................................
A	Ground Displacement Amplitudes.........................
Δ	Epicentral Distance (Km)............
h	Source Depth
T	Period ....
$\sigma(\Delta, h)$	Distant and Depth Dependent Factor
C_R	Regional Correction.......................................
C_{STA}	Station Correction...
$\bar{E}$	The Residual at Each Station......................................
σ	Standard Deviation
$\bar{E}_{station}$	Station Correction at Each Station..........................
$M_{Lstation}$	Local Magnitude Values at Each Station..........................
a_0, a_1, a_2	Station, Attenuation and Distance Dependent Constant
D	Signal Duration (sn),..................................
$M_{L\text{-Thesis}}$	Local Magnitude is determined by the Thesis..
$M_{D\text{-BU KOERI}}$	Duration Magnitude is determined by BU KOERI Seismological Laboratory.
$M_{L\text{-BU KOERI}}$	Local Magnitude is determined by BU KOERI Seismological Laboratory.
$M_{L\text{-TUBITAK}}$	Local Magnitude is determined by TUBITAK-MRC
$M_{B\text{-CSEM}}$	Body Wave Magnitude is determined by EMSC-CSEM...........

1. INTRODUCTION

The size of an earthquake has been represented by various quantities that can be related to the physical parameters of the source. Such measures include various magnitude scales, seismic moment and radiated seismic energy. Although earthquake magnitude scales in general do not directly represent any physical parameters of the source, they can be used to represent the relative size of earthquakes. Because of the simplicity of magnitude scales, they can be used to process large numbers of events in a very short time and can provide the public with quick information on the size of an earthquake. Magnitudes also provide a fundamental data to be included in earthquake catalogs, which are the basis for a variety of scientific research projects. The magnitude scales currently used for measuring the relative sizes of earthquakes are based on empirical formulas, which give results that depend on the wave types and the frequency band used. For earthquakes recorded at local and regional distances (a few kilometers up to about 2000 km from the source), magnitude scales strongly depend upon the regional geological structure.

In this study, the earthquakes in Turkey are mainly assigned with Richter's (1935, 1958) local magnitude, M_L. In Turkey, various magnitude scales are used, but M_D (Lee et al., 1972) is the magnitude assigned to most events by the BU KOERI Seismological Laboratory. M_D is determined for almost all earthquakes, using vertical-component records from 1-sec short period seismometers. In general, M_D tends to underestimate the magnitude of events larger than 4.0, by as much as 0.5 magnitude units. This has resulted in magnitude scales that are difficult to relate to each other, compounded by improper application of M_D formula. Hence, it has been difficult to transport some of the important earthquake parameters obtained in Turkey to other catalogs. There is a need to calibrate these regional magnitude scales in Turkey eventually to some physical source parameters, such as the seismic moment and radiated seismic energy of the earthquakes. However since these parameters are not always easy to determine in an on-line process, the M_L appears to be a good compromise for determining the size of an earthquake.

It is difficult to calibrate the magnitude scale for earthquakes in Turkey, due to the shortage of large earthquakes whose magnitude can be well determined by telesismic data and the regional/local networks. The poor station density and geometry, and sometimes-inadequate instrumentation inhibit the study of small to moderate sized earthquakes in this region.

In this study, we attempted to determine Richter's (1935, 1958) local magnitude scale magnitude scale for the small to moderate sized regional earthquakes in western Turkey by using the newly available broadband data. The key to evaluating M_L is to assume an appropriate attenuation curve. We used the original Richter curve (1958) as the valid attenuation relation. The advantage of the local magnitude, M_L, which is the first magnitude scale introduced to seismology (Richter, 1935), is its simple and uniform methodology when compared with magnitude scales developed later.

Various institutes and organizations are using several magnitude calculation methods in order to understand size of earthquakes. In this thesis, we focused on the M_L calculation and we have compared the results to other approaches. The data which is used in the study was collected by BU KOERI network which is the permanent broadband network operated by B.U Kandilli Observatory and Earthquake Research Institute. It includes 7 stations with various frequency properties. They are located in İstanbul (ISKB), Balıkesir (BALB), Edirne (EDRB), Yalova (YLVX), Çatalca (CTTX), Marmara Island (MRMX), Mürefte (MFTX) (Table 1).

In order to calculate M_L from the broadband data, it is essential that of new, well tested magnitude calculation method is developed at BU KOERI. This is important in the context that M_D cannot be responded to our goals for large earthquakes up to 6.0. In chapter 2, we gave the basic principles of M_L calculation in detail. We have also included a description of the initial concept for the calculation of M_L.

Before going into the details of processing, we explain in Chapter 3 what kind of data was used in this study. Data collection is very important since high quality data mean accurate solution and result. We developed an M_L calculation program for accurate amplitude based magnitude scale, which is given in detail in Chapter 4. We used SAC routines and shell script in order to calculate the M_L from SAC formatted data. There are two main shell scripts that are used: the first one updates the header block of SAC data, inserting locations and determining the distances, and the second one actually calculates the maximum amplitude and magnitude unit. Presently, this program is running on both operating systems Linux and Windows. The Linux shells and the SAC-scripts routines were translated to Visual Basic code for adaptation to Windows environment (Yılmazer, 2003). It has been tested extensively, and it is at the stage of being used for on-line operations at BU KOERI Seismological Laboratory. After we obtaining the results for M_L calculation, we interpreted them according to distance and magnitude. The statistical properties of the M_L magnitude determined for 200 events are analyzed and interpreted in Chapter 5. In Chapter 6, we gave some suggestions about the future of magnitude policy at BU KOERI and what can be done to improve the magnitude calculation practice. We have also included detailed plans on how to include nearly 50 one-component vertical short period stations into the routine M_L magnitude calculation. Station corrections for each station were also determined and interpreted in Chapter 6. We compared our results to the ones from other institution, and the differences between various computational approaches were interpreted in Chapter 7. Finally, we reached some conclusions that are given in Chapter 8, which also contains some suggestions to be considered in future.

2. BASIC PRINCIPLES of M_L CALCULATION

Richter (1935) plotted the logarithm of maximum trace amplitudes A_{max} measured in records of standard Wood-Anderson (WA) horizontal component torsion seismometers as a function of epicentral distance Δ. The WA seismometers had the following parameters: natural period T_s = 0.8 s, damping factor D_s = 0.8, maximum magnification V_{max} = 2800. Richter found that log A_{max} decreases with distance along parallel curves for earthquakes of different size. In order to be able to calculate M_L also for other epicentral distances Δ between 30 and 600 km Richter (1935) provided attenuation corrections. They were later complemented by respective values for Δ < 30 km assuming a focal depth (h) of 18 km (Gutenberg and Richter, 1942) and published together in tabulated form by Richter (1958) as correction factor –log A_0 (Δ). The basic 'Local Magnitude' formula is

$$M_L = \log A_{max} - \log A_0 \quad (1)$$

Magnitudes can also be determined on the basis of equation below by reading $(A/T)_{max}$ for any wavelet or wave group of body (e.g. P, S, S_g, PP) or surface waves (L or L_g, R or R_g) for which calibration functions for either vertical (V) and/or horizontal (H) component records available.

$$M = \log (A/T)_{max} + \sigma(\Delta, h) + C_R + C_{STA} \quad (2)$$

A: Ground displacement amplitudes,

T: Period, Δ: epicentral distance,

h:source depth,

where C_r: regional correction,

C_s: station correction.

As compared with the general magnitude, formula in (2) and M_L considers only the maximum displacement amplitudes but not their periods. Reason is WA instruments are relatively narrow-band and short period and the traditional analogue recorders had a limited paper speed. Proper reading of the period of high-frequent waves from local events was rather difficult. It was assumed, therefore, that the maximum amplitude phase (which corresponds in case of local events generally to S_g, L_g or R_g) has always roughly the same predominant period. Also, -log A_0 does not consider the above discussed depth dependence of σ (Δ , h) since seismicity in southern California is always shallow (mostly less than 15 km).

Of two earthquakes having the same hypocenter and recorded at the same stations, the larger should have larger seismograms at any one station. If the epicenters differ, the smaller shock may be so much closer to a given station that it results in larger seismograms there. Accordingly, the general procedure is first to determine the epicenter for each shock and then to plot the maximum ground motion at each station as ordinate with the corresponding epicentral distance. Of two curves thus plotted for different earthquakes, one will probably be higher than the other, indicating that it represents the larger event.

In Richter's definition, A_{max} is the recorded trace amplitude for a given earthquake at a given distance as observed by the standard type of instrument. A_0 is the recorded trace amplitude for a particular earthquake selected as the standard size. The magnitude is thus a number characteristic of the earthquake and independent of the location of the recording stations.

The zero level A_0 can be fixed by naming its value at a particular distance. This was taken to be one thousandth of a millimeter at a distance of 100 kilometers from the epicenter; an equivalent statement is that an earthquake recording with trace amplitude of 1 millimeter measured on a standard seismogram at 100 kilometers is assigned magnitude 3. Naturally, events of magnitude near zero can be recorded only on seismograms observed at very short distances; their study requires additional instruments with magnification higher than the standard.

Applicability of the magnitude scale depends on establishing standard values of log A_0 as a function of distance Δ (see in Table 2 in Appendix A).

It is necessary to know the epicentral distance of the recording station, at least approximately. Small errors in distance affect the magnitude only slightly. The maximum trace amplitude on a standard seismogram is then measured in millimeters, and its logarithm taken. To this is added the quantity tabulated as –log A_0 for the corresponding distance. The sum is a value for M_L.

This procedure is adequate for assigning magnitudes to earthquakes recorded at short distances. In using the data of a station with standard seismographs recording also on horizontal components, it is correct to determine magnitude independently from each component and to take the mean of the two determinations. This method is preferable to combining the components vectorially, for the maximum motion need not represent the same wave on the two seismograms, and it even may occur at different times. Rough rules like this are necessary for routine work in assigning magnitudes to hundreds of earthquakes.

A correction is applied for each station, or still better for each instrument. It is determined by examining statistically the magnitude determinations for a large number of shocks and finding the systematic deviation of the magnitude determined for any one instrument from that found from the mean result for all instruments. This procedure attaches to each instrument a correction similar to the ‘’personnel equation’’ of an individual observer. It is probably related chiefly to the local conditions of ground and installation.

3. SEISMOLOGICAL DATA UTILIZED

The analysis presented here is based on broadband digital seismograms from 200 earthquakes that occurred in Western Turkey and the surrounding region between January 2002 and July 2002.The events are listed in Table 3 in Appendix A, and number of event in each magnitude range is shown in diagram 1. The location of broadband station used for the study is shown in Figure 1. The earthquakes that occurred during January 2002 to July 2002 recorded at BU KOERI stations are depicted in Figure 2.

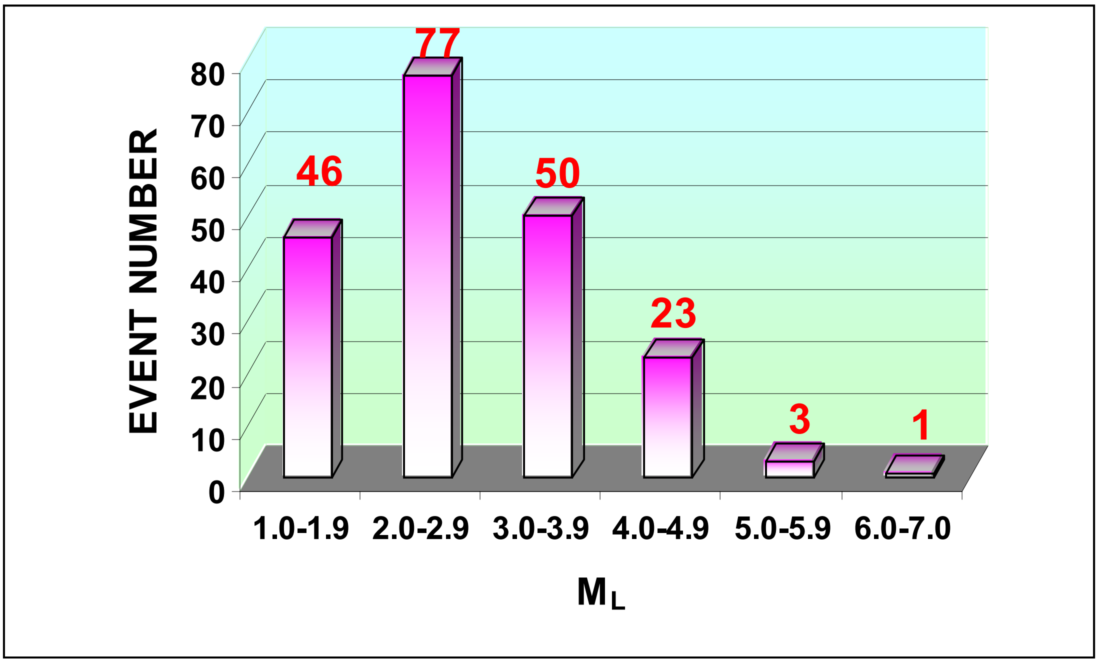

Diagram 1. Diagram of magnitude distribution of test events (January 2002 - July 2002)

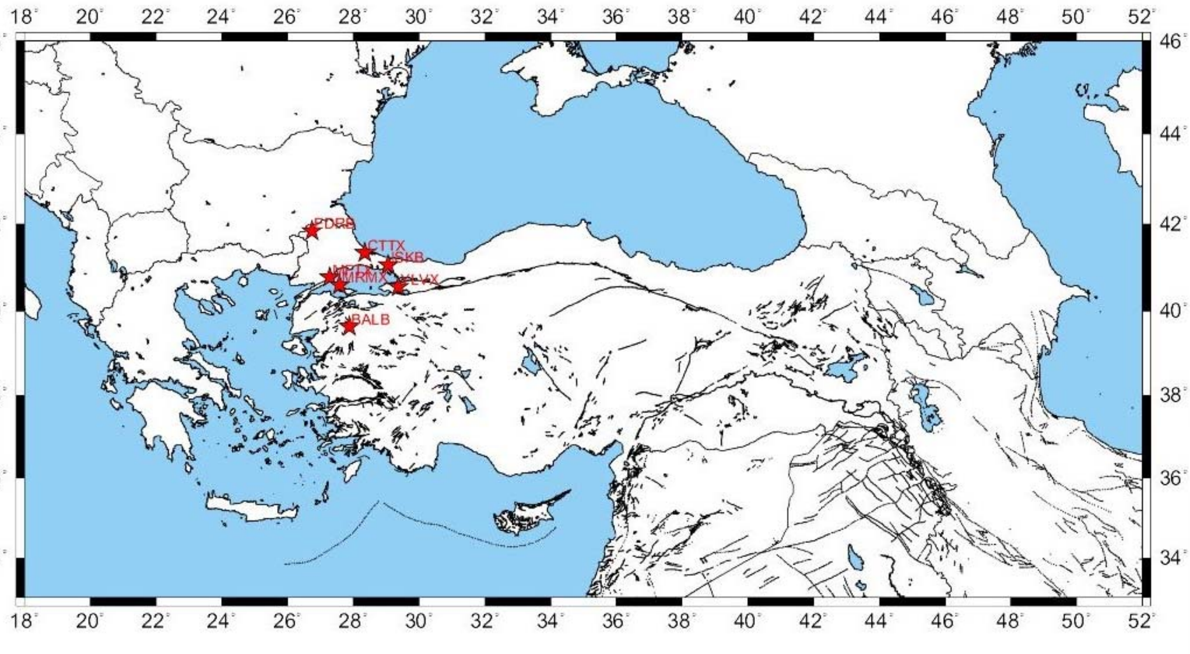

Figure 1. Station Utilize

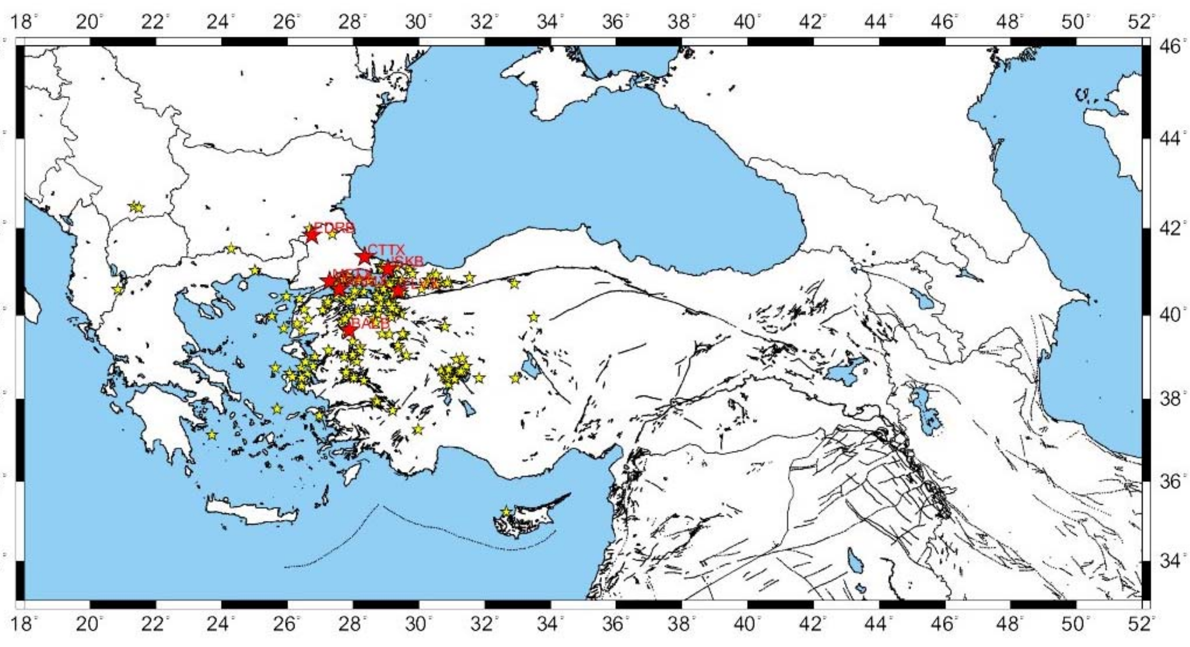

Figure 2. Choice of test data and location of events

These events are well recorded by the broadband seismographs deployed since 1996 in this region. Approximately 1560 three-component regional records in the distance range of 8 to 785 km were used for the analysis (Figure 3) and all determined 1560 M_L values of each waveform are plotted in diagram 2 according to distance.

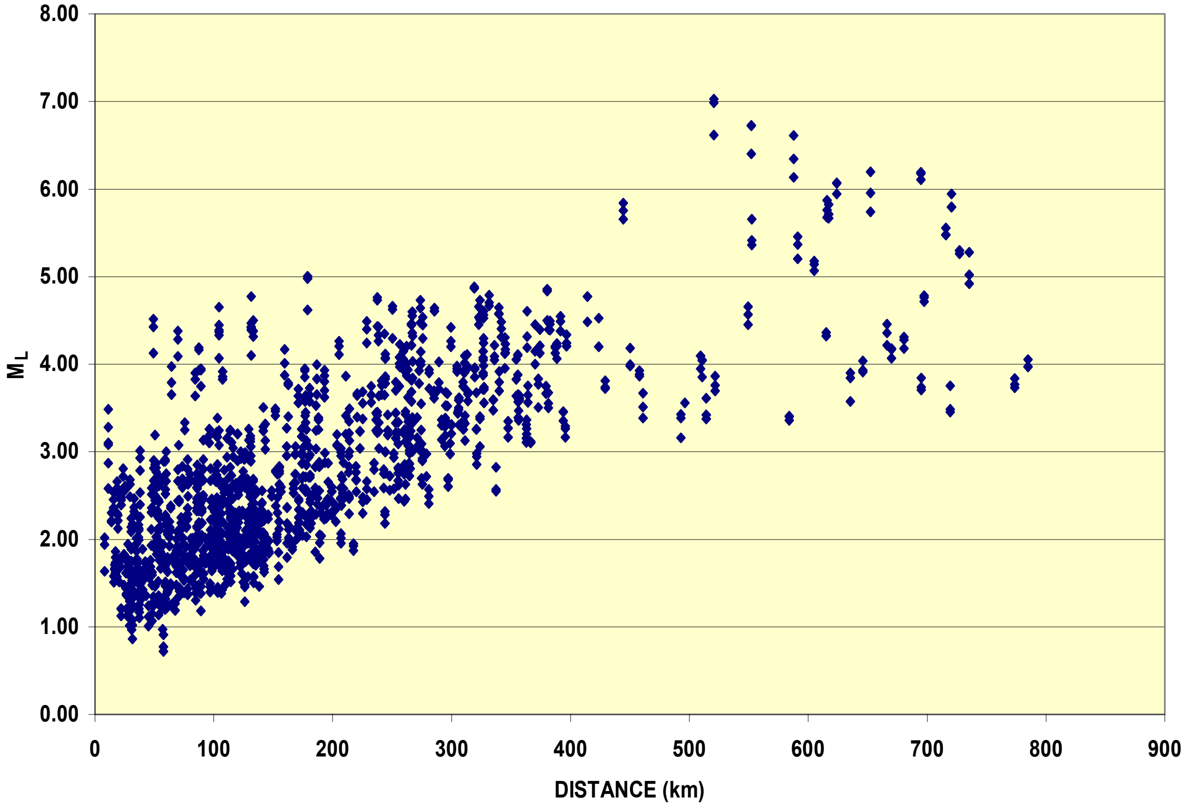

Figure 3. Magnitude & Distance Relationship

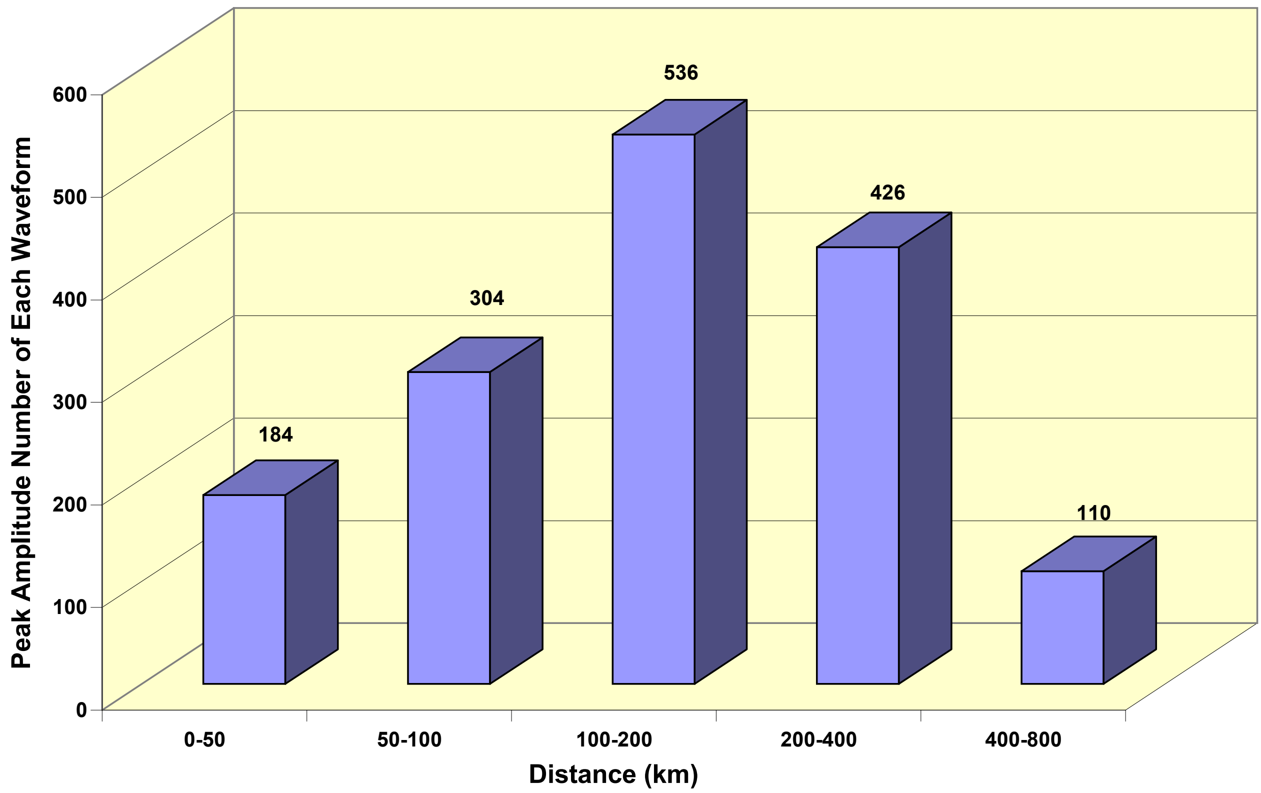

Diagram 2. All determined M_L values of each waveform according to distance

All of the waveform data are recorded by 7 BU KOERI three-component broadband seismographs. Two of them are very broadband CMG-3T, T_0 =300 second, code names are BALB and EDRB. One of them is broadband CMG-3T, T_0 = 100 second, code name is ISKB. They were recorded with a sample rate of 50 samples/sec. Their standardized instrument response is -195 dB to input ground velocity in the frequency band 0,05 – 25 Hz. Four of them CMG- 40T , T_0 = 40 second, code names are YLVX, CTTX, MFTX, MRMX that provide waveform data with a sample rate of 100 samples/sec, and the istrument responses are -180 dB to input ground velocity from 0,1 – 50 Hz.

4. DATA PROCESSING

Individual local and regional earthquakes were read by several analysts and interactively located using P and S wave arrival times. Event locations were generally good, particularly for those events within the network; on the other hand some events located at the edge or outside of the network were less accurate. A large subset of these events was located using the HYPO71 algorithm. Thus, most events used in this study have good locations.

To determine M_L, synthetic Wood-Anderson seismograms were calculated by removing the instrument response of each record and convolving the resulting signal with the standard Wood-Anderson torsion seismograph response (T_0 = 0.8 second, damping constant, h = 0.8, and static magnification, V = 2800; Anderson and Wood, 1925; Richter, 1935). This is a simple process used by many researchers (e.g., Bakun et al.,1978; Kanamori and Jennings, 1978; Uhrhammer and Collins, 1990; Kanamori et al., 1993; among others).

In this study, we did not use any station correction coefficients, but they were estimated and shown on Table 6 in Appendix A. The attenuation curve depends on the amplitude decay of the signal due to anelastic attenuation, scattering, and geometrical spreading along the event-station path and it is obtained empirically from the slope of the maximum amplitude versus epicentral distance. We used the original Richter attenuation relation as mentioned before. However, in order to obtain a continuous curve for interpolation we have developed a polynomial approach.

The approximate attenuation curve is calculated using the polynomial fitting routines available in MATLAB. We obtain two polynomial equations each valid for a different portion of distance range: For

distance < 200 km $p(x) = 0.00000040224x^3 - 0.00019236x^2 + 0.0334x + 1.2650$ (3)

distance > 200 km $p(x) = -0.0000059628x^2 + 0.0082x + 2.1173$ (4)

The original Richter values and the new approximate values are shown in Figure 4. We notice that the approximation gives reliable polynomial fit.

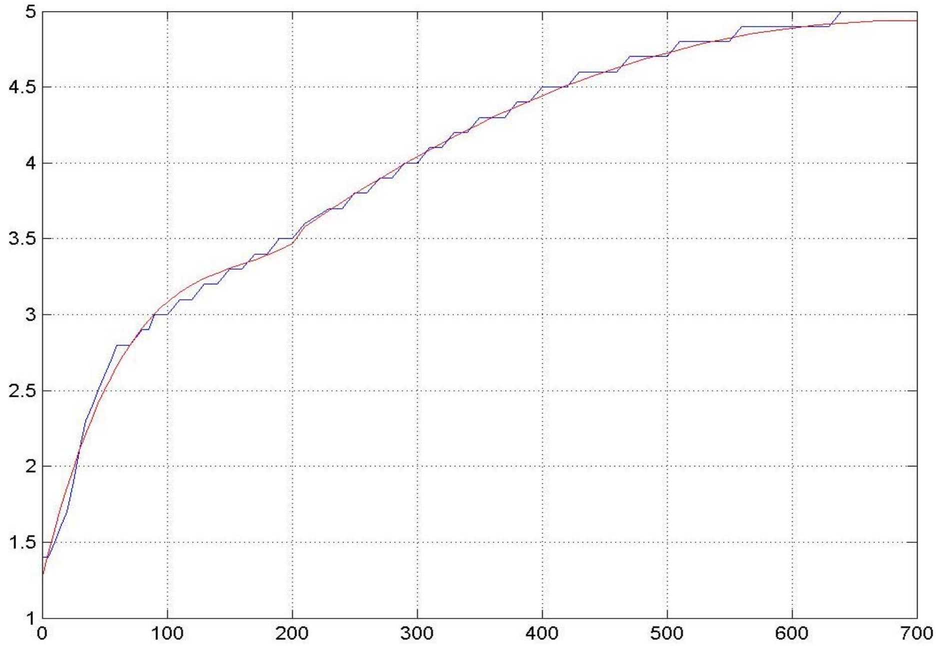

Figure 4. Richter and Approximate Curve

Information concerning the location of the event and the station were taken from the catalog. They are placed into the header of the corresponding data in SAC format. We corrected the BU KOERI broadband data for the instrument responses of the CMG-3T and CMG-40T seismometers. Maximum amplitudes are read using a millimeter scale and incorporated into the empirical formula for M_L.

We wrote a computer program in Linux system by using SAC script files (Seismic Analysis Code) to convert the displacements into Wood-Anderson form and then the maximum amplitude of both horizontal and vertical traces were automatically read for each station to produce the maximum amplitude data. In Figure 5 and Figure 6, seismograms are given to compare the original Guralp seismometer and the Wood-Anderson seismometer recordings of the same earthquake, at BALB and ISKB stations respectively. The first window shows the Wood-Anderson waveform and the one immediately below shows the corresponding original waveform as recorded by the Guralp seismometer. Each component, are plotted from top to bottom, in the order of east-west, north-south and vertical, respectively. The Wood-Anderson waveforms are generated synthetically by SAC routines.

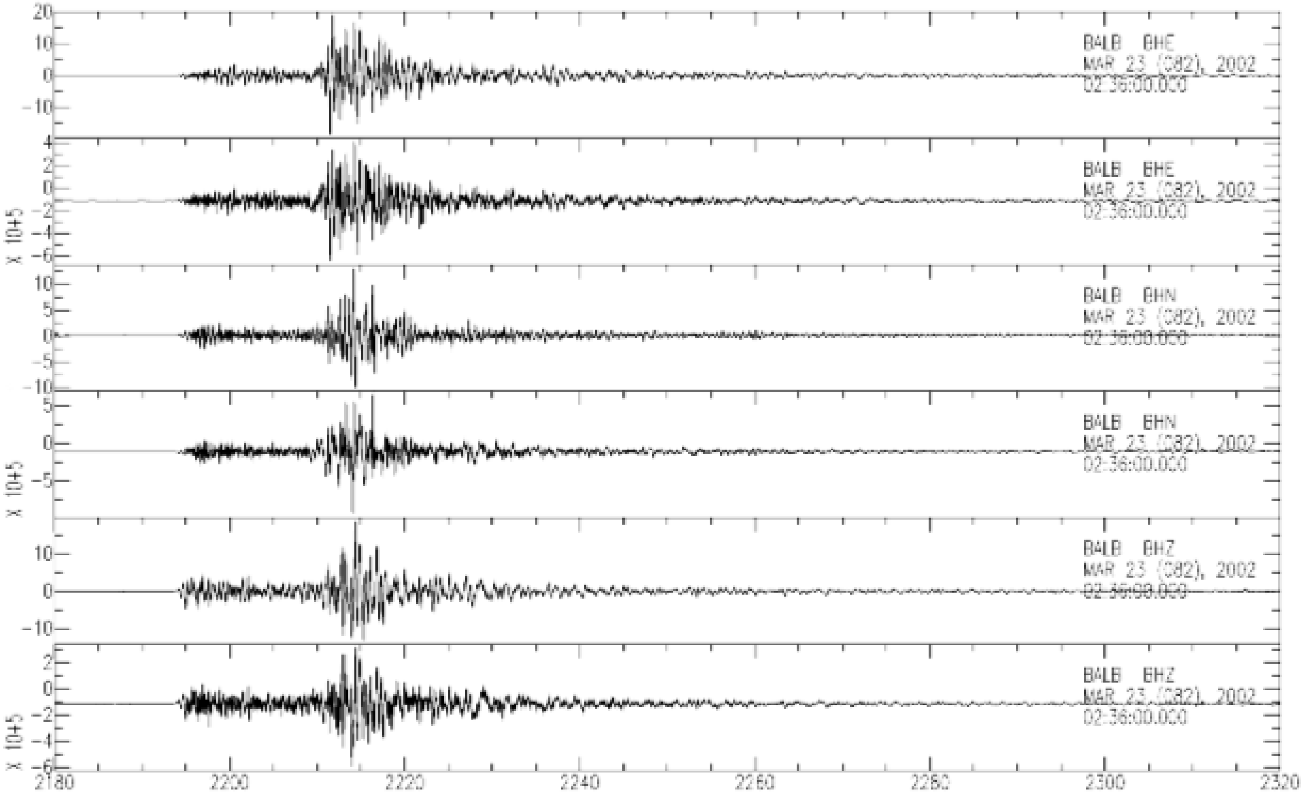

Figure 5. Recorded Waveforms on BALB

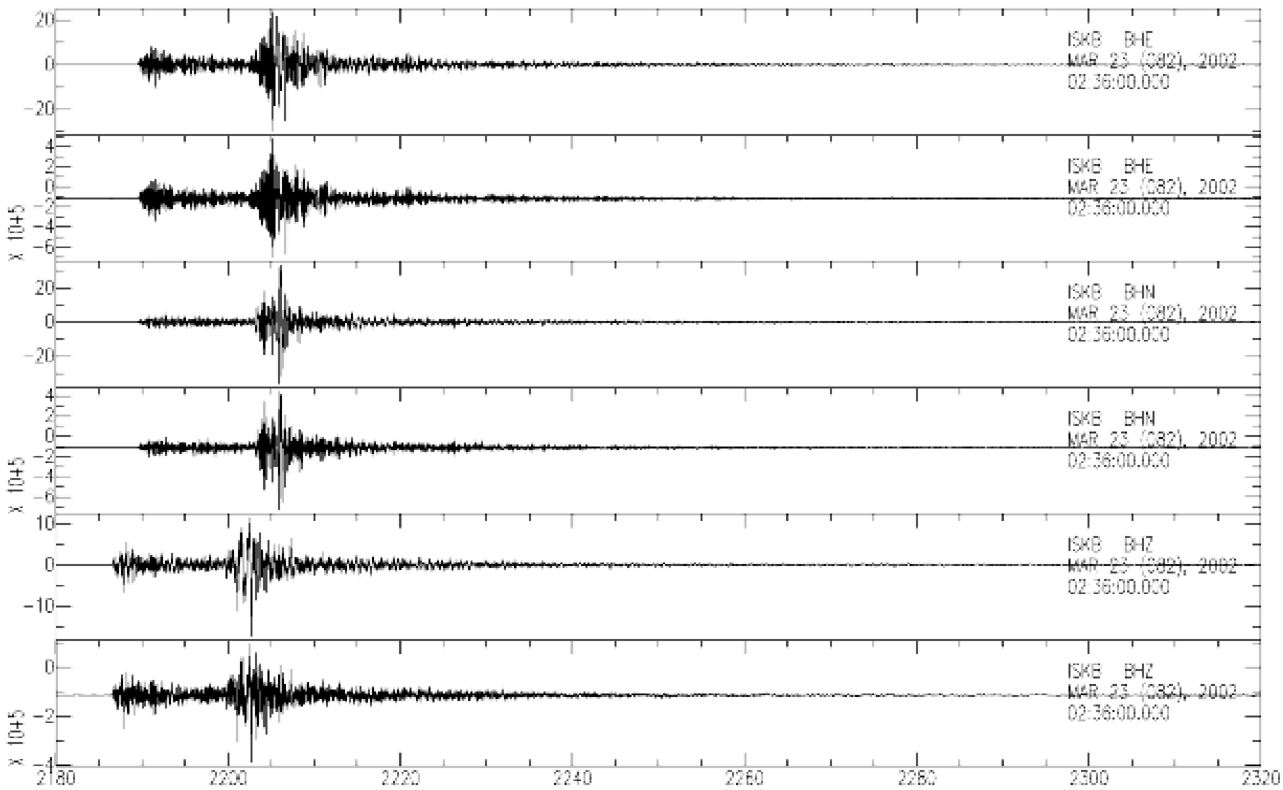

Figure 6. Recorded waveforms on ISKB

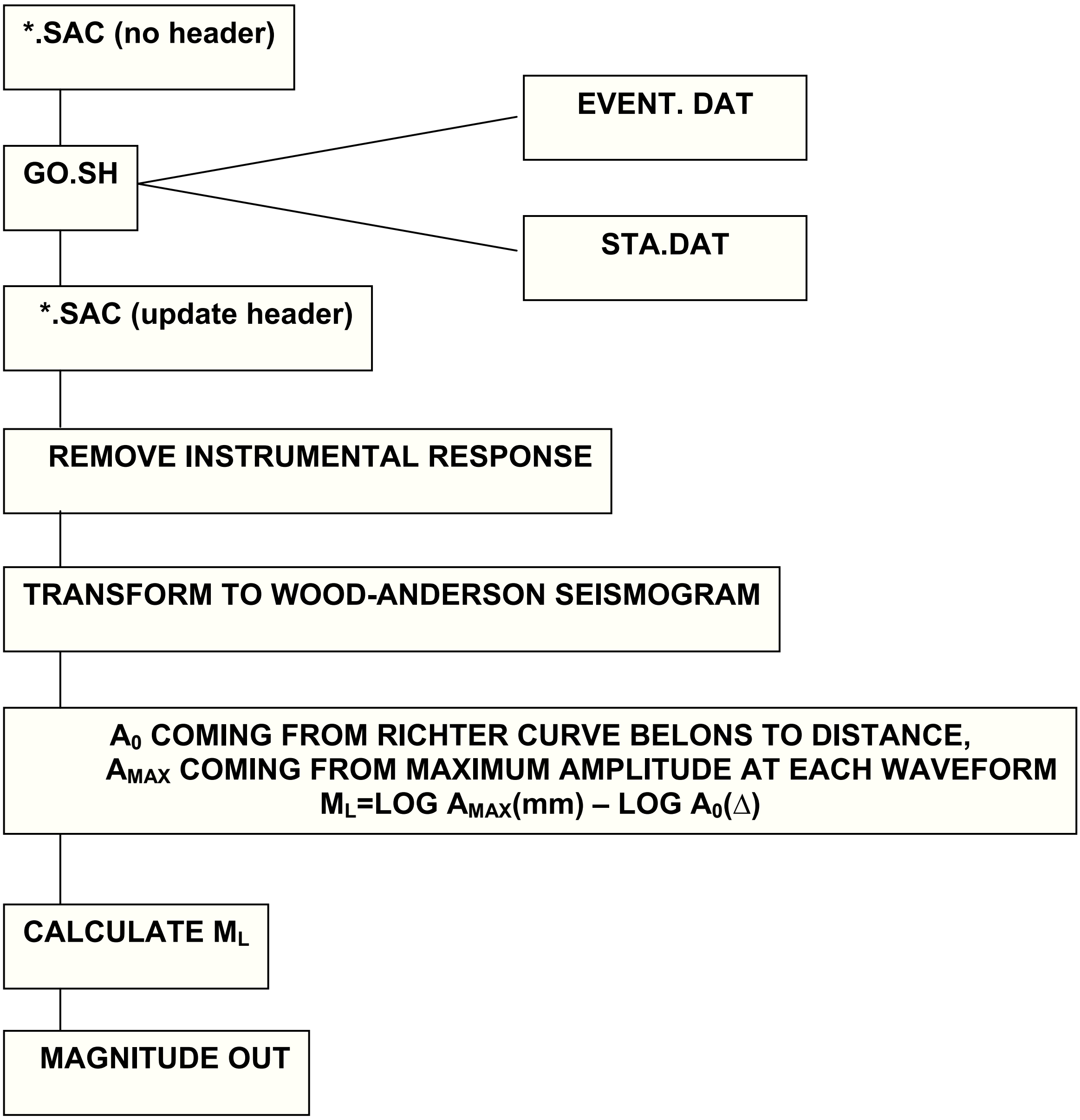

Figure 7. Computer Processing of M_L Calculation.

The flow of the computer procedures used for the calculation of M_L, is shown in a diagram, in Figure 7. Each step of the magnitude calculation program is seen in the figure, illustrating the automatic calculation of M_L. The program uses SAC routines and shell-script in Linux operating system. Whole data processing takes less than 30 minutes on a PC, for treating 1560 waveforms from 200 earthquakes. The most important feature of the program is the fast and reliable procedures, which are easy to adapt to real time seismic networks.

M_L calculation in Linux is divided into several parts. First, we prepare the C-shell script to calculate M_L magnitude. We get the earthquake data from the EARTHWORM system (Dean and Kömec, 2003) in SAC format, without any header information. On the other hand, we prepare two vital input data files. The first one is the file named ‘event.dat’ that contains information about the earthquake itself (i.e. the epicenter, the depth and the occurrence time). This information comes from the Kandilli catalog which a single line contains the data illustrated on Table 4. The first and the second columns are the more important fields for our purpose. These event latitude and longitude values are put into SAC header block. The latitude and longitude of the station are taken from a ‘sta.dat’ file. We run shell script called ‘go.sh’, to combine the latitude/longitude data with the SAC waveform data and update the header block. When the two latitudes and longitudes are combined, the SAC internal routines automatically calculate the epicenter distance to the station. Based on the epicenter distance, the program calculates the approximate A_0 value for each station, using the polynomials obtained before. All these operations are done in C-shell script and SAC-script files.

Latitude	Longitude	M_D	Depth(Km)	DD.MM.YY	Hour:min:sec	Location
40.839	27.858	4.8	14.13	23.03.2002	02:36:11.04	Marmara Sea

Table 4. Contents of ‘event.dat’ input file.

After introducing the required information into the SAC files, we calculate M_L using the new updated SAC files. We then remove the mean, the trend and the instrument response of each waveform, then we convert to Wood-Anderson synthetic seismogram. We find the maximum amplitude and $-\text{Log}A_0$ related to distance, coming from the approximate attenuation curve. Amax is coming from maximum trace amplitude that is measured from each waveform. The program measures two kind of trace amplitude: the first one is from zero to negative trace amplitude and the second is from zero to positive trace amplitude. They are shown on Table 5. The fourth column in Table 5 is zero to negative and fifth column is zero to positive value of trace amplitude. We later select the absolute value of the whichever is greater than the other one. We calculate M_L for each waveform and we put all information into ‘magnitude out’ which is the output file is shown on Table 5.

JULIAN DAY	TIME	STATION	MAX AMP1	MAX AMP2	DISTANCE	M_L	M_D	LATITUDE	LONGITUDE
82	02:36:11	BALB.BHE	18.50	18.74	133	4.38	4.80	40.84	27.86
82	02:36:11	BALB.BHN	23.40	25.03	133	4.50	4.80	40.84	27.86
82	02:36:11	BALB.BHZ	13.36	16.24	133	4.31	4.80	40.84	27.86
82	02:36:11	CTTX.BHE	50.39	52.40	70	4.38	4.80	40.84	27.86
82	02:36:11	CTTX.BHN	38.25	42.08	70	4.29	4.80	40.84	27.86
82	02:36:11	CTTX.BHZ	29.23	26.84	70	4.09	4.80	40.84	27.86
82	02:36:11	ISKB.BHE	29.89	26.69	104	4.33	4.80	40.84	27.86
82	02:36:11	ISKB.BHN	36.07	34.80	104	4.45	4.80	40.84	27.86
82	02:36:11	ISKB.BHZ	17.40	14.49	104	4.07	4.80	40.84	27.86
82	02:36:11	MFTX.BHE	77.22	83.01	49	4.42	4.80	40.84	27.86
82	02:36:11	MFTX.BHN	91.95	102.29	49	4.51	4.80	40.84	27.86
82	02:36:11	MFTX.BHZ	37.34	41.61	49	4.12	4.80	40.84	27.86
82	02:36:11	YLVX.BHE	20.95	21.60	132	4.43	4.80	40.84	27.86
82	02:36:11	YLVX.BHN	18.91	21.09	132	4.42	4.80	40.84	27.86
82	02:36:11	YLVX.BHZ	9.68	10.21	132	4.10	4.80	40.84	27.86

Table 5. Output File, Max Amp 1 = Maximum trace amplitude, zero-to-peak (in '+' field), Max Amp 2 = zero-to-peak (in '-' field).

We first choose the maximum value among the three components (Vertical, NS or EW) at each station, without any station magnitude correction. This is called the station magnitude and is represented by $M_{L,station}$. The final magnitude of the event is found by taking the mean of the maximum $M_{L,station}$ values calculated at each station.

$$M_L = 1/N \sum_{staion=1}^{N} M_{L,station}, \qquad (5)$$

Where N is the number of station, which supplies a M_L value. In this study, M_L value was determined for each 200 earthquakes.

The deviation at each station is defined as the difference between the final M_L and the $M_{L,station}$ calculated at this station only.

$$\bar{E} = M_L - M_{L,station} \tag{6}$$

Where $\bar{E}$ is the residual at each station.

We analyze the deviation at each station according to both magnitude and the distance.

5. DATA INTERPRETATION

We interpreted the results of the residuals mainly in two categories. The first one is according to the magnitude and the second one is according to distance. We reached important conclusions about magnitude policy in BU KOERI Seismological Laboratory.

5.1 Variation of the M_L Deviation with the Magnitude

The scatter of all measured $M_{L,station}$ values against M_L, illustrates the quality of the M_L determinations at each station, at various magnitude values (Figure 8.1-8.7) in Appendix B.

The average scatter of $\bar{E}$ (residual at each station) for most of the stations determined in this study is around zero line and symmetrical between -0.5 and 0.5 except at BALB and EDRB, which give positive residual. These two stations give a sign that there may be a problem with instrument responses, which should be checked. On the other hand, the remaining residuals shown in Figure 8.1-8.7 are independent of $M_{L.}$

There is irregular scattering at ISKB, and there is no detectable change with the magnitude. Most of values in Figure 8.2 are in positive field, a situation commonly seen in many Guralp CMG-3T broadband seismometers.

There are random scattering at YLVX, MRMX and CTTX. But MFTX is different from the others having a mild slope between M_L = 2.0 and M_L = 4.0. On the other hand most values are in negative field as sometime seen in other CMG-40T seismometers. Hence, this situation shows that we may calculate greater magnitude with CMG-40T than the average magnitude. Magnitude values are between M_L = 1.0 and M_L = 5.0 dominantly, and we have a few earthquakes that are greater than 5.0.

5.2 Variation of the M_L Deviation with the Distance

The scatter of all measured $M_{L,station}$ values against M_L, illustrates the quality of the M_L determinations at each station, at various distance values (Figure 9.1-9.7) in Appendix B.

We see clearly that all errors on BALB and EDRB are in the positive side. These figures show that, instrument responses of EDRB and BALB may have problem. We should check instrument responses of these stations. The residuals shown in Figure 9.1-9.7 are independent of distance, we conclude that M_L magnitude error does not depend on the distance. Instrument responses of BALB and EDRB have systematical problem that gives a smaller magnitude calculation than the average.

In addition, the other CMG-3T station is ISKB values are positive field mostly, this situation shows ISKB, BALB and EDRB have smaller M_L values. There is no distance trend with these stations.

We look at Figure 9.7, there is a slope in negative field. All MFTX values calculate greater M_L values than the average values. The CMG-40T values at CTTX, MRMX, YLVX stations are scattering around zero-line, and there is no distance trend at these station. We cannot conclude for any significant changing of magnitude error according to the distance. However we must note that our database is not a complete one, it does not contain many events up to 400 km. Furthermore, local magnitude saturate after 700 km so that we should not use it after 700 km.

In addition to these, we found errors of M_{L-Z} from only vertical components of the broadband stations. These error values are seen in Figure 10.1-10.7. According to the results, almost all values are positive side. This is proof, when we use only vertical components, almost all M_{L-Z} values give lower local magnitude values than the average.

6. PROPOSED IMPROVEMENTS FOR FUTURE M_L CALCULATION AT BU KOERI

Based on the results obtained in this study, it is possible to propose some improvements in the process of M_L magnitude calculation at BU KOERI. The proposed improvements for M_L magnitude calculation are divided into two parts. The first one is to find station correction coefficient of each broadband station in order to reduce the M_L scattering at each observation point. The second one is to include the short period one-component stations in magnitude calculation. Note that the actual implementation of these improvement's procedures are not included in this thesis.

While we calculate local magnitude (M_L) from broadband stations, we find small differences in M_L results obtained at each broadband station. This is a common situation, because in practice, the final M_L value is the one found by taking the average of different magnitude values from different stations. These differences are due to two basic reasons: a)systematic error due to station location, b)the random error due to the arriving signal.

The systematic station error may be due to several reasons. These are inappropriate installation (improper leveling), wrong station response functions, etc. These sources of error do not change rapidly with time, therefore they can be corrected if any systematic deviation is detected. For example, if a station calculates M_L higher or lower than average due to reasons associated with the crustal structure, this error can be found by statistical analysis and a station correction coefficient may be added to the M_L formula. This correction coefficient has sometime validity for a whole region, then it is called regional correction coefficient. However, the errors due to the nature of signal itself, such as the radiation pattern and transients in communication lines, have no fixed character therefore can not be corrected.

In this study, the station correction coefficients (C_{STA}) are found for each station, but they are not taken into account for the final M_L computation. The main reason for not using C_{STA} is that a larger data base is needed for obtaining a stable correction terms. Although they are not used in this study, an explanation is given below on the procedure to find the C_{STA}.

The second correction topic is to use the short period stations operating at the Seismological Laboratory, for M_L calculation. At present time, approximately 50 short period one-component stations are used for locating the earthquakes and calculating their duration magnitude (M_D). These types of stations are installed nearly on the whole of Turkey, so we expect them to contribute significantly to M_L calculation, particularly in regions where broadband stations are scarce. In this study, the method for the improvement is proposed in detail, however the actual application is excluded from the thesis.

6.1. Station Correction

It is very common to find different magnitude results at each station for a same earthquake. This situation can be seen clearly when using same type of seismometer at different station locations. The properties of the crustal structure in one station, do not change with time and can cause some systematic bias. These kind of bias can be determined using large database. These differences are called ‘’Station Correction’’ (C_{STA}) which can be added to M_L calculation to decrease to minimum all effects caused by the crustal structure.

For finding C_{STA}, we subtract M_L values at each station from the average M_L values. Then we can sum all the errors and also find the mean. Consequently the mean of the errors is ‘’Station Correction’’ coefficient.

$$\text{Station Correction} = \bar{E}_{station} = 1/N \sum_{i=1}^{N} (M_L - M_{Lstation}), \tag{7}$$

$\bar{E}_{station}$: Station Correction at each station,

M_L : average local magnitude values for each earthquakes,

$M_{Lstation}$: local magnitude values at each station.

Furthermore, we can find variance values for each station:

$$\text{Variance} = \sigma^2 = 1/N \sum_{i=1}^{N} (E - \bar{E}_{station})^2 , \tag{8}$$

E : $M_L - M_{Lstation}$,

$\bar{E}_{station}$: this is coming from equation (7).

The main purpose to find the variance (the square of the standard deviation) is to estimate the scattering of the error values, in other words, to interrogate the reliability of the error calculation. The mean and variance of the error are not only found for the whole magnitude range, but also for selected magnitude ranges of 1.0-2.0, 2.0-3.0, 3.0-4.0, 4.0-5.0 and 5.0-6.0. The values obtained can be seen in detail on Table 6 in Appendix A, but these correction values are not used in the present M_L computations. The reason is that we do not have sufficient events (in this study 200 earthquakes are used) to obtain a stable estimate. Meanwhile, all values are given in Figure 11.1-11.14. According to these figures, the standard deviations (σ) are mostly smaller than 0.1 magnitude units which can be accepted as being a reasonable one. The station corrections in the gains used; this can be adjusted later if such errors are found.

Station corrections probably represent the combined effect of differences in site amplification due to local geology, seismograph miscalibration etc. The set of 7 additive station corrections determined by the regression is listed in Table 6 in Appendix. The station corrections at ISKB, YLVX, MFTX, CTTX, and MRMX are smaller than 0.1 magnitude units, on the other hand the station corrections of BALB and EDRB are above the 0.1 magnitude units. For example, the station correction of BALB is 0.17, the station correction of EDRB is 0.35 in magnitude units. These are the only two stations that use Guralp CMG-3T (300 sec) sensors, therefore this deviation may reflect possible errors in the use of instrument response functions.

We note the when magnitude increases, the error values also increase. This may be because of insufficient events available in the high magnitude range between 4.0-5.0 and 5.0-6.0. Especially, for magnitude range between 5.0-6.0, there are only 3 earthquakes and consequently this number is insufficient for a reliable determination of station correction for events in that range.

6.2. Use of 1-D Station:

Today approximately 50 short period one-component stations are used at the BU-KOERI Seismological Laboratory. These stations are used for locating earthquakes and calculating duration magnitude (M_D). All stations can also be used for M_L calculation which will have a major contribution for local magnitude determination for whole Turkey. For this purpose, we propose some suggestions. These are:

- If it is possible, we should find the instrument response function of each station or at least the instruction manual for each station. Through this direction, we can form the transfer function of short period station and convert it to Wood-Anderson correctly.
- If it is not possibly to find the data sheet for the instruments, there is an approximate way that can be applied. Almost most of the short period stations contain L-4C and SS-1 seismometers that use the natural period of 1 second. This is quite similar to

Wood-Anderson type seismometer which has a natural frequency of 0.8 Hz. However we do not know the magnification and also the damping. Neglecting the effect of the damping, we concentrate only to magnification. The magnification at the station can be estimated the same way as we have estimated the station correction values with the broadband stations. For that purpose, we only have to calculate the M_L at the short period and find the statistical mean of the error by comparison with M_L obtained at broadband stations.

- During our analysis, we found lower M_L values than average M_L results, for the vertical-component of each broadband station. This situation is valid for other one-component vertical stations. We can see that if magnitudes were to be estimated using the vertical components, we would have an underestimation of about 0.2 unit. This situation belongs to nature of M_L calculation because M_L is calculated from horizontal component. If we find correction coefficient for short period stations, C_{STA} can also include underestimation coefficient.

We can apply magnitude correction procedure for these vertical component short period stations and this will allow all 1-D stations to be calibrated by the new M_L station correction values. Also amplitude based M_L calculation is more reliable than M_D calculation.

7. QUALITY COMPARISON of M_L CALCULATION

The M_L values calculated in this study are compared with magnitude calculation determined by the other agencies using different method and/or different database. These other agencies are shown below;

- Duration magnitude (M_D) determined by BU KOERI Seismological Laboratory,
- Local magnitude (M_L) determined by BU KOERI Seismological Laboratory,
- Local magnitude (M_L) determined by TUBITAK-MRC,
- Body wave magnitude (M_B) determined by EMSC-CSEM.

The purpose of these comparisons is to evaluate the reliability of the magnitudes calculated. We also want to know the difference between our method and the other methods. We can see clearly amplitude based magnitude calculation is more efficient than the other methods. The goal of this study is to install the new M_L calculation method for everyday use in Seismological Laboratory and revise the existing M_D catalogs.

In this chapter, we compared our M_L calculation with the other agencies and institutes. First, we compared with M_D determined by BU KOERI. This section contains basic principles of M_D calculation, evaluation of M_D reliability and quality assessment for M_D calculation Seismological Laboratory. Next, we compared our M_L with the ones occasionally determined by BU KOERI. Third, we made a comparison with M_L determined by TUBİTAK-MRC. The last comparison is for teleseismic earthquakes determined by EMSC-CSEM.

7.1.Comparison of M_L Calculation in Thesis with M_D Determined by BU KOERI.

At BU KOERI Seismological Laboratory, M_D formula has been used since the beginning of the 1980's. The M_D calculation needs duration of signal on seismogram on paper drum hardcopy or on computer screen for digital data. General M_D formula is:

$$M_D = a_0 + a_1 + \log D + a_2 \Delta \tag{9}$$

Where D is signal duration (sn),

Δ is distance (km),

a_0, a_1, a_2 are coefficients.

One of the most important matter of M_D calculation is the distance which should be less than 350 km. According to Eaton (1992), there should use distance correction after 350 km, otherwise M_D calculation is not efficient and not valid.

When a seismologist uses analogue seismogram at Seismology Laboratory, there are some problems on coda readings on short period seismic stations, depending on the noise level. For example, some seismic stations gains are adjusted to 36 dB, however some others are 16 or 24dB. As a result of this situation, seismologists sometimes read wrong code length and this causes wrong M_D values. Furthermore, sometimes noise level is very high to decrease the signal quality, so that it becomes difficult to determine where the coda ends. It very common that high noise level causes different M_D values for the same earthquake.

This comparison contains 200 well-determined earthquakes. M_D values are determined by BU KOERI Seismological Laboratory are compared with the Ml obtained in this thesis. The results reveal some important points that are given below;

- The relation between $M_{L\text{-Thesis}}$ and $M_{D\text{-BU KOERI}}$ is drawn in Figure 12 in Appendix B. In ordinary situation, the ideal line should be $M_{L\text{-Thesis}} = M_{D\text{-BU KOERI}}$, which corresponds to the situation where all points are on 45^0 line (this line can be seen in Figure 12). But it is seen clearly that the magnitudes determined are very different from each other. The points on the comparison curve are scattered on a different line that the diagonal one. On the one hand, this difference changes also with the magnitude values. The least square method is applied for fitting a linear line:

  $$M_{D\text{-BU KOERI}} = 0.54 * M_{L\text{-Thesis}} + 1.6 \qquad (10)$$

- The cross-over point of these two line (the ideal and the actual one) is at $M_{L\text{-Thesis}} = 3.5$. In other words, all of $M_L < 3.5$ earthquakes are overestimated by M_D determined in the Seismological Laboratory, and all of the $M_L > 3.5$ earthquakes are underestimated by M_D determined by Seismological Laboratory. It is important to identify the source of the error in M_D determination. It is also recommended that past earthquakes should also be corrected based on statistical analysis and therefore the catalog has to be revised. Our suggestion is that we need larger database than the present one, in order to determine more reliable corrections terms and make the ultimate catalog revision.
- We can see residuals more clearly in Figure 13 in Appendix B. Here we present the plot of the error between the two calculations, which is obtained by

subtracting $M_{D\text{-BU KOERI}}$ from $M_{L\text{-Thesis}}$. This figure gives more detail about the existing error. Again for earthquakes of $M_L \leq 3.5$, M_D overestimates and earthquakes of $M_L \geq 3.5$, M_D underestimates. The scattering can be seen clearly in this figure. The range of scattering is between 1.0 and -1.5. As an example, for an earthquake of M_L= 1.0, M_D gives 2.5, and conversely for another one with M_L= 4.8, M_D estimates 3.9. This deviation is too large to be permitted in observatory practice.

According to the results, M_D calculation cannot be a good reference for our purposes. It is advised to use amplitude based local magnitude calculation and revise the existing catalog. Seismological Laboratory is the one of the main authority for magnitude determination in Turkey. The error must be reduced to minimum because any negligence may have important consequences considering that many risk analysis are made using the KOERI catalogs.

7.2. Comparison of M_L Calculation in Thesis with M_L Determined by BU KOERI Seismological Laboratory.

There are several magnitude calculation programs at BU KOERI. One of them is a FORTRAN program developed by BU KOERI, which is using the same parameters such as the original Richter's curve values and the standard Wood-Anderson parameters. Although the program is using equation (1) and the same parameters, calculated M_L values by this program are higher than $M_{L\text{-Thesis}}$ values by at least 0.2 magnitude units. The data and results are given in Table 3 in the Appendix A.

The $M_{L\text{-Thesis}}$ values compared with $M_{L\text{-BU KOERI}}$ are shown in Figure 14 in Appendix B. The results approach the 45^0 line drawn with black color. The $M_{L\text{-BU KOERI}}$ values are about at least 0.2 magnitude units larger than corresponding $M_{L\text{-Thesis}}$. This results show that there are a systematical problem with this $M_{L\text{-BU KOERI}}$ formula. The values show that $M_{L\text{-BU KOERI}}$ overestimate independently for all values. There should make a linear regression if much more event number than now using. The difference is about 0.4 magnitude units for the

23.03.2002 02:36 event in the Marmara Sea that gives $M_{L\text{-Thesis}}$ = 4.45. This difference is too high for being tolerable.

Figure 15 in Appendix B shows the same scattering but in more detail. We note that almost all errors are in negative side. Consequently, we observe that $M_{L\text{-BU KOERI}}$ overestimates all magnitude values systematically, but scattering ratio lower than $M_{D\text{-BUKOERI}}$.

7.3. Comparison of M_L Calculation in Thesis with M_L Determined by TUBITAK.

Tubitak Marmara Research Center determined local magnitudes (M_L) for 111 earthquakes common with the thesis, using records from Guralp instruments T_0 = 40 sec, 24 bit REFTEK recorder, 1 Hz short period Mark product L-4C seismometers and calibrated MIDAS recorder that have operated during January 2002 to July 2002. Same methodology used in this thesis is applied by Tubitak-MRC but using different stations. The normalized amplitudes are used to compute the M_L using equation (1).

All values are compared to $M_{L\text{-Thesis}}$ values. The residuals show that good consistency exist between $M_{L\text{-Thesis}}$ and $M_{L\text{-TUBITAK}}$. The catalog of M_L determined by Tubitak for 111 events is given in Table 3 in Appendix A. The magnitudes of earthquakes in the $M_{L\text{-TUBITAK}}$ catalog range between 1.16 and 4.86. The relation between $M_{L\text{-Thesis}}$ determined in this study and the $M_{L\text{-TUBITAK}}$ shows a scatter between -0.5 to 0.5 magnitude units which quite acceptable (Figure 17 in Appendix B). Also residuals are aligned around the zero line symmetrically. The relation indicates that the $M_{L\text{-TUBITAK}}$ is slightly greater than $M_{L\text{-Thesis}}$ but the difference is negligible. The 45^0 line and residuals can be seen in Figure 16 in Appendix B. There is a close relationship. This is proof of reliability of M_L calculation with different institutes but same methodology.

7.4. Comparison of M_L Calculation in Thesis with M_B Determined by EMSC-CSEM.

There are several magnitude scales at EMSC-CSEM. We take only M_B used by Emsc-Csem. First, we describe M_B that Gutenberg (1945b and c) developed a magnitude relationship for teleseismic body-waves such as P, PP, and S in the period range 0.5 s to 12 s. It is based on theoretical amplitude calculations corrected for geometric spreading and attenuation and then adjusted to empirical observations from shallow and deep-focus earthquakes:

$$M_B = \log (A/T)_{max} + Q (\Delta, h) \qquad (11)$$

Gutenberg and Richter (1956a) published a table with Q(D) values for P, PP and S waves observations in vertical (V) and horizontal (H) components for shallow shocks, complemented by diagrams Q (D, h) for PZ, PPZ and SH which enable also magnitude determinations from intermediate and deep earthquakes.

There are several institutes, which are sending data to EMSC-CSEM for magnitude calculation of each event. We picked up M_B values determined by EMSC-CSEM and other institutes, which are member of the European Mediterranean Research Centers.

In Figure 18 in Appendix B, 13 earthquakes are compared in terms of $M_{L\text{-Thesis}}$ and $M_{B\text{-CSEM}}$. Their residuals are close to diagonal line. There is also seen no high deviation of the residuals in the more detailed representation of Figure 19 in Appendix B. The scattering range is between 0.5 and –0.5. This result is quite reasonable. One of the 13 earthquakes shown has larger deviation than the others as much as 0.6 magnitude units, (drawn with red circle) which is slightly different then the other. This event is an Aegean Arc earthquake occurred on 2002/01/22 ($M_{L\text{-Thesis}}$ = 5.3), therefore considerably far away from our network, which means not suitable for M_L calculation.

8. CONCLUSION

We measured peak amplitudes on software simulated Wood-Anderson seismograph and computed local magnitudes. 1560 three-component broadband digital records from 200 earthquakes in the distance range of 8 to 785 km were used. We obtained M_L magnitudes of each event, values were not considered to be reliable above the distance range of 700 km. The whole procedure is developed as a new automatic magnitude calculation program in Linux system. The routines are also ported on Visual Basic to Windows environment to be inserted in BU KOERI Seismological Laboratory routine practices. We used SAC script files to handle the data in SAC format in order to calculate the hypocenter distance by internal SAC routines. The distance automatically gives the $-\log(A_0)$ value by using an approximate form of the original Richter curve.

Maximum M_L values at each station have been calculated also purely in SAC environment. The average of all stations gives the final M_L magnitude. All maximum values have been subtracted from final M_L magnitude to obtain the scatter of the local magnitude residuals. These are plotted against distance and M_L magnitude. In normal situation, all measured error will scatter around zero line symmetrically. This is verified for most stations. In general the scattering value is less than 0.5 in magnitude.

Residual values against distance and magnitude on BALB and EDRB are systematically in the positive field. There are probably due to instrument response problem on EDRB and BALB.

We also calculated the local magnitude residuals using only the vertical component. The question is what happens if only the vertical component was used for M_L calculation. Almost all residuals at each station are in the positive area. This shows that M_L calculated from the vertical component only, is lower than average magnitude value. This means that if the magnitude is to be calculated from one-component vertical stations, they are underestimated and we need to add a correction coefficient to reach the accurate M_L value.

All errors against magnitude and distance have been analyzed and gave similar results. The first one is that, almost all residuals at most stations are scattering around the zero line systematically, the second one is that there is no obvious trend related to magnitude and distance. The station corrections were obtained by computing the mean of the station residuals for all events. Most stations corrections values are relatively small (except at BALB and EDRB) and they were ignored during the calculations done in this thesis. However they should be reconsidered by using a larger database and need to be introduced for correction purposes, into the routine magnitude calculations.

The calculated M_L values are compared with the duration magnitude (M_D) determined by Seismological Laboratory and listed in BU KOERI catalogs. The difference between M_L and M_D scattering spans a magnitude range between -1.5 to 1.0 magnitude units. On the other hand, the relation between M_L determined in this study and the TUBITAK M_L values shows that there is a relatively good consistency. This means that the actual M_D calculations used in Seismological Laboratory are not reliable.

For 32 events, M_L formula determined by Seismological Laboratory were compared, we note an overestimation M_L. There may be a systematical problem with this M_L formula used in the computation but the difference is not very large.

For 13 events, M_L values determined in this study were compared with M_B values determined by EMSC-CSEM. These earthquakes are regional earthquakes including the M_B = 6.1 24/04/2002 Kosova Earthquake. The results of this comparison show that $M_{L\text{-Thesis}}$ is slightly greater than M_B.

As general results, we conclude that we should increase the number of earthquake used in testing and we should make a regression analysis for reaching more reliable transition formulas between different magnitude scales. It is advised to use amplitude based local magnitude calculation which are easier to implement automatically, and which also give a more reliable measure of the earthquake size.

More important is the fact that, we should revise our past M_D catalog according to the new $M_{L\text{-Thesis}}$ results. Seismological Laboratory is one of the main authorities for magnitude determination in Turkey. The error must be reduced to a minimum, because any negligence may have important consequences considering the fact that nearly all risk analysis in Turkey are based upon the KOERI catalogs.

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APPENDIX A

BROADBAND STATIONS	Station Code	Latitude	Longitude	Seismometer
	ISKB	**41.065**	**29.059**	**CMG-3T**
	BALB	**39.640**	**27.880**	**CMG-3T**
	EDRB	**41.847**	**26.743**	**CMG-3T**
NANOMETRICS STATIONS	Station Code	Latitude	Longitude	Seismometer
	CTTX	**41.342**	**28.357**	**CMG-T40**
	MFTX	**40.786**	**27.281**	**CMG-T40**
	MRMX	**40.605**	**27.583**	**CMG-T40**
	YLVX	**40.566**	**29.372**	**CMG-T40**

Table 1. List of Stations

Δ (km)	-Log Ao	Δ (km)	-Log Ao	Δ (km)	-Log Ao	Δ (km)	-Log Ao
0	1.4	90	3	260	3.8	440	4.6
5	1.4	95	3	270	3.9	450	4.6
10	1.5	100	3	280	3.9	460	4.6
15	1.6	110	3.1	290	4	470	4.7
20	1.7	120	3.1	300	4	480	4.7
25	1.9	130	3.2	310	4.1	490	4.7
30	2.1	140	3.2	320	4.1	500	4.7
35	2.3	150	3.3	330	4.2	510	4.8
40	2.4	160	3.3	340	4.2	520	4.8
45	2.5	170	3.4	350	4.3	530	4.8
50	2.6	180	3.4	360	4.3	540	4.8
55	2.7	190	3.5	370	4.3	550	4.8
60	2.8	200	3.5	380	4.4	560	4.9
65	2.8	210	3.6	390	4.4	570	4.9
70	2.8	220	3.65	400	4.5	580	4.9
75	2.9	230	3.7	410	4.5	590	4.9
80	2.9	240	3.7	420	4.5	600	4.9
85	2.9	250	3.8	430	4.6		

Table 2. Logarithms* of the Amplitudes A_0 (in millimeters) with which a Standard Torsion Seismometer ($T_0 = 0.8$, $V = 2800$, $h = 0.8$) should register an earthquake of magnitude zero.

*Since A_0 is less than 1, its logarithm is negative, and the table shows values for $-\text{Log } A_0$.

DD/MO/YR	HH:MM:S	Latitude	Longitude	Depth	$M_{L-Thesis}$	$M_{D-BU KOERI}$	$M_{L-TUBITAK}$	$M_{L-BU KOERI}$	$M_{Emsc-Csem}$
03.01.2002	10:36:13.63	40.710	29.138	5.85	1.89	2.40			
04.01.2002	04:07:54.61	39.895	26.638	5.37	2.80	3.00	3.08		
10.01.2002	21:21:48.84	40.755	30.930	8.06	3.27	3.00	3.42		
18.01.2002	21:15:44.00	39.220	29.390	5.43	3.04	2.90	3.22		
19.01.2002	01:38:26.50	39.286	29.360	5.00	2.59	2.80	2.81		
21.01.2002	14:34:23.75	38.675	27.825	10.66	4.64	4.70			
22.01.2002	04:53:47.8	34.938	26.125	47.81	5.30	5.30			6.00
23.01.2002	20:10:56.17	38.597	27.785	8.69	3.68	3.20	3.64		
23.01.2002	21:22:11.48	38.652	27.783	11.27	4.03	3.50	3.83		
24.01.2002	01:24:34.57	39.914	28.616	5.40	2.16	2.70			
01.02.2002	23:26:01.45	40.738	29.144	14.39	1.49	2.50	1.56		
02.02.2002	00:51:48.03	40.847	29.299	5.00	1.25	2.60			
02.02.2002	23:30:21.40	40.754	30.692	7.38	2.30	2.60	2.56		
03.02.2002	08:22:28.84	38.360	30.917	10.29	3.92	3.10			
03.02.2002	10:02:08.89	38.593	30.815	5.00	4.11	3.10	4.53		
03.02.2002	20:09:34.05	38.577	30.964	14.32	3.67	2.90			
03.02.2002	21:13:11.83	38.635	30.840	5.00	3.36	2.90			
04.02.2002	21:03:04.96	38.663	30.810	8.92	3.59	3.70	4.32		
05.02.2002	07:12:48.32	38.528	30.816	5.37	3.96	2.90			
19.02.2002	03:37:26.87	39.252	28.208	9.78	3.43	3.70	3.42	3.70	
19.02.2002	18:55:20.14	40.543	28.291	18.91	2.83	3.30	3.00	3.26	
21.02.2002	18:04:06.28	38.727	30.909	5.00	4.22	4.20		4.26	
21.02.2002	18:39:53.18	38.703	30.962	10.05	3.81	4.20	3.98	4.16	
27.02.2002	21:26:23.44	39.950	33.493	8.43	3.53	4.10			
05.03.2002	05:23:42.6	41.033	25.019	33.10	4.78	3.90	4.67	4.82	4.70
10.03.2002	03:18:05.34	40.594	28.946	5.00	1.68	2.70			
19.03.2002	09:49:29.73	40.062	29.149	12.10	2.03	2.60			
19.03.2002	09:55:33.51	40.013	29.456	8.57	2.20	2.70			
19.03.2002	10:01:56.55	40.072	29.354	9.77	2.35	2.90	2.69	3.07	
19.03.2002	10:11:28.67	40.083	29.311	8.65	2.78	3.30	3.04	3.50	
20.03.2002	08:18:21.20	40.472	28.665	5.62	1.85	2.50			
20.03.2002	17:18:42.01	40.156	29.295	9.51	2.83	3.00	3.15	3.67	
22.03.2002	01:31:10.33	38.688	30.695	7.17	3.20	3.30	3.55	3.32	
22.03.2002	10:29:10.12	40.806	28.200	7.68	2.41	2.80	2.75	2.77	
22.03.2002	14:22:37.90	40.024	28.755	11.14	2.50	3.00	3.11	3.10	
23.03.2002	02:36:11.04	40.839	27.858	14.13	4.45	4.80	4.45	4.80	4.20
23.03.2002	04:02:14.95	40.814	27.877	5.41	1.45	2.60			
23.03.2002	04:57:30.16	39.554	28.886	8.37	2.95	3.10	3.20	3.20	
23.03.2002	05:38:42.02	40.820	27.878	9.74	3.19	3.80	3.27	3.80	
26.03.2002	15:20:41.03	40.519	29.489	10.29	3.49	3.00			
28.03.2002	08:37:00	40.839	27.858	15.00	4.71	4.80	4.32		
24.04.2002	06:27:46.28	38.948	31.141	8.73	3.46	3.70		3.62	
24.04.2002	10:51:51.5	41.530	24.292	5.00	6.39	5.70		6.87	6.10
25.04.2002	01:12:08.18	39.635	26.444	5.00	2.82	3.10			
25.04.2002	07:12:41.48	40.380	26.368	20.14	2.13	2.90	2.86		
25.04.2002	07:28:00.00	40.590	20.840	9.00	3.73	4.20	3.72		3.70

25.04.2002	08:10:32.87	39.379	27.989	8.68	2.49	2.80	2.58		
25.04.2002	17:06:50.09	40.314	29.112	7.77	1.65	2.60	1.86		
25.04.2002	22:34:48.15	35.240	32.660	59.00	3.90	4.00			
26.04.2002	06:31:11.00	42.456	21.478	10.00	4.66	4.10			3.90
04.05.2002	23:26:25.91	40.746	30.859	16.17	2.77	3.10	2.88	3.15	
05.05.2002	09:22:10.07	40.543	28.319	6.59	3.99	4.30	4.22	4.40	
05.05.2002	09:40:39.55	40.539	28.332	9.22	2.49	3.00	2.57	2.91	
05.05.2002	10:36:18.27	40.546	28.288	5.72	1.74	2.60		2.08	
05.05.2002	17:54:50.82	40.817	30.278	5.65	2.22	2.60	2.56	2.62	
07.05.2002	20:37:06.50	40.545	28.331	5.18	1.57	2.50			
07.05.2002	23:30:35.47	40.128	26.510	8.74	2.01	2.70	2.13		
08.05.2002	10:23:36.20	38.624	26.074	11.80	3.86	3.60	4.11		
09.05.2002	01:49:57.3	37.140	23.710	5.00	3.96	4.30	3.91		4.20
12.05.2002	23:33:58.09	40.641	28.785	5.39	2.56	2.90	2.78	2.83	
13.05.2002	11:42:48.74	38.657	31.254	5.00	4.29	4.40		4.43	
14.05.2002	13:06:08.29	41.094	28.856	5.47	1.66	2.20	1.53		
14.05.2002	19:32:23.42	40.465	28.704	8.17	2.95	3.10	3.27		
14.05.2002	19:55:20.55	40.325	28.730	20.25	2.20	3.80	2.45		
14.05.2002	21:20:22.64	39.814	28.686	11.64	2.23	3.50	2.26		
14.05.2002	22:02:15.70	40.821	27.646	5.00	2.16	3.10			
14.05.2002	22:41:53.08	40.451	28.712	6.34	2.08	2.90	2.26	2.23	
15.05.2002	15:35:49.21	41.096	29.306	5.16	1.53	2.90	1.82		
16.05.2002	15:54:45.67	41.132	28.831	5.00	1.71	2.70			
16.05.2002	19:43:01.58	40.076	29.323	16.00	2.22	3.40			
18.05.2002	00:25:11.99	40.435	27.483	5.00	1.85	2.50	2.15		
18.05.2002	03:13:14.09	39.013	28.045	8.43	2.59	3.10			
18.05.2002	20:39:34.95	40.717	30.193	8.92	2.82	3.20	3.25	3.20	
19.05.2002	02:12:02.00	39.163	27.258	12.41	3.68	3.30			
19.05.2002	10:45:57.20	38.598	26.618	5.00	4.47	3.90	4.22		4.00
19.05.2002	11:07:35.53	38.507	26.438	5.00	3.79	3.60			
19.05.2002	12:21:05.25	38.324	26.430	5.92	3.95	3.70			
19.05.2002	12:26:56.52	38.518	28.024	5.57	2.84	3.40		3.17	
19.05.2002	19:04:32.75	38.449	28.331	5.00	2.79	3.40	2.68		
20.05.2002	09:26:58.28	40.696	27.470	5.50	2.00	2.50	2.23		
20.05.2002	09:36:47.70	41.086	29.320	16.63	1.06	2.50	1.25	1.05	
21.05.2002	10:36:45.15	40.753	29.107	30.54	2.08	2.90	2.19	2.43	
21.05.2002	11:45:25.59	38.748	25.633	31.89	3.38	3.30			
21.05.2002	20:53:18.4	36.115	23.443	56.40	5.69	5.60		5.60	5.60
23.05.2002	00:53:41.66	40.258	27.218	9.53	3.07	3.10	3.16	3.13	
23.05.2002	04:48:04.70	38.756	26.425	14.41	4.59	4.60	4.86		4.00
24.05.2002	13:44:23.73	41.044	29.656	4.61	3.01	3.20			
25.05.2002	00:45:08.61	40.554	28.114	11.06	1.78	2.70	1.94		
27.05.2002	16:26:13.33	39.729	30.785	5.00	2.79	2.90			
27.05.2002	19:54:47.81	38.646	31.190	5.00	3.36	3.20			
27.05.2002	20:21:34.93	37.768	25.687	5.98	3.60	3.60			
28.05.2002	01:26:07.81	39.995	27.886	15.26	2.27	3.00	2.51		
30.05.2002	01:58:59.96	40.857	27.782	5.90	1.72	2.80			
30.05.2002	20:29:51.02	38.689	30.900	5.37	3.42	3.30	3.00		

30.05.2002	22:31:16.99	40.583	27.495	20.53	1.65	2.80			
30.05.2002	23:14:13.22	40.386	27.733	6.04	1.84	3.00			
31.05.2002	03:25:02.45	38.605	30.923	8.53	3.34	3.10	2.67		
31.05.2002	09:59:38.29	39.948	29.181	9.30	1.73	2.80	2.67		
31.05.2002	11:24:12.90	39.974	25.532	26.21	3.39	3.00			
31.05.2002	14:22:29.24	40.815	29.231	6.29	1.87	2.60	1.93		
01.06.2002	18:21:14.39	39.011	27.731	13.67	3.12	3.20	3.10		
02.06.2002	17:01:46.47	38.554	30.754	7.50	3.33	3.00			
03.06.2002	11:58:09.28	40.603	30.090	5.00	1.74	2.60	1.81		
03.06.2002	14:34:03.34	43.291	31.793	5.00	3.36	3.50			
03.06.2002	18:08:35.92	40.523	29.014	6.18	1.33	2.80			
04.06.2002	00:53:45.84	38.532	26.153	14.45	2.80	3.20			
04.06.2002	02:56:54.00	37.607	26.972	23.28	2.82	3.10			
04.06.2002	05:21:46.97	40.432	25.976	5.00	1.87	2.90	2.07		
04.06.2002	07:00:58.83	40.887	27.846	5.54	1.26	2.70			
04.06.2002	22:40:47.25	40.632	29.058	11.68	1.68	2.70			
06.06.2002	05:04:26.77	38.494	30.865	5.00	3.23	3.20	3.24		
06.06.2002	05:10:12.00	39.051	28.005	8.70	4.06	4.00	4.26	4.44	
06.06.2002	09:31:06.22	38.999	28.019	11.92	2.60	2.90	2.56		
06.06.2002	13:01:56.88	38.939	28.018	12.96	2.05	2.80			
06.06.2002	13:40:42.00	40.868	31.540	4.51	2.54	3.10			
06.06.2002	13:54:25.86	40.265	28.830	2.78	1.53	2.60	1.58		
06.06.2002	14:55:55.02	38.903	28.119	21.02	2.46	2.90		2.87	
06.06.2002	22:35:36.6	35.432	25.989	78.29	4.98	5.00			5.10
07.06.2002	13:43:16.55	40.454	27.992	4.74	2.01	2.70	1.99		
07.06.2002	19:19:17.87	39.145	28.212	12.11	3.87	3.40	3.92		
07.06.2002	20:48:02.00	40.751	29.164	5.00	1.78	2.80	1.69		
08.06.2002	16:10:53.05	41.862	27.374	8.90	2.09	2.80			
08.06.2002	20:40:08.37	38.792	31.433	14.63	2.98	3.10	2.37		
08.06.2002	21:07:14.46	38.505	31.828	4.62	3.41	2.90	2.49		
09.06.2002	00:21:18.33	40.305	27.229	10.50	1.30	2.50	1.16		
09.06.2002	15:03:38.01	40.728	32.907	5.00	4.22	4.00			
09.06.2002	16:21:32.11	39.987	29.103	9.39	1.90	2.70			
09.06.2002	19:22:14.11	39.638	27.770	5.45	2.49	2.90	2.39		
09.06.2002	23:51:24.45	40.705	30.521	15.67	2.32	3.00	2.44		
10.06.2002	09:27:34.01	40.397	28.830	7.19	1.58	2.60	1.72		
10.06.2002	15:46:48.98	41.144	28.880	5.00	1.60	2.80			
11.06.2002	09:25:24.57	39.518	29.548	15.18	2.27	2.80	2.43		
12.06.2002	09:10:46.96	40.171	28.440	5.00	1.76	2.70			
12.06.2002	10:46:03.77	40.558	28.055	5.88	1.43	2.60			
12.06.2002	11:00:27.73	39.559	29.531	5.00	2.31	2.70			
13.06.2002	00:31:02.64	40.096	28.160	8.62	2.01	2.90			
13.06.2002	06:44:49.46	39.068	27.989	4.72	2.96	3.20	3.02		
13.06.2002	23:23:12.28	38.537	30.891	5.00	3.26	3.20			
14.06.2002	12:19:52.63	41.357	28.339	4.50	1.85	2.70	2.29		
14.06.2002	12:28:30.92	40.713	27.264	7.60	2.68	2.80	2.66		
15.06.2002	09:08:36.88	41.070	28.861	2.66	1.71	2.50			
17.06.2002	04:43:49.70	36.300	22.200	10.00	4.13	3.20			4.10

17.06.2002	14:02:36.54	41.100	29.328	5.66	2.75	2.00			
17.06.2002	14:48:02.25	40.304	27.865	3.32	2.57	2.80	2.53		
17.06.2002	22:47:31.06	40.936	30.427	8.88	2.34	2.90	2.58		
18.06.2002	17:17:01.13	40.284	29.113	6.53	1.54	2.50	2.01		
18.06.2002	21:36:57.75	39.016	26.834	5.00	2.93	3.10			
18.06.2002	22:38:04.31	39.842	27.654	27.62	2.53	3.10	2.59		
19.06.2002	04:26:25.89	39.899	27.757	9.27	1.82	2.80			
19.06.2002	09:02:28.92	39.556	29.499	4.61	2.25	3.00	2.58		
19.06.2002	17:11:21.37	40.238	29.129	6.05	1.75	2.40			
19.06.2002	19:41:58.58	39.051	29.615	5.60	2.13	2.70			
20.06.2002	02:05:23.16	40.730	27.490	12.33	1.58	2.60			
20.06.2002	02:27:35.85	38.790	26.784	19.54	2.95	3.10			
20.06.2002	11:03:29.58	40.161	28.790	12.65	1.51	2.50			
20.06.2002	12:25:26.60	41.024	29.732	13.09	2.57	2.60			
20.06.2002	12:53:08.33	38.717	30.910	9.61	3.84	3.90	3.74		
20.06.2002	14:36:30.01	41.978	26.683	6.62	2.60	3.00			
20.06.2002	23:51:24.45	40.704	30.521	5.00	1.90	3.00	1.49		
21.06.2002	05:14:14.04	40.904	31.113	8.70	3.38	3.40	3.67		
21.06.2002	08:09:49.45	40.250	29.247	10.37	2.06	2.70	2.39		
21.06.2002	10:42:04.72	40.261	29.081	5.74	1.50	2.50	1.75		
21.06.2002	12:27:31.60	39.952	29.173	5.44	2.66	2.80	2.78		
23.06.2002	11:00:31.09	40.084	29.319	9.87	2.34	2.90	2.55		
23.06.2002	23:09:27.18	40.770	29.110	10.70	2.53	3.00	2.75		
23.06.2002	23:19:18.95	40.750	29.115	5.42	1.94	2.40	2.21		
25.06.2002	15:18:27.83	40.483	29.226	4.19	2.33	2.80	2.29		
26.06.2002	21:31:18.78	38.598	31.333	5.16	4.43	3.70			
27.06.2002	11:08:10.42	38.497	31.112	5.00	3.87	3.50	3.45		
27.06.2002	20:55:22.83	40.739	27.435	17.09	2.15	2.70	2.12		
28.06.2002	00:37:33.14	40.773	27.205	19.40	2.08	2.80			
28.06.2002	01:11:14.56	40.752	27.403	5.06	2.43	2.90	2.12		
28.06.2002	10:47:55.10	38.661	31.267	5.27	4.46	4.50	4.47		
28.06.2002	11:04:46.20	38.666	31.356	5.00	3.39	3.30			
28.06.2002	11:29:10.10	38.486	31.091	5.70	3.50	3.20			
28.06.2002	14:26:45.90	38.652	31.239	3.10	3.75	3.70	3.08		
28.06.2002	16:02:12.11	38.665	31.281	5.00	4.03	3.70	4.21		
28.06.2002	19:27:17.91	40.798	28.140	8.44	2.04	2.80	2.30		
29.06.2002	11:30:47.83	39.797	26.293	13.83	1.93	2.90			
29.06.2002	16:39:16.92	38.889	26.548	9.30	3.64	3.40			
30.06.2002	00:09:50.03	39.547	29.105	16.10	2.20	2.70	2.01		
30.06.2002	12:10:47.56	40.932	30.522	2.13	2.28	2.70			
30.06.2002	13:27:27.29	40.950	29.806	31.73	2.57	2.60	2.33		
30.06.2002	23:13:35.35	40.826	27.496	5.45	2.49	2.70	2.59		
01.07.2002	10:33:33.82	39.683	25.890	7.75	2.71	2.80			
01.07.2002	21:56:53.39	40.826	28.534	5.70	2.04	2.70	2.23		
01.07.2002	23:29:05.13	40.791	28.478	5.00	1.57	2.60	2.17		
02.07.2002	04:24:57.56	40.114	27.068	20.45	2.18	2.90			
02.07.2002	11:07:38.53	40.164	29.183	12.67	2.35	2.60	2.78		
03.07.2002	09:25:51.61	40.686	29.131	4.84	1.83	2.80	2.00		

03.07.2002	10:08:16.67	40.598	28.927	16.51	3.00	3.20	2.93		
03.07.2002	10:12:13.77	40.603	28.926	7.90	2.44	2.80	2.93		
04.07.2002	02:14:05.60	40.718	27.549	5.22	2.76	2.90	2.80		
04.07.2002	02:31:33.00	37.266	29.977	4.51	4.13	3.60			
04.07.2002	16:43:53.80	37.968	28.694	4.25	3.33	3.30			
04.07.2002	22:42:45.44	37.947	28.731	5.00	3.51	3.50	3.42		
05.07.2002	23:13:35.00	40.826	27.495	5.50	2.55	2.70			
23.07.2002	03:27:18.62	40.827	27.732	7.01	3.17	3.00			
23.07.2002	04:17:44.44	40.832	27.715	6.00	3.01	2.90			
30.07.2002	12:20:23.61	37.723	29.198	7.94	4.71	4.50			4.40

Table 3. Event List

Latitude	Longitude	M_D	Depth(Km)	DD.MM.YY	Hour:min:sec	Location
40.839	27.858	4.8	14.13	23.03.2002	02:36:11.04	Marmara Sea

Table 4. Contents of ‘event.dat’ input file.

JULIAN DAY	TIME	STATION	MAX AMP1	MAX AMP2	DISTANCE	M_L	M_D	LATITUDE	LONGITUDE
82	02:36:11	BALB.BHE	18.50	18.74	133	4.38	4.80	40.84	27.86
82	02:36:11	BALB.BHN	23.40	25.03	133	4.50	4.80	40.84	27.86
82	02:36:11	BALB.BHZ	13.36	16.24	133	4.31	4.80	40.84	27.86
82	02:36:11	CTTX.BHE	50.39	52.40	70	4.38	4.80	40.84	27.86
82	02:36:11	CTTX.BHN	38.25	42.08	70	4.29	4.80	40.84	27.86
82	02:36:11	CTTX.BHZ	29.23	26.84	70	4.09	4.80	40.84	27.86
82	02:36:11	ISKB.BHE	29.89	26.69	104	4.33	4.80	40.84	27.86
82	02:36:11	ISKB.BHN	36.07	34.80	104	4.45	4.80	40.84	27.86
82	02:36:11	ISKB.BHZ	17.40	14.49	104	4.07	4.80	40.84	27.86
82	02:36:11	MFTX.BHE	77.22	83.01	49	4.42	4.80	40.84	27.86
82	02:36:11	MFTX.BHN	91.95	102.29	49	4.51	4.80	40.84	27.86
82	02:36:11	MFTX.BHZ	37.34	41.61	49	4.12	4.80	40.84	27.86
82	02:36:11	YLVX.BHE	20.95	21.60	132	4.43	4.80	40.84	27.86
82	02:36:11	YLVX.BHN	18.91	21.09	132	4.42	4.80	40.84	27.86
82	02:36:11	YLVX.BHZ	9.68	10.21	132	4.10	4.80	40.84	27.86

Table 5. Output File, Max Amp 1 = Maximum trace amplitude, zero-to-peak (in ‘+’ field), Max Amp 2 = zero-to-peak (in ‘-‘ field).

	magnitude range	mean of error	error variance
ISKB	**1.0-6.0**	**0.0523**	**0.0295**
	1.0-2.0	0.0367	0.0267
	2.0-3.0	0.0044	0.0234
	3.0-4.0	0.0245	0.0318
	4.0-5.0	0.1629	0.0294
	5.0-6.0	0.2050	0.0420
BALB	**1.0-6.0**	**0.1611**	**0.0298**
	1.0-2.0	-0.0900	0.0225
	2.0-3.0	0.2438	0.0285
	3.0-4.0	0.1864	0.0118
	4.0-5.0	0.072	0.0257
CTTX	**1.0-6.0**	**-0.0427**	**0.0326**
	1.0-2.0	0.0782	0.0148
	2.0-3.0	-0.0172	0.0274
	3.0-4.0	-0.1043	0.0504
	4.0-5.0	-0.3429	0.0712
	5.0-6.0	-0.6100	0.0441
YLVX	**1.0-6.0**	**-0.0363**	**0.0260**
	1.0-2.0	0.0697	0.0213
	2.0-3.0	-0.0306	0.0232
	3.0-4.0	-0.1090	0.0166
	4.0-5.0	-0.2232	0.0514
	5.0-6.0	-0.1650	0.0012
MRMX	**1.0-6.0**	**-0.0402**	**0.0258**
	1.0-2.0	0.0548	0.0307
	2.0-3.0	-0.0583	0.0193
	3.0-4.0	-0.0489	0.0190
	4.0-5.0	-0.0642	0.0101
	5.0-6.0	-0.3300	0.0225
MFTX	**1.0-6.0**	**-0.1051**	**0.0312**
	1.0-2.0	0.0763	0.0221
	2.0-3.0	-0.0812	0.0142
	3.0-4.0	-0.1367	0.0195
	4.0-5.0	-0.2167	0.0176
	5.0-6.0	-0.1900	0.0021
EDRB	**1.0-6.0**	**0.3538**	**0.0380**
	1.0-2.0	0.3950	0.0462
	2.0-3.0	0.3033	0.0220
	3.0-4.0	0.3567	0.0511

Table 6. Station Corrections (Mean of Error) and Error Variances

APPENDIX B

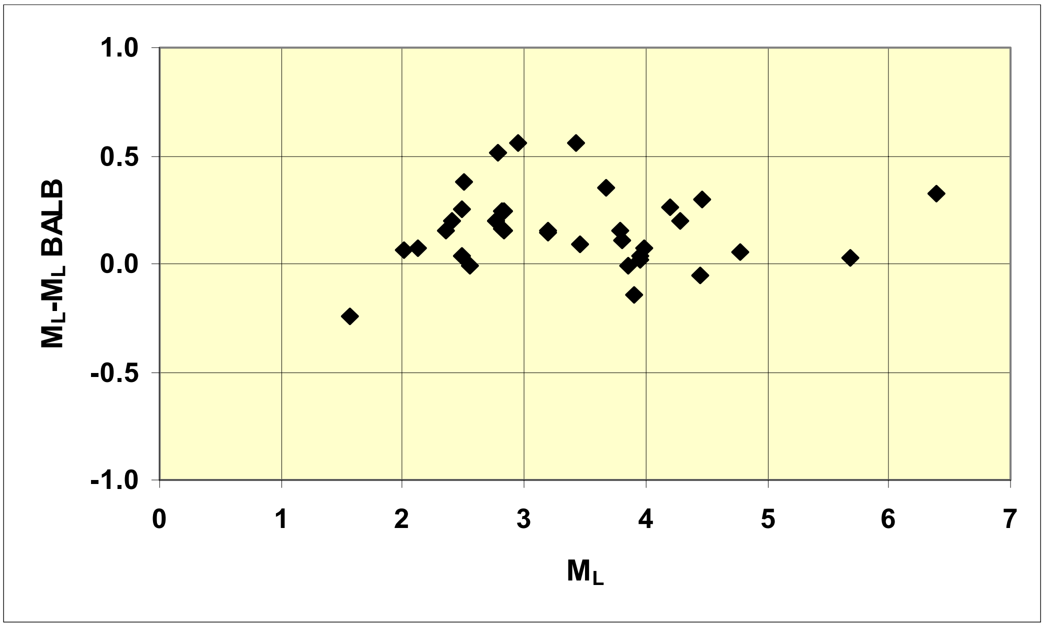

Figure 8.1. Deviation at BALB according to magnitude error

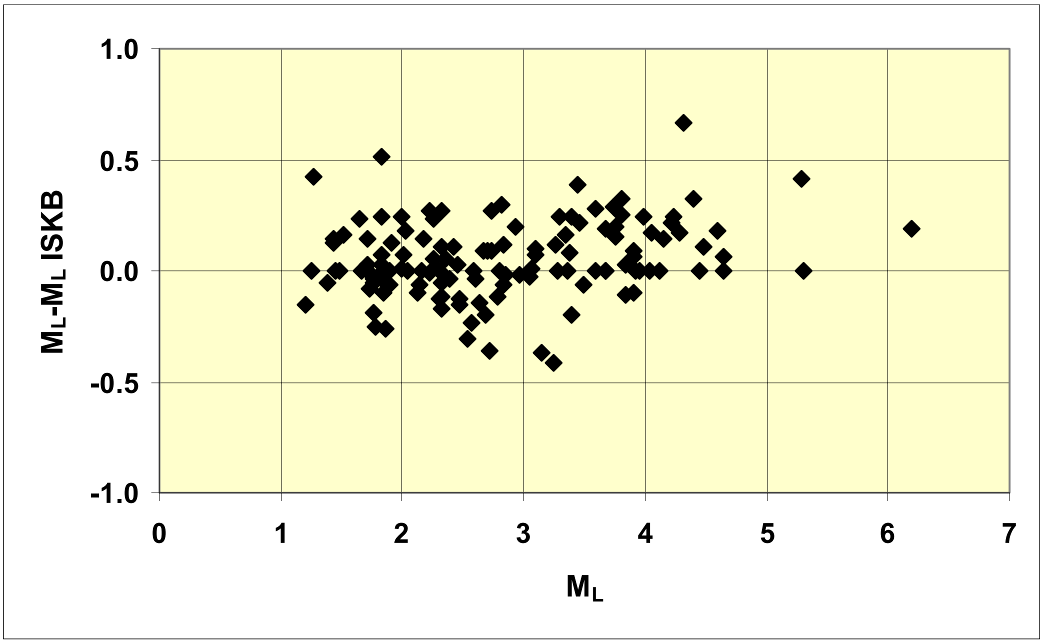

Figure 8.2. Deviation at ISKB according to magnitude error

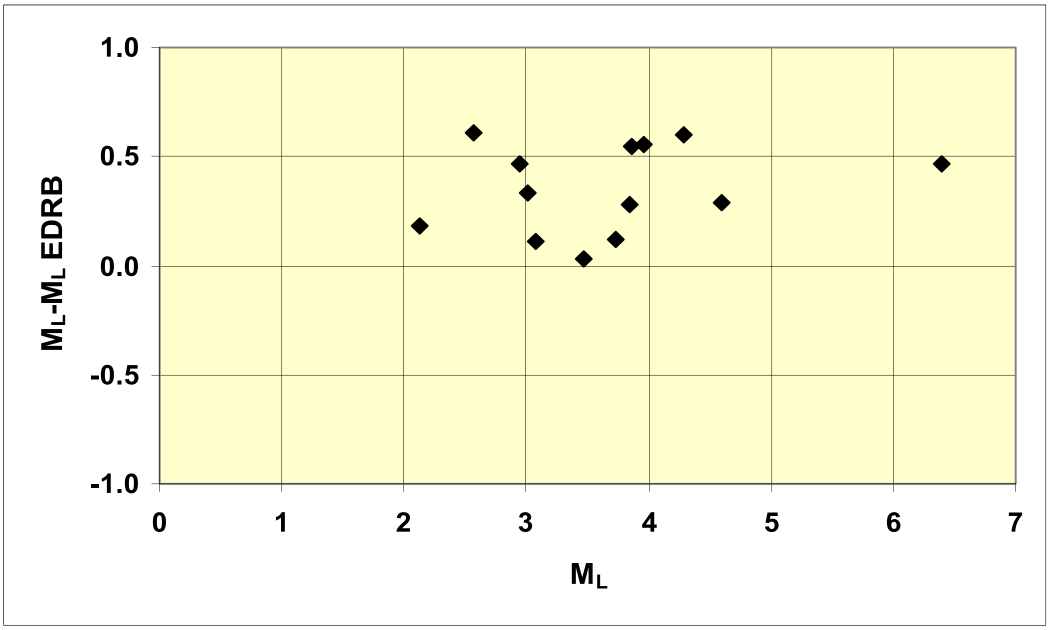

Figure 8.3. Deviation at EDRB according to magnitude error

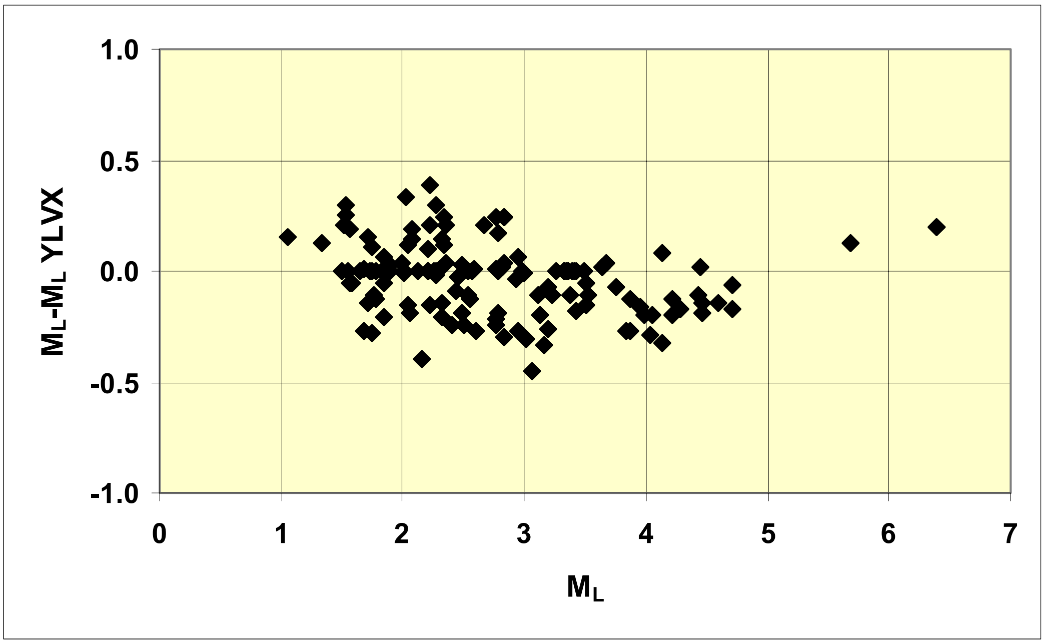

Figure 8.4. Deviation at YLVX according to magnitude error

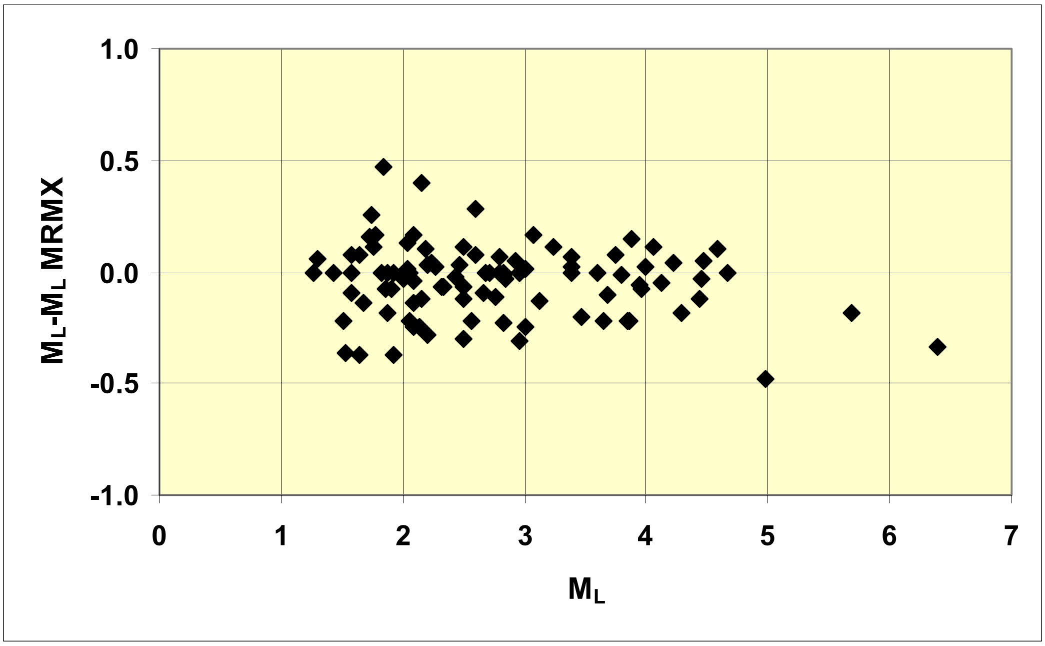

Figure 8.5. Deviation at MRMX according to magnitude error

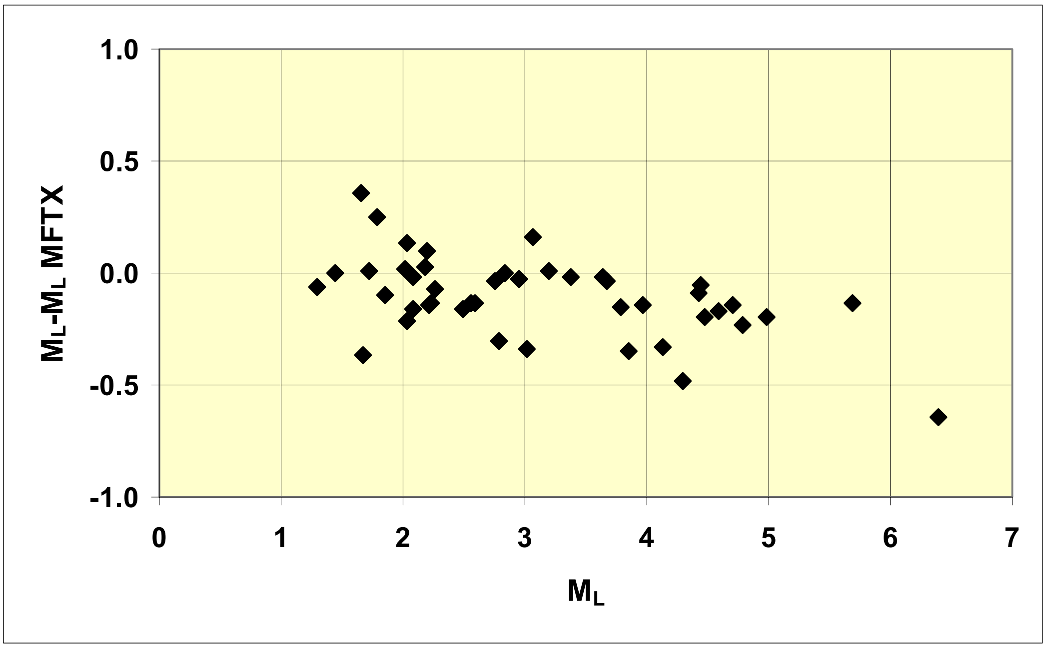

Figure 8.6. Deviation at MFTX according to magnitude error

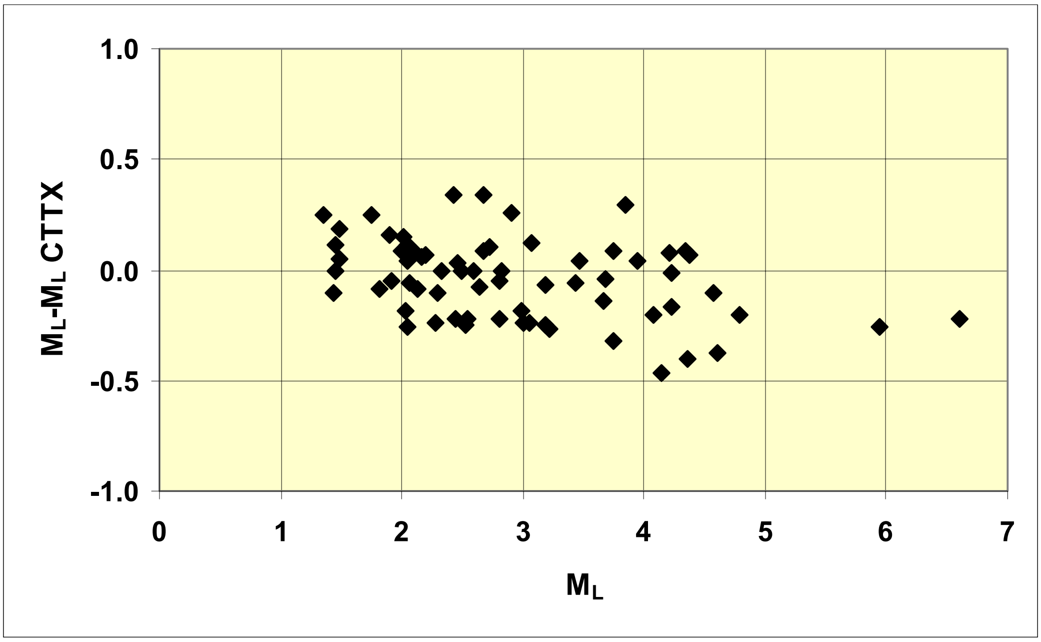

Figure 8.7. Deviation at CTTX according to magnitude error

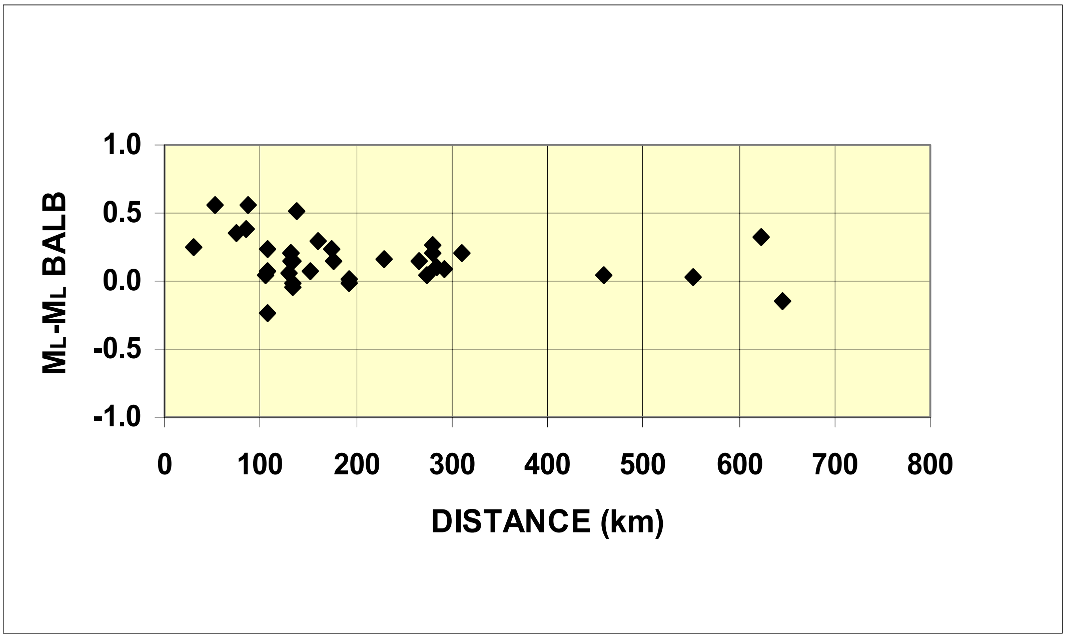

Figure 9.1. The scatter of the Ē (error) at BALB is plotted against distance.

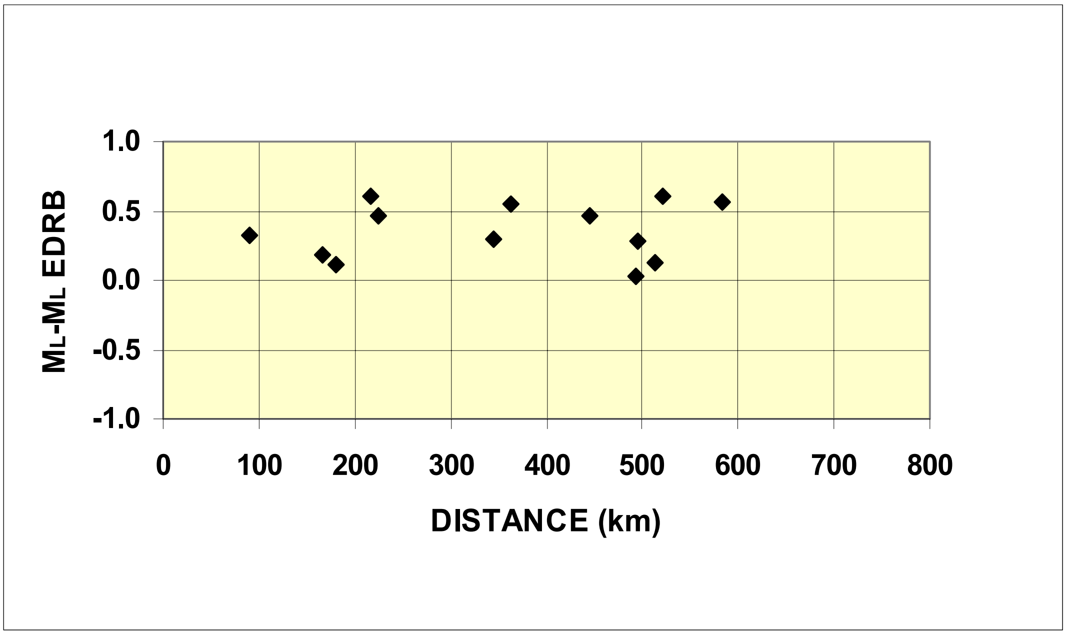

Figure 9.2. The scatter of the Ē (error) at EDRB is plotted against distance.

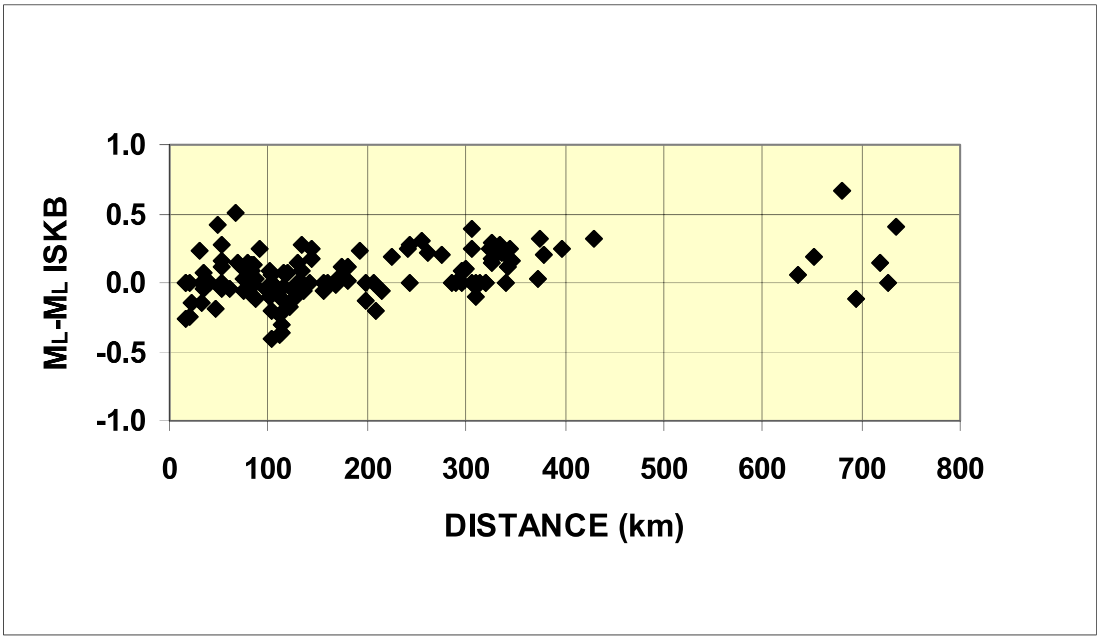

Figure 9.3. The scatter of the Ē (error) at ISKB is plotted against distance.

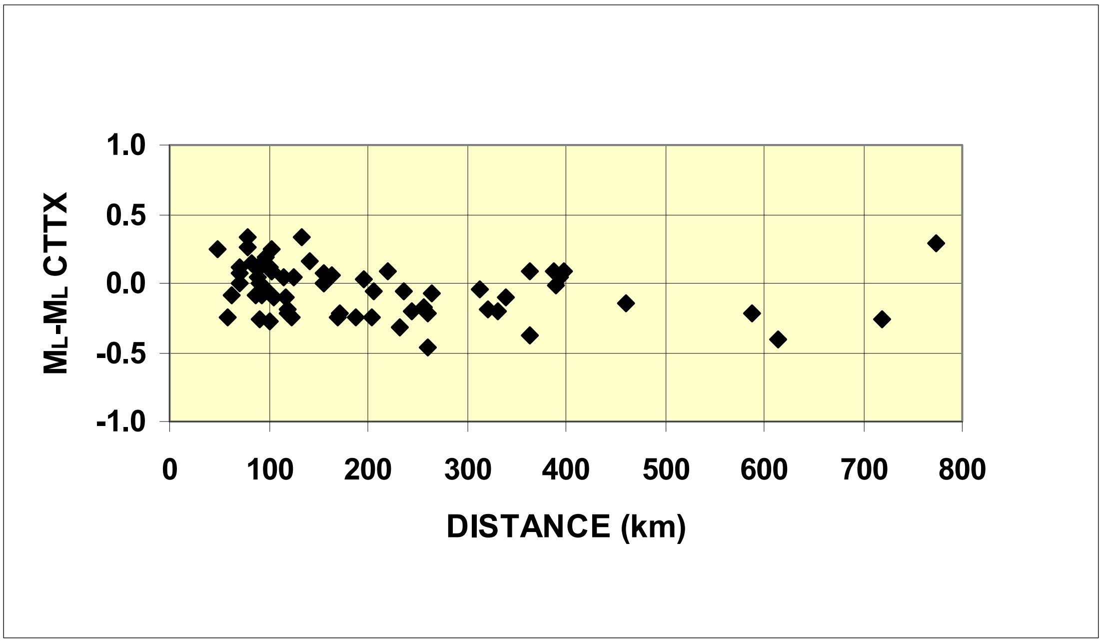

Figure 9.4. The scatter of the Ē (error) at CTTX is plotted against distance.

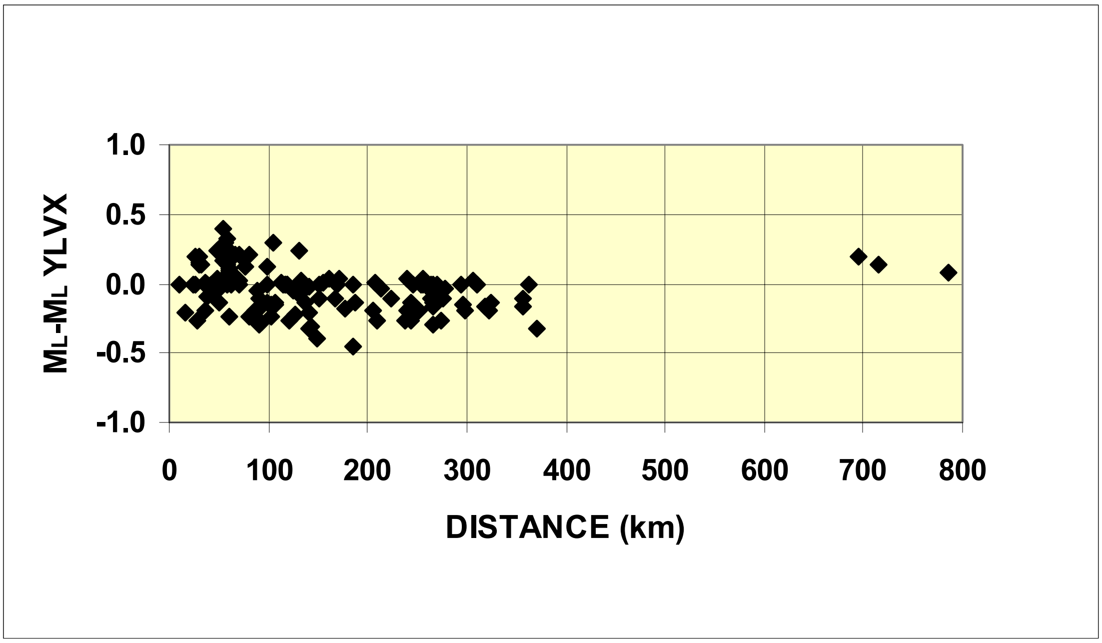

Figure 9.5. The scatter of the Ē (error) at YLVX is plotted against distance.

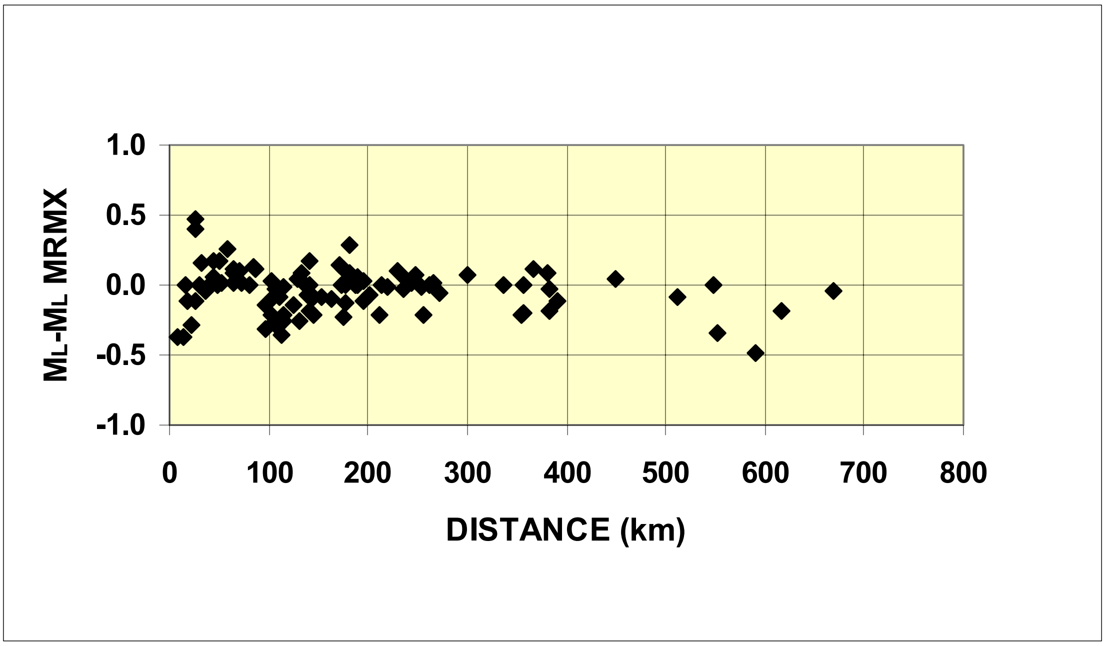

Figure 9.6. The scatter of the Ē (error) at MRMX is plotted against distance.

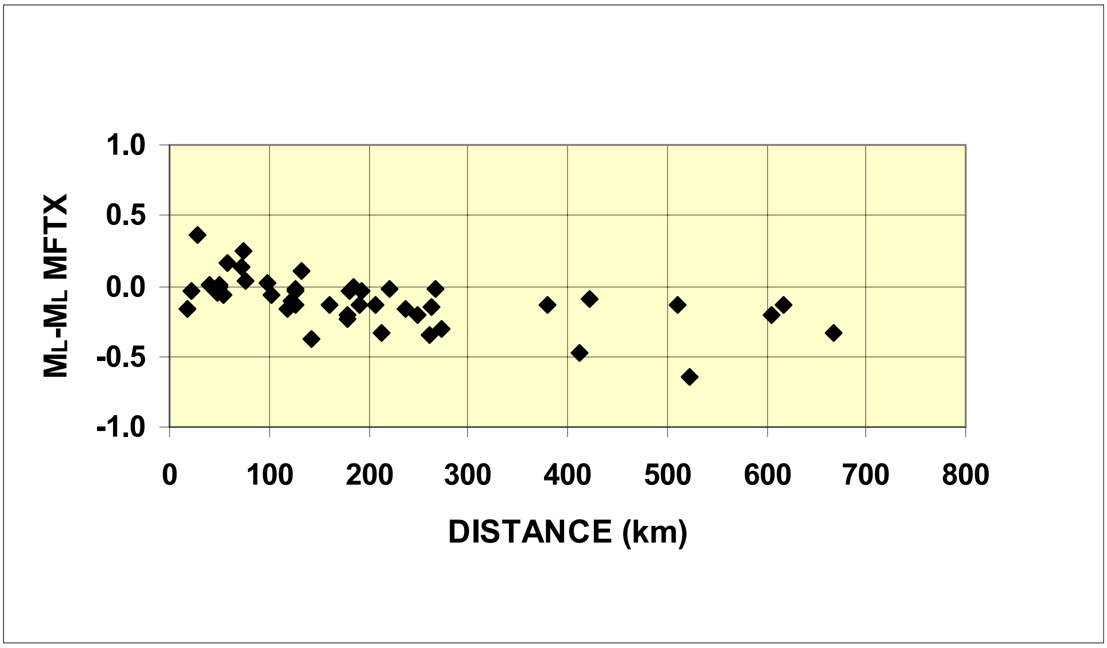

Figure 9.7. The scatter of the Ē (error) at MFTX is plotted against distance.

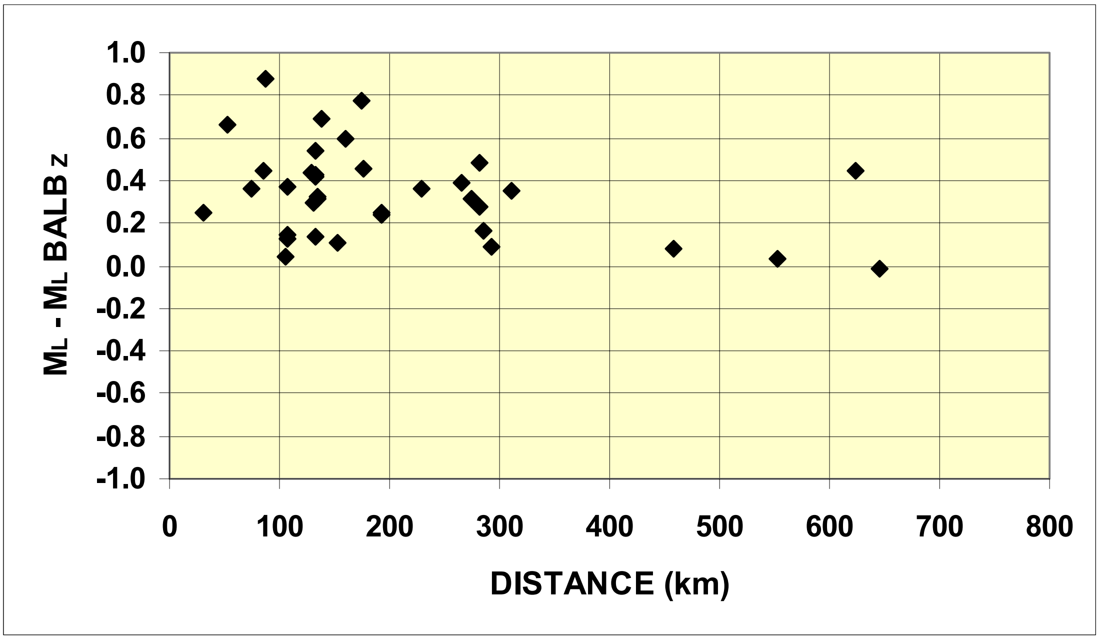

Figure 10.1. The scatter of the Ē (error) at vertical component of BALB is plotted against distance.

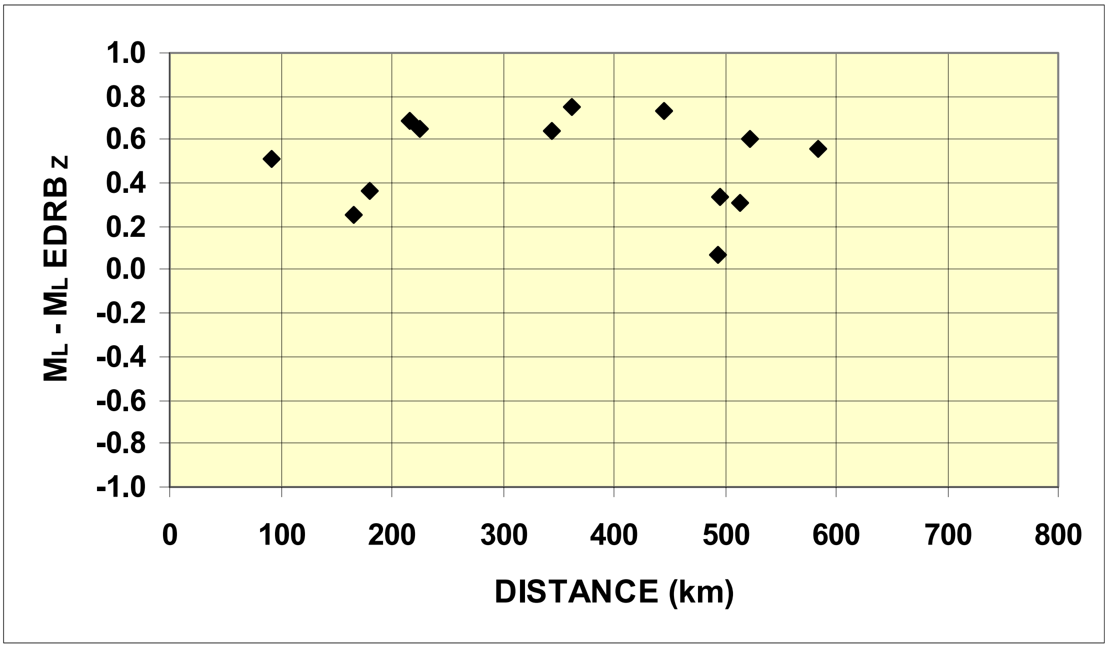

Figure 10.2. The scatter of the Ē (error) at vertical component of EDRB is plotted against distance.

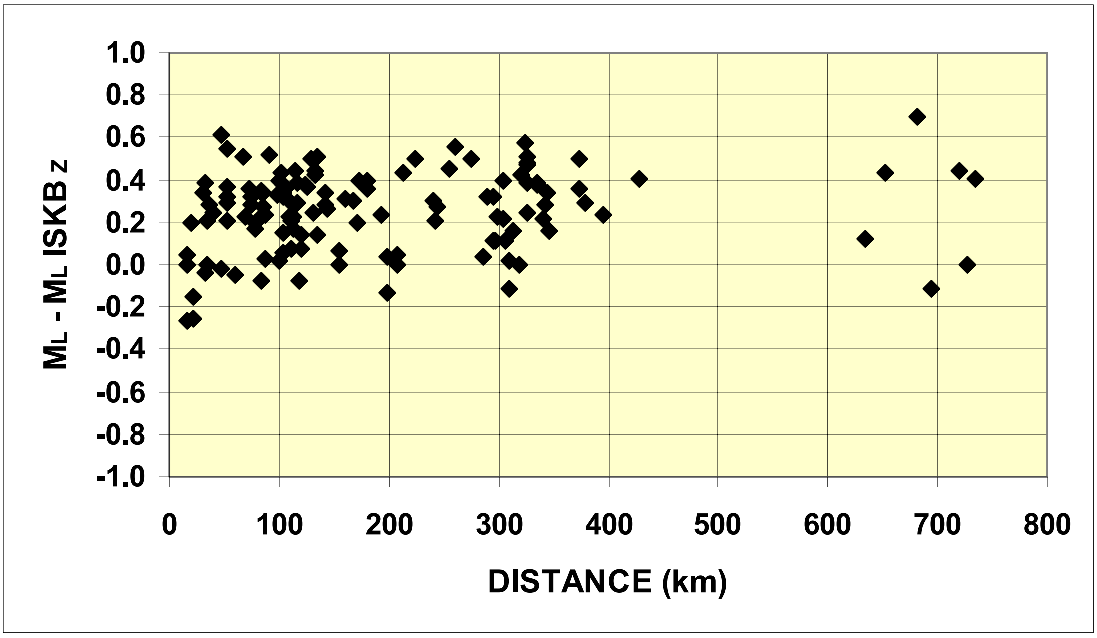

Figure 10.3. The scatter of the Ē (error) at vertical component of ISKB is plotted against distance.

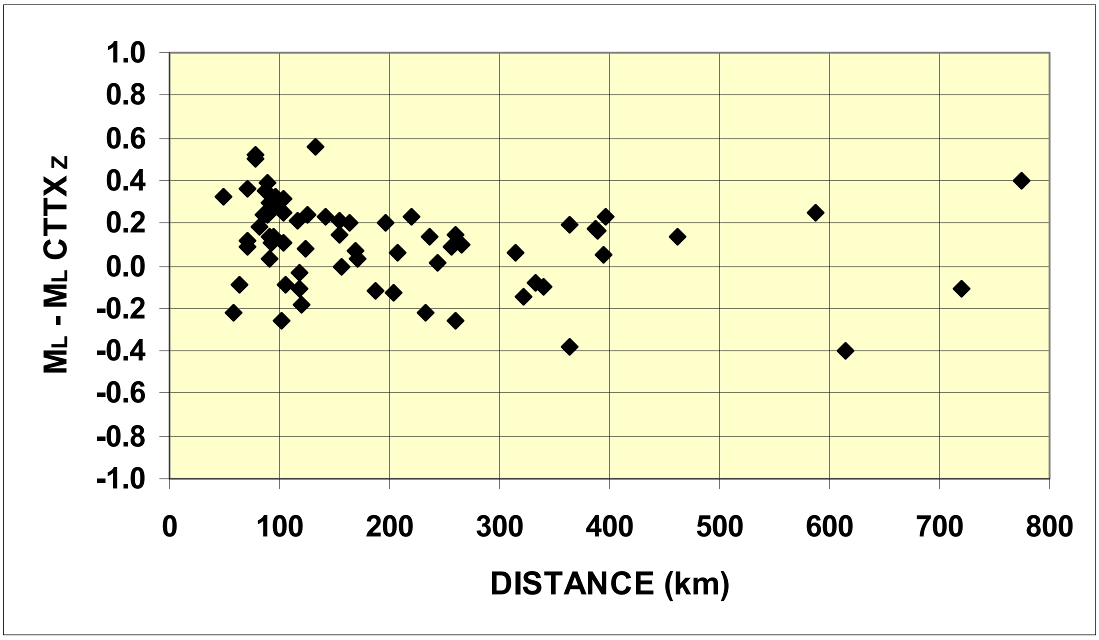

Figure 10.4. The scatter of the Ē (error) at vertical component of ISKB is plotted against distance.

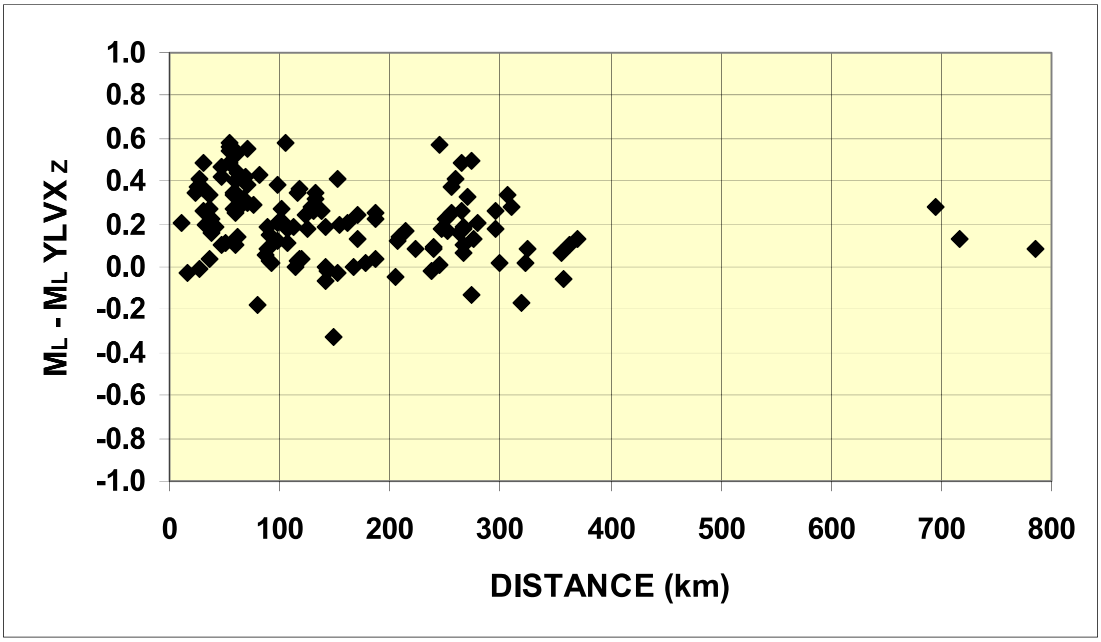

Figure 10.5. The scatter of the Ē (error) at vertical component of YLVX is plotted against distance.

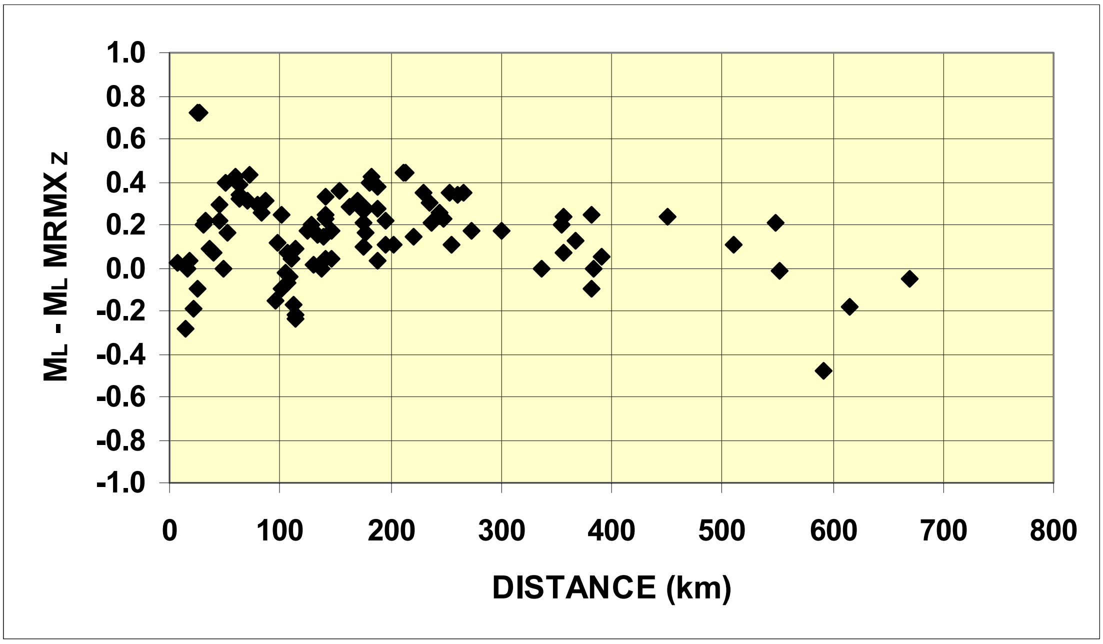

Figure 10.6. The scatter of the Ē (error) at vertical component of MRMX is plotted against distance.

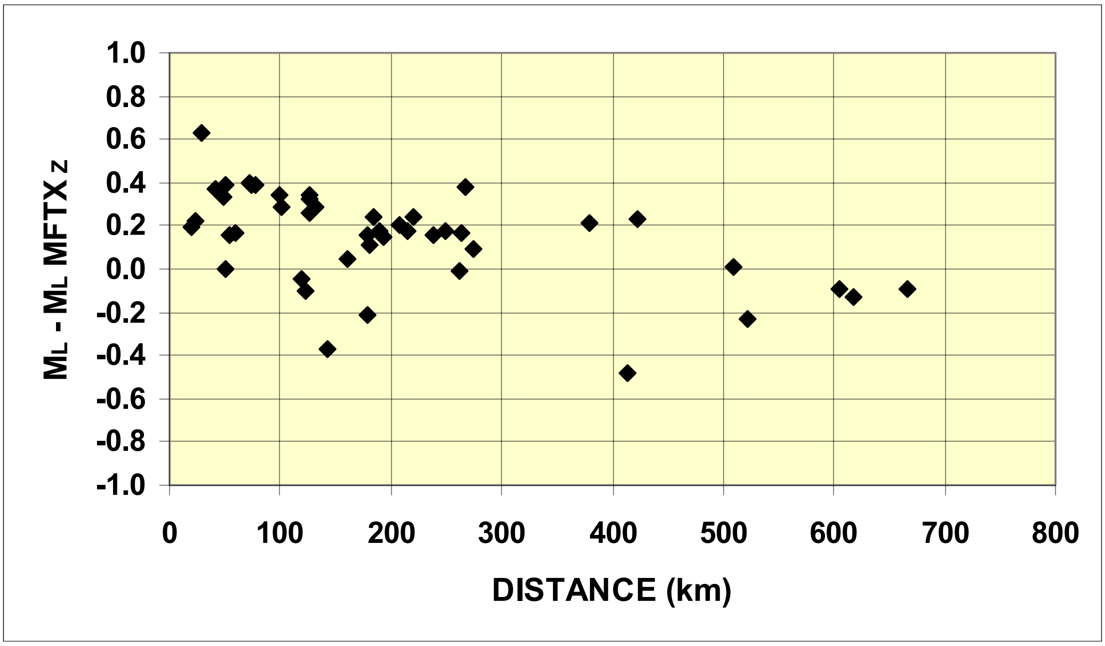

Figure 10.7. The scatter of the Ē (error) at vertical component of MFTX is plotted against distance.

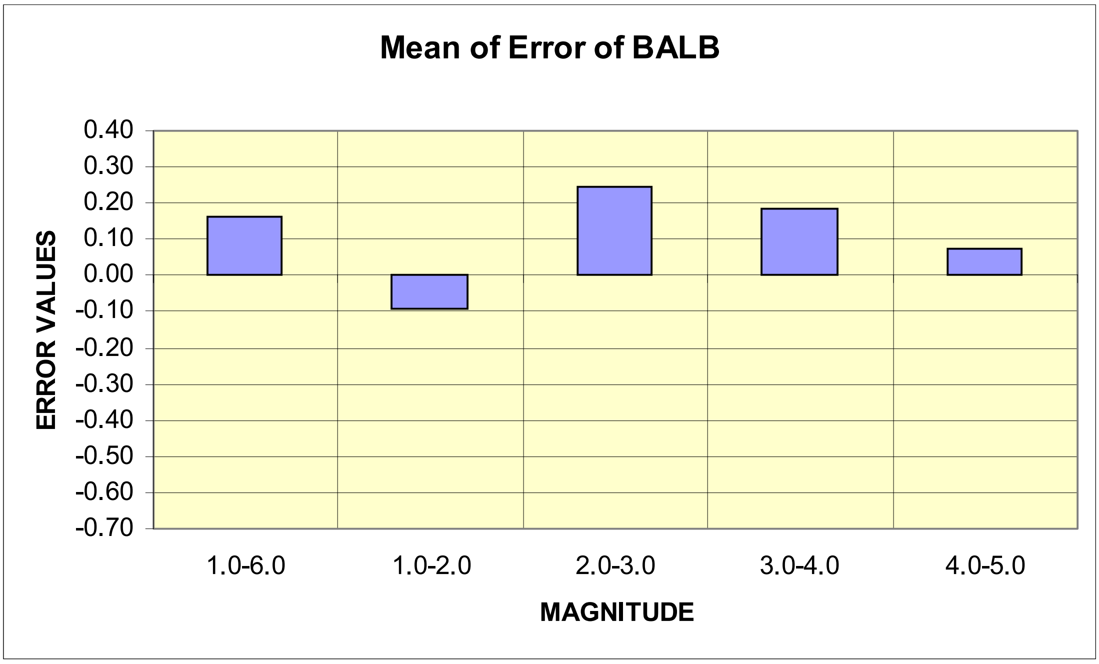

Figure 11.1. Mean of Error of BALB

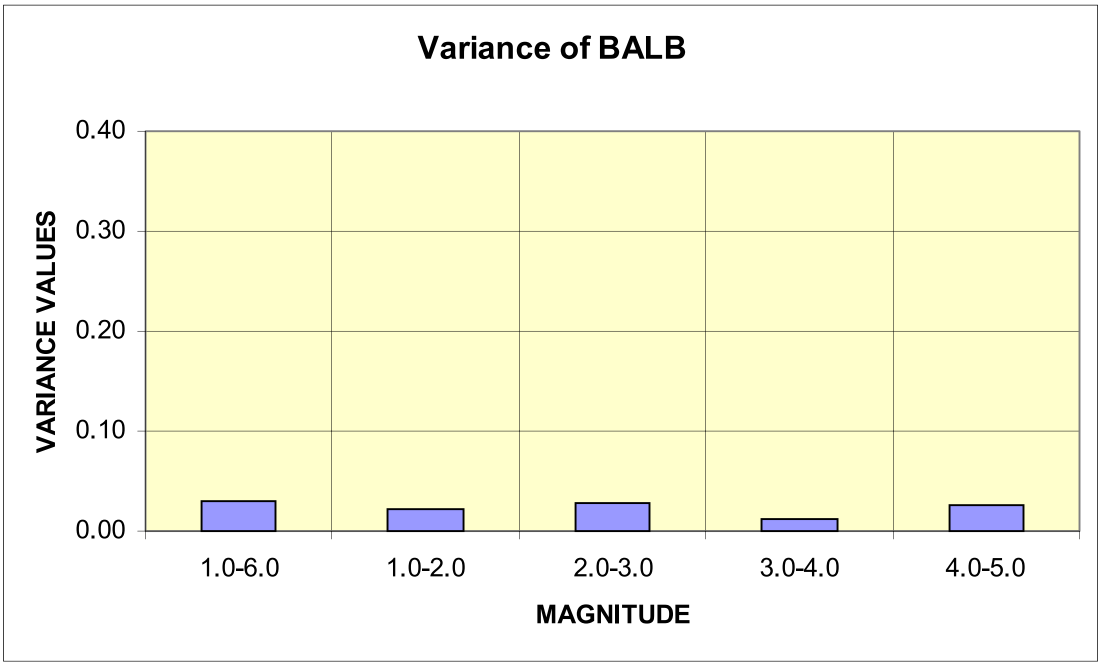

Figure 11.2. Variance of BALB

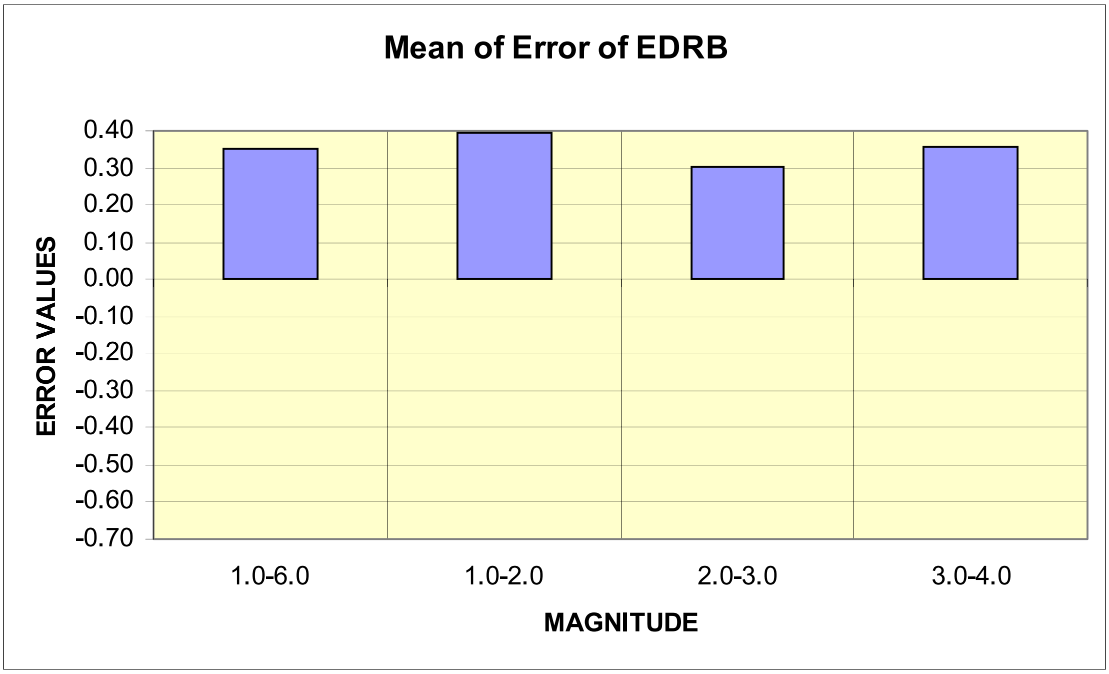

Figure 11.3. Mean of Error of EDRB

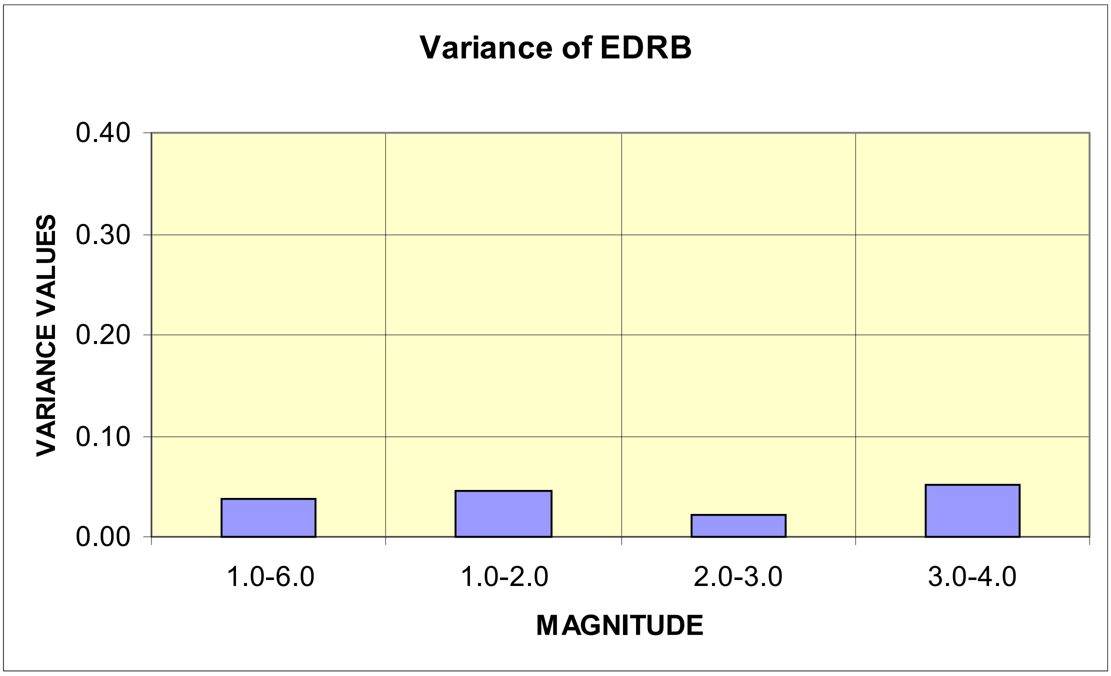

Figure 11.4. Variance of EDRB

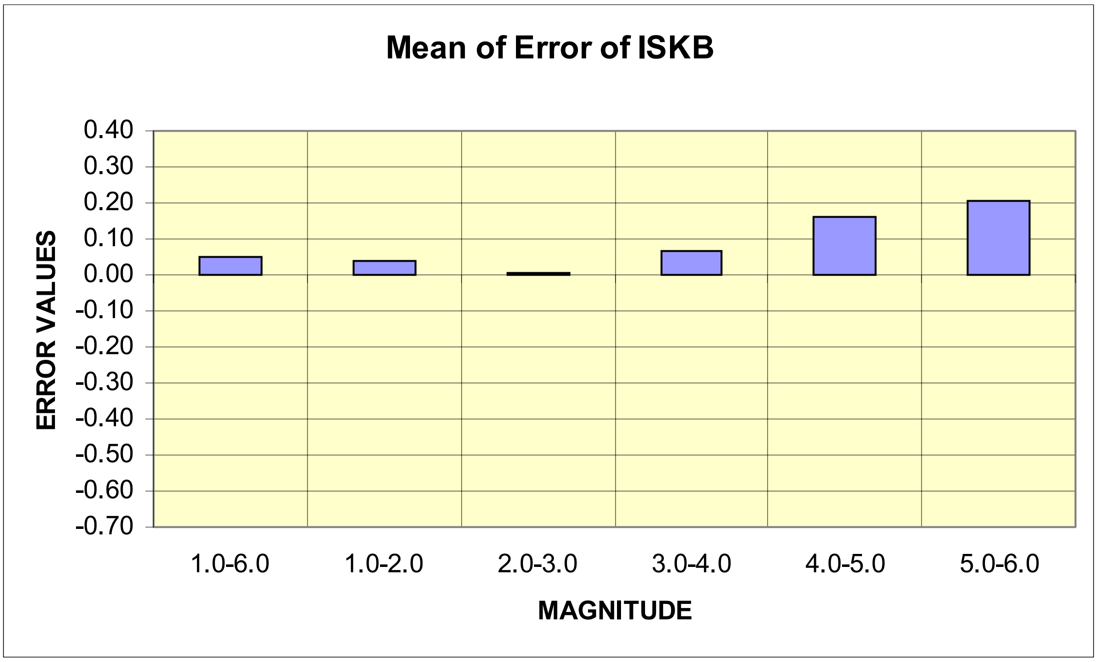

Figure 11.5. Mean of Error of ISKB

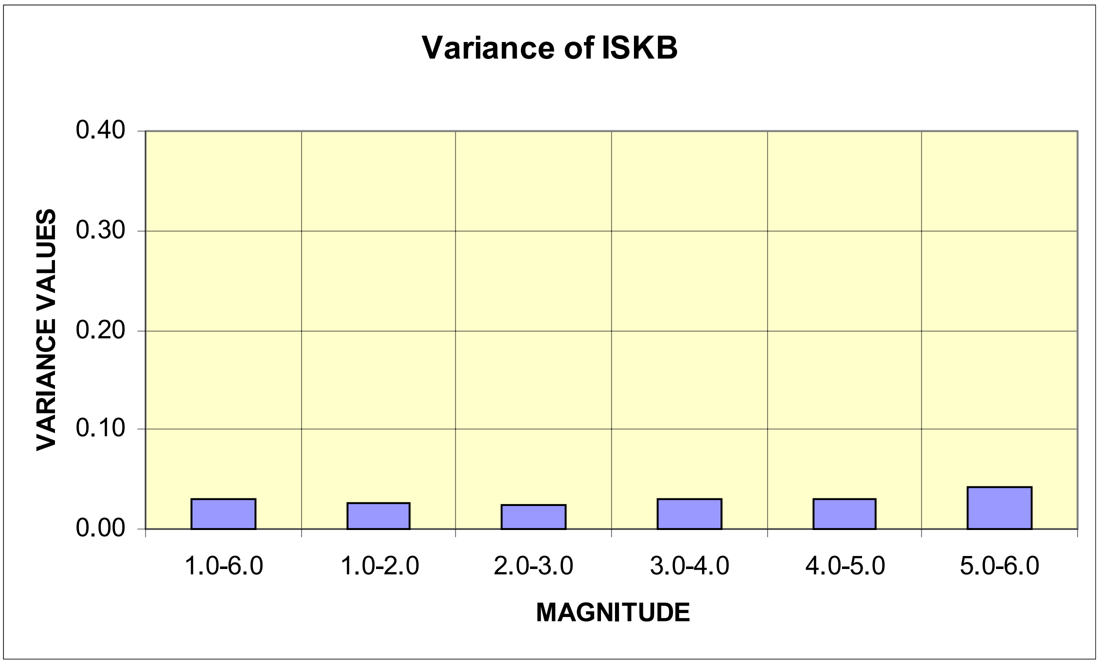

Figure 11.6. Variance of ISKB

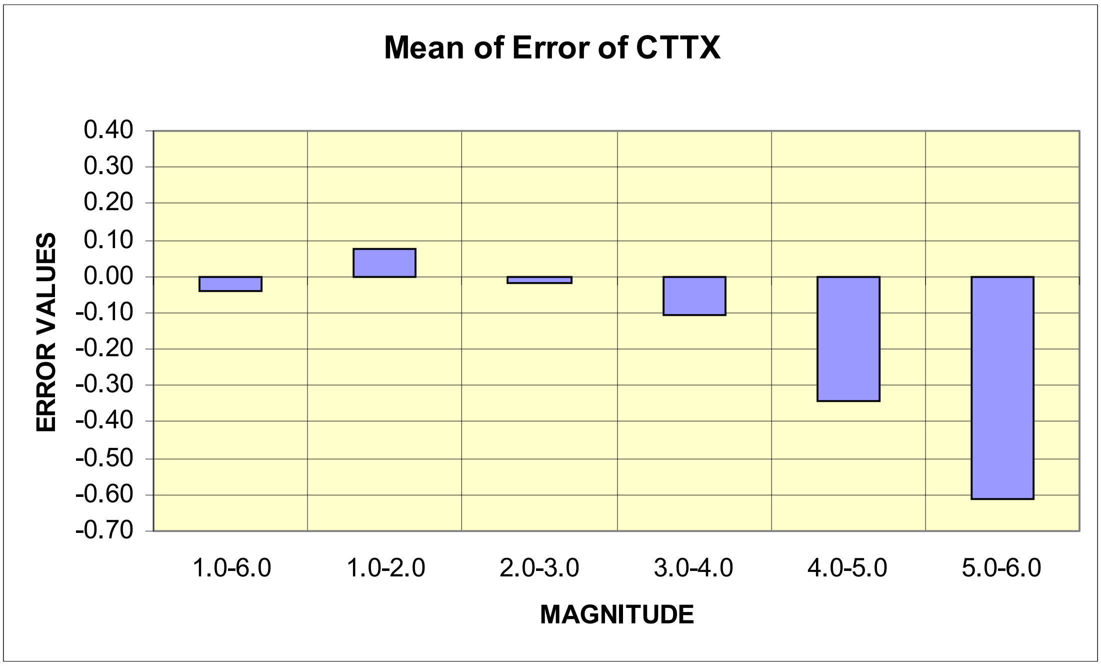

Figure 11.7. Mean of Error of CTTX

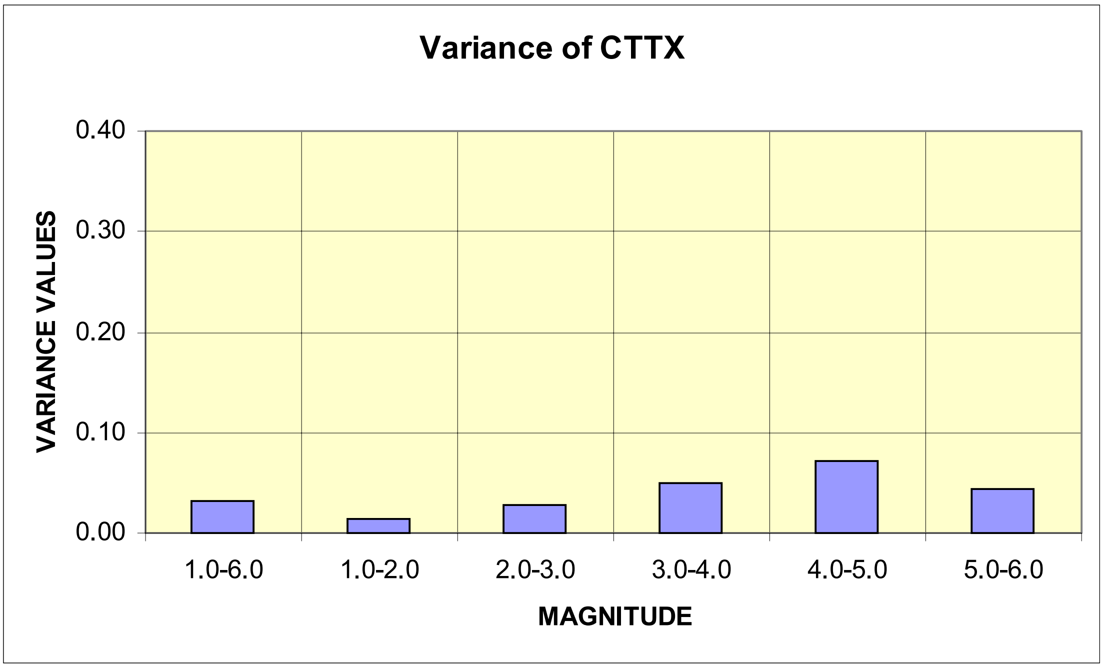

Figure 11.8. Variance of CTTX

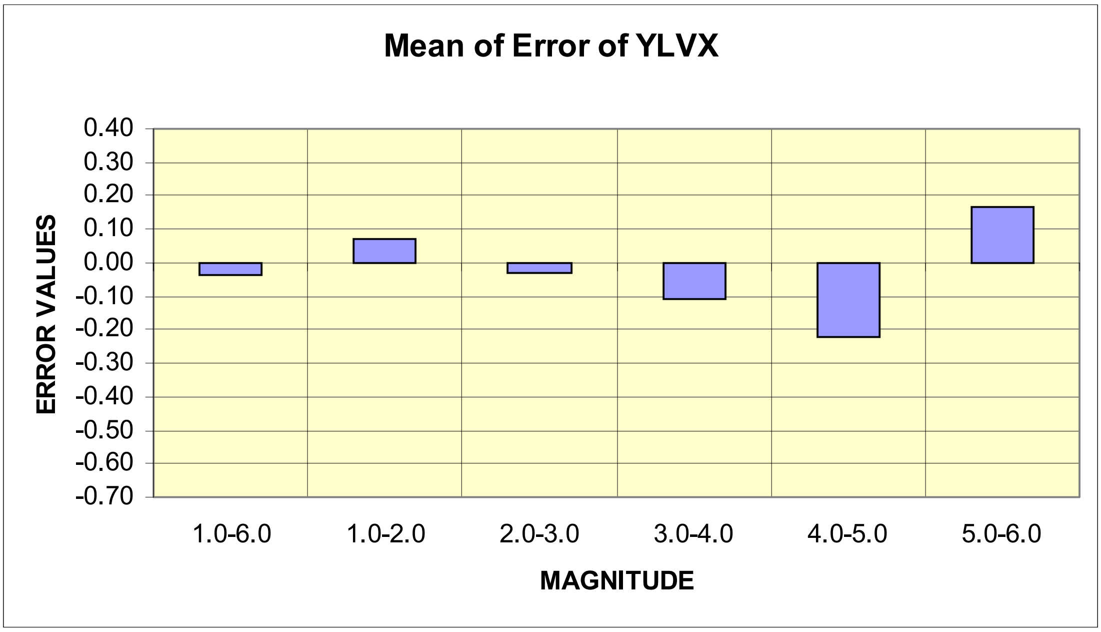

Figure 11.9. Mean of Error of YLVX

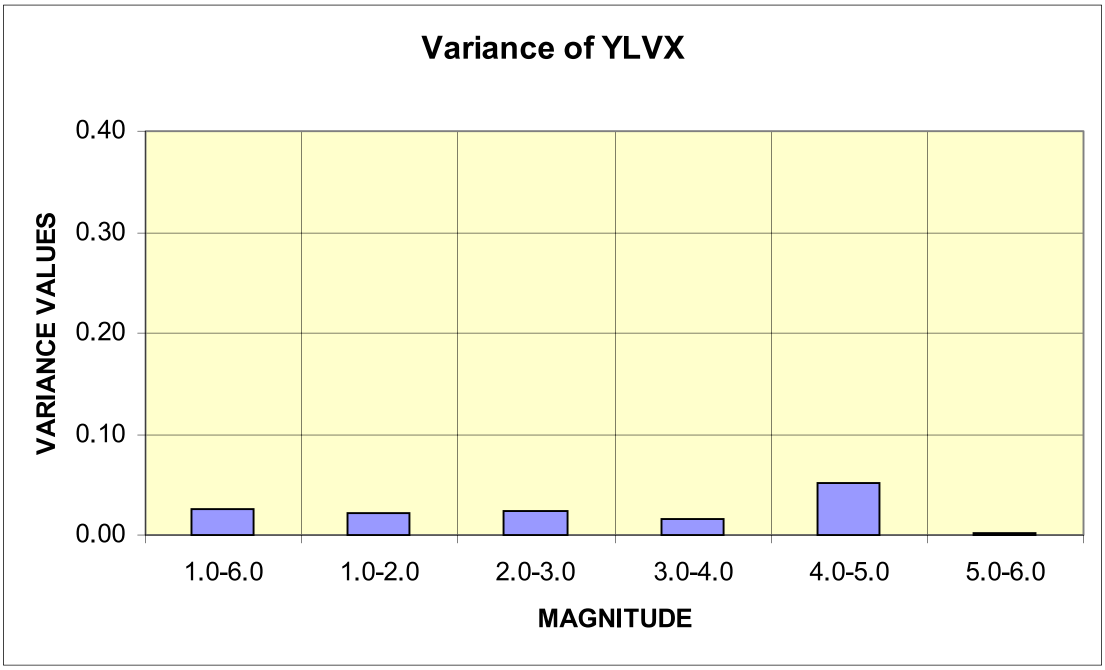

Figure 11.10. Variance of YLVX

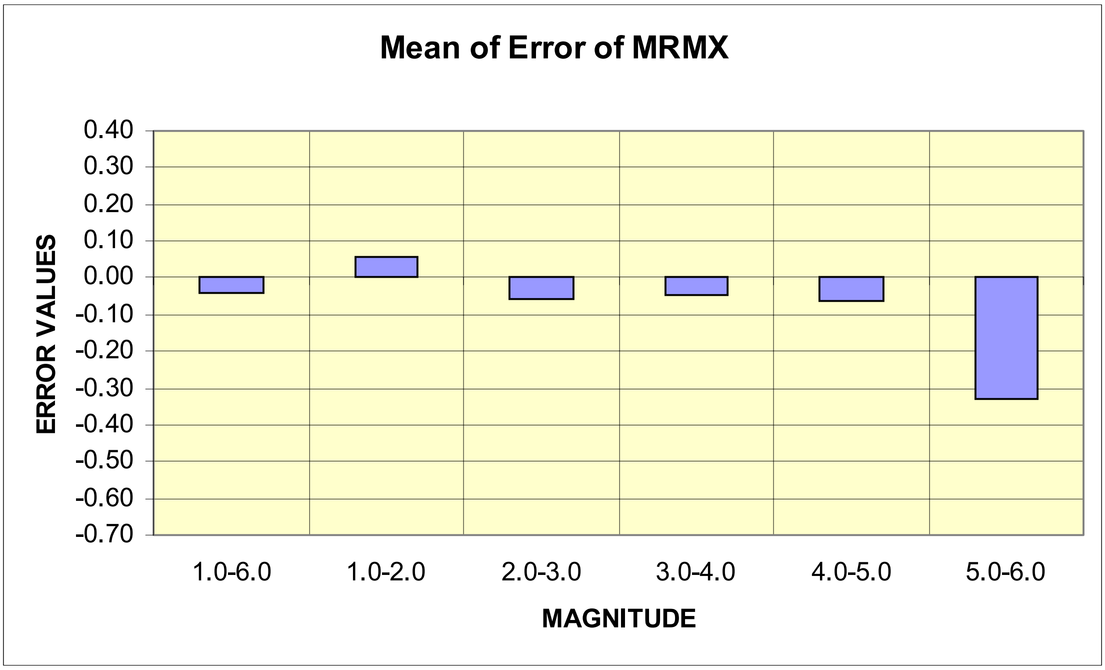

Figure 11.11. Mean of Error of MRMX

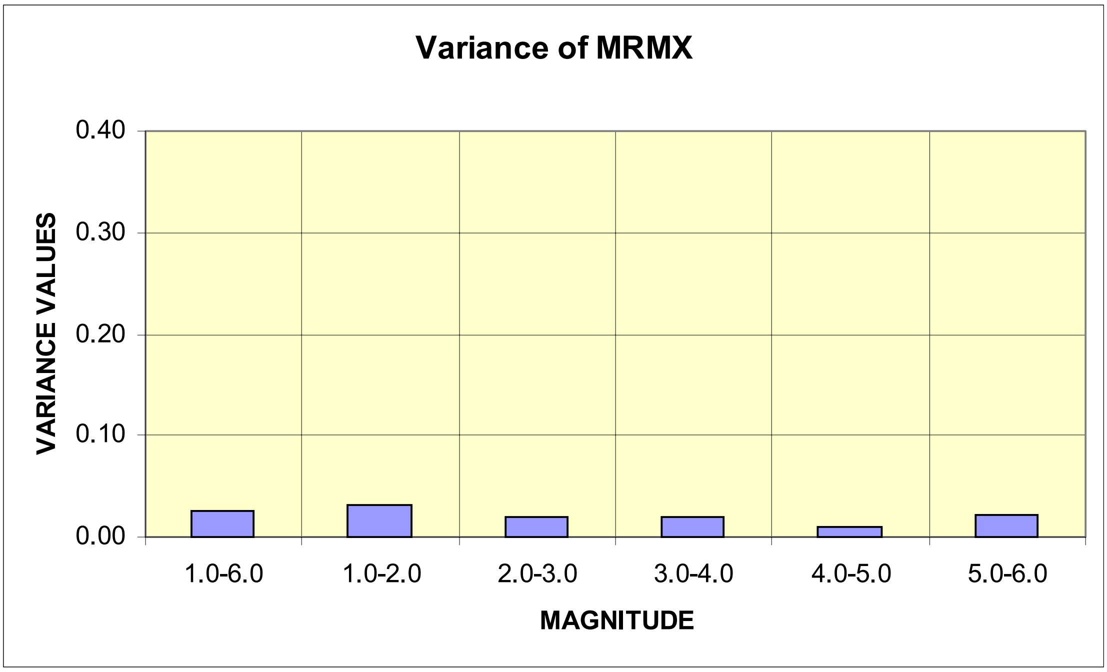

Figure 11.12. Variance of MRMX

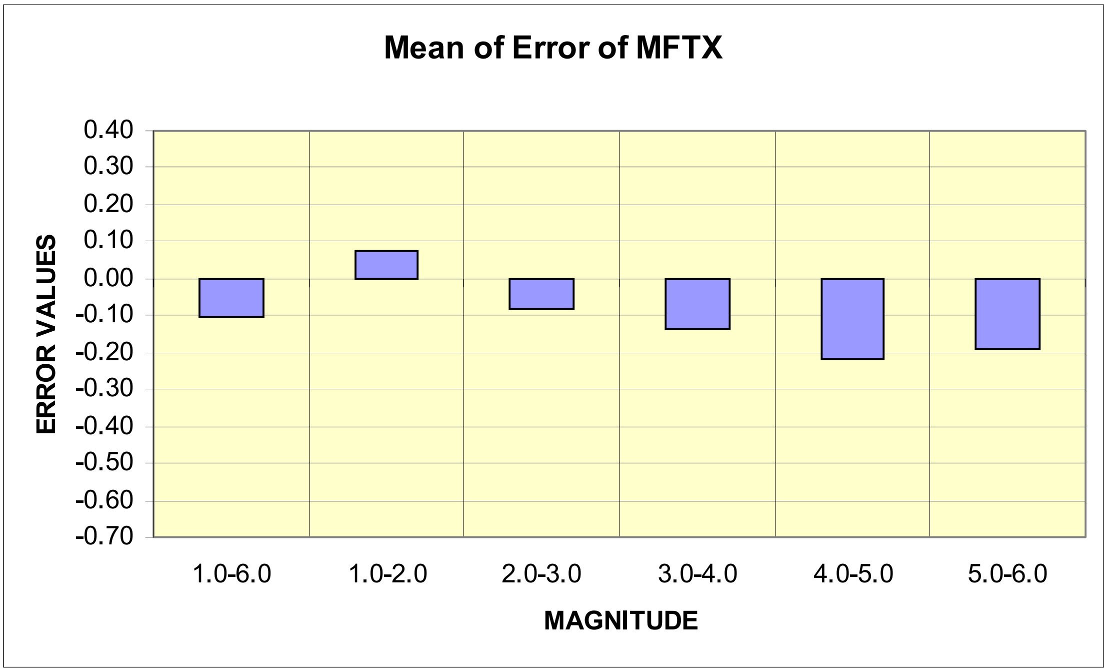

Figure 11.13. Mean of Error of MFTX

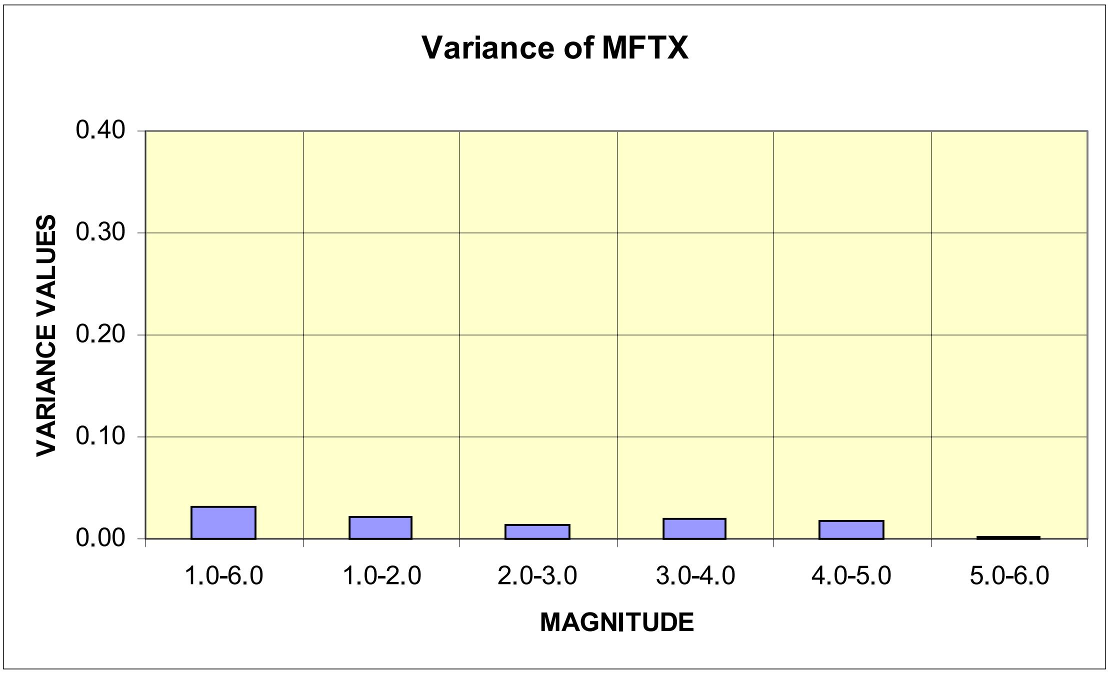

Figure 11.14. Variance of MFTX

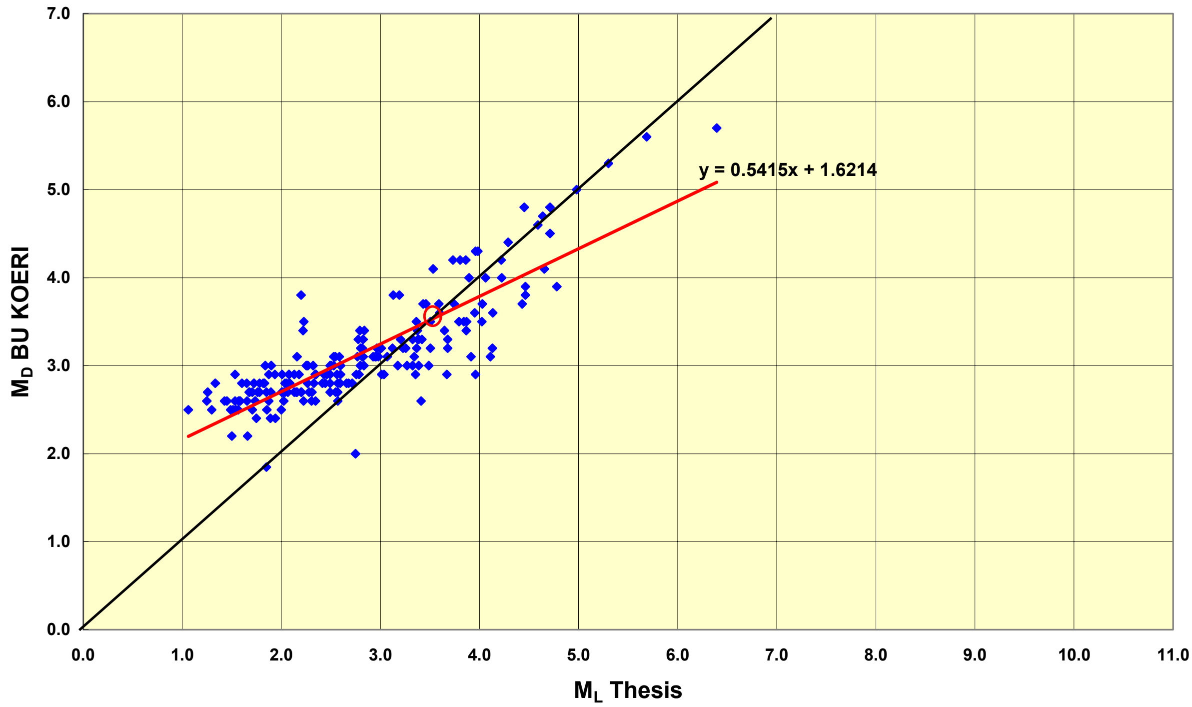

Figure 12. Comparison of $M_{L\text{-Thesis}}$ and $M_{D\text{-BU KOERI}}$

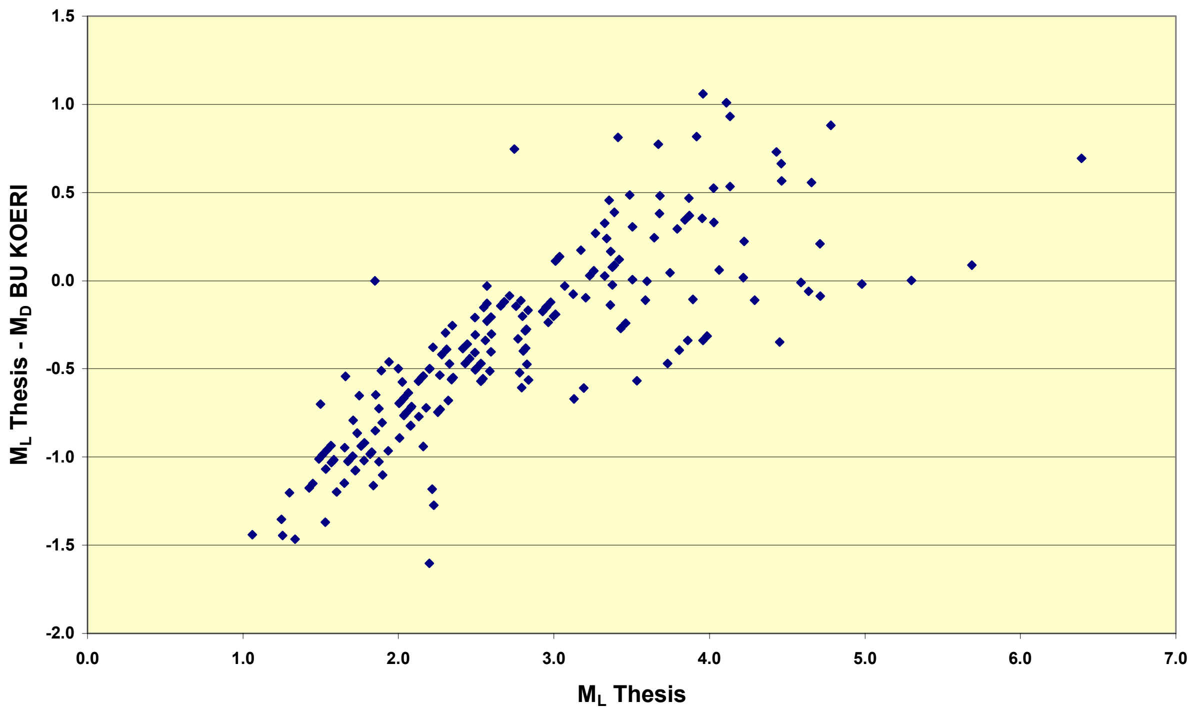

Figure 13. Residuals of $M_{L\text{-Thesis}}$ - $M_{D\text{-BU KOERI}}$

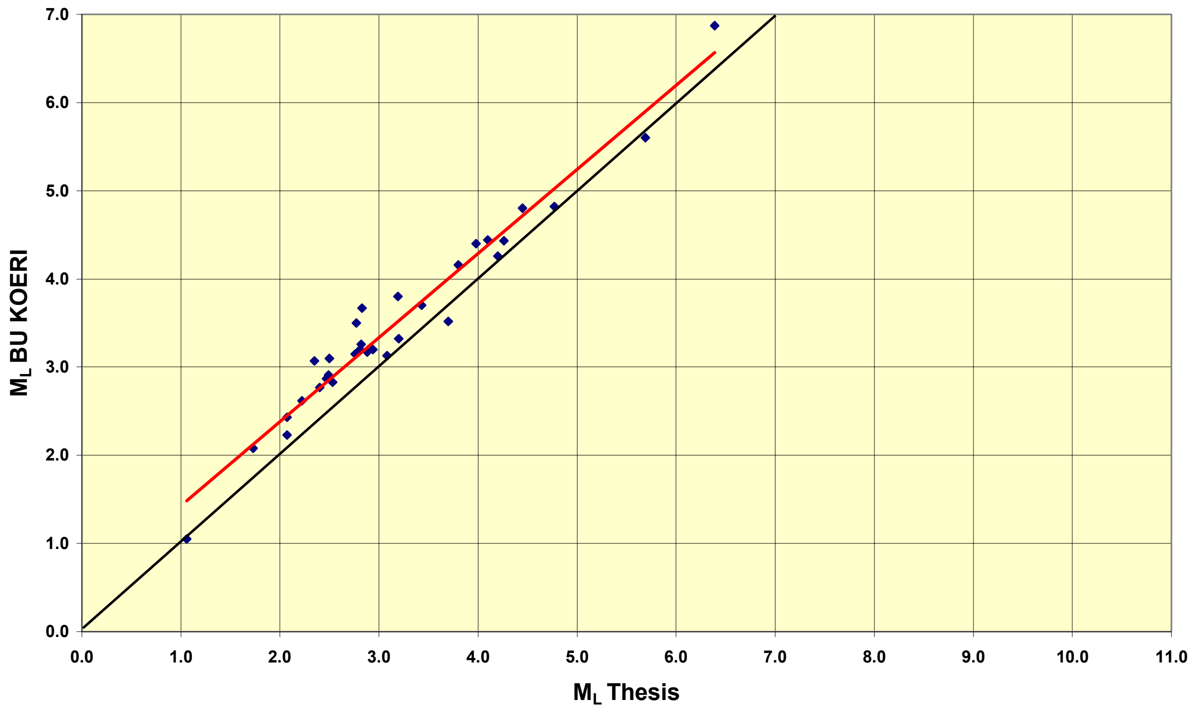

Figure 14. Comparison of $M_{L\text{-Thesis}}$ and $M_{L\text{-BUKOERI}}$

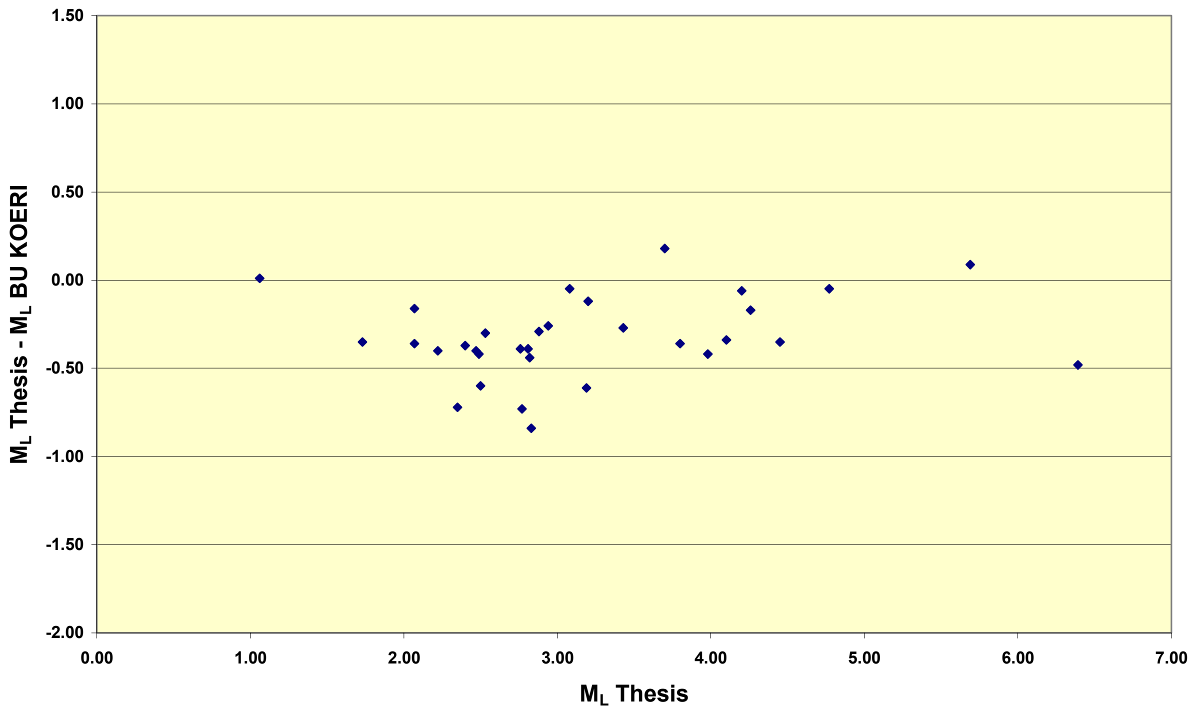

Figure 15. Residuals of $M_{L\text{-Thesis}} - M_{L\text{-BUKOERI}}$

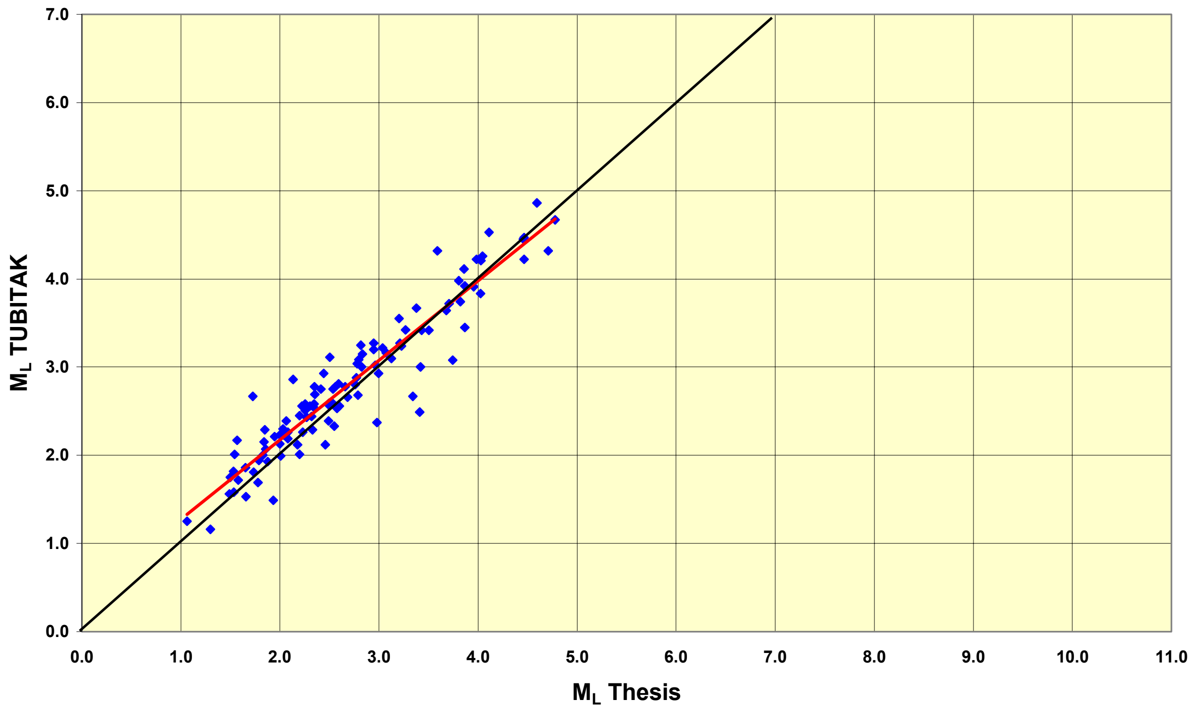

Figure 16. Comparison of $M_{L\text{-Thesis}}$ and $M_{L\text{-TUBITAK}}$

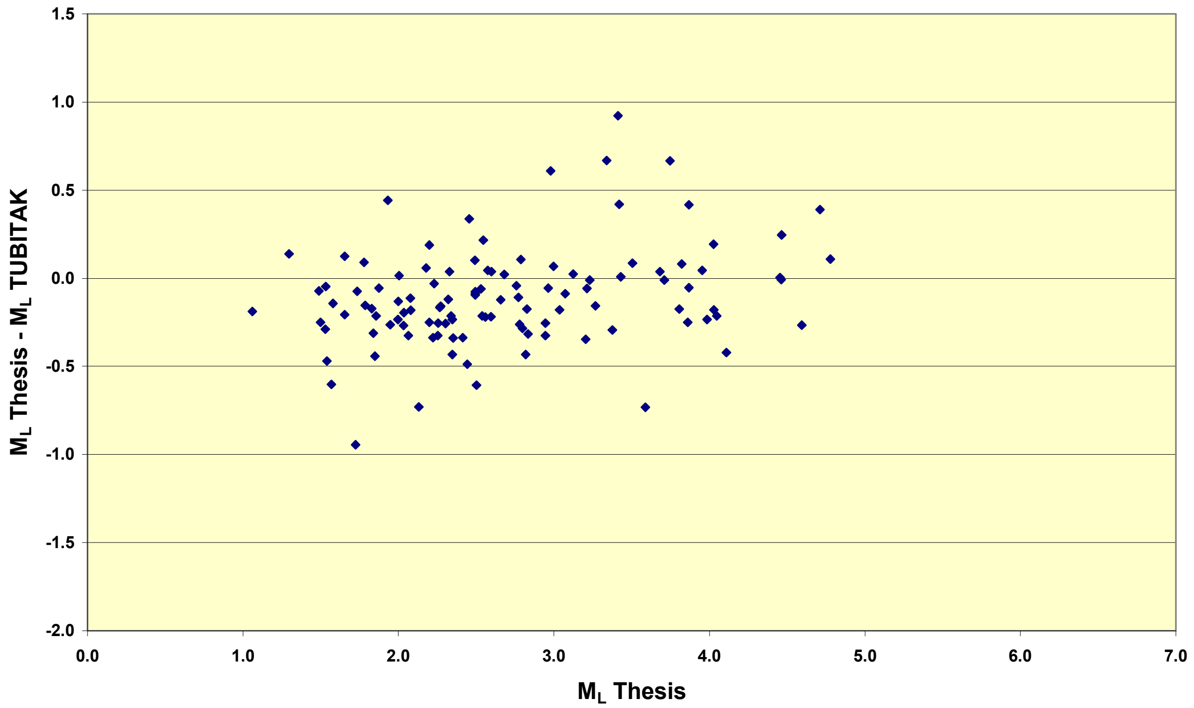

Figure 17. Residuals of $M_{L\text{-Thesis}}$ and $M_{L\text{-TUBİTAK}}$

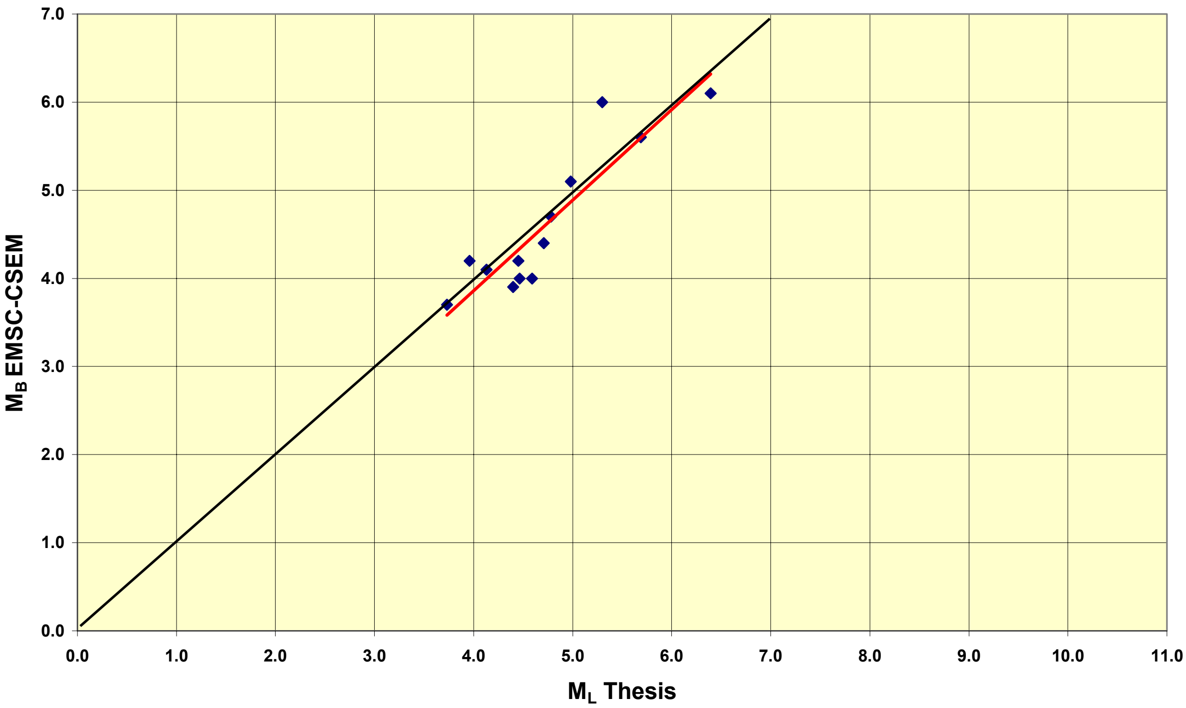

Figure 18. Comparison of $M_{L\text{-Thesis}}$ and $M_{B\ \text{EMSC-CSEM}}$

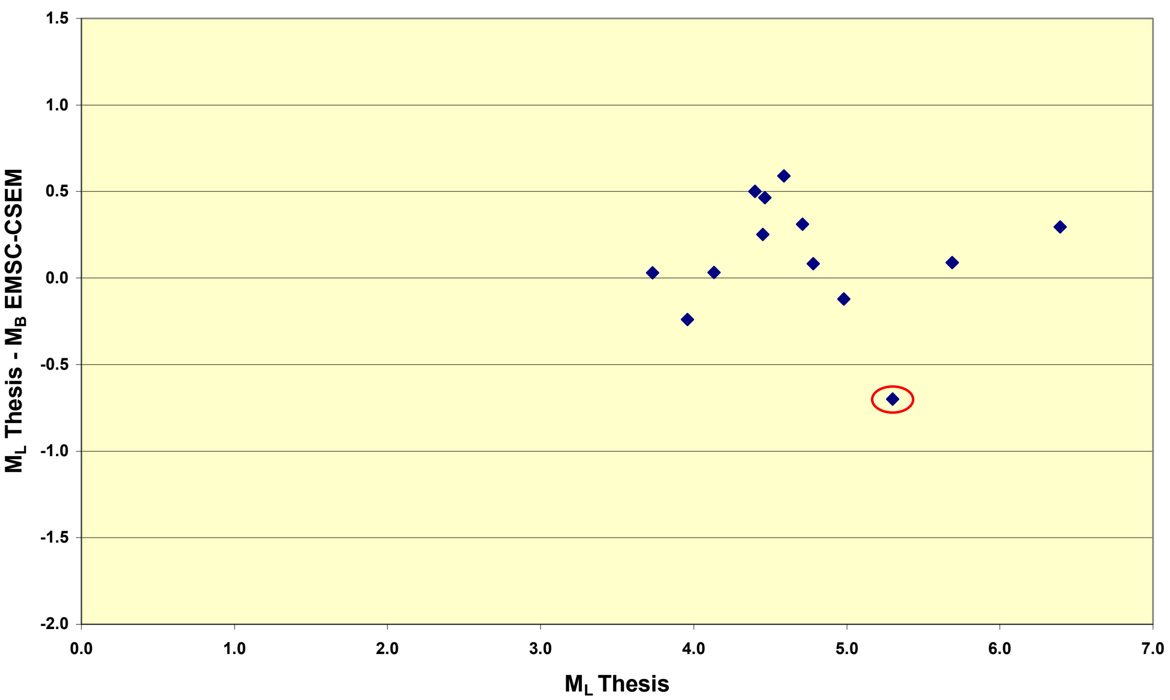

Figure 19. Residuals of $M_{L\text{-Thesis}}$ - the M_B determined by Emsc-Csem