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Historical reinterpretation of damaging intensity events and site effects in Eastern Turkey

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ABSTRACT: In this paper, early earthquakes of highly active seismic areas in eastern Turkey were studied. These historical destructive events happened between the years 1000-1900 AD of which intensity values at different sites had not been determined so far. Here, historic records and resources were scrutinized, the damage of structures due to each earthquake was examined, the vulnerability classes of structures at the time were determined and the macroseismic intensity values of different affected sites were assigned according to the European Macroseismic Scale (EMS-98). However, given limited historical reports of damaged locations and thus determined intensity values, Intensity Prediction Equations (IPEs) were required to generate intensity maps. Most IPEs only include site effects as part of the uncertainty term and thus, in this study, some local IPEs were selected and modified with an additional site effects term to improve the fit to the past intensity data and provide a spatially consistent map of intensities.

1 INTRODUCTION

In seismic loss scenario calculations, a realistic ground motion intensity map is a key aspect. This requires an extensive knowledge of past events if we assume that future earthquakes have characteristics similar to previous earthquakes. Therefore, collecting adequate data about all experienced earthquakes in a specific region is the first step to achieving reliable results. In contrast to contemporary events for which enough data and recordings are frequently available, the resources for historic events are usually insufficient. A lot of studies have been done through historic resources to compile the seismic parameters and to catalogue the data of early events (Ambraseys 1988 & Shebalin et al. 1997, etc.).

However, the macroseismic data points (MDPs) or macroseismic intensity values for affected sites are usually limited for early events due to lack of historical accounts. Macroseismic intensity values are useful seismic parameters which define the damage to structures due to an earthquake in a semi-quantitative manner, yet also relate to the subjected ground motion at the location. Because of this feature, they are indispensable data for seismic loss assessments of the affected area in locations where no seismic stations are available.

MDPs can be generated empirically through inspection of the affected sites and damaged structures by experts. With scientific judgment about the vulnerability classes of structures and damage grades, the intensity values are assigned in accordance with a standard scale such as European Macroseismic Systems 98 (EMS-98) (Grünthal 1998). This method is subjective and dependent on expert interpretation of the vulnerability and damage level of the buildings. Macroseismic intensity maps for an area can be obtained using MDPs via interpolation techniques such as kriging. A spatial raster of intensity across a given location is a helpful tool to study the effects of earthquakes rather than only specific sites.

The other procedure to generate intensity values, is to apply intensity prediction equations (IPEs). An IPE is generated by statistical methods based on the knowledge of previous earthquakes in an area and usually is a function of magnitude and distance metrics. Most IPEs do not include site effects explicitly within the function, however incorporate this within the given uncertainty bounds of the IPE.

The scope around this study is collecting a seismic catalogue for Erzincan in eastern Turkey as well as historical intensity characteristics in order to use this for future infrastructure loss estimation of the area, which is ongoing research by the authors. The North-South collision of Arabian and Eurasian continental plates caused development of active faults such as North Anatolian Fault (NAF) and East Anatolian Fault (EAF) and resulted in tectonic escape of Anatolian block (Barka et al. 1993, Barazangi et al. 2006). Erzincan, located on Anatolian block, is in vicinity of NAF, EAF, Ovacik fault, and North-East Anatolian Fault (NEAF) and has been hit by many large events over the past millennium, two events of which caused major damage – 1939 and 1992. Although much is known about these events, the collecting of intensity values for big events outside of these in this area is also our focus.

We collected and evaluated the data for all experienced earthquakes (Mw>5) up to present in Eastern Turkey from all related accessible catalogues, and resources such as Ambraseys (2009), Shebalin et al. (1997), Guidoboni et al. (2005), SHARE project, Global Historical Earthquake Archive (GHEA), KOERI, Eyidogan et al. (1991) & Ayhan et al. (1980), etc. Although numbers of studies have been done for recent big events (years 1900-present) and intensity maps (Isoseismal maps) as well as MDPs have been generated for them (Eyidogan et al. 1991 & Ayhan et al. 1980), the MDPs for early events (years 1000-1900 AD) are scarce.

In order to generate MDPs for early events in eastern Turkey, which have not been determined so far, we scrutinized resources and the description of the damage to the area. Among the earthquakes that affected Erzincan area between 11^{th} to 20^{th} century, we managed to find to some extent enough information for three events to assign additional macroseismic intensity values to those previously seen. Through a review of historic construction methods and materials in eastern Turkey, the vulnerability classes of structures were assumed according to the EMS-98 classification. Finally, the macroseismic intensity values for affected sites are assigned as per EMS-98.

Some researchers studied the effect of involving site effects in intensity prediction models in order to achieve more realistic results. For example, Allen et al. 2012 in their study to generate global IPEs, also applied a site amplification factor as a function of topographic gradient which led to small reduction of residuals in higher intensity levels.

Generating a new IPE is beyond the scope of our study, here to study the effect of considering site effects in macroseismic intensity models, we modify the two different IPEs with a new site effect term in order to reduce the residual. The applied modification parameter is a function of epicentral distance and the average shear wave velocity in the upper 30 meter of the surface (V_{s30}).

2 METHOD

2.1 *Determination of intensity values from historic loss information*

Macroseismic intensity values are assigned for the affected sites in accordance with a standard scale such as EMS-98 by knowing the vulnerability class of structures and their damage grade due to earthquake. Therefore, construction materials and techniques in the area for the years when events happened need to be understood. Pinar (1956) studied the construction methods historically in Turkey and divides the country in 5 different zones regarding their climate and common historic construction materials. According to his study, the zone of central and eastern Anatolia, in dry areas like Erzincan, people used timber in 70-100 cm spacing as horizontal reinforcement of thick adobe walls. In Erzurum, located in the same zone but in high and cold areas, horizontal timber reinforcements in 70-80 cm vertical spacing in thick stone walls were dominant type of structures. He also indicates an architectural technique was applied in main historical mosques in Turkey between 15^{th} to 19^{th} centuries, which was a system of connected cupolas to support the main cupolas. In this way the consistency and stability of the structure were increased and made them more resistant during historic seismic events. Pinar claims that though having experience of frequent earthquakes over the centuries, this led people to build seismically resistant structures with simple local materials.

All the information about the damage of structures in affected sites has been gathered from available historic resources, and catalogues (Ambraseys 2009, Guidoboni et al. 2005 & Shebalin et al. 1997, etc.). The description of damage leads to an estimation of damage grades for the structures according to EMS-98, given that we have assumed the vulnerability class of structure. Consequently, the intensity level is assigned following the EMS-98 methodology.

2.2 *Testing compatibility with existing GMPEs and IPEs*

We also compare our intensity values with the results of available prediction models. Therefore, we calculate MDPs for scenarios similar to the 3 early events by two IPEs (Musson et al. 2000 & Sorensen et al. 2009), also by applying two Ground Motion Prediction Equations (GMPE) (Boore et al. 2008 & Akkar et al. 2014) and converting derived engineering intensities to macroseismic intensity by two different conversion equations (Bilal et al. 2014 & Arioglu 2001).

2.2.1 *GMPE*

The second step was generating at least 30 scenarios similar to the 3 events in OpenQuake by using two different Ground Motion Prediction Equations (GMPE) of Akkar et al. 2014 & Boore et al. 2008. The derived ground motion parameter (here Peak Ground Acceleration (PGA)), has been converted to macroseismic intensity values via two different local conversion equations, as follows

Bilal et al. 2014

$$\mathrm{I} = 0.132 - 3.884\log(\mathrm{PGA}) \tag{1}$$

Arioglu et al. 2001

$$\mathrm{I} = -1.078 - 1.748\ln(\mathrm{PGA}) \tag{2}$$

Where, in equations 1 and 2 the standard deviations are 0.54 and 0.8 respectively, and the unit of PGA is gal (cm/s^2),

2.2.2 *IPE*

Intensity values for the sites also have been derived through IPEs. A Python script was developed in order to plot a raster of intensity via the IPEs and modified IPEs as well as to check against the output of intensity at each site from OpenQuake. IPEs were applied as follows,

Musson et al. 2000

$$I = 1.063 + 1.522M_s + 1.102ln\ (R) - 0.0043R \tag{3}$$

Sorensen et al. 2009

$$I = 0.793M_w + 3.417 - 2.157log_{10}\sqrt{\frac{R_{epi}^2 + h^2}{h^2}} - 0.0065\left(\sqrt{R_{epi}^2 + h^2} - h\right) \tag{4}$$

Where in equations 3 and 4, the standard deviation is 0.486 and 0.742 respectively. R and h are hypocentral distance and depth respectively and R_{epi} is the epicentral distance, where the unit for all these parameters is kilometers

2.3 *Site effect*

Usually IPEs are a function of magnitude and distance metrics. Here we propose one additional term of site effect as S(V_{s30},d) which is shown in equation 5. For example, by rewriting the equation 4 and separating it as the magnitude term G(M), and the attenuation term H(d), our modified IPE with S(V_{s30},d) term would be like equation 6.

$$S(V_{s30}, d) = \frac{(650 - V_{s30})}{250} \cdot \frac{log_{10}(h)}{log_{10}(d) + log_{10}(h)} = \frac{(650 - V_{s30})}{250} \cdot K(d) \quad (5)$$

$$I(M, d,\ V_{s30}) = G(M) - H(d) + S(V_{s30}, d) \quad (6)$$

Where $d = \sqrt{1 + \frac{R_{epi}^2}{h^2}}$, $G(M) = 0.793M_w + 3.417$, and $H(d) = 2.157log_{10}(d) + 0.0065\ h(d-1)$

The form of the site effect term is unusual because it is dependent on the distance to the epicenter. It is justified by empirical observations in this study which better fit this form. The specific mathematical form provides a site effect that is quite strongly reduced within distances of 2 or 3 times the hypocentral depth and stays fairly constant for larger distances.

3 DATA

It should be mentioned that, in our catalogue, we have applied regional conversion equations of Erdik et al. 2012, which is also mentioned in SHARE European Earthquake Catalogue (SHEEC), to convert surface wave magnitude (M_S) to Moment Magnitude (M_w), as following:

$$M_w = 2.1117 + 0.6633M_s \qquad 2.8 \leq\ M_s \leq\ 6.1 \quad (7)$$

$$M_w = 0.4491 + 0.9307M_s \qquad 6.2 \leq\ M_s \leq\ 8.2 \quad (8)$$

Table 1 shows the known big events that have been experienced so far in Erzincan area. It includes all seismic events till present that had a surface wave magnitude more than 6.8.

All the information about the active faults in Erzincan area has been collected from Earthquake Model of the Middle East (EMME) project of SHARE and USGS. Moreover, in order to study site effects, we have applied the Vs_{30} data of Turkey from USGS.

3.1 *Event description*

For early events, descriptions of damage to the structures due to an earthquake in related historic reports and the probable secondary effects of the event such as liquefaction, landslides,

Table 1. The big seismic events in Erzincan area up to present.

Year	Month	Day	Lat	Long	Magnitude	Intensity
1045	0	0	39.75	39.5	6.8	IX
1268	0	0	39.75	40.4	6.8	IX
1457	4	23	39.5	40.5	7	X
1477			40.2	38.0	7	
1482	12	21	39.75	39.5	6.8	IX
1583	6	27	39.5	40	7	
1584	6	17	39.75	39.5	6.8	VIII
1668	8	17	40.5	36	7	
1784	7	18	39.5	40.2	7	VIII-X
1859	6	2	39.9	41.3	6.8	VIII
1866	5	12	39.2	41	7	
1874	5	3	38.5	39.5	7	
1875	11	1	39.9	41.3	7.3	X
1893	3	2	38.4	38.7	6.8	
1905	12	4	38.1	38.6	6.8	IX
1939	12	26	39.8	39.7	7.8	XI
1949	8	17	39.4	40.8	6.9	IX
1971	5	22	39	40.7	6.8	VIII
1992	3	13	39.72	39.63	6.8	VIII-IX

surface rupture, etc. are used to assume the damage grade in the area under study. We looked for the description of damage in several affected sites for each historic event and we managed to collect the desired data for 3 early events; 23th of April 1457, 18th of August 1668, and 18th of July 1784.

3.1.1 *April 23, 1457*
Erzincan; In this event almost the whole city was demolished (Ambraseys 2009), some sources mention that the earthquake damaged the banks of the river and water had flowed toward Erzincan (Guidoboni et al. 2005), but Ambraseys interprets the sentence of "Erzincan was overthrown and sank into water" from historic reports as secondary effect descriptions of earthquake-induced liquefaction. We assumed the vulnerability class of A and B (Adobe and simple stone respectively) from classification of EMS-98 for the building style in Erzincan. We also assumed that many buildings with class A completely collapsed (which is the damage grade 5 according to EMS-98) and a few to many buildings with class B suffered damage grade 5. As per EMS-98, we prescribe macroseismic intensity values of IX-X for Erzincan. These values are consistent with the pertinent intensity values in GHEA & Guidoboni et al. (2005), as they mentioned intensity X for Erzincan. Kigi; Half of the Citadel of Kigi, a town which is located about 90km south-eastern of Erzincan, collapsed and a castle was destroyed. Although most of the time, castles had more resistant structures than ordinary buildings, the damage to them cannot be generalized. The citadel is generally located at an elevated location above towns and would likely have been subjected to focusing of earthquake waves due to topography and amplification. Often, in past events, intensities are in the order of 1-2 points higher when looking at focusing (Jafarzadeh et al. 2015, Kaiser et al. 2014 & Gao et al. 1996). By a judged vulnerability class similar to Erzincan and considering the distance of Kigi to epicenter, the lack of a description of damage to Kigi town apart from to the citadel, means that the effect of earthquake in this city can be categorized as damaging yet likely not destructive; in other words, intensity values can be assumed to be between VII and IX with great uncertainty. The only information available for Sivas, Bitlis and Mardin, cities in that area is the event had been felt, without mentioning about any damage. They are distant from the epicenter, and low intensities are possibly reasonable, but they are still considered as affected sites. The MDPs for this event are listed in Table 2.

3.1.2 *August 18, 1668*
Although the epicenter is far from the city of Erzincan (about 350km), there is just a note about the damage due to this event in Erzincan which says Erzincan collapsed (Ambraseys 2009). Rest of the affected sites by this event that are mentioned in historic description are not in eastern Turkey, the area of this study. Thus, we do not discuss their damage here and just show the assigned MDPs in this study in Table 2. More information about this event is available in Ambraseys 2009.

3.1.3 *July 18, 1784*
Erzincan; The earthquake occurred at midnight and it shook the area for 7-8s. About 95% of the buildings, almost the whole city, were demolished and just the main mosque and a public bath remained (Ambraseys 2009). Many of historical and main buildings (we assumed had been built better than ordinary buildings) collapsed, and the fact they had survived from previous earthquakes up until this one, attests that 1784 was a severe earthquake. We assumed the vulnerability class as A-C, and the damage Grade 4-5, the intensity value according to EMS-98 is assigned as X. Kigi; Ambraseys (2009) mentions that the city destroyed. We assumed a vulnerability class similar to Erzincan, but with a little lower damage grade, because of its distance from the epicenter. Therefore, the intensity value is assigned as IX. Mus; Some part of Surb Karapet Monastery was damaged, which is located about 20 km northwest of today's location of Mus. The convent and belfry of the monastery collapsed due to earthquake and needed to be replaced. By assuming mainly masonry structures with brick and stone walls for Mus area, the vulnerability class considered as A-B and damage graded as 3-4, therefore intensity level can be VII. Tercan; About 60km from epicenter and was

collapsed due to earthquake, by assuming vulnerability class A-C and damage grading 3-4, the intensity value assigns IX. Erzurum; Walls of houses were demolished, and a previously damaged castle suffered extra damage due to this earthquake. In historic reports it is mentioned that a few days after earthquake, some people escaped from Erzincan to Erzurum (Ambraseys 2009), this could mean Erzurum did not suffer too much damage and was a safer area for people to shelter. Therefore, by assuming damage class A-C and damage grade of 1-2, the intensity value can be defined as VI. The MDPs for this event are listed in Table 2.

4 RESULTS

Table 2 shows the assigned MDPs in this study for the three events of 1457, 1668, 1784 for the affected area. These values have been compared with the values calculated by two IPEs and two GMPEs for similar scenarios. In most of the cases the assigned values were higher than the calculated values. It should be mentioned that in calculation with both IPEs and GMPEs we applied the median predicted value.

Most of historic resources were not written by experts and are not technical reports, and the exaggerations in these documents are a misleading issue. For example, some of the resources for the damage in the cities are the petitions written in the aftermath asking to be exempted from the taxes of the year. These letters inherently included exaggeration to be accepted by the government and can cause overestimation in assigning intensity values. On the other hand, the lack of written engineering information about the construction methods of structures in time of early events is also an uncertainty issue in assigning intensity values for early events.

In a note about 1668 earthquake, it was indicated that the Erzincan collapsed due to this earthquake which Ambraseys (2009) also implies is an exaggeration. Considering the distance to epicenter (approximately 350km) and the calculated intensity for Erzincan we concluded that it is an exaggerated damage description. It should be mentioned that; although some distances may be out of limits of the applied IPEs and GMPEs, we assumed they are still reliable in far distances like this case of 350 km. Since the high intensities are more important for our study and they are in the distance restriction of the applied equations.

Table 2. The Generated MDPs for Events 1457, 1668, 1784.

				MDPs		
Sites	Lat	Long	Population*	April 23, 1457 5 points	August 18, 1668 11 points	July18,1784 5 points
Erzincan	39.75	39.49	96,159	IX-X	V	X
Kigi	39.32	40.35	3,286	VII-IX		IX
Sivas	39.75	37.02	344,185	VI		
Bitlis	38.4	42.11	51,071	IV		
Mardin	37.32	40.74	168,600	V		
Mus	38.73	41.49	95,717			VII
Tercan	39.78	40.38	5,608			IX
Erzurum	39.91	41.28	760,476			VI
Ilgaz	40.92	33.62	7,795		VIII	
Tokat	40.31	36.55	152,314		VIII	
Bolu	40.73	31.61	168,187		IX	
Osmancik	40.97	34.8	28,557		VIII	
Ladik	41.52	35.58	16,126		VII	
Amasya	40.65	35.83	109,240		X	
Ankara	39.93	32.87	5,445,026		VII	
Merzifon	40.87	35.46	57,363		IX	
Asarcik	41.03	36.27	16,819		IX	
Kastamonu	41.38	33.78	233,814		VII	

* http://www.tuik.gov.tr

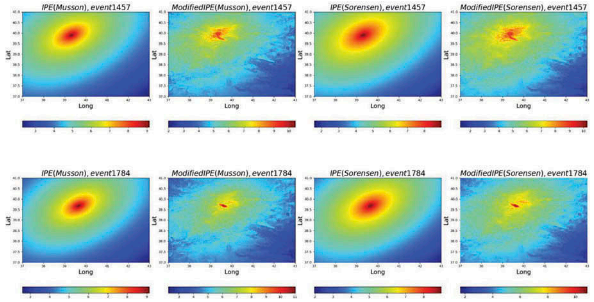

Figure 1. Comparison of the modified intensity models for events 1457 and 1784 with the original models shows the involving site effects term caused more realistic intensity maps. (In plots above, the horizontal and vertical axes are longitude in range of 37 to 43 and latitude in range of 37 to 41, respectively).

Table 3. Comparison of Assigned MDPs for 1457 earthquake and Modified Musson`s IPE.

MDPs				
	This study			
Sites	Assigned	Modified IPE Modified Musson	IPE Musson 2000	GMPE, Akkar et al. 2014 Conversion Eq. Bilal et al. 2014
Erzincan	X	9.93	8.93	9.453
Kigi	VII-IX	7.48	6.65	6.503
Sivas	VI	6.057	5.29	4.124
Bitlis	IV	5.55	4.93	4.218
Mardin	V	6.94	6.16	5.563

A detailed fault break for the 1668 event was needed as results showed that some of the IPE approaches significantly underestimated locations like Amasya which were close to the epicenter. One limitation of the current study is the lack of finite fault or slip information on the fault, which impacts the ground motion distribution. Thus, this study should be seen as a preliminary estimate of an intensity distribution.

By comparing the intensity maps with and without site effects as shown in Figure 1, it can be concluded that more realistic intensity maps are possible with considering site effects. Table 3 shows the result of the modified IPE of equation 3 for event 1457 and comparison with the assigned MDPs and the intensity values with the equation 3 also calculated MDPs by one of the applied GMPEs in this study. It should be mentioned that, we compared raw calculated intensities with the assigned integer intensity values, thus part of residuals might come from this case.

The results of the IPE mostly had a better consistency with our values in comparison with the result of intensities derived by GMPEs. The results of two IPEs for the studied events were almost similar. The intensities calculated through the GMPE derived by Akkar et al. (2014) and converted by equation of Bilal et.al had better consistency with the assigned MDPs for these 3 events than the other applied GMPE and conversion equation.

5 CONCLUSIONS

In order to provide a catalogue of experienced events in eastern Turkey, all available descriptions of early events were examined, and the Macroseismic intensity Data points were assigned for 3 early events. Also, similar scenarios generated and the predominant MDPs were calculated through IPEs and GMPEs. The assigned MDPs were compared with the calculated values and their consistency was tested. Moreover, in order to optimize the intensity maps for loss calculations, site effects were tested. Two IPEs were modified through a proposed Site effect term in this study and as a result, up to 37% reduction in residuals has been observed. Shakemaps were generated by the modified IPEs for the three early events of this study and compared with the intensity maps of original IPEs. The future work includes using these intensity maps for loss assessment of today`s exposure and vulnerability of the building stock.

REFERENCES

Akkar, S., Sandikkaya, M.A. & Bommer, J. 2014. Empirical Ground-Motion Models for Point- and Extended- Source Crustal Earthquake Scenarios in Europe and the Middle East. *Bulletin of Earthquake Engineering* (2014), 12(1): 359–387.

Allen, T.I., Wald, D.J. & Worden, C. B. 2012. Intensity Attenuation for Active Crustal Regions. *Journal of Seismology*.16(3): 409–433.

Ambraseys, N.N. 2009. Earthquakes in Mediterranean and Middle East: A Multidisciplinary Study up to 1900. *Cambridge University Press*. Cambridge, United Kingdom.

Ambraseys, N.N. 1988. Engineering Seismology. *Earthquake Engineering & Structural Dynamics*, 17: 1–105.

Arioglu, E., Arioglu, B. & Girgin, C. 2001. Assessment of the Eastern Marmara earthquake in terms of acceleration values. BetonPerfabrikasyon: 57–58 (in Turkish).

Ayhan, E., Alsan, E., Sancakli, N. & Üçer, S.B. 1980. Türkiye ve Dolayları Deprem Kataloğu 1881–1980.Boğaziçi Üniversitesi Yayınevi. 126p. (in Turkish).

Barazangi M., Sandvol E. & Seber D. 2006. Structure and tectonic evolution of the Anatolian plateau in eastern Turkey, in Dilek, Y., and Pavlides, S., eds., Postcollisional Tectonics and Magmatism in the Mediterranean Region and Asia: Geological Society of America Special Paper. 409.

Barka, A., Eyidogan, H. 1993. The Erzincan Earthquake of 13 March1992 in Eastern Turkey. Terra-Nova,5: 190–194.

Bilal, M. & Askan, A. 2014. Relationship between Felt Intensity and Recorded Ground-Motion Parameter for Turkey. *Bulletin of Seismological Society of America*.104(1): 484–496.

Boore, D.M. & Atkinson, G.M. 2008. Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5%-damped PSA at spectral periods between 0.01 s and 10.0 s. Earthquake Spectra. 24(1): 99–138.

Erdik M., Şeşetyan K., Demircioğlu M.B., Tüzün C., Giardini D., Gulen L., Akkar D. & Zare M. 2012. Assessment of Seismic Hazard in the Middle East and Caucasus: EMME (Earthquake Model of Middle East) Project. Proceedings of 15th World Conference on Earthquake Engineering.Paper No. 2100.

Eyidogan, H., Utku, Z. & Güçlü, U. 1991. Türkiye Büyük Depremleri Makro-Sismik Rehberi (1900–1988). *Yayınevi: İstanbul Teknik Üniversitesi Maden Fakültesi Jeofizik Muhendesi Bolumu*.199p. (in Turkish).

Gao, S., Liu, H., Davis, P.M. & Knopff, L. 1996. Localized Amplification of Seismic Waves and Correlation with Damage due to the Northridge Earthquake: Evidence for Focusing in Santa Monica. *Bulletin of the Seismological Society of America*. 86(1B): S209–S230.

GEM (2018). The OpenQuake-engine User Manual. Global Earthquake Model (GEM) OpenQuake Manual for Engine (version 3.0.1). 198p.

Grünthal, G. (Ed.).1998. European Macroseismic Scale 1998 (EMS-98) European Seismological Commission, sub commission on Engineering Seismology, Working Group Macroseismic Scales. *Conseil de l'Europe, Cahiers du Centre Européen de Géodynamique et de Séismologie*. 15. Luxembourg.

Guidoboni E. & Comastri A. 2005. Catalogue of earthquakes and tsunamis in the Mediterranean area from the 11th to the 15th century. INGV-SGA, Bologna.1037p.

Jafarzadeh, F., Shahrabi, M.M. & Farahi Jahromi, H. 2015. On the Role of topographic amplification in seismic slop instabilities. *Journal of Rock Mechanics and Geotechnical Engineering*. 7(2):163–170.

Kaiser, A.E., Holden, C. & Massey, C. I. 2014. Site amplification, polarity and topographic effects in the Port Hills during the Canterbury earthquake sequence. GNS Science Consultancy Report 2014/121). 33p.

Musson, R.M.W. 2000. Intensity Based Seismic Risk Assessment. *Soil Dynamics and Earthquake Engineering*. 20:353–360.

Pinar, N. 1956. Historical and Modern Earthquake -Resistant Construction in Turkey. World Conference on Earthquake Engineering (Berkely).

Shebalin N.V. & Tatevossian R.E. 1997. Catalogue of large historical earthquakes of the Caucasus. In: Giardini D. and Balassanian S. (eds). Historical and Prehistorical Earthquakes in the Caucasus. NATO ASI Series 2: Environment. Kluwer Academic Publishers. 28: 201–232.

Sorensen, M.B., Stromeye, D. & Grunthal, G. 2009. Attenuation of Macroseismic Intensity: A new Relation for the Marmara Sea Region, Northwest Turkey. *Bulletin of the Seismological Society of America*. 99(2A): 538–533.