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A study on the determination of damage levels in reinforced concrete structures for different earthquakes

Ercan IŞIK*, Ali Emre ULU, Şakir TUNÇ, Ali KESKINER

Bitlis Eren University, Department of Civil Engineering, TR-13000, Bitlis, Türkiye

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ABSTRACT

It is important for spatial planning and urban transformation to determine and manage all the information about the buildings damages after the earthquake. In this respect, the first damage assessments should be made as quickly and practically as possible, especially immediately after the earthquake. Within the scope of this study, the reinforced-concrete structure's damage classification that given in the European Macro-Seismic Scale (EMS) was used, taking into account five different earthquakes in Turkey. Sample buildings were identified for five different degrees of damage foreseen in the EMS. In addition to the information about these earthquakes, seismic parameters were obtained for these earthquake epicenters. The peak ground acceleration values measured for all earthquakes considered in this study were compared with the currently recommended peak ground acceleration values.

1. Introduction

Earthquakes occur in seismically active regions and different levels of structural damage can occur as a result of destructive earthquakes. It is important to detect structural damage as a result of destructive earthquakes and to decide on repair and strengthening or demolition depending on the damage situation. Post-earthquake damage assessment is one of the important steps of modern disaster management. In particular, the first damage assessments to be made immediately after the earthquake should be carried out quickly. The need for rapid damage assessments is made both for the continuation of the social life after the earthquake and for deciding whether the structures in the earthquake zone will be used immediately or whether repair and strengthening are needed (Bilgin et al., 2021; Hadzima-Nyarko et al., 2018; Tabrizikahou et al., 2021; Harirchian et al., 2021; Arslan and Korkmaz, 2007). Due to the large scale of the damage, the size of the affected area and the lack of sufficient expert personnel, damage assessments are not carried out quickly and practically. Insufficient public resources and difficult terrain conditions also negatively affect the damage assessment process (Işık et al., 2017; Doğan et al., 2021). It is necessary to act as fast as possible and to reach the maximum building in the minimum time while the damage assessment processes are being carried out (Işık et al., 2021). In this respect, the information to be collected about the damages should be as necessary. For all these reasons, the

* *Corresponding author.* Tel.: +90 (434) 222 00 30; fax: +90 (434) 222 91 45
E-mail address: aeulu@beu.edu.tr
ORCID : 0000-0001-8057-065X *(E. Işık), 0000-0001-7499-3891 (A. E. Ulu), 0000-0002-1711-654X (Ş. Tunç), 0000-0002-4382-0952 (A. Keskiner)*

building data that will be the basis for the first damage assessments after the earthquake should be selected correctly. Damage assessment forms can be used to apply this information in the field is an easy, fast and practical way. With the help of these forms filled in the field, evaluations to be made in a more comfortable environment, a final decision can be made about the building. Damage assessments to be carried out systematically will significantly affect the loss of life and property in a possible second earthquake (Işık et al., 2021a).

In addition, the calculation of seismic ground motion parameters (acceleration, velocity, displacement) required for calculating the seismic loading conditions to which soil and engineering structures will be exposed in the future can be obtained by seismic hazard analysis (Moehle and Deirlein, 2004). Geographical location of the epicenter, earthquake acceleration, earthquake magnitude or intensity and loss of life and property are statistical data that are recorded after each earthquake and can be used afterwards.

Within the scope of this study, five different destructive earthquakes that occurred in Turkey were taken into account. These are the 1999 Düzce, 2003 Bingöl, 2011 Van, 2020 Sivrice (Elazığ) and 2020 İzmir earthquakes. Peak ground acceleration (PGA) and peak ground velocity (PGV) values for all earthquake epicenters were obtained for the last two earthquake hazard maps. These obtained values were compared with the values measured after the earthquake. The loss of life and property caused by the magnitude of these earthquakes is stated. In the next part of the study, information on why the damage assessment forms should be used is given. By giving information about the European Macro-Seismic Scale (EMS-98), which is used for damage grading of reinforced-concrete (RC) structures, sample RC buildings were selected for damage grading for five different earthquakes. The study will contribute to this and similar studies in terms of obtaining the seismic parameters of these earthquake epicenters, as well as the use of EMS-98 for five different destructive earthquakes.

2. Considered Earthquakes

Seismicity is based on geological, tectonic and statistical data. Macro seismic data about the earthquake's time, central and supracentral location, source parameters and its effects are the most important parameters in determining the earthquake hazard of a region. The seismicity of a region is an indicator of a future earthquake in that region (Kramer,1996; Morell et al. 2020; Özmen and Can, 2016; Kutanis et al., 2018). Within the scope of this study, five important earthquakes in recent years, which caused significant losses for Turkey, were taken into account. The representation of these earthquakes on the map is given in Figure 1.

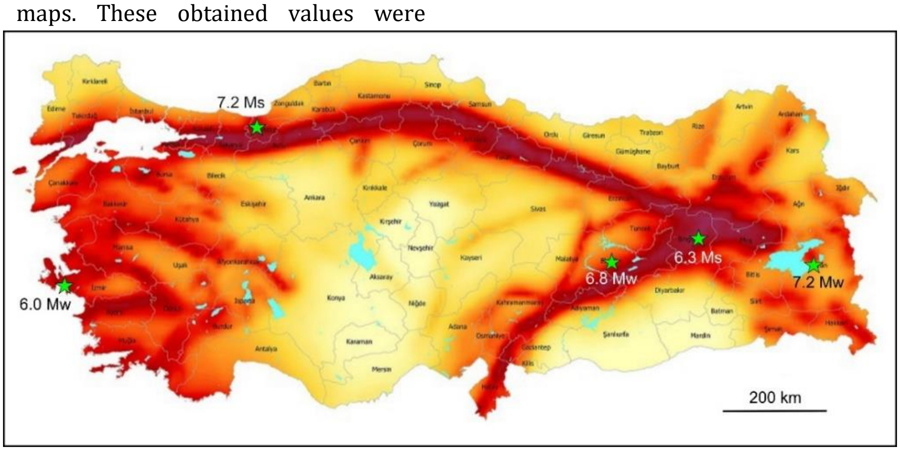


Figure 1. Earthquakes considered in the study.

The magnitude, location, and loss of life and property of these considered earthquakes are shown in Table 1. The data are taken from the database of institutions that record important earthquake data of Turkey, such as AFAD and KOERI.

Table 1. Characteristics of the considered earthquakes.

No	Date	Lat.	Lon.	Magnitude			Loss of Life	Number of Damaged Buildings	Location
				Mb	Ms	Mw			
1	12.11.1999	40.81	31.19	6.2	7.2		763	35519	Düzce
2	01.05.2003	39.00	40.46	5.7	6.3		176	6000	Bingöl
3	23.10.2011	38.76	43.36			7.2	644	17005	Van
4	24.01.2020	38.48	39.12			6.8	41	1915	Sivrice (Elazığ)
5	30.10.2020	37.90	26.74			6.0	117	259	Seferihisar (İzmir)

In the earthquakes examined in this study, a total of 1741 lives were lost and 60698 buildings were damaged. In each earthquake, on average, 350 citizens lost their lives and 12150 buildings were damaged. This clearly demonstrates the destructiveness of these earthquakes in Turkey.

While only one ground motion level was expressed in the previous earthquake code (TSDC-2007), four different earthquake ground motion levels were expressed in the current seismic design code (Turkish Building Earthquake Code/TBEC-2018). Within the scope of this study, four different earthquake ground motion levels, 2%, 10%, 50% and 68%, were taken into account. The four different ground motion levels considered are included in the current earthquake code and are shown in Table 1.

Table 3. Earthquake ground motion levels (TBEC-2018)

Earthquake level	Repetition Period (year)	Probability of exceedance (in 50 years)	Description
DD-1	2475	0.02	Largest earthquake ground motion
DD-2	475	0.10	Standard design earthquake ground motion
DD-3	72	0.50	Frequent earthquake ground motion
DD-4	43	0.68	Service earthquake movement

The comparison of PGA and design spectral acceleration coefficients (S_{DS}) predicted for five earthquakes in the last two seismic design code is given in Table 2.

Table 2. Comparison of PGA and S_{DS} values

No	Location	TSDC-2007 Seismic Zone	TSDC-2007 PGA (g)	TBEC-2018 PGA (g)	PGA2007/ PGA2019	S_{DS} 2007	S_{DS} 2018	S_{DS2007}/S_{DS2018}
1	Düzce	1	0.400	0.588	0.680	1.000	1.291	0.775
2	Bingöl	1	0.400	0.633	0.632	1.000	1.403	0.713
3	Van	2	0.300	0.399	0.752	0.750	0.844	0.889
4	Sivrice (Elazığ)	1	0.400	0.542	0.738	1.000	1.184	0.845
5	Seferihisar (İzmir)	1	0.400	0.449	0.891	1.000	0.983	1.017

The currently used code and the PGA values predicted in the map for the five earthquakes were higher than the previous ones. In the design spectral acceleration coefficients, while the current values for the four earthquake epicenters were higher, they were lower for only the İzmir earthquake.

'AFAD Turkey Acceleration Database and Analysis System' (TADAS) is used to provide a better understanding of damaging earthquake characteristics. Measured values for earthquakes were obtained using this system for all cases. These obtained values were compared with the values predicted in the last two seismic design codes and earthquake hazard maps. The comparison of the measured values with the four different ground motion levels stipulated in the current seismic design code is also given in Table 3. The values for the current code were obtained using the Turkey Earthquake Hazard Map Interactive Web Earthquake Application (TEHMIWA).

Table 3. Comparison of PGA values

Earthquke No	Date	Measured Values			PGA $_{2018}$				PGA $_{2007}$
		PGA (cm/s^2)	PGV (cm/s)	PGD (cm)	DD-1	DD-2	DD-3	DD-4	DD-2
1	30.10.2020	179.31	22.53	5.16	0.825	0.449	0.175	0.126	0.400
2	24.01.2020	292.80	45.34	10.99	0.957	0.542	0.201	0.152	0.400
3	23.10.2011	178.35	26.11	5.55	0.837	0.399	0.109	0.073	0.300
4	01.05.2003	501.44	37.21	15.74	1.121	0.633	0.256	0.175	0.400
5	12.11.1999	806.98	80.16	47.79	0.996	0.588	0.211	0.123	0.400

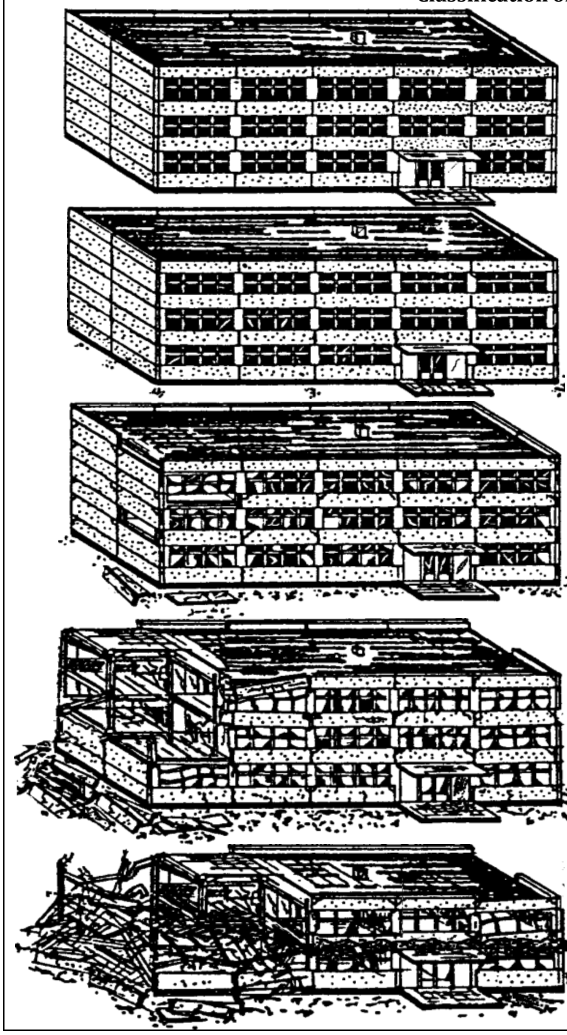
The PGA values measured for the 2020 İzmir, 2020 Sivrice (Elazığ), 2011 Van earthquakes were lower than the values predicted in the last two maps for the design earthquake ground motion level. The PGA value measured for the 2003 Bingöl earthquake was higher than the predicted value in the previous map, but lower than the predicted value in the current map. The PGA value measured in the 1999 Düzce earthquake was greater than the PGA values predicted for the standard design earthquake ground motion level on both maps. However, it was smaller than the predicted PGA value for DD-1, which is the largest earthquake ground motion level for this earthquake base. Therefore, only Düzce earthquake was greater than the PGA value predicted for the design ground motion level in the current map, and for the other four earthquakes, it was below the predicted values for the design earthquake ground motion level.

3. Damage Rating in RC Structures

The characteristics of earthquakes directly affect the loss of life and property. In addition, the structural characteristics of the existing building stock in the earthquake zone directly affect the loss of life and property. Obtaining accurate and timely information on structural damage will guide both the reduction of casualties and the effective implementation of emergency rescue (Zhai and Zeng, 2017; Xian et al., 2016). In this respect, an important factor in fast and practical damage analysis based on observations is to have a detailed and accurate building inventory and comprehensive damage data (Bessason and Bjarnason, 2016). Damage information of buildings is essential for rescue, humanitarian and reconstruction operations in the disaster area. Building damages can be graded in the field using damage scales (Sharma et al., 2017).

There are many different macro seismic scales to assess and classify structural damage after an earthquake more quickly (Zanini et al., 2019; Gómez Capera, 2007). The European Macroseismic Scale (EMS-98) was developed by the European Seismological Commission (ESC), taking into account the wider damage levels, considering the security gaps in the (Mercalli-Cancani-Sieberg (MM-31 ve MM-56) and Medvedev, Sponheuer-Karnik (MSK-64 ve MSK-81) gauges (Zanini et al., 2018; Grunthal, 1998; Grünthal and Levret, 2001). Within the scope of this study, earthquake damages were determined for different earthquakes by using five different damage ratings for RC structures in the European Macro-Seismic Scale -98 (EMS-98). While determining earthquake damages, academic studies on earthquakes were taken into account. Damage grading of RC structures in EMS-98 is shown in Figure 2.

Classification of damage to buildings of RC



Grade1: Negligible to slight damage (no structural damage, slight non-structural damage)

Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.

Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.

Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)
Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.

Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage) Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns.
Collapse of a few columns or of a single upper floor.

Grade 5: Destruction
(very heavy structural damage) Collapse of ground floor or parts (e. g. wings) of buildings.

Figure 2. Damage grades in RC structures according to EMS-98

The visuals used in the 1st degree damage grade for the considered earthquakes are shown in Figure 3.

2003 Bingöl	2020 Sivrice(Elazığ)	2011 Van
(Doğangün, 2004)	(Şahin et al., 2020)	(Özden et al., 2011)

Figure 3. Negligible to slight damage for different earthquakes (Grade 1)

The moderate damage (Grade 2) for RC buildings for selected earthquakes are shown in Figure 4.

2003 Bingöl	2020 Sivrice (Elazığ)	2003 Bingöl
(Emre et al., 2003)	(Şahin et al., 2020)	(Doğangün, 2004)

Figure 4. Moderate damaged RC buildings

The substantial to heavy damaged (Grade 3) RC buildings for selected earthquakes are shown in Figure 5.

1999 Düzce	2011 Van	2011 Van
(AFAD, 2021)	(Aydın, 2012)	(Erdil, 2017)

Figure 5. The substantial to heavy damaged (Grade 3) RC buildings

Very heavy damaged buildings for selected earthquakes are shown in Figure 6.

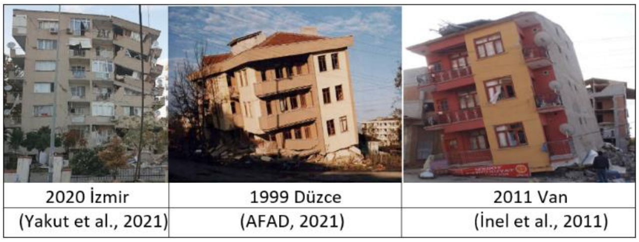


Figure 6. Very heavy damaged (Grade 4) RC buildings

Destruction of some RC buildings (Grade 5) for selected earthquakes are shown in Figure 7.

Figure 7. Destruction of (Grade 5) RC buildings

Total collapse, soft story damage, cracks in structural system elements, infill wall damages and damages in column-beam junctions are the damages observed in the buildings studied. The reasons for such damages are that the building does not receive engineering service and that the earthquake-resistant building design principles are not taken into account both in the design and during the construction phase. In addition, poor workmanship, lack of inspection, low material strength and design errors are other factors that can increase the amount of damage. Soft/weak floors, strong beams – weak columns, short columns, irregularities in plan and vertical, which adversely affect the behavior of buildings under earthquake effects, increase the probability of damage to structures. Insufficient lateral rigidity and insufficient use of RC shear walls can negatively affect the behavior of structures under earthquake effects and increase the amount of damage. In addition, factors such as generally made similar mistakes in reinforcement processing (insufficient wrapping, insufficient or incomplete reinforcement arrangements, insufficient or incorrect clamping, etc.) affect the degree of damage.

4. Conclusions

Within the scope of this study, seismic parameters were obtained for the last two earthquake hazard maps for five different earthquake locations. The predicted PGA values on these maps were compared with the PGA values measured during the earthquake. The seismic parameter values predicted on a regional basis in the previous map have been replaced by site-specific seismic parameter values. The study once again demonstrated the importance of site-specific calculation of seismic parameters. Except for the 1999 Düzce earthquake, for the other four earthquakes considered, the design in the current map was lower than the PGA values predicted for ground motion. However, the value measured for the 1999 Düzce earthquake was lower than the value recommended for the largest ground earthquake (DD-1) for that location. In this respect, it can be stated that the current earthquake hazard map is sufficient to reveal the earthquake hazard.

In addition, damage grading of RC buildings was carried out for five different earthquakes considered in the study using EMS-98. Quick and practical determination of damage after an earthquake is a part of modern disaster management for the continuation of social life. At this point, people who will make earthquake damage assessment should first receive training on how to do damage assessments. As a result of this process, field studies will be faster and more reliable. Successful data collection often heavily depends on this preparation. Otherwise, field studies need to be renewed to collect data.

All kinds of data to be obtained as a result of any damage assessment and rating to be made after the earthquake are valuable data in terms of civil and earthquake engineering. With the help of these data, the seismicity of the region and the characteristics of the building stock, its strengths and weaknesses can be revealed. In addition, it is possible to make necessary arrangements in earthquake resistant building design principles by using these data. One of the most obvious examples that can be given to this is the concrete class. Generally, damages in RC structures are associated with low concrete strength. In this respect, while the lowest concrete class envisaged in the 1975 earthquake code in Turkey was C14, it was increased to C20 in the 2007 seismic design code and to C25 in the current seismic design code.

Damage degrees in buildings under earthquake effects generally depend on structural features. It is not possible to predict earthquakes with today's technologies. Therefore, the fact that the amount and degree of earthquake damage is much lower is related to the use of earthquake resistant building design principles both in the construction and design phases. In this context, Turkey has demonstrated its sensitivity in this regard by renewing and updating its earthquake resistant building design principles many times. At this point, the sensitivity of decision makers and practitioners in the building sector will contribute to lower earthquake damage.

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References

Arslan, M.H., and Korkmaz, H.H., 2007. What is to be Learned from Damage and Failure of Reinforced Concrete Structures During Recent Earthquakes in Turkey? Engineering Failure Analysis, 14(1), 1-22.

Aydın, A., 2012. Van depreminde hasar gören mevcut betonarme bir binadaki hasarın, DBYBHY 2007'ye göre yapılan performans analiz sonuçları ile karşılaştırılması, Yüksek Lisans Tezi, Fen Bilimleri Enstitüsü, İstanbul.

Bessason, B., and Bjarnason, J.Ö. 2016. Seismic Vulnerability of Low-rise Residential Buildings Based on Damage Data from Three earthquakes (Mw6. 5, 6.5 and 6.3). Engineering Structures, 111, 64-79.

Bilgin, H., Shkodrani, N., Hysenlliu, M., Ozmen, H.B., Isik, E., and Harirchian, E., 2022. Damage and Performance Evaluation of Masonry Buildings Constructed in 1970s during the 2019 Albania Earthquakes. Engineering Failure Analysis, 131, 105824.

DEMP, 2020. Interactive earthquake map web page for the 08.06.2020 available at https://tdth.afad.gov.tr/

Dogan, G., Ecemis, A.S., Korkmaz, S.Z., Arslan, M.H., and Korkmaz, H.H., 2021. Buildings Damages after Elazığ, Turkey Earthquake on January 24, 2020. Natural Hazards, 1-40.

Doğangün, A., 2004. Performance of Reinforced Concrete Buildings During the May 1, 2003 Bingöl Earthquake in Turkey. Engineering Structures, 26(6), 841-856.

Emre, Ö., Herece, E., Doğan, A., Parlak, O., Özaksoy, V., Çiplak, R., and Özalp, S., 2003 Bingöl Depremi Değerlendirme Raporu. Maden Tetkik Arama Enstitüsü Rapor, (10585).

Erdil, B., 2017, 2011 Van Depremlerinin Ardindan: Tasarim ve Uygulama Farkları. 4. Uluslararası Deprem Mühendisliği ve Sismoloji Konferansı 11-13 Ekim 2017, Anadolu Üniversitesi , Eskişehir, Türkiye

Gómez Capera A.A., Albarello, D., Gasperini, P., 2007. Aggiornamento Relazioni fra l'Intensità Macrosismica e PGA, Technical Report. Convenzione INGV-DPC 2004-2006.

Grünthal, G., 1998. European Macroseismic Scale 1998. European Seismological Commission (ESC).

Grunthal G., Levret A. 2001. L'échelle macrosismique européenne. Conseil de l'Europe – Cahiers du Centre Européen de Géodynamique et de Séismologie, Vol. 19. 2001.

Hadzima-Nyarko, M., Ademovic, N., Pavic, G., and Sipos, T.K., 2018. Strengthening techniques for Masonry Structures of Cultural Heritage According to Recent Croatian Provisions. Earthquakes and Structures, 15(5), 473-485.

Harirchian, E., Hosseini, S.E.A., Jadhav, K., Kumari, V., Rasulzade, S., Işık, E., and Lahmer, T. 2021. A Review on Application of Soft Computing Techniques for the Rapid Visual Safety Evaluation and Damage Classification of Existing buildings. Journal of Building Engineering, 102536.

http://www.koeri.boun.edu.tr/new/ (Accessed date: 05 January 2022)

https://deprem.afad.gov.tr/galeri/246572 (Accessed date:05 January 2022)

https://tadas.afad.gov.tr/list-event (Accessed date: 05 January 2022)

https://tdth.afad.gov.tr (accessed date:06 January 2022).

Isik, E., Aydin, M.C., and Buyuksarac, A., 2020. 24 January 2020 Sivrice (Elazığ) Earthquake Damages and Determination of Earthquake Parameters in the Region. Earthquakes and Structures, 19(2), 145-156.

Işık, E., Işık, M.F., and Bülbül, M.A., 2017. Web Based Evaluation of Earthquake Damages for Reinforced-Concrete Buildings. Earthquakes and Structures, 13(4), 423-432.

Işık, E., Özdemir, M., and Karaşin, İ.B., 2018. Performance Analysis of Steel Structures with A3 Irregularities. International Journal of Steel Structures, 18(3), 1083-1094.

Işık, M., Işık, E., and Haricihian, E., 2021. Application of IOS/Android Rapid Evaluation of Post-Earthquake Damages in Masonry Buildings. Gazi Mühendislik Bilimleri Dergisi (GMBD), 7(1), 36-50.

Işık, E., 2015. Hasarlı bir Betonarme Binanın Performans Puanının Hesaplanması. International Anatolia Academic Online Journal Sciences Journal, 3(2), 47-52.

IMO İzmir Şubesi, 2020, İzmir Depremi Raporu.

İnel, M., Özmen, H.B., and Çaycı, B.T., 2013. Simav and Van Depremleri (2011) Yapı Hasar Nedenlerinin Değerlendirilmesi. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 19(6), 256-265.

Kramer, S.L., 1996. Geotechnical earthquake engineering. Pearson Education India.18TC005365.

Kutanis, M., Ulutaş, H., and Işik, E., 2018. PSHA of Van Province for Performance Assessment Using Spectrally Matched Strong Ground Motion Records. Journal of Earth System Science, 127(7), 1-14.

Mercalli G. 1902. Intensity scales. Bollettino della Societa Sismologica Italiana 8:184–91.

Moehle, J., and Deierlein, G.G., 2004. A Framework Methodology for Performance-based Earthquake Engineering. In 13th World Conference on Earthquake Engineering (Vol. 679).

Morell, K.D., Styron, R., Stirling, M., Griffin, J., Archuleta, R., and Onur, T., 2020. Seismic Hazard Analyses from Geologic and Geomorphic Data: Current and Future Challenges. Tectonics, 39(10), e20

Özden, Ş., Akpinar, E., and Atalay, H.M., 2011 Tarihli Van Depreminde Gözlenen Yapi Hasarlari. Kocaeli Üniversitesi, Kocaeli.

Özmen, B., and Can, H., 2016. Ankara için Deterministik Deprem Tehlike Analizi. Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 31(1).

Şahin H., Alyamaç K.E., Durucan A.R., Demirel B., Ulaş Açikgenç M., Bildik A.T., Durucan C., Demir T., Ulucan M., and Demirbaş N., 2020. 24 Ocak 2020 Mw 6.8 Sivrice/Elazığ Depremi Elazığ Bölgesi Yapısal Hasarlar İnceleme ve Analiz Raporu, Yapı ve Beton Uygulama ve Araştırma Merkezi, Fırat Üniversitesi, Rapor No:2020/D001, Elazığ, Türkiye.

Sharma, R.C., Tateishi, R., Hara, K., Nguyen, H. T., Gharechelou, S., and Nguyen, L. V. 2017. Earthquake Damage Visualization (EDV) Technique for the Rapid Detection of Earthquake-Induced Damages Using SAR Data. Sensors, 17(2), 235.

Tabrizikahou, A., Hadzima-Nyarko, M., Kuczma, M., and Lozančić, S., 2021. Application of Shape Memory Alloys in Retrofitting of Masonry and Heritage Structures Based on their Vulnerability Revealed in the Bam 2003 Earthquake. Materials, 14(16), 4480.

TBEC-2018, 2018. Turkish Building Earthquake Code, T.C. Resmi Gazete; 30364 Ankara Turkey.

Xian, L., He, Z., and Ou, X., 2016. Incorporation of Collapse Safety Margin into Direct Earthquake Loss Estimate. Earthquakes and Structures, 10(2), 429-450.

Yakut, A., Sucuoğlu, H., Binici, B., Canbay, E., Donmez, C., İlki, A., and Ay, B.Ö., 2021. Performance of Structures in İzmir after the Samos Island Earthquake. Bulletin of Earthquake Engineering, 1-26.

Zanini, M.A., Hofer, L., and Faleschini, F., 2019. Reversible Ground Motion-To-Intensity Conversion Equations Based on the EMS-98 Scale. Engineering Structures, 180, 310-320.

Zhai, W., and Zeng, W., 2017. Building Damage Assessment Using a Single Post-Earthquake Polsar Image: a Case of the 2010 Yushu Earthquake. In IOP Conference Series: Earth and Environmental Science (Vol. 57, No. 1, p. 012018). IOP Publishing.