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Seismic risk estimation of the Kirikkale province through street survey based rapid assessment method (SSRA)

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Abstract. The seismic vulnerability of Turkey is relatively high due to its active fault systems with potential to create destructive earthquakes. Thus, reducing the loss of life and property, the number of the earthquake-prone buildings and their retrofit requirements are considerably significant key issues under the scenario earthquakes. The street survey based rapid assessment (SSRA) method can be considered as a powerful tool to determine the seismic vulnerability of building stock of an earthquake-prone city/state. In this study, the seismic vulnerability of the building stock of the Kirikkale province in Turkey is aimed to be estimated adopting the street survey based rapid assessment method (SSRA). For this purpose, central 2074 existing reinforced concrete (R/C) buildings were structurally surveyed with rapid visual site screening and disadvantages such as, the existence of short-column, soft-story, heavy overhangs, pounding effect and local soil conditions were determined for obtaining the structural performance score of each. The results obtained from the study demonstrate that 11-25% of the surveyed buildings in the study region needs to be investigated through more advanced assessment methods. Besides, higher correlation between increasing story number and unsafe/safe building ratio is obtained for the buildings with soft-story parameter than that for those with heavy overhangs and short-column parameters. The conformity of the results of the current study with the previous documented cases of rapid assessment efforts in the recent earthquakes in Turkey shows that the SSRA method for the Kirikkale province performed well, and thus this methodology can be reliably used for similar settlement areas.

Keywords: rapid assessment, seismic vulnerability, building stock, reinforced concrete structures, structural performance score

1. Introduction

Turkey is surrounded with important active fault systems with the capability of creating destructive earthquakes. Approximately 92% of Turkey lies on seismic belt, which also means that 69.7% of the population of the country lives in the 1st or 2nd degree earthquake zone (Binici 2013). Mostly, reinforced concrete building structures (R/C) are more vulnerable to destructive earthquakes occurred in Turkey and the world than other types of structures, such as steel ad masonry structures. The Marmara earthquake in 1999 led to minimum, moderate or severe damage in about 250,000 R/C structures (Gross and Phan 2000). These results demonstrated the need to discuss the problems of earthquake performance of the existing structures located on seismically active regions and to perform elaborate investigations with the purpose of diminishing social and economic problems of the cities of Turkey after destructive earthquakes. For this aim, many attempts have been made to determine the seismic vulnerability of existing building stock. (Hassan and Sozen 1997, Polat and Mete 1999 Sucuoglu and Yazgan 2003).

A case study on the rapid structural seismic identification of a total number of 19,885 commercial buildings in the Auckland region was carried out by Walsh *et al*. (2017). They considered certain structural parameters of structural system such as, lateral load, number of stories and construction time, and concluded that the considerations in that study could be reliably utilized for investigation on rapid assessment of earthquake vulnerable building structures. A similar investigation was carried out by Ajay *et al*. (2017) for determination of the risk of residential area in Himachal Pradesh, India using rapid visual screening method. They proposed a new rapid seismic visual screening method by inspecting approximately 9100 building structures. Apart from the prediction, Palanci and Senel (2013) demonstrated that a rapid seismic performance assessment method for precast buildings might be developed comparing analytical results with those obtained from the site observations in the recent earthquakes in Turkey. In literature, many studies e.g., (Jain *et al*. 2010, Özhendekci and Özhendekci 2012, Ilki *et al*. 2014, Al-Nimry *et al*. 2015, Albayrak *et al*. 2015, Perrone *et al*. 2015) were conducted on rapid seismic assessment for different purposes.

Recent approaches to the evaluation of seismic vulnerability of buildings during earthquake motion are generally presented in three steps. The first step is the basic level of "*Rapid Street Survey*". In this level, no detailed

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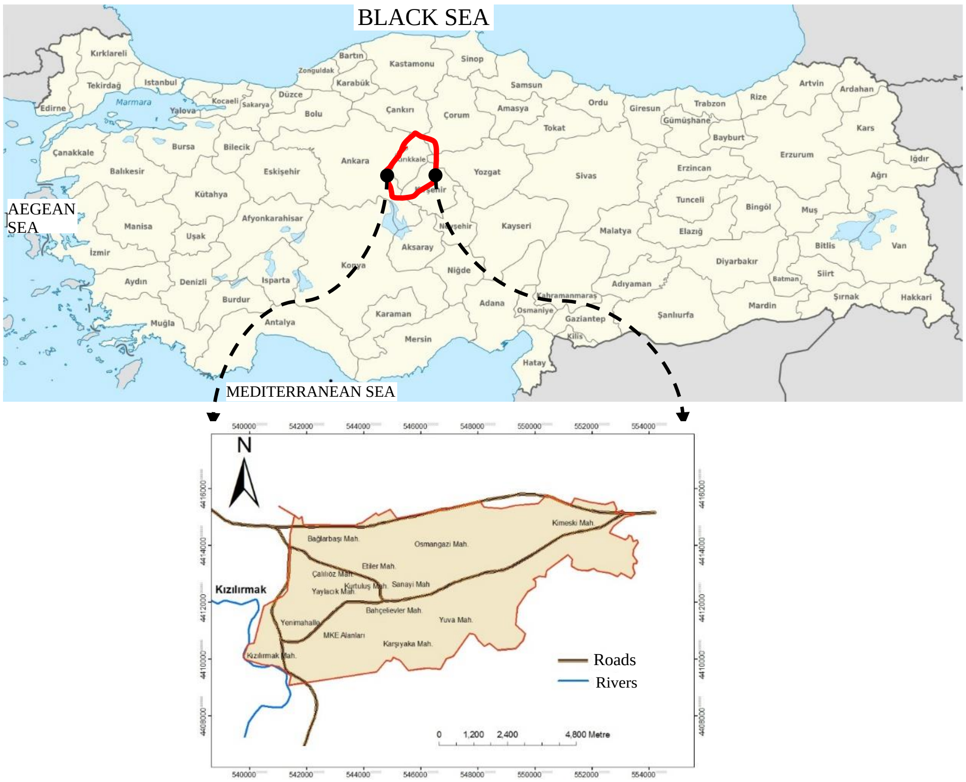

Fig. 1 Location of the city of Kirikkale

analysis of building structures is employed. Potential buildings with high seismic vulnerability are determined with rapid street survey based on their official inventory. The assessment methods proposed by Level-I, FEMA-310 (1998) Level-I, and Sucuoglu and Yazgan (2003) consider this step as a starting point for initial assessment of buildings. Simplified structural analysis of buildings is made in the second step. This step requires to obtain the project specifications of structural and non-structural elements of buildings considered. The methods developed by FEMA-310 (1998) Level-2, Ozcebe *et al*. (2003), Yakut *et al*. (2003) adopted this step in the rapid assessment of buildings. Ozcebe *et al*. (2006) showed that the method could be implemented to large building stock within a suitable time. In the last step, detailed structural properties of buildings are obtained and they are used to perform advanced linear and non-linear analyses of buildings. ATC-40 (1996), FEMA-356 (2000), EC8 (2004), Sucuoğlu *et al*. (2004) included this task so as to properly make a decision on the performance of structures.

1.1 Aims and scope of the study

In the current study, the city center of Kirikkale as shown in Fig. 1, which is located on the active earthquake zone of the Central Anatolia, is considered. The city center of Kirikkale is located on the 1st degree i.e., the highest earthquake region according to the map of Turkish earthquake zones. Due to the previously occurred earthquakes in the vicinity of the city, it is necessary to assess the seismic risk and vulnerability of building stock of the city center of Kirikkale and to take the required measures depending on the outcomes from the present study. Therefore, the main aim of the study is to show the importance of the rapid street survey on determining the current structural performance of R/C building stock and to classify R/C buildings as safe/unsafe considering their structural irregularities. Based on the aims of the study, the city center of Kirikkale is considered for the investigation of rapid street survey assessment in the present study. The first effort is made to determine the variation of Peak Ground Velocity (PGV) of Kirikkale province through the probabilistic seismic hazard analysis (PSHA). The obtained PGV distribution of the city is then utilized to understand the street survey data and to specify the structural performance score of the building stock of the city center of Kirikkale. Finally, structurally observed buildings are considered to estimate seismic risk and structural performance of the buildings as well as the retrofit requirements under the possible scenario earthquake motion.

2. Methodology

Seismic vulnerability of building stock of the city center of Kirikkale is determined considering the first level of street survey based rapid assessment (SSRA) method proposed by Sucuoglu and Yazgan (2003), based on the general urban properties of Kirikkale province. The proposed method was statistically developed according to the post-earthquake assessment of 447 buildings with severe, moderate and low/no-damaged buildings after the 1999 Duzce earthquake. As given in Table 1, the method

Table 1 Rapid seismic assessment form

SECTION I: BUILDING IDENTIFICATION				
Street				
Number Of Residential Unit				
Map Section/Block No/Parcel No				
City Information System No				
Construction Year				
Geographical Coordınates (Lat/Long.)				
SECTION: II BULDING DESCRIPTION				
Number of Stories (Except for basement)	Ground (…) Clerestory (…) Half-Story (…) Normal (…) Top (..)			
Embedded Basement	Yes ☐			No ☐
Free Story	Number of (…..)			
Corrosion	Yes ☐	No ☐	Unobserved ☐	
Approx. Width of Front Garden	(…m)			
Approx. Building Front Side Depth	(…m)			
Heavy Overhangs	Yes ☐			No ☐
Building Order	Separate ☐	Contiguous ☐	Corner Contiguous ☐	
Weak/ Soft Story	Yes ☐			No ☐
Short Column	Yes ☐			No ☐
Columns at Cantilever Beam	Yes ☐			No ☐
Height Difference Between Contiguous Buildings	Yes ☐			No ☐
Slab Levels Between Contiguous Buildings	Yes ☐			No ☐
Roof Geometry	Gamble ☐	Terrace ☐		Hip ☐
Observed Building Quality	Good ☐	Moderate ☐		Poor ☐
Construction Area Slope	No ☐	Low ☐		Steep ☐
Near to Historical Buildings	Yes ☐			No ☐
SECTION III: PLANNING INFORMATION				
Occupancy	Dwelling ☐	Commercial ☐	Industrial ☐	Public ☐
Ground Story				
Clerestory				
Normal Story				
Neighborhood Occupancy	Front Garden Yes ☐	No ☐	Back Garden Yes ☐	No ☐
Fire Escape	Yes ☐	No ☐		
Lift	Yes ☐	No ☐		

consists of a form including the observational features of buildings and the earthquake performance score of each building is obtained according to the structural parameters specified within the street survey. Considering the score scale given in the method, the assessed buildings are classified either seismically risky or not. The structural parameters, which are the most crucial part of the method, are explained in detail below.

√ Number of stories: A linear relationship between the number of stories and damage level of reinforced concrete structures was obtained on the post-earthquake field evaluation after 1999 Kocaeli and Duzce earthquakes. Damage level is observed to increase in the buildings with the increase in the number of stories (Sucuoglu and Yazgan 2003).

√ Soft story: The vertical bearing structural elements of columns and piers on the side and inner grids of buildings at the enterance-level (1^{st} story) are higher than that of other story and/or are removed from the frame system for obtaining larger area for various commercial aims. Due to this irregularity, the strength and rigidity of the vertical bearing elements at this story are generally lower than those at the other stories (DolŠEk and Fajfar 2001).

√ Short column: This irregularity problem is defined as no continuous infill wall along the height of columns. When earthquake hits the buildings, heavy damage resulting from shear failure is observed on the vertical bearing elements of columns. The short-column irregularity is generally observed at the columns of the first story modified for commercial aims. In many post-earthquake assessments after the destructive earthquakes in Turkey, this irregularity was observed in heavily damaged and collapsed buildings (Guevara and Garcı´a 2005).

√ Heavy Overhangs: Overhangs are basically used to expand the plan of the buildings at the upper stories. This irregularity leads to difference between the bottom and upper story total plan areas, which is another irregularity of mass and stiffness and the beam discontinuity on side frames of buildings. Thus, the required continuous frame system idealization is not provided for the stories with heavy overhangs. Therefore, earthquake and service loads are not

Fig. 2 One of the considered R/C buildings with some irregularities

transferred to the other frames of building. The field reconnaissance carried out after the destructive earthquakes indicated that the build3ings with heavy overhangs were damaged more than those with no overhangs (Sucuoglu and Yazgan 2003).

√ Pounding effect: This effect is observed on the contiguous buildings with different story level/heights. Due to the different vibration frequencies under the earthquake motion, damage level can be very high for the upper stories of buildings (Anagnostopoulos and Spiliopoulos 1992).

√ Topographic effect: The topographic amplification is another factor magnifying the effect of the earthquake motion on the buildings. Foundations that are settled on the hills with slope angle higher than 30° generally do not show a good performance for transferring service and earthquake loads to soil. Besides, uniform settlement may not be provided with this type of topographic condition. Damage level is observed to increase in the buildings placed on critical topographic regions (Sucuoglu and Yazgan 2003).

√ Visional quality: This parameter helps to observe the general quality of the construction material used for the buildings. Maintenance efforts can also be inspected with this parameter. Street survey made after the destructive earthquakes in Turkey demonstrated a very close agreement between the visional quality and damage level of buildings.

√ Local soil condition: Local soil condition is one of the main parameters leading to change in the damage level of buildings and the ground motion parameters. Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV) are the indicators to specify the local soil condition effect. PGV can be more accurate than PGA under the earthquakes with high magnitude to determine the soil conditions (Yakut *et al*. 2003). The past destructive earthquakes also indicated high correlation between PGV value and damage level of buildings. Due to low sensitivity of PGV to the high frequency content, PGV identifies ground motion parameters very well.

Table 2 Initial performance and corresponding penalty score of buildings (Sucuoglu and Yazgan 2003)

STORY	VR I 60 <PGV <80	VR II 40 <PGV <60	VR III 20 <PGV <40	SS	HO	VQ	SC	PE	TE
1	90	125	160	0	-5	-5	-5	0	0
2	90	125	160	0	-5	-5	-5	0	0
3	90	125	160	-10	-10	-10	-5	-2	0
4	80	100	130	-15	-10	-10	-5	-3	-2
5	80	90	115	-15	-15	-15	-5	-3	-2
6	70	80	95	-20	-15	-15	-5	-3	-2
7	70	80	95	-20	-15	-15	-5	-3	-2

NS: Number of story VR: Velocity region PGV: Peak ground velocity SS: Soft story HO: Heavy overhangs VQ: Visional quality SC: Short column PE: Pounding effect TE: Topographic effect

In Fig. 2, certain irregularities of one of the considered reinforced concrete (R/C) buildings in the present study are shown. These structural parameters are first investigated for each building and then earthquake performance scores of buildings are determined by decreasing the corresponding parameter score from initially given score that is assigned according to the peak ground velocity (PGV) of potential earthquake in the region considering the local soil condition. As given in Table 2, the associated penalty scores are defined for each structural parameter. Thus, seismic performance score of buildings is calculated by Eq. (1) (Sucuoglu and Yazgan 2003)

$$Total\ Score = Velocity\ region\ score\ (HB) - \sum_{1}^{6} (Penalty\ score \times Parameter) \quad (1)$$

3. Determination of Peak Ground Velocity (PGV)

In the rapid seismic assessment method, the most critical parameter is PGV in an effort to define initial performance score. PGV values are obtained conducting elaborate site response analyses through previously obtained site soil condition data.

In order to determine peak ground velocity (PGV) of the city of Kirikkale, a probabilistic seismic hazard analysis (PSHA) is first carried out for study region. The historical earthquakes of the region, used in PSHA, are compiled from the catalogues of the Directorate of Turkish Disaster Affairs (AFAD), Bogazici University Regional Earthquake-Tsunami Monitoring Center (BDTIM), and the United States Geological Survey (USGS). The earthquakes within a circle of 100 km radius, centered on the city center of Kirikkale, are identified and used in the PSHA. Each source zone could not be analyzed separately since the number of ground motions with a moment magnitude greater than 4.5 in the source regions of the study area, which are the Karakecili Fault Zone, the Seyfe Fault Zone, the Keskin Fault Zone and the Kırıkkale-Sungurlu Fault Zone as depicted in Fig. 3, are inadequate. Special attention was

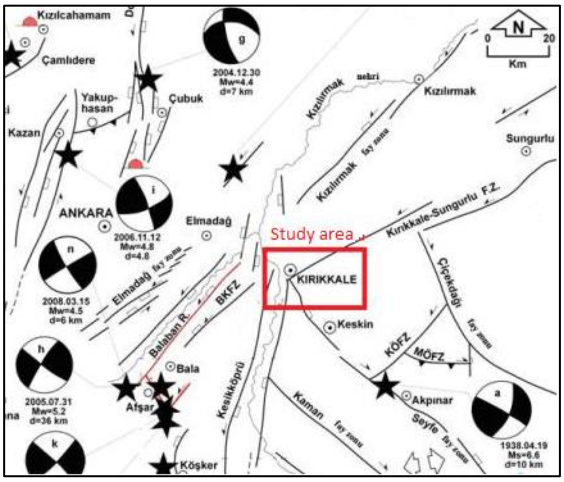

Fig. 3 Significant faults around Kirikkale city (Koçyiğit 2008)

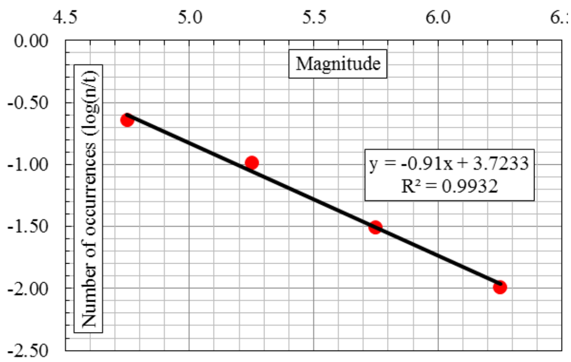

Fig. 4 Relation between the magnitude and the frequency of the earthquake

paid not to use identical data (the same ground motion record) from different catalogues in the analyses.

The probability distribution of earthquake magnitudes is derived from the relations that give the relationship between magnitudes and the number of occurrences of earthquakes. The well-known equation proposed by Gutenberg and Richter (1956) is used in the present analysis for estimating the distribution of number of earthquakes with different magnitudes Eq. (2)

$$logn(M) = a - b \cdot M \qquad (2)$$

where, *n(M)* corresponds to the number of earthquakes with a magnitude greater than or equal to *M* for a duration and in a certain region; *a* is the average annual seismic activity index parameter; *b* is the parameter accounting for the characteristics of seismic activities in the region.

Using the earthquake data obtained from the earthquake catalogues for a circle of 100 km radius centered on the city center of Kirikkale, the relations between the amplitude and the frequency of the earthquakes given in Table 3 are obtained as shown in Fig. 4. In addition, using Poisson probability model, the moment magnitude corresponding to 10 % exceedance probability in 50 years (475 years return period) for the city of Kirikkale is determined as M_w=7.0 (moment magnitude).

In the seismic analyses of structures, three major

Table 3 Earthquake motion records for PGV analysis

Date of the Earthquake (dd/mm/year)	Latitude	Longitude	Depth (km)	Magnitude (M_w)
16/01/1918	38.800	32.900	10	5.5
06/09/1919	40.680	33.890	10	5.3
10/04/1928	40.220	33.670	10	5.8
09/04/1930	39.700	34.000	30	5.3
28/06/1933	39.300	33.200	30	4.9
07/12/1935	40.600	33.600	10	5.3
19/04/1938	39.440	33.790	10	6.4
27/04/1938	39.890	34.100	10	4.8
21/05/1958	40.650	33.360	10	4.8
20/01/1965	40.500	34.000	33	4.7
19/02/1973	40.280	33.860	22	5.0
27/04/1973	38.650	32.920	29	4.9
22/09/1975	40.360	33.400	3	4.9
04/07/1978	39.450	33.190	23	4.9
04/21/1983	40.650	33.360	36	4.8
04/06/1985	39.550	32.930	5	4.5
08/05/1990	40.230	33.880	17	4.7
24/08/1999	39.610	32.620	8	4.8
08/12/2001	40.220	33.810	10	4.5
30/07/2005	39.420	33.110	1	5.4
20/12/2007	39.423	33.067	7	5.5
31/01/2008	40.245	33.200	5	5.0
15/03/2008	39.459	33.008	12	5.2

characteristics of an earthquake, namely the amplitude, the duration and the frequency content, need to be properly identified. The ground motion parameters at a site (PGD: peak ground displacement, PGV: peak ground velocity and PGA: peak ground acceleration) associated with the strong ground motion at the source are estimated according to the attenuation relationships. These attenuation relationships account for the ground conditions, source distance, magnitude and energy losses of the seismic waves. In a recent project (Next Generation Attenuation WEST2, i.e., NGA-WEST2) supported by the Pacific Earthquake Engineering Research Center (PEER), new generation attenuation relationships are developed by different study groups: Abrahamson *et al.* (2013) (ASK13), Boore *et al.*(2013) (BSSA13), and Campbell and Bozorgnia (2013) (CB13). Attenuation relationships, developed within the NGA-WEST2 project, are employed in the present study to obtain the PGA values and the target spectrum at the bedrock level of the study site from the earthquakes at the sources. As can be seen in Fig. 3, the study area is located at a distance of 5.0 km from the Karakecili Fault Zone and 10.0 km from the Kirikkale-Sungurlu Fault Zone.

When the target spectrum is determined from the attenuation relationships, the moment magnitude of M_w=7.00 determined from the PSHA is taken into account and the worst case is determined as 5.0 km according to the earthquake scenario. The target spectra from different attenuation relationships (ASK13, BSSA13 and CB13) are shown in Fig. 5.

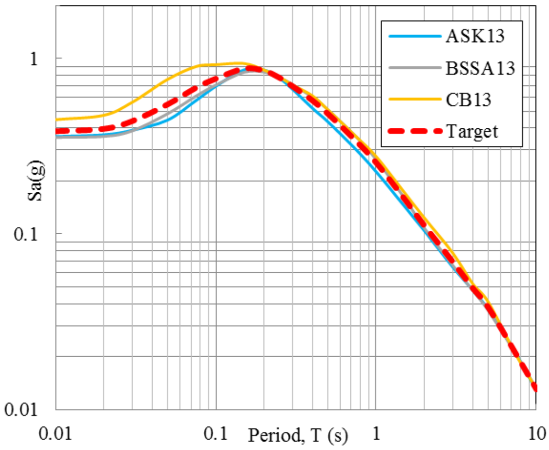

Fig. 5 The target response spectra at the bedrock level

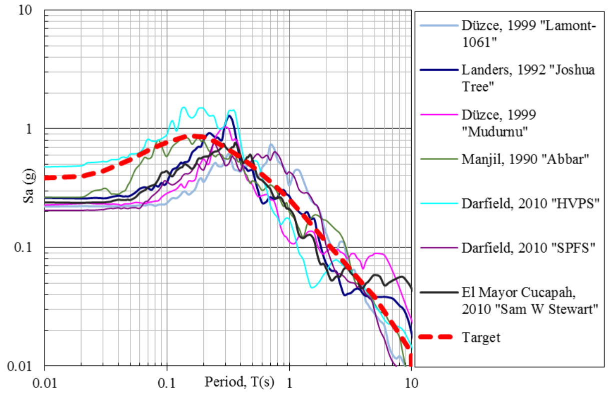

Fig. 6 Target and scaled response spectra

Earthquake records are selected from the PEER database based on the earthquake magnitude, soil conditions, fault type and distance to the fault of the study area. As depicted in Fig. 6, the earthquake records also have moment magnitudes close to the design earthquake (M_w=7.0) and distance to fault values in good agreement with the respective value of the study area.

The variation of the shear wave velocity (V_s) from ground surface to the bedrock is determined according to Standard Penetration (SPT) values from 108 boreholes, 6 Multi-channel Analysis of Surface Waves (MASW), Refraction Microtremor (Re-Mi) and 15 seismic refraction tests conducted in the field. In the first 15-20 m depth of the soil profile, SPT-N values are utilized; however, from this depth to the bedrock, V_s is obtained using MASW, Re-Mi and seismic refraction tests. As given Eq. (3), the V_s values for all soil types are calculated using empirical expression developed by Iyisan (1996) for Turkish sites.

$$V_s = 51.5 \cdot N^{0.516} \tag{3}$$

where, V_s: shear wave velocity (m/s), N: SPT blow count values.

In this study, the model proposed by Darandeli (2001) is adopted to perform surface response spectrum analysis, which proved that damping and moduli of soils under cyclic loading condition are related to soil confinement pressure and plasticity indices. Based on the information obtained from boreholes from site investigation, a representative soil

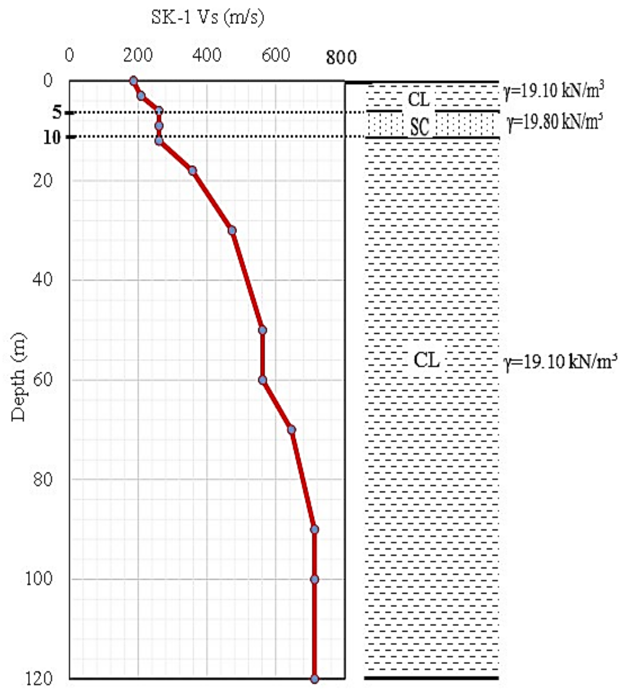

Fig. 7 The Vs-Depth variation of the soil considered

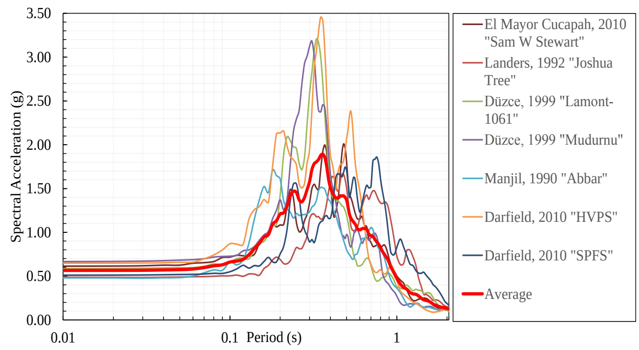

Fig. 8 Average and surface response spectrums

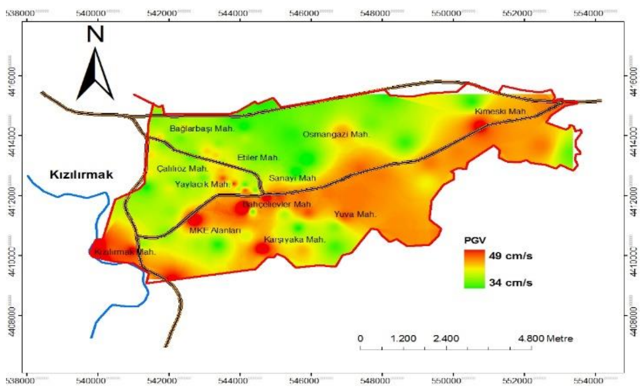

Fig. 9 PGV value distribution of for the city center of Kirikkale

profile is obtained as sown in Fig. 7 and for equivalent linear site response spectrum analyses through the SHAKE2000 software (GeoMotions-LLC 2017), this profile is utilized. The seven earthquake records scaled according to the target spectrum as demonstrated in Fig. 6 are considered as input motions for the analyses.

Accordingly, the surface response spectrums and their average of them are obtained as given in Fig. 8. In the analyses, PGV values are determined as 34.0 cm/s<PGV <49.0 cm/s about the spectral acceleration value of 2.0 g. Distribution of shear wave velocity is also given in Fig. 9 with a contour map. As shown in Fig. 9, the PGV values are relatively high for the southern and middle part of the city (specifically, MKE regions, Kızılırmak, Bahçelievler, Yuva and Kimeski streets).

4. Evaluation of the Data Obtained From the Kirikkale Province

Total building stock of the Kirikkale province consists of 27,000 R/C buildings. In this study, approximately 10 % of the stock that corresponds to 2074 buildings are observationally inspected by the professional team in the region. The parameters Section II are identified and the form given in Table 1 is prepared for each building. Earthquake performance score of buildings is calculated by decreasing the corresponding parameter score from initial score that is assigned according to the peak ground velocity (PGV) of potential earthquake in the region.

Considering the PGV value distribution of the city indicated in Fig. 9, the velocity region is selected as II (40<PGV<60) to determine the initial earthquake performance of the buildings. The distribution of the inspected buildings in terms of the number of stories and the earthquake performance score are given in Fig. 10 and Fig. 11, respectively.

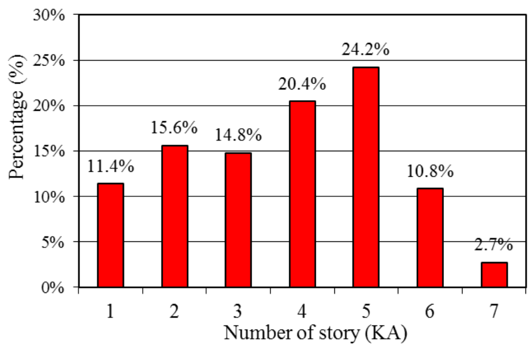

Fig. 10 The distribution of the inspected buildings according to the number of stories

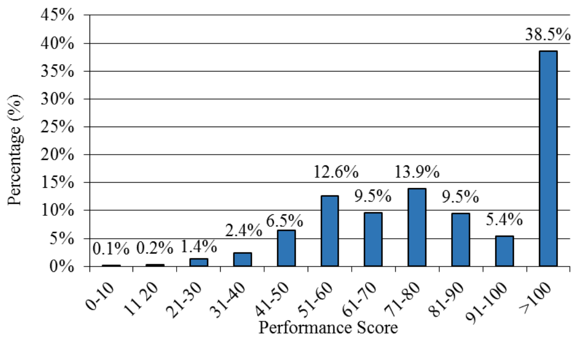

Fig. 11 The distribution of the inspected buildings according to the earthquake performance score

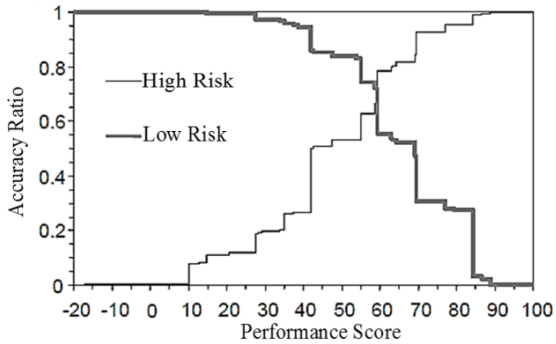

Fig. 12 The relationship between the accuracy ratio and the calculated earthquake performance score based on the Duzce earthquake database (Sucuoglu 2007)

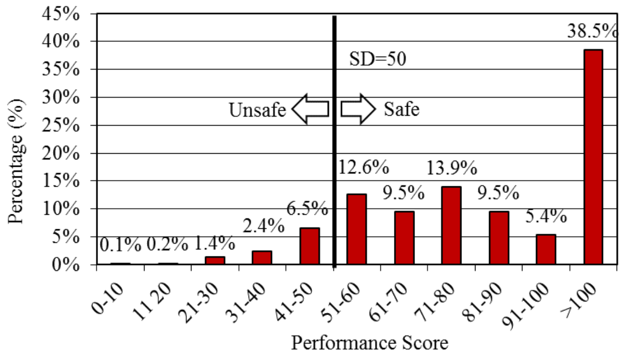

Fig. 13 The distribution of the inspected buildings according to earthquake performance score for SD=50

According to initially defined earthquake performance score, Fig. 11 also presents an important information that the majority of the buildings are located on velocity region II (VR II).

Another important point of the street survey-based methods is to correctly determine the "limit score" of earthquake performance that is safe (low-risk) or unsafe (high-risk). This limiting score of 50 was proposed by Sucuoglu and Yazgan (2003). The relationship between the accuracy ratio and the calculated earthquake performance score, which was determined by Sucuoglu (2007) adopting the Duzce (1999) earthquake database, is presented in Fig. 12 for the safe and unsafe buildings. As indicated in Fig. 12, the intersection point of 60 performance score demonstrates that 75% of the buildings with the earthquake performance score lower than 60 are considered as unsafe while 75% of the buildings with the earthquake performance score higher than 60 are safe. Thus, the earthquake performance score lower than 60 can be utilized reliably for the unsafe buildings and the score higher than 60 is considered as more suitable for the safe buildings.

In order to specify the safe buildings (low-risk) or unsafe (high-risk) buildings, limit earthquake performance score (SD) of both 50 and 60 are considered in the current study. The performance score distribution of the inspected building are given in Fig. 13 for SD=50. To be limits, Fig. 14 presents the distribution of safe and unsafe building ratios for SD value of 50. According to SD value of 50, the distribution maps are given in Fig. 15 and Fig. 16 for

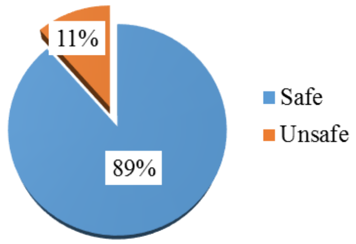

Fig. 14 Safe and unsafe building ratio for SD=50

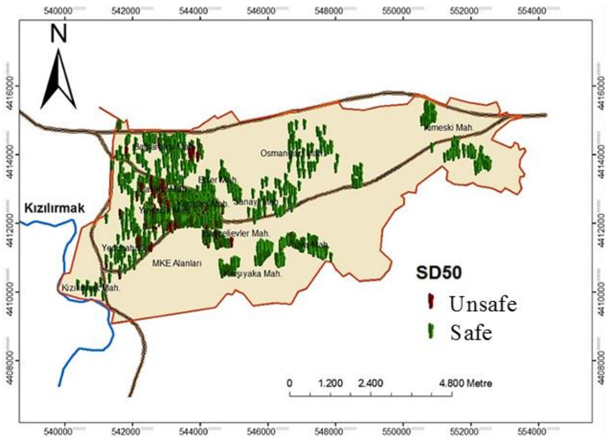

Fig. 15 Safe and unsafe buildings map for SD=50

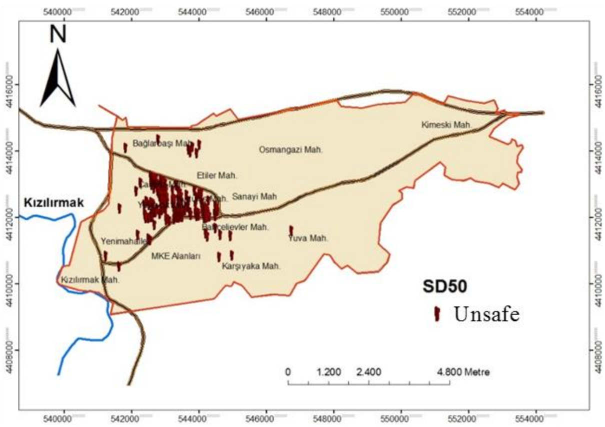

Fig. 16 Unsafe buildings map for SD=50

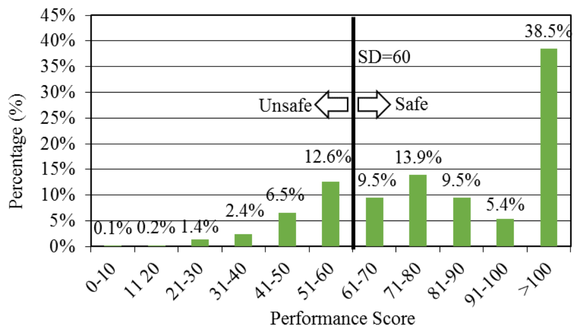

Fig. 17 The distribution of the inspected buildings according to earthquake performance score for SD=60

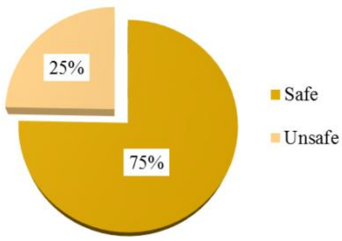

Fig. 18 Safe and unsafe building ratio for SD=60

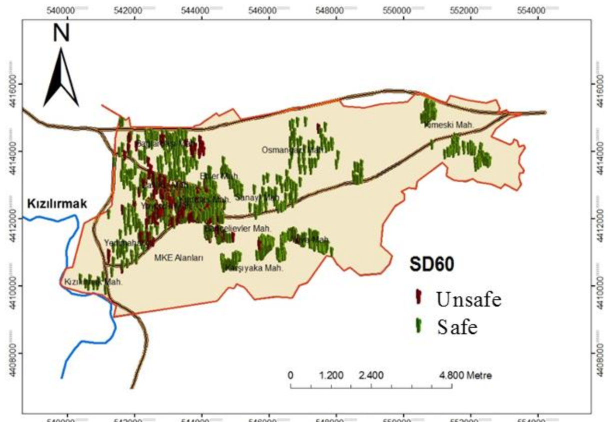

Fig. 19 Safe and unsafe buildings map for SD=60

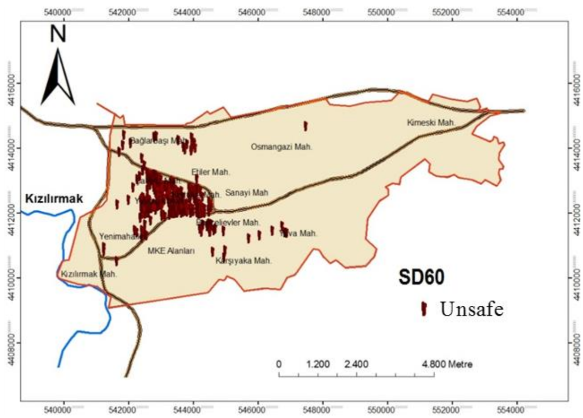

Fig. 20 Unsafe buildings map for SD=60

safe/unsafe and only unsafe buildings, respectively. Similar efforts are made for the limit score value of SD=60 and the results using this limit are presented in Figs. 17-21.

The percentage distribution of the inspected buildings according to the earthquake performance score for SD=60 given in Fig. 17 indicates that approximately 50% of the considered building stock shows good performance with the earthquake performance score higher than 80. As expected, the ratio of unsafe buildings is obtained to be higher for SD=60 than that for SD=50 as depicted in Fig. 18. The distribution maps given in Figs. 19-20 illustrate of the obtained results.

Based on the outcomes from the analyses, 11% of buildings are unsafe for the limit earthquake performance score of SD=50. The corresponding value for SD=60 is 25%. In the study conducted by (Sucuoglu 2007), the ratio of the collapsed and heavily damaged buildings to the considered building stock was determined as 20% during the 1999 Duzce earthquake. A similar ratio was obtained for the buildings in Golcuk and Adapazari regions during 1999 Kocaeli earthquake. Taking the similar seismic vulnerability

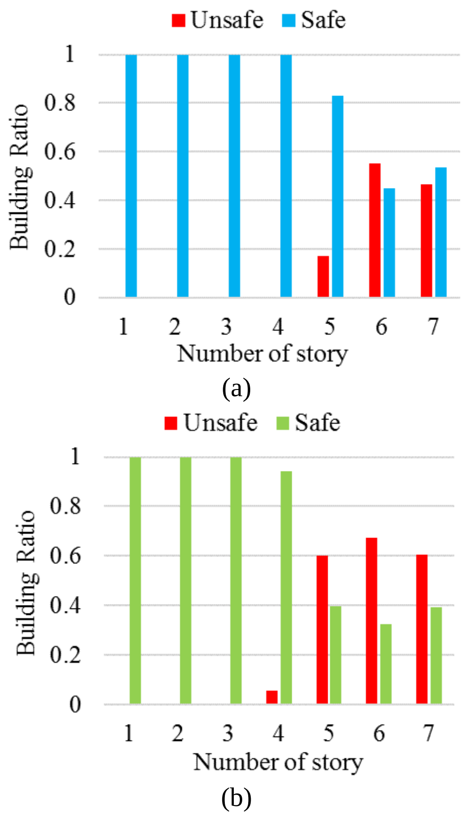

Fig. 21 Safe and unsafe building ratio according to the number of story: (a) SD=50 (b) SD=60

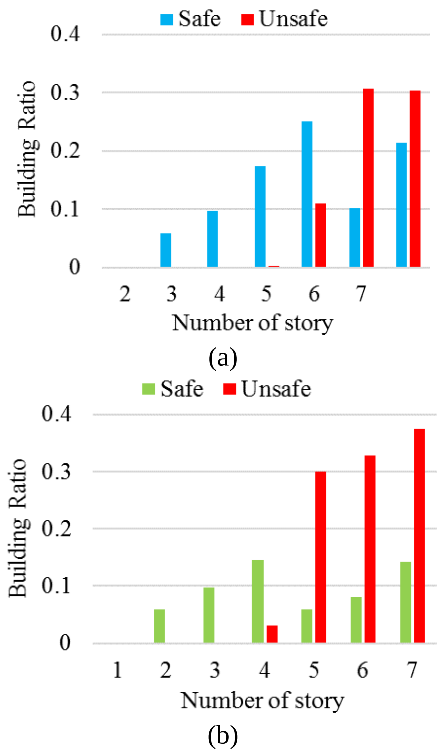

Fig. 22 Safe and unsafe building ratio according to the heavy overhangs: (a) SD=50 (b) SD=60

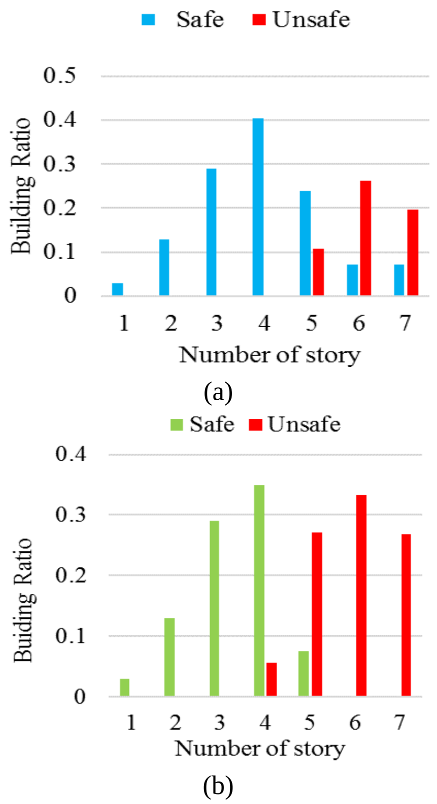

Fig. 23 Safe and unsafe building ratio according to the soft-story: (a) SD=50 (b) SD=60

of the cities on the active faults into account, the ratios about 20-25 can also be expected for the city of Kirikkale. The results from this study have shown similar ratio ranging between 11-25% unsafe buildings under the possible scenario earthquake depending on the selected SD value.

In Fig. 21, safe and unsafe building ratios are given according to the number of stories for SD=50 and SD=60. The effect of the number of stories on the building vulnerability are also shown in Figs. 22-24 in terms of the parameters of heavy overhangs, soft story and short column, respectively for SD=50 and SD=60. Unsafe building ratios increase with increasing number of stories for both limit earthquake performance scores. The results also clearly show that the buildings with more than stories are more vulnerable to earthquake effect than those with less than four. Therefore, the number of stories can be considered as one of the main parameters for seismic vulnerability evaluation.

According to Fig. 22, safe building ratios for approximately all story decreased as 70%-80% due to heavy overhangs. As expected, this ratio also decreased more with increasing number of stories. Similar results are obtained for the parameters of short-column and soft stories, given in Fig. 23 and Fig. 24, respectively. However, the most effective parameter on the decrease in the safe building ratio is determined as the short column owing to 90% decrease.

The variation of the visional quality parameter with the building ratios is shown in Figs. 25-26 for SD=50 and SD=60 according to the number of stories. Unsafe building ratio values are obtained to be higher for six and seven-story buildings with low visional quality compared to the others.

The visional quality parameter also affects the safe

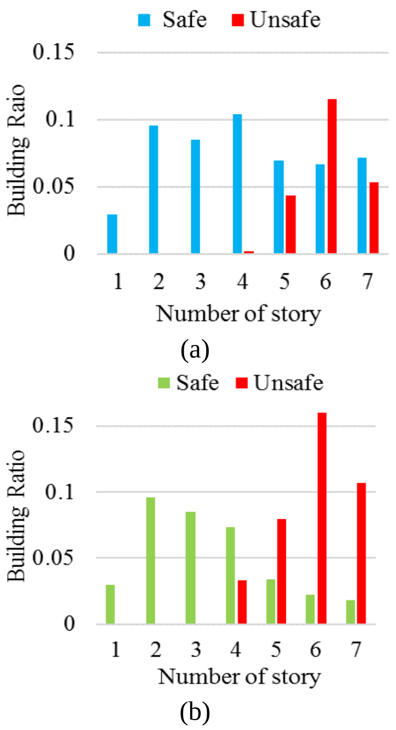

Fig. 24 Safe and unsafe building ratio according to the short-column: (a) SD=50 (b) SD=60

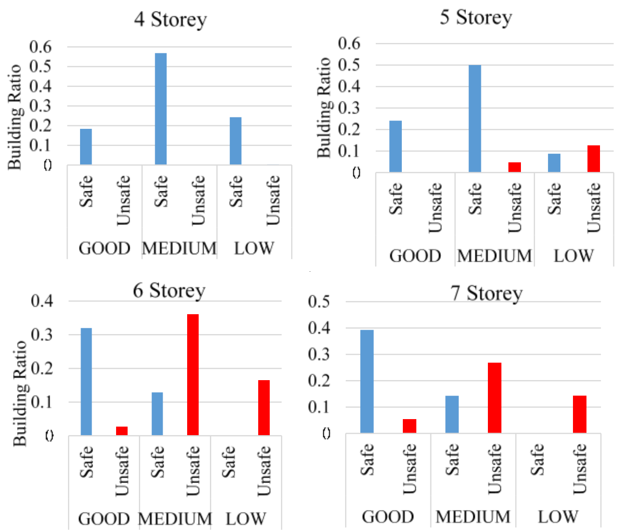

Fig. 25 Safe and unsafe building ratio according to the visional quality for SD=50

building ratio with nearly 50% for both limit performances as shown in Fig. 25 and Fig. 26. Based on the results, the effect of visional quality level of good, medium and low on the ratios is determined to be linear. It is also predicted from the results that high-rise buildings are influenced more from environmental condition (durability condition).

5. Conclusions

The street-survey-based-rapid-assessment (SSRA) methods aim to qualitatively determine seismically vulnerable

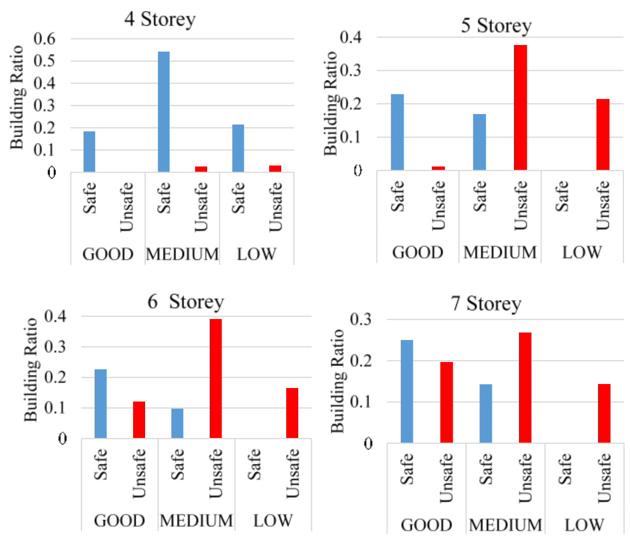

Fig. 26 Safe and unsafe building ratio according to the visional quality for SD=60

buildings at the city center and to investigate further them with advanced methods. In the current study, an investigation on the determination of seismic vulnerability of the building stock of the city center of Kirikkale is carried out adopting the SSRA method. The peak ground velocity (PGV) estimation is obtained to be the most important task due to its influence on assigning initial earthquake performance score to buildings. Therefore, a comprehensive site investigation study, consisting of 108 boreholes, 6 Multi-channel Analysis of Surface Waves (MASW), Refraction Microtremor (Re-Mi) and 15 seismic refraction tests, is conducted for the determination of PGV for the city center of Kirikkale.

The outcomes of the study have shown that the number of high-risk (unsafe) buildings increases and the number of low-risk (safe) buildings in the city decreases with an increase in the number of stories. Thus, a high correlation between the number of stories and seismic vulnerability is obtained for the buildings in the city center of Kirikkale. For buildings with the other important parameters of the heavy overhangs, soft story and short column, the number of safe buildings generally decreases with the increase in number of stories. In addition, a higher correlation is obtained for the buildings with soft story irregularity than that for those with the other considered irregularities. Upon considering these parameters, the safe building ratios decrease relatively high, which reaches to 70-90%. The most decrease in the safe building ratios is obtained for the short-column parameter with 90%. This ratio is determined as 70% and 60% for the heavy overhangs and soft-story parameters, respectively. Therefore, these structural parameters should be considered as significant variables for rapid visual screening process of buildings.

With the increase in the number of stories, the adverse effect of visional quality on the damage level of buildings also increases. Based on these results, the buildings with multi-story and low visional quality are expected to be vulnerable under the scenario earthquake for the city of Kirikkale. The effect of visional quality level of good, medium and low on the safe/unsafe building ratios is determined to be linear. Thus, the influences of this parameter can be easily estimated in the process. The environmental condition (durability) resistance of high-rise buildings is also predicted from the results to be lower than low-rise buildings.

The present study conducted for the Kirikkale province demonstrates a close agreement with the other post-earthquake visual screening data in Turkey is obtained in terms of safe/unsafe building ratios. Thus, this concludes that the considerations and structural parameters mentioned in the present study are specified adequately for the Kirikkale region and that they can be reliably utilized for detailed investigation on rapid structural assessment of buildings on this or nearby region. In order to mitigate adverse effects of earthquakes and to especially reduce the loss of lives, the street-survey-based-rapid-assessment (SSRA) methods that help to quickly obtain the seismic vulnerability of the buildings should be complemented with more detailed investigations by considering further important parameters such as, soil liquefaction.

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