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A rapid seismic risk assessment method for existing building stock in urban areas

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Abstract

Eskisehir is a city in the northwestern part of Turkey which is seismically quite active zone. For this reason, identifying and strengthening of the deficient buildings in northern part of Eskisehir city center is very important in terms of minimal loss of life and damage. The proposed methodology for seismic failure risk assessment in urban building stock is based on the techniques of the screening procedure developed by Sucuoğlu. Rapid street screening for potential seismic hazards is a simple and effective seismic risk assessment method. The procedure is applied to detect, inventory, and rank the most vulnerable buildings in specified region that may damage during a forthcoming earthquake. Applied method is based on the observations and giving score for the selected buildings, considering some selected parameters from the street walking. The risk assessment considered criteria as the age of building, number of stories, existence of soft story, short column, heavy overhangs, pounding affect, topographic effects, visual building construction quality and earthquake zone where the building was located. After the first step evaluation on site, determined performance score (Earthquake Risk Score–E.R.S) of each building was calculated and the most dangerous buildings in terms of earthquake safety were identified. In a large scale in-situ investigation a set of 1643 buildings within the northern part of Eskisehir were seismically assessed. According to the E.R.S. points, each inspected building was classified into one of three vulnerability classes which are high risk, moderate risk and low risk. The results revealed that total 218 among 1643 buildings were classified as high risk and more detailed evaluations of these buildings were recommended before confirming the building as earthquake risk.

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Keywords: Seismic risk assessment ; Earthquake risk score ; Urban buildings ; Visual screening ; Street survey

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1. Introduction

More than 92% of Turkey's territory is exposed to earthquake hazards and 95% of the total population lives under high seismic risk [1]. Approximately 250.000 buildings in the earthquake area subjected to damages from light to total collapse in 1999 Marmara Earthquake [2]. The most important developments related to rapid assessment methods were formed by FEMA-ATC reports [3], [4]. Since 1992 Erzincan earthquake, some rapid assessment methods are used to identify collapse vulnerable buildings in Turkey [5], [6], [7]. Seismic performance scores of the 477 damaged buildings surveyed in Düzce are correlated statistically with a two-level risk assessment procedure [8]. The applied methodology in this study, for seismic failure risk assessment in urban building stock is based on the techniques of the screening procedure developed by Sucuoğlu [9]. Eskisehir is a city in the northwestern part of Turkey which is seismically quite active zone. Eskisehir city center is identified in Seismic Zone 2, according to the earthquake zonation map of Turkey [10]. The largest earthquake in this century on Eskisehir history occurred with a moment magnitude of 6.4 on 20th February 1956 and approximately 2800 buildings were heavily damaged [11]. In 1999 Marmara Earthquake, 70 buildings were heavily damaged and one of them was collapsed in Eskisehir in spite of 130 km distance between two cities [12].

2. Method

2.1. Characteristic of Investigated Regions

In this study, the procedure is applied to detect, inventory, and rank the most vulnerable buildings in northern part of Eskisehir that may damage during a forthcoming earthquake. In a large scale in-situ investigation a set of 1643 buildings within the northern part of Eskisehir were seismically assessed with sidewalks by educated observers. Investigated districts and territories are shown on a map in Figure1.

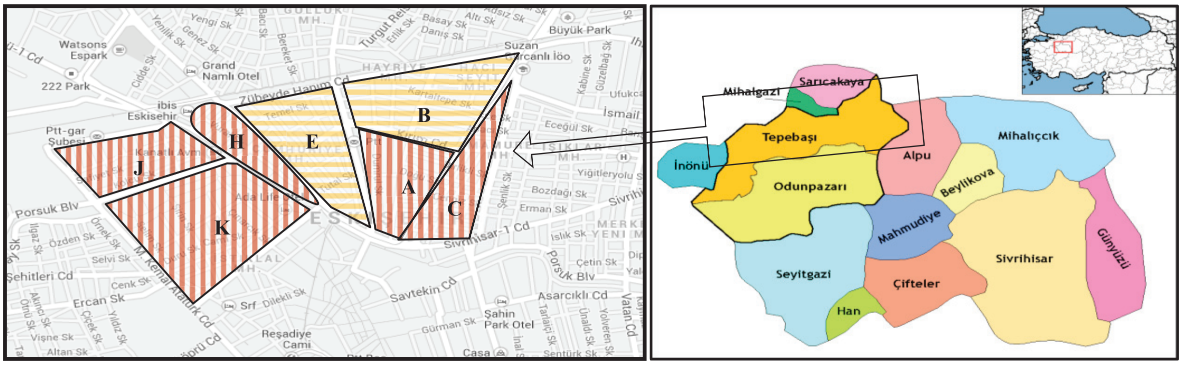


Figure 1. Investigated districts and territories

2.2. Street Surveying

Seismic risk assessment procedure for R.C. buildings applied in this study is based on the techniques of the street surveying developed by Sucuoğlu [9]. Some easily observed building parameters from the street surveying are evaluated, such as: Age of building, number of stories, soft story, short column, heavy overhangs, pounding effect etc. The investigated parameters which are selected to symbolize the seismic vulnerability of each building are the followings:

- Age of the Building: The length of time during which a building has existed.
- Number of Stories: Number of stories above ground level; Attic, basement and mezzanine are accepted as a normal story.
- Soft Story: First story of a building is much less rigid than the stories above because of openings on the ground floor such as wide doors, parking garages or commercial establishments with large windows [13].

- Short Column: Short column is stiffer than normal column and damage or failure under strong earthquakes because of high shear forces. R.C. frames with half-height infill walls, ribbon windows, formation of mid-story beams around stair landings cause short column effect in R.C. buildings [14].
- Heavy Overhang: Presence of big balcony and overhanging floor caused increments on earthquake forces and overturning moments during earthquakes [9].
- Pounding Effect: Different number of stories or floor levels creates interaction between adjacent buildings because of pounding which is a result of different periods during an earthquake [15].
- Topographic Effect: Buildings on sloping ground more than 30 degrees may subject to earthquake loads that can cause landslide [16].
- Visual Construction Quality: The material, workmanship and maintenance status of a building indicate the apparent quality of a construction that is classified into one of three cases as good, moderate or poor [9]
- Local Soil Conditions: The intensity of ground motion and inevitable structural damage majorly depends on the distance the fault and local soil conditions [17]. PGV is selected as to represent the ground motion intensity in Eskisehir which soil conditions are reported to correspond to Z4. The distance the fault is 15 km and earthquake magnitude is 6.4 in Northern part of Eskisehir thus PGV(cm/s) is determined as 40 cm/s Base score values are classified into 5 different case according to number of story and PGV values [18].

1975 Construction in Disaster Zones Code, 1997 Turkish Seismic Design Code, 1999 Marmara Earthquake and 2007 Turkish Earthquake Code are the main points for determining the time periods to calculate performance score. Between the dates of 1997-1999, there was not any punishment for unapplied code requirements. After 1999 Marmara earthquake, building inspection companies were founded and ready-mixed concrete has been made compulsory. In 2007, the assessment and rehabilitation of existing buildings chapter entered to Turkish Earthquake Code. There is not any score reduction in base score for the buildings constructed after 2007 shown in Table 1.

Table 1.Risk Factors

Number of Story	Base Score (B.S)		Risk Factors										
			Soft Story *	Heavy Overhang *	Short Column *	Pounding Effect *	Topographic Effect *	Visual Construction Quality **	Age of Building				
									2007-	2000-2006	1997-1999	1976-1996	-1975
1-2-3	130	Score Reduction Values (S.R.V)	-5	-5	-5	0	0	-5	0	0	-3	-5	-10
4-5	120		-10	-10	-5	-2	0	-5	0	0	-10	-15	-15
6	110		-15	-15	-5	-3	0	-10	0	0	-15	-20	-25
7	100		-20	-15	-10	-5	-2	-10	0	-3	-20	-25	-30
8 or more	90		-25	-20	-10	-5	-2	-15	0	-5	-25	-30	-35

* V.P.M = 1 if the risk factor exist; otherwise 0.

** V.P.M = 2 if the visual construction quality is “poor”, V.P.M=1 if it is “moderate”, V.P.M=0 for “good” condition

Vulnerability parameter multiplies (V.P.M) of each buildings (0,1,2) obtained from street surveying are multiplied by score reduction values (S.R.V) and processed earthquake score table . Each building has a base score and the base score is reduced for each risk factor considering the values given in Table 1. Earthquake Risk Score (E.R.S) can be calculated by Eq.1

$$(\text{E.R.S}) = \text{Base Score (B.S.)} + \sum \left[\text{Score Reduction Value (S.R.V)} \times \text{Vulnerability Parameter Multiply (V.P.M)}\right] \quad (1)$$

Table 2.Earthquake Risk Scores (E.R.S)

Earthquake Risk Score (E.R.S)	E.R.S.≤ 30	30 < E.R.S.≤ 70	70 < E.R.S.≤ 100	100 < E.R.S.
Risk Status	High	Moderate	Low	No risk

2.3. Case Study

A 9 story R.C. building presented below as a case study to determine E.R.S. shown in Figure 2.

H.1 (Z4 Soil.)	Status	Score
Number of Story	9	90
Age of Building	15	-5
Soft Story	YES	-25
Heavy Overhang	YES	-20
Short Column	YES	-10
Pounding Effect	NO	0
Topographic Effect	NO	0
Visual Construction Quality	MOD.	-15
Result	HIGH RISK	∑ = 15 (E.R.S.)

Figure 2. Example building and E.R.S. calculation table

3. Evaluation of Northern Eskisehir Building Database

3.1. Assessment of Building Database

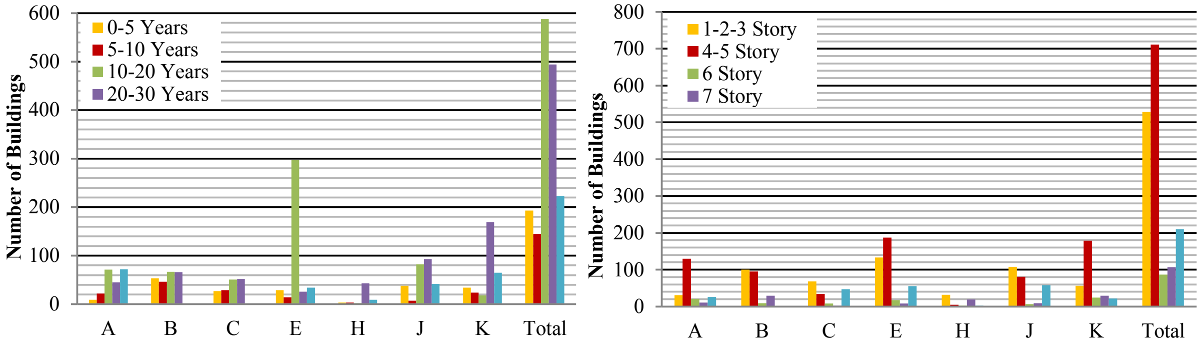
A total of 1643 concrete buildings are evaluated in Northern Eskisehir region in terms of age of buildings, number of stories, presence of soft story, short column, heavy overhangs and pounding effects presented in Table 3.

Table 3. Number of buildings with respect to investigated parameters

Territory	Age of Building					Number of Story					Soft Story		Short Column		Heavy Overhang		Pounding Effect	
	0-5 years	5-10 years	10-20 year	20-30 year	30 + years	1-2-3 str.	4 -5 story	6 story	7 story	8 + story	YES	NO	YES	NO	YES	NO	YES	NO
A	9	22	71	45	72	31	130	21	11	26	155	64	23	196	18	201	219	0
B	53	46	67	66	1	100	95	9	29	0	147	86	85	148	56	177	144	89
C	27	29	51	52	0	68	34	8	2	47	122	37	4	155	122	37	74	85
E	29	14	297	26	34	133	187	17	8	55	203	197	125	275	88	312	264	136
H	3	3	2	43	9	32	5	2	19	2	57	3	18	42	12	48	56	4
J	38	7	82	93	42	108	81	6	9	58	191	71	163	99	163	99	261	1
K	34	24	18	169	65	56	179	24	29	22	199	111	129	181	147	163	282	28
Total:	193	145	588	494	223	528	711	87	107	210	1074	569	547	1096	1081	562	1301	342
%	11.7	8.8	35.8	30.1	13.6	32.1	43.3	5.3	6.5	12.8	65.4	34.6	33.3	66.7	65.8	34.2	79.2	20.8

3.2. Age of Buildings

After 1999 Marmara earthquake, all of the structures were controlled thus age of building was come into question. Distribution of the age of buildings and the number of stories with respect to territories shown in Figure 3 and street survey results showed that 36% of concrete buildings in Northern Eskisehir are 10-20 years old.



(a) Age of Buildings **(b) Number of Stories**

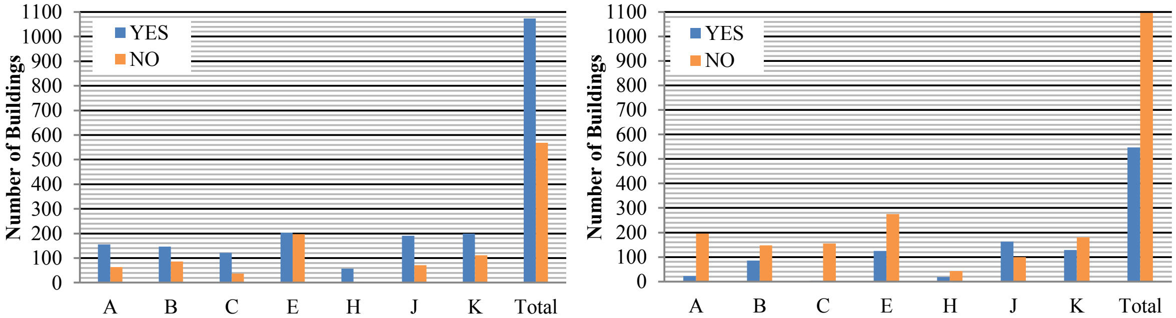
Figure 3. Distribution of the age of buildings and the number of stories with respect to territories

3.3. Number of Stories

In entire region, number of building with 8 or more stories is 210 corresponding 12.8%. Base score of a building with 8 or more stories is 90 so these types of buildings classified as high risk even if have not any risk reduction factor. 43% of concrete buildings in Northern Eskisehir are 4-5 story structures based on survey results shown in Figure 3.

3.4. Existence of Soft Story

Distribution of the presence of soft stories and short columns with respect to territories are shown in Figure 4. Street survey results showed that 65% of concrete buildings in Northern Eskisehir have soft stories because of many of them have commercial establishments with large windows on their ground floors.



(a) Soft Story **(b) Short Column**

Figure 4. Distribution of the presence of soft stories and short columns with respect to territories

3.5. Existence of Short Column

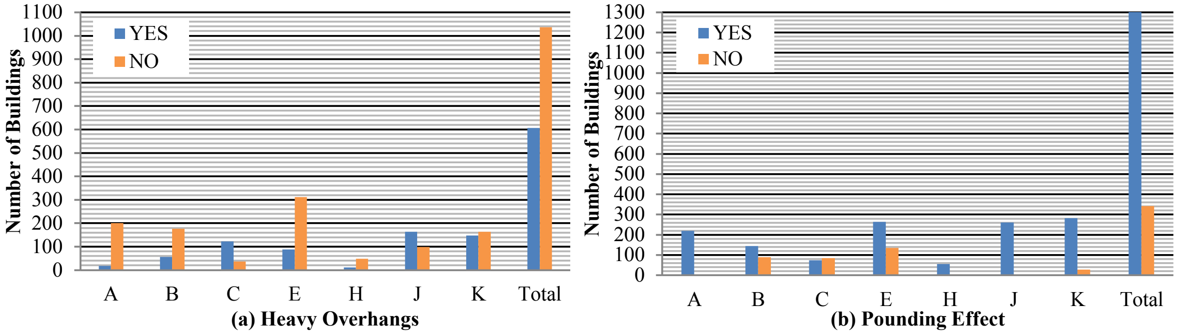
The numbers of buildings with short column are considerably less than to the building without it. Distribution of the presence of soft stories and short columns with respect to territories are given in Figure 4. The rate of short column presence is 33% in entire region therefore many buildings have entresols and ribbon windows that give rise to short column effect in R.C. buildings.

3.6. Existence of Heavy Overhangs

Wide-heavy balconies and overhanging cantilever floors in R.C. buildings lead increased earthquake effects [19]. Distribution of the presence of heavy overhang with respect to territories are illustrated in Figure 5-a. The rate of heavy overhang presence is 37% in entire region because of the buildings have overhanging cantilever floors to take advantage more than the land area.

3.7. Pounding Effect

Adjacent buildings with different periods during an earthquake may pound each other due to lack of adequate gaps [19]. Distribution of the presence of pounding effect with respect to territories are given in Figure 5-b. The rate of pounding effect presence is 79% in entire region because of terraced houses which are one of several buildings that are joined together.



(a) Heavy Overhangs **(b) Pounding Effect**

Figure 5. Distribution of the presence of heavy overhang and pounding effect with respect to territories

3.8. Visual Construction Quality

Observed building qualities for entire region do not constitute a risk factor. The rate of buildings with "poor" construction quality is 14.4 % (total 237) in northern part of Eskisehir while 1153 buildings out of 1643 (70.2%) are classified "moderate" and only 253 buildings out of 1643 (15.4%) are defined "good" in terms of visual construction quality.

4. Seismic Risk Assessments of Buildings in Northern Eskisehir

The applied procedure is based on some parameters that can be easily determined such as the age of building, number of stories, existence of soft story, short column, heavy overhangs, pounding affect, topographic effects, visual construction quality and earthquake zone where the building was located. Determined Earthquake Risk Score–E.R.S of each building was calculated and each considered building was classified into one of four risk classes which are high risk, moderate risk, low risk and no risk, in terms of the associated E.R.S. ranges shown in Table 6. The table shows that, if E.R.S. $\leq$ 30 than High Risk, 30 < E.R.S $\leq$ 70 than Moderate Risk, 70 < E.R.S $\leq$ 100 than Low Risk and E.R.S.>100 were classified in the No Risk group. Distributions of building numbers with respect to E.R.S. intervals for High Risk situation are given in Table 5.

Table 5. Distribution of building numbers with respect to E.R.S. intervals for High Risk

E.R.S.	A	B	C	E	H	J	K
0 - 9	2	0	33	22	3	20	19
10 - 19	2	2	1	20	2	30	14
20 - 29	5	5	8	12	5	6	7
Total	9	7	42	54	10	56	39

Table 6. Earthquake Risk – Number of Buildings

Region	Base Scores					Earthquake Risk Scores (E.R.S)				Risk Status			
	130	120	110	100	90	DRP≤ 30	30<DRP≤ 70	70<DRP≤ 100	DRP>100	No	Low	Mod.	High
A	31	130	21	11	26	9	27	64	119	119	64	27	9
B	100	95	9	29	0	7	21	60	145	145	60	21	7
C	68	34	8	2	47	42	11	34	72	72	34	11	42
E	133	187	17	8	55	54	21	119	206	206	119	21	54
H	32	5	2	19	2	10	10	7	33	33	7	10	10
J	108	81	6	9	58	56	17	72	117	117	72	17	56
K	56	179	24	29	22	40	34	136	100	100	136	34	40
Total	528	711	87	107	210	218	141	492	792	792	492	141	218

Number of buildings with respect to E.R.S. interval is illustrated in Figure 6. 792 buildings out of 1643 (48.2%) are classified as "No Risk" while 218 buildings out of 1643 (13.3%) are defined "High Risk" shown in Figure 6.

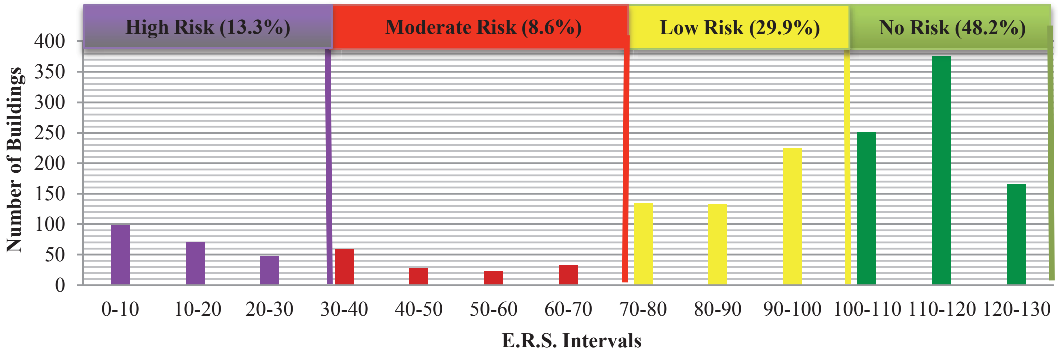
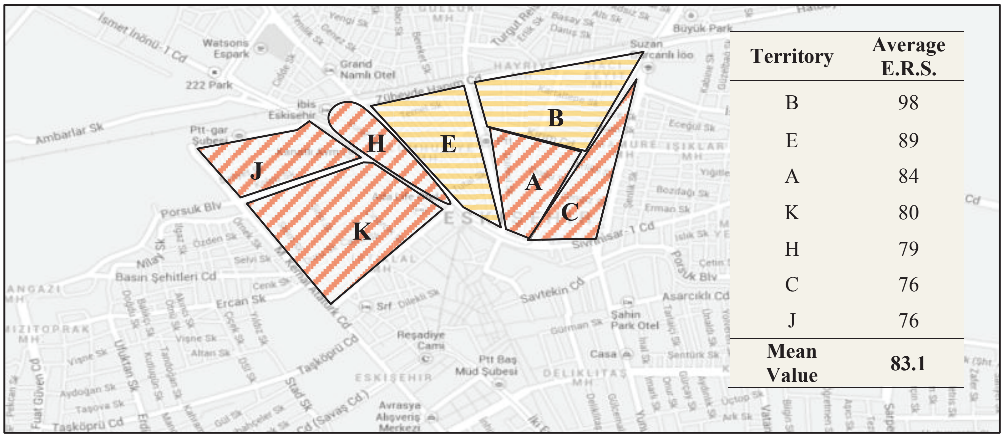


Figure 6. Number of Buildings with respect to E.R.S. intervals and risk groups

Average Earthquake Risk Score–E.R.S values for every territory are illustrated on a map in Figure 7. E.R.S values of all buildings in a territory are summed and divided to total number of buildings in same territory to find mean values. The territories with high average E.R.S values are B and E while the lowest score is belong to C and J. The average E.R.S value for entire Northern Eskisehir is 83 in accordance with "Low Risk" with respect to Table 2.



Territory	Average E.R.S.
B	98
E	89
A	84
K	80
H	79
C	76
J	76
Mean Value	**83.1**

Figure 7. Earthquake Risk Map with respect to average E.R.S.

5. Conclusions and Discussions

This study is a seismic vulnerability assessment application to detect, inventory, and rank the most vulnerable buildings in Northern Eskisehir city center. One of the aims of the study is creating a building database and ranking the buildings with respect to an expected earthquake with a moment magnitude of 6.5~7. In this study, Earthquake Risk Score–E.R.S of each building was calculated and the most dangerous buildings with respect to the expected amount of earthquake damage were identified. The results revealed that 218 buildings (mostly having 6 stories or more) among 1643 buildings were rated in the high risk while 492 buildings are low risk thus more detailed evaluations of these buildings were recommended before confirming the building as earthquake risk. Number of stories and age of building are the most significant parameters in identifying the seismic failure vulnerability of R.C. buildings for Northern Eskisehir region. For example, almost all of the buildings which are constructed before 1975 are in high risk group. The main aim of this study is not to decide at a definitive conclusion about building seismic risk but identifying priority buildings in terms of detailed investigations. All of the examined buildings within the scope of this study were named and addressed systematically on google maps and their pictures were taken. In this way more detailed assessments of the buildings which are rated in the high risk can be achieved individually.

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