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Consistency of the rapid assessment method for reinforced concrete buildings

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Abstract. Determination of earthquake-safety of existing buildings requires a rather long and challenging process both in terms of time and expertise. In order to prevent such a tedious process, rather rapid methods for evaluating buildings were developed. The purpose of these rapid methods is to determine the buildings that have priority in terms of risk and accordingly to minimize the number of buildings to be inspected. In these rapid evaluation methods detailed information and inspection are not required. Among these methods the Canadian Seismic scanning method and the first stage evaluation method included in the principles concerning the determination of risk-bearing buildings promulgated by the Ministry of Environment and Urbanization in Turkey are used in the present study. Within the scope of this study, six reinforced concrete buildings damaged in Van earthquakes in Turkey are selected. The performance scores of these buildings are calculated separately with the mentioned two methods, and then compared. The purpose of the study is to provide information on these two methods and to set forth the relation they have between them in order to manifest the international validity.

Keywords: reinforced concrete; first stage; seismic screening rapid assessment

1. Introduction

The main objective in the determination of building's earthquake safety is to enable to give correct decisions on the existing building stock by conducting the necessary inspections and evaluations on existing buildings in advance of a possible earthquake. Determination of earthquake-safety of existing buildings requires a rather long and challenging process both in terms of time and expertise. It is unlikely that all existing buildings can be inspected in detail. In order to prevent such a tedious process, rather rapid methods for evaluating buildings were developed. In this context accurate results may be achieved by employing methods that enables faster evaluation of buildings and provides more accurate results. The purpose in these rapid methods is to determine the buildings that have priority in terms of risk and accordingly to minimize the number of buildings to be inspected.

The literature concerning the rapid evaluation of buildings includes several methods. In the regulation published by the Ministry of Environment and Urbanization in 2013, the first stage evaluation method concerning the determination of risk-bearing buildings (DRBB) was based on legal

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grounds (DRBB 2013). With this regulation, the parameters to be taken into consideration in the first stage evaluation method and the method of calculating performance scores are set forth.

In order to manifest the international validity of Turkish method, which has been based on legal grounds in Turkey, the buildings in question were also evaluated by means of the Canadian seismic scanning method in the present study.

Within the scope of the study information on both of the mentioned methods are provided and in order to see realistic results of these methods, they are implemented on six reinforced concrete buildings damaged during Van province earthquakes. Results obtained from these two methods are compared with each other. This study also gives the information about seismicity of Van.

2. Methodology

Earthquake performance is defined as the safety of a building determined in relation with the level and distribution of the damages the building may suffer under a certain impact of earthquake (Sucuoğlu 2007). The possible damages that would be caused by natural disasters (such as earthquake, flood, etc.) increase in line with the increasing vulnerability of buildings. The magnitude of natural disasters and failures in establishing adequate safety of buildings and in complying with the provisions of related regulations, or in other words adverse building characteristics, would directly affect the possible damages (Işık 2013). The main objective in determining earthquake safety is to conduct the essential inspections and calculations on existing buildings in advance of a possible earthquake and accordingly to be able to decide on the improvement activities required for rendering the buildings considered inadequate to the targeted level of performance.

Reducing building stock vulnerability is an essential step towards reduction of seismic risk. Large-scale assessment methods are praised by decision-maker for assessing building stock as they are not expensive and easy to use (Chever 2012). An efficient tool to assess the seismic vulnerability of existing buildings is also an important factor for planning urban/regional-scale emergency response and earthquake protection/retrofitting schemes to protect human lives and economy (Ahmed *et al*. 2014).

Seismic risk assessment of reinforced concrete buildings needs consideration of seismic hazard, building vulnerability and consequence of failure. Different statistical methods are proposed to discern vulnerable buildings for retrofit prioritization (Tesfamariam and Liu 2010).

It becomes important to identify and strengthen the seismically deficient buildings to protect human lives and economy of a country. When dealing with a large building stock, one needs evaluation methods for quick assessment of the seismic safety of existing buildings so that corrective retrofitting measures may be undertaken on the deficient buildings (Sudhir *et al*. 2010).

Seismic screening methods, more specifically rapid visual screening or score assignment procedures, are intended to be coarse screening procedures using little resources per building (Tischer *et al*. 2011, Tischer *et al*. 2012).

The fundamental procedure of both of the methods that used in this study are presented below.

2.1 First stage evaluation method for reinforced concrete buildings

The first stage evaluation methods that take into consideration building characteristics and earthquake risk may be used for the purpose of determining the priorities in certain areas and the regional distribution of the buildings that may bear risk within the scope of the law promulgated by the Turkish Ministry. In case a more precise prioritization is required, also second stage evaluation methods may be employed (DRBB 2013). It is not possible to exactly state whether buildings found out to have low risk comply with the available earthquake regulations. As mentioned above, this is only an initial, first stage evaluation. Therefore, exact results can be obtained only in consequence of exact analysis methods. This method solely aims to determine the priorities of the buildings to be inspected in the second stage evaluation method. This method can be used for existing RC buildings which have 1-7 stories. Using parameters for first stage method is given below;

- Structural system type
- Number of Story
- Current situation and visual quality
- Soft /weak story
- Vertical irregularity
- Heavy overhangs
- Irregularity in plan / torsion
- Short column
- Building regulation / pounding
- Hillside effect
- Seismicity and soil type

Performances score can be calculate for RC buildings after collecting related data's. Performance score for RC buildings is calculated as

$$PP = TP + \sum_{i=1}^{n} O_i * OP_i + YSP \tag{1}$$

The above formulation is described as; PP- Performance Score; TP- Base Score; Oi- Irregularity Score and YSP- Structural System Score. The final scores are compared each other for risky buildings and provide priority for retrofit.

2.2 Canada seismic screening method

Screening entails assessing buildings to ascertain their level of seismic risk following a simplified procedure whose main objective is to determine if the building should or should not be subjected to a more detailed investigation (Foo *et al*. 2002). Buildings can be screened using rapid visual screening methods. One of these methods is "Manual for Screening of Buildings for Seismic Investigation" that developed by the National Research Council of Canada (NRC 1993). This paper gives also an overview of the Canadian Seismic Screening Method.

Canada Seismic Screening Method is based on a seismic priority index which accounts for both, structural and non-structural factors including soil conditions, building occupancy, building importance and falling hazards to life safety and a factor based on occupied density and the duration of occupancy (Srikanth *et al*. 2014). Like FEMA 154, in NRC Guidelines, a final cut off score is developed, upon which the decisions can be made (Alam *et al*. 2012).

Information for each building is collected by using parameters that given in NRC. Each parameter has a score. The scores are then used to rank all buildings of the inventory for detailed seismic evaluation. The scoring system is made up of a structural index (SI) and a non-structural index (NSI). SI is related to possible risk to the building structure and NSI is related to the risk of non-structural building components (Foo and Davenport 2003, NRC 1993). Past earthquakes have illustrated that the failure or collapse of the so-called nonstructural components has caused most casualties and property damage (McKevitt *et al*. 1995). The sum of structural index and non-structural index was called as Seismic Priority Index (SPI). In the assessment buildings process, a detailed investigation is performed on buildings with medium to high priority by SPI.

The methodology is based on the key factors that affect risk of seismic hazards for any building; seismicity, soil conditions, type of structure, irregularities of the structure and the presence of non-structural hazards. It is also based on the importance of the building as affected by its use and occupancy since this affects the consequences of seismic damage (NRC 1993). Using parameters for Canada Seismic Screening methods is given below;

- Seismicity of the region (A)
- Local soil conditions (B)
- Type of structural system (C)
- Floor system (D)
- Irregularities of the building (E)
- Importance of building (F)
- Building condition (G)
- Non-structural components (H)

A parameter defines the earthquake risk of the place where buildings to be examined are located. A parameter takes variable values between 1-5. High A values defines the regions with high earthquake risk. B parameter is used to define to define surface conditions. Value of B parameter is 1 in rock or very strong grounds while it is 1.5 in grounds with liquefaction risk. C parameter is about the load bearing system of the structure to be examined. It takes values between 1 and 3.5. It takes low value in ductile load bearing systems constructed according to structure design that is resistant to earthquake. For example 1 corresponds to a load bearing system that is detailed as ductile while 3.5 correspond to brittle systems. D parameter depends on the installation system used in the structure and varies between 1 and 2. This coefficient takes low values in installation systems which are light and demonstrates diaphragm property. E parameter is related with the structural disorders of the building to be examined. Structural disorders can be listed as vertical disorder, contortion disorder, short column, soft/weak storey, hammering effect, important changes in building load bearing systems that are out of the project and various structural damages. There is a score between 0.3 and 1.0 for each structural disorder. The sum of the scores obtained for each disorder gives the value of E parameter. F parameter can be named as building importance coefficient and depends on the number of people living in the building. (N) In buildings where less than 10 people lives (low importance level) it is 0.7, in buildings where 10-300 people lives (normal importance level) it is 1.5, in buildings where 300-3000 people lives (school and high importance level) it is 2.0; in buildings where more than 3000 people lives (usage right after earthquake and very high importance level) it is 3.0. G parameter defines the visual quality of the building during observation. It takes values between 1 and 4. Visual quality is considered as very good, good, bad and very bad. As the visual quality of structure worseness this value increases. H parameter is used to consider non-structural factors. It consists of components such as independent parapets and chimneys, mechanical and electrical equipments, shelves and masonry walls within the building. 1.0 point is given for each internal and external factor and value of H parameter is calculated with the sum of these values (NRC 1993, Foo *et al*. 2002, Çelik *et al*. 2007, Altıner 2008).

In this method, each parameter is named with a letter. Each of parameters are calculated by using coefficient that given in Canada Seismic Screening Method. In first step, Structural Index (SI) is calculated as

$$SI = AxBxCxDxExF \quad (2)$$

Then Non-Structural Index (NSI) was calculated for each building as

$$NSI = BxFxGxH \quad (3)$$

Seismic Priority Index (SPI) was calculated as the sum of structural index and not structural index as

$$SPI = SI + NSI \quad (4)$$

The results has obtained are compared with the limit values that are given in Table 1 for a decision to seismic priority of the building.

The comparison of parameters that used for assessment of buildings for each method is given in Table 2.

Each irregularity of the buildings is described separately in Turkish rapid screening method. All type of irregularities is collected under a parameter in Canada Seismic screening method. The comparison of irregularities that used both methods is given in Table 3.

Low scores are described priority group of buildings in Turkish rapid screening method. But in Canada seismic screening method, priority group of buildings are described by high scores. Earthquake risk priorities of buildings are determined by SPI index obtained by structural and non-structural parameters. High SPI index means high priority.

Table 1 Priority levels for buildings in Canada Seismic Screening Method (Çelik 2007)

Score type	Limit values	Evaluation
SI / NSI	1.0 - 2.0	Sufficient seismic safety
SPI	<10	Low priority buildings
SPI	10- 20	Middle priority buildings
SPI	>20	High priority buildings
SPI	>30	Very hazardous buildings

Table 2 Comparison of methods that used in this study

Parameter	Turkish	Canada
Seismicity of the region	X	X
Local Soil Conditions	X	X
Type of structural system	X	X
Floor system		X
Building Irregularities	X	X
Building Importance		X
Building Condition	X	X
Non-structural items		X
Risk zone	X	
Number of story	X	

Table 3 Comparison of the irregularities

Irregularity Type	Turkish	Canada
Vertical	X	X
Horizontal	X	X
Short concrete columns	X	X
Soft/weak story	X	X
Major modifications		X
Deterioration	X	X
Pounding	X	X
Heavy overhangs	X	X

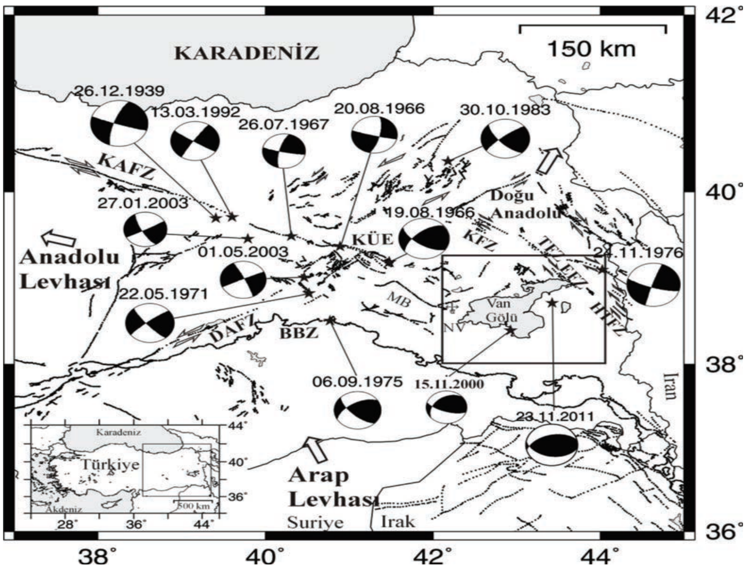

Fig. 1 Major tectonic elements of Eastern Anatolia (Utkucu 2014)

3. Seismicity of Van, Turkey

The buildings which have evaluated in this study were located in Van. Seismicity of the region was an important parameter for evaluation of the buildings. Van province was located in Eastern Anatolia near Lake Van. Seismic hazard analysis of the earthquake-prone Eastern Anatolia region of Turkey has become more important due to its growing strategic importance as a global energy corridor and closer integration with the European Union. In this study Van province is selected as the study area. The town of Van, capital of province, has a population 400,000 (including the surroundings) as of the year 2000. The town is located 5 km from Lake Van (Ulutaş 2012).

General tectonic setting of Eastern Anatolia is mainly controlled by the collision of northerly moving Arabian plate against the Anatolian plate along a deformation zone known as Bitlis Thrust Zone (Fig. 1). The collision leads to the westward extrusion of the Anatolian plate along the two notorious transform faults with different sense of slip, the dextral North Anatolian Fault and the sinistral East Anatolian Fault zones, which join each other in Karlıova Triple Junction (KTJ) in the

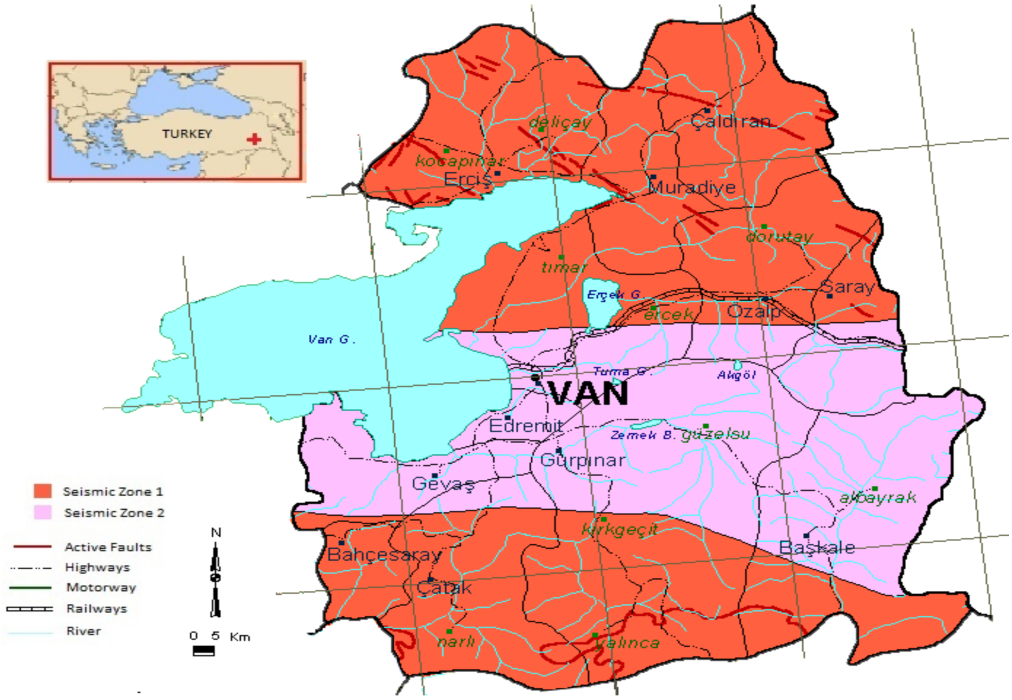

Fig. 2 Seismic Hazard Map of Van Region (where the red areas indicate the first degree zone with a minimum effective acceleration of 0.40 g and the pink areas mark the second degree zone with a minimum acceleration of 0.30 g

Eastern Anatolia (Fig. 1). In the eastern side of KTJ; however, the collision deformation is largely accommodated within the Eastern Anatolian Block through distributed NW-SE trending dextral faults and NE-SW trending sinistral faults representing escape tectonics, and shortening of the continental lithosphere along the Caucasus thrust zone. East-west trending Mush-Lake Van and Pasinler ramp basins constitute other conspicuous tectonic properties within the Eastern Anatolian border (Sengor *et al*. 1985, Barka and Kadinsky-Cade 1998, Mc Clusky *et al*. 2000, Reilinger *et al*. 2006, Utkucu 2013).

Van Centre is in first degree of seismic zones in current seismic hazard map of Turkey (Fig. 2). Fig. 2 indicates first and second degree of seismic zones (TEC 2007).

The local geological soil conditions change the characteristics of surface seismic response. It is a known fact that this may cause damage on the existing structures built on these grounds (Borcherdt 1990). Soil type for all building is selected as Z2 for Van Province.

4. Building examples

A total of 6 reinforced concrete buildings damaged in Van earthquakes are included in the scope of the study. In order to be able to use the first stage evaluation in the principles used in Turkish Method for determining risk bearing buildings, maximum 7 storey buildings are selected. Although the structural system of the selected building V1 was free of damage, the building comes into prominence with the damages its non-structural elements suffered. V1 is a 6 storey building and its ground floor height is higher than normal floor height. The building referred to as V2 is used as a dormitory. Exhibiting soft floor behavior, its ground floor has completely collapsed. The building V3 has a 5 storey reinforced concrete frame system and its ground floor is also completely collapsed due to its soft floor characteristic. Although the building V4 exhibits ductile behavior against earthquake, it still has been damaged due to the impact of its neighboring building. The building resisted to the effect of earthquake but was still damaged by its neighbor building. V5 on the other hand is a 4 storey building that could show no resistance against earthquake due to its weak story characteristic. Finally, although V6 was a 5 storey reinforced concrete building, it turned into a 4 storey building due to soft floor characteristics shown against earthquake. Pictures of these 6 buildings are presented in Fig. 3.

Results obtained from Turkish first stage evaluation method for these six reinforced concrete buildings are given in Table 4.

Fig. 3 Pictures of investigated buildings

Table 4 Results of assessment using Turkish Screening Method

Building Code	Number of Story	Soil Type	Earthquake zone	Risk zone	Base score	Soft/weak story	Heavy overhangs	Short columns	Visual quality	Hill/slope effect	Vertical irregularity	Plan irregularities	Pounding	Total score of irregularities	Performance score (PS)	PRIORITY FOR EVAULATION
V1	6	Z2	I	II	65	-30	0	0	0	0	0	0	0	-30	35	6
V2	7	Z2	I	II	65	-30	0	0	-30	0	0	0	0	-60	5	3
V3	5	Z2	I	II	80	-30	0	0	-50	0	0	0	0	-80	0	2
V4	7	Z2	I	II	65	-30	0	0	0	0	0	0	-15	-45	20	5
V5	4	Z2	I	II	90	-30	0	0	-60	0	0	-10	-15	-115	-25	1
V6	5	Z2	I	II	65	-30	0	0	-25	0	0	0	0	-55	10	4

Table 5 Results of assessment using Canada Seismic Screening Method

BUILDING CODE	A	B	C	D	E	F	G	H	SI	NSI	SPI	EVALUATION OF BUILDING	PRIORITY FOR EVAULATION
V1	5	1,25	1	1	1	1,5	1	1	9,38	1,88	11,25	Middle priority	6
V2	5	1,25	3,5	1	1,5	1,5	2	1	49,22	3,75	52,97	Very hazardous	3
V3	5	1,25	3,5	1	1,5	1,5	3	1	49,22	5,63	54,84	Very hazardous	2
V4	5	1,25	2,5	1	1	1,5	1	1	23,44	1,88	25,31	High priority	5
V5	5	1,25	3,5	1	1,5	1,5	2	2	49,22	7,50	56,72	Very hazardous	1
V6	5	1,25	3,5	1	1,5	1,5	2	1	49,22	3,75	52,97	Very hazardous	4

Table 6 Comparison of Canada and Turkish methods

BUILDING CODE	PRIORITY FOR EVAULATION	
	Turkish	Canada
V1	6	6
V2	3	3
V3	2	2
V4	5	5
V5	1	1
V6	4	4

The seismic evaluation results of the buildings using Canada seismic screening method are given in Table 5.

Priority of the investigated buildings for both methods is given in Table 6.

5. Results and discussion

The extensiveness of the existing building stock leads to rather unrealistic results of the evaluations conducted on these buildings, mainly due to the lack of sufficient time and expertise. In order to obtain scientifically reliable results from these evaluations faster evaluation methods are needed. With these evaluation methods it is possible to determine some of the parameters that would affect the building's behavior in case of an earthquake partially without even entering the building and partially through the data obtained from the interior of the building. A score is defined for each of the obtained parameters and by utilizing the relation among these scores the performance scores of buildings are calculated. With this calculation risk priorities of buildings are determined.

Within the scope of this study six reinforced concrete buildings damaged in Van earthquakes are evaluated by means of the Turkish and Canadian Seismic Screening methods and information on both methods are provided. The similarity of the parameters taken into consideration in both methods is noteworthy. Generally in the evaluation of a building, the local conditions of the region the building is in (seismicity of the region and soil class), the type of the building (its carrier system type and floor system) and the negative aspects of the building (visual quality, weak/soft story, vertical/horizontal irregularity, heavy overhangs, pounding, etc.) are taken into consideration.

Detailed info was given about both methods used in the study and the comparisons of the parameters in the methods were made. In Table 2, parameters considered in both methods were compared. In Turkish method floor system, building importance and non-structural items parameters were not taken into consideration while they are taken into consideration in Canada method. On the other hand number of story and risk zone parameters is present in Turkish method but not present in Canada method. Comparison of structure negativity parameters taken into consideration in both methods is given in Table 3. The only difference between two methods is the major modifications in Canada Seismic Screening method. All factors causing most of the earthquake damages and which will weaken building defense mechanism were considered as negativity parameters in both methods. In terms of negativity parameters both methods consider almost the same parameters. Risk priorities were found to be the same for 6 examined buildings in both methods. This proposes the consistency of both methods with each other. When the damages occurring in examined buildings it can be stated that the obtained results are in accordance with real situation.

It is not possible to exactly state whether buildings determined to have low risk always comply with the available earthquake regulations. As mentioned above, this is only an initial, first stage evaluation. Therefore, exact results can be obtained only in consequence of exact analysis methods. This method solely aims to determine the priorities of the buildings to be inspected in the second stage evaluation method. However, selecting the buildings, the earthquake behaviors of which are known, has rendered the results more valuable.

Keeping in mind the saying in Turkish “one should take action before the pot is broken”; during the design in buildings their possible negative aspects should be taken into consideration. It should be ensured that the buildings have no -or as less as possible- negative aspects during the design. Negating buildings’ earthquake vulnerability means to render them more durable in the case of a possible earthquake. In this context, the importance of building designers’ compliance with the provisions of the regulations concerning building design gains prominence. In addition, after the design phase it is essential to conduct the required and adequate controls during the actual construction of buildings. In order to ensure that a project gains both technical and scientific significance, the sensitivity shown during the construction phase should be maintained throughout the whole process of the project.

Building priority rankings obtained by means of the two methods are found to be identical with each other. Comparing the actual results and the results obtained from the evaluation of the buildings in question showed that both of the methods are valid and applicable. Generally, in the determination of the priority of the existing building stock fast evaluation methods may be used conveniently.

Such a work will lead to system of earthquake prevention, which will be used to analyze an inventory of building stock against earthquake. While taking precautionary measures against reducing earthquake risk after producing a building inventory, the buildings, which are not safe and not economical to strengthen, need to be demolished.

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Nomenclature

PP	performance score
TP	base score
O_i	irregularity score
YSP	structural system score
SI	structural index
NSI	non-structural index
SPI	seismic priority index
A	seismicity of the region
B	local soil condition
C	type of structural system
D	floor system

E	irregularities of the building
F	importance of building
G	building condition
H	non-structural components