Chapter 2
Rapid Seismic Assessment Procedures for the Turkish Building Stock

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Abstract Seismic performance assessment procedures based on street survey have been developed for low- to mid-rise reinforced concrete and masonry buildings in Turkey. These procedures rely on data that can be collected through visual examination of each building. The data is collected through the forms designed for that purpose. The attributes that are believed to affect seismic performance have been determined and used to evaluate seismic vulnerability. It is important to note that these procedures are not appropriate for determination of seismic vulnerability of individual buildings but to rank a population of buildings according to their relative vulnerability. The primary parameters used for RC buildings include seismic hazard, structural system, number of stories, irregularities in plan and elevation, architectural features and building adjacency. Similar parameters are

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A. Ilki and M.N. Fardis (eds.), *Seismic Evaluation and Rehabilitation of Structures*, Geotechnical, Geological and Earthquake Engineering 26,
DOI 10.1007/978-3-319-00458-7_2,

used for masonry buildings. The procedures developed use the selected attributes to determine seismic vulnerability scores for each building. These scores include a base score that is modified for each attribute to get the vulnerability score. The procedures proposed for rapid seismic assessment were validated and calibrated based on field data and results of detailed assessment procedures.

2.1 Introduction

Observations from recent earthquakes in Turkey reveal that a remarkable number of existing buildings have poor seismic performance. In order to reduce the seismic risk in future earthquakes, seismic assessment procedures that are applicable to Turkish buildings need to be developed. Reinforced concrete and masonry buildings are the two dominant construction types in Turkey. Given the large population of building stock to be assessed, quick assessment procedures are preferred over detailed ones as the first level to classify buildings with high risk. In this context, quick seismic assessment procedures were developed to rank seismic risk of RC and masonry buildings in Turkey. The procedures are generally based on visual examination of each building, from outside and limited entry to the building, to identify attributes that are considered to influence seismic performance. These procedures take into account not only building attributes but also the seismicity of the location based on the current seismic zone map of the country.

Since RC buildings are very common both in Turkey and around the world, a number of previous studies have focused on their seismic performance assessment. Several rapid or preliminary assessment procedures have been proposed: FEMA 154 (2002), Japanese Seismic Index (Kaminosono 2002), DURTES (Temür 2006), P25 (Bal et al. 2007), Sextos et al. (2008), İlki et al. (2003), Yakut (2004). Among these, FEMA 154 is a rapid assessment procedure that has been developed for US buildings, thus reflects practice there. Other procedures require more detailed data than those used in the proposed methodology.

Masonry buildings in Turkey can be classified into two major groups: urban-type and rural-type. Rural-type masonry buildings reside in small residential areas, towns and villages. They are generally low-rise dwellings built of adobe, brick or stone units. They are also called “non-engineered buildings” since they have been constructed in a traditional manner without the intervention of an engineer or architect. On the other hand, urban-type masonry buildings are low-rise or mid-rise dwellings with a larger floor area than rural counterparts, sometimes having irregular plan geometry with many projections. Generally, brick units and concrete blocks are used in their construction and they have an “engineering touch” as opposed to rural-types. The major earthquakes that have occurred in Turkey in the last three or four decades revealed the fact that both rural- and urban-type masonry buildings suffered damages to different extents, while a considerable portion were severely damaged or collapsed. This is also the case in many earthquake-prone regions of the world, especially in developing countries. Hence it is not surprising to encounter various rapid screening procedures developed for masonry buildings.

The most popular rapid visual screening methodology, which was developed by the Applied Technology Council (ATC) for the Federal Emergency Management Agency (FEMA) in 1998 and was updated in 2002 (ATC 2002), includes also the seismic safety assessment of masonry buildings among various construction types. But it should be stated that some of the specific structural parameters regarding masonry buildings are not included in the FEMA evaluation form since the methodology had been designed to evaluate 15 different types of structures with one single form. In another study that has been inspired by the FEMA approach, rapid visual screening of existing buildings, including reinforced and unreinforced masonry construction, has been carried out for the province of Quebec in Canada (Karbassi and Nollet 2008). The researchers modified the base scores of the FEMA methodology in order to represent the characteristics of the building stock in Quebec. Arya (2007) also worked on a rapid screening methodology similar to the FEMA approach, but he added some more structural parameters regarding masonry structures in the proposed data collection form.

There also exist rapid visual screening methodologies developed in Turkey for the seismic safety assessment of unreinforced masonry buildings in urban and rural regions. One such a method was developed under the project “Earthquake Master Plan for Istanbul (EMPI)” as the first-stage evaluation of a multi-stage approach in order to prevent or mitigate seismic risk, and prepare emergency rescue and restoration plans for the earthquake prone areas identified in the city of Istanbul (Sucuoğlu et al. 2007). In the first-stage evaluation procedure, also referred to as the “sidewalk survey”, the masonry buildings under inspection were examined from the street by considering their basic structural parameters that can be determined without entering the building. Then the results of the first-stage evaluation were used to distinguish those buildings with high damage risk, to be examined in detail in the second stage. The details of the methodology and its application to sub-provinces of Istanbul can be found elsewhere (Erberik 2008, 2010).

Another method was developed by the technical teams from the (formerly known as) Ministry of Public Works and Settlement in order to assess the seismic safety of existing buildings in the province of Denizli (Kocaman et al. 2009). Within the context of this study, 4,151 masonry buildings were examined from the street and the obtained information was gathered in a database with the help of data collection forms. Then this information was used in order to rank the buildings in a relative manner according to their seismic vulnerabilities.

2.2 Proposed Procedure for RC Buildings

The procedure developed for low- to mid-rise (1–7 stories) reinforced concrete buildings is an extension of a previously developed procedure (Sucuoğlu and Yazgan 2003; Sucuoğlu et al. 2007) incorporating more parameters and treating seismic hazard differently. The parameters considered, the form developed for data collection and the methodology are described in the following sections.

2.2.1 Parameters Employed

The structural system, number of stories, existing condition and apparent quality, soft story, vertical irregularity, heavy overhangs, plan irregularity, short column, building adjacency, topography, seismic hazard and soil type are the primary parameters considered. These parameters have been determined based on examination and analyses of observations from recent earthquakes, previous studies on the vulnerability of Turkish buildings, peculiarities and practice for the local building stock. A short description of these parameters is given below.

1. The number of unrestrained (free) stories (n_s): This is one of the most important parameters for the seismic vulnerability of RC buildings in Turkey (Sucuoglu and Yazgan 2003; Ozcebe et al. 2004). This parameter shows the number of stories above the ground level for buildings without basements. It represents the number of unrestrained stories for buildings with basements.
2. Type of structural system: Reinforced concrete frame buildings (RCF), RC frame buildings with shear walls (RCFS) and RC shear wall buildings (RCS) are among the RC systems considered.
3. Apparent quality and existing condition: This parameter is expected to reflect the quality of workmanship and material. Apparent quality of the building is assigned considering three classifications as good, moderate and poor.
4. Soft story: This attribute is determined visually based on the height difference as well as a significant difference in the rigidities of stories, including the potential contribution of the infill walls, if possible.
5. Vertical irregularity: Discontinuous frames, columns and shear walls along the height are reflected through this parameter.
6. Heavy overhangs: It represents the difference between the floor area of the ground floor and floors above. It causes irregularity in elevation by shifting the frames and beam lines at the stories above and has a significant negative influence on seismic performance of RC buildings in Turkey.
7. Irregularity in plan torsion: Unsymmetrical plan and distribution of vertical elements may cause torsion. If this effect can be determined visually then it should be taken into account.
8. Short column: This attribute can easily be observed from street survey.
9. Building adjacency/pounding: Due to inadequate gap between the adjacent buildings pounding may result in damage. Buildings located at corner of blocks are affected the most. Additionally, if floor levels of adjacent buildings are different then the effect of pounding becomes more significant. All these cases can easily be determined during street survey.
10. Topographic effect: This attribute is taken into consideration for buildings that are located at hills having a significant slope.
11. Seismicity and soil type: The level of seismicity is considered, based on the seismic zone map and soil types in the Turkish seismic code (TEC 2007).

2.2.2 Data Collection Form

The parameters explained above are determined based on data collected through a form developed for this purpose. This form also helps develop a building inventory. The form shown in Fig. 2.1 has two sides; the front side contains necessary information for determining the parameters and the back side gives some examples and explanations for identifying certain features.

2.2.3 Performance Assessment Methodology

The main objective of the proposed procedure is to make a risk prioritization using the parameters that can be determined through a walk down survey with limited entry to the building. Based on the analysis of the parameters and considering their relative influence on the performance, a quantitative evaluation is carried out to calculate a performance score for each building. These performance scores are first determined for a reference seismicity and are then modified to reflect the effect of the building's hazard and soil conditions. The performance scores of all buildings are used to obtain a risk prioritization.

a

RAPID ASSESSMENT DATA COLLECTION FORM FOR RC

DATE :

FORM 1 BUILDING ID **No:……….**

REGION NO					
MAHALLE					
STREET					
APT NAME AND NUMBER					
PAFTA / ADA / PARSEL					
CITY INFO. SYST.NO					
BUILDING AGE					
COORDINATES (GPS) (E/ N)					
FORM 2 BUILDING DATA					
STRUCTURAL SYSTEM	☐ RC FRAME	☐ RC WALL		☐ RC FRAME AND WALL	
NUMBER OF FREE STORIES	....				
CORROSION LEVEL	☐ NO	☐ LIGHT	☐ MODERATE ☐ HEAVY		
MEMBER STRUCTURAL DAMAGE	☐ LIGHT		☐ MODERATE ☐ HEAVY		
PLAN WIDTH	.............m				
PLAN LENGTH	.............m				
ADJACENCY	☐ SEPARATED ☐ ADJACENT ☐ ADJACENT CORNER				
FLOOR LEVEL	☐ SAME	☐ DIFFERENT			
ADDITIONAL STORY	☐ YES (........)	☐ NO	☐ UNKNOWN		
HEAVY OVERHANGS	☐ YES	☐ NO			
WEAK / SOFT STORY	☐ YES	☐ NO			
SHORT COLUMN	☐ YES	☐ NO			
VERTICAL IRREGULARITY	☐ YES	☐ NO			
PLAN IRREGULARITY	☐ YES	☐ NO			
SOIL CLASS	☐ Z1	☐ Z2	☐ Z3	☐ Z4	

Fig. 2.1 (**a**) Data collection form for RC (*front side*). (**b**) Data collection form for RC (*back side*)

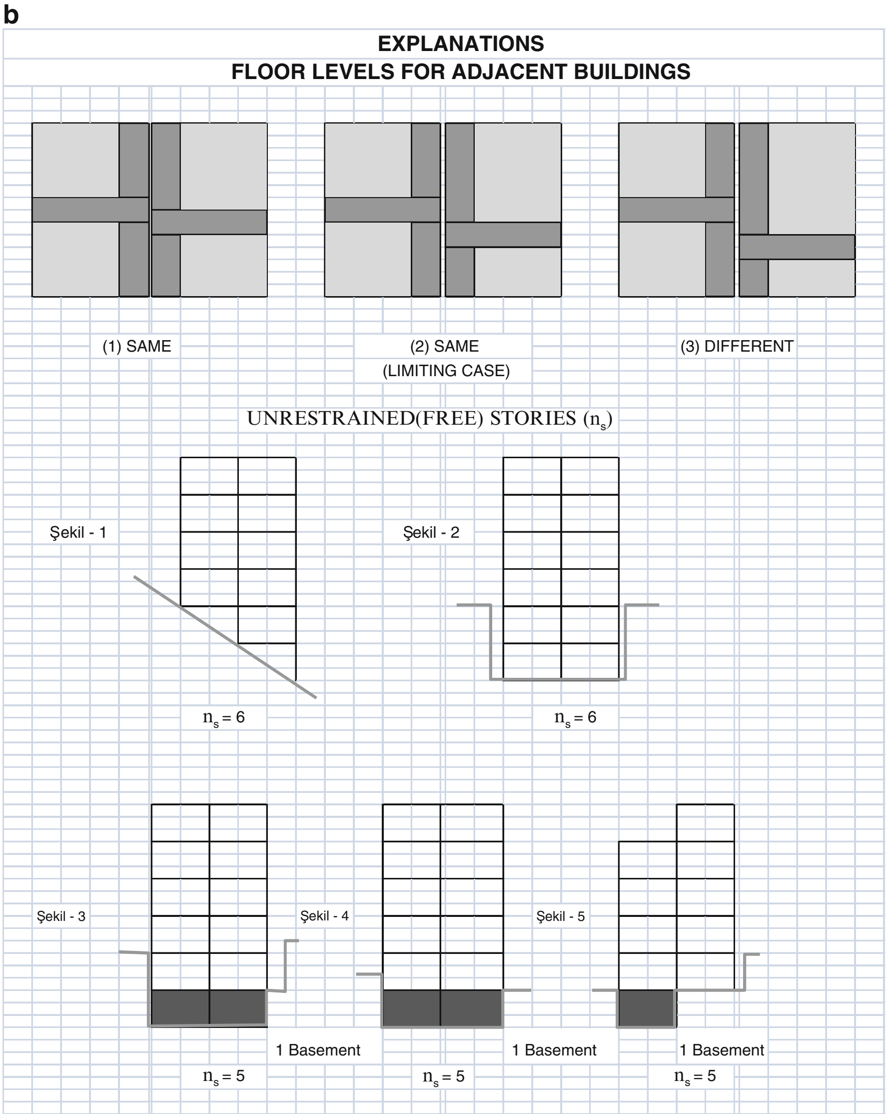


Fig. 2.1 (continued)

2.2.4 *Calculation of Performance Score*

Performance scores of buildings are calculated based on the seismicity of the building's location and the parameters reflecting its properties. Turkey is divided into four hazard zones determined based on the current seismic zone map and soil types defined in the Turkish seismic code (TEC 2007). A base score (BS) is

Table 2.1 Base and structural system type scores

Number of unrestrained stories	Base score (BS) Seismic hazard zone I	II	III	IV	Positive scores (POS) Structural system RCF	RCFS	RCS
1 or 2	90	120	160	195	0	100	200
3	80	100	140	170	0	85	170
4	70	90	130	160	0	75	150
5	60	80	110	135	0	65	130
6, 7	50	65	90	110	0	55	110

assigned to the building according to its hazard zone and the number of unrestrained stories. The base scores have been determined taking reinforced concrete frame buildings (RCF) as reference. For RCFS and RCS additional positive scores (POS) are assigned to take into account the structural system type. Apparent quality, soft story, heavy overhang, pounding effect, irregularities, short column and topographic effect are included through penalty scores (PESi).

Tables 2.1 and 2.2 give the base scores and penalty scores for each parameter, respectively. The relationship between the seismic hazard zones, number of stories and base scores is given in Table 2.1, and the current seismic zone map and soil types in the code in Table 2.3. The performance score is calculated via Eq. (2.1). Here, "yes" or "no" type of assessment is made for all parameters having negative influence, except for the apparent quality and building adjacency. The influence indices (Ii) for these parameters take a value of 0 for "no" and 1 for "yes". If the apparent quality assessment is "good", the influence index is 0, for "moderate" it is 1 and for "poor" 2. Table 2.4 gives influence indices for each parameter.

$$PS = BS + \sum I_i * PES_i + POS \tag{2.1}$$

2.2.5 Calibration of Proposed Procedure

The scores assigned to the parameters used in the performance assessment procedure explained above are based on observations from past earthquakes and their relative influence on structural performance. Accuracy and validity of these scores are assessed using two databases: 1. Building damage database compiled after the 1999 Düzce earthquake; 2. Buildings whose seismic performance was assessed using detailed procedures.

Table 2.2 Penalty scores for parameters employed

Number of unrestrained stories	Penalty scores (PES)										
	Soft story	Apparent quality	Heavy overhang	Floor level/building adjacency				Vertical irregularity	Plan irregularity/ torsion	Short column	Topographic effect
				Same Middle	Same Edge	Different Middle	Different Edge				
1, 2	−10	−10	−10	0	−10	−5	−15	−5	−5	−5	−3
3	−20	−10	−20	0	−10	−5	−15	−10	−10	−5	−3
4	−30	−15	−30	0	−10	−5	−15	−15	−10	−5	−3
5	−30	−25	−30	0	−10	−5	−15	−15	−10	−5	−3
6 or 7	−30	−30	−30	0	−10	−5	−15	−15	−10	−5	−3

Table 2.3 Seismic hazard zones according to current seismic zones and soil types in the code

Seismic hazard zone (PGV, m/s)	Seismic zones (TEC 2007)	Soil type (TEC 2007)
I (0.60–0.80)	1	Z3/Z4
II (0.30–0.60)	1	Z1/Z2
	2	Z3/Z4
III (0.15–0.30)	2	Z1/Z2
	3	Z3/Z4
IV (0–0.15)	3	Z1/Z2
	4	All soils

Table 2.4 Influence indices for parameters

Parameter	Influence indices (I_i)
Soft story	No (0); Yes (1)
Heavy overhang	No (0); Yes (1)
Apparent quality	Good (0); Moderate (1); Poor (2)
Short column	No (0); Yes (1)
Topographic effect	No (0); Yes (1)
Plan irregularity	No (0); Yes (1)
Vertical irregularity	No (0); Yes (1)

Table 2.5 Damage distribution of buildings in Düzce database

	Observed damage state				
No. of stories	None	Light	Moderate	Heavy/collapsed	Total
3	18	62	29	15	124
4	17	43	60	27	147
5 or 6	18	30	60	75	183
Total	53	135	149	117	454

2.2.5.1 Application to Düzce Database

After the 1999 earthquakes, a comprehensive post earthquake damage assessment that contained 454, 3–6 story buildings in Düzce was carried out (Ozcebe et al. 2004; SERU 2003). The buildings were classified into four damage states; none, light, moderate, and heavy or collapsed. Results of damage assessment are summarized in Table 2.5.

In order to check the predictions of the proposed procedure, performance scores have been calculated (HPS) for each building in the Düzce database. A separate score to reflect observed performance (GPS) has been assigned to each building based on its damage state. The relation between observed damage score and the damage state is shown in Table 2.6. A threshold score value (SD) is needed to classify the buildings according to their HPS. Therefore, if HPS is less than SD and the GPS score for this building classifies it as “high risk” then the building can be considered to be correctly classified. Similarly, if HPS is greater than SD and the GPS score classifies the building as “low risk” then this building is also classified

Table 2.6 Observed performance scores

Observed damage	Corresponding risk level	Observed performance score (GPS)
None	Low	100
Light	Low	80
Moderate	Low	50
Heavy/Collapse	High	0

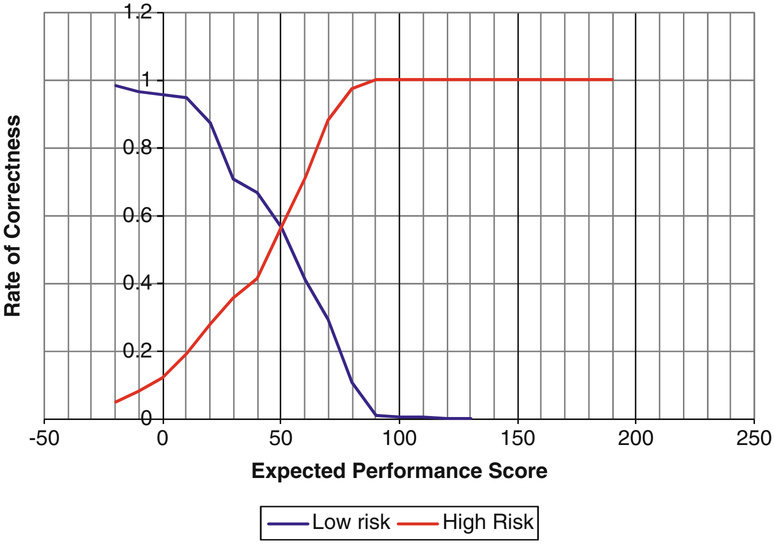


Fig. 2.2 Correctness ratio for Düzce database

correctly. Consequently, a correctness ratio that shows the ratio of correctly classified buildings in the Düzce database to the buildings in the same classification according to their observed behavior (i.e. GPS) can be defined. Figure 2.2 shows the correctness ratio for a selected SD for low and high risk buildings. If SD is taken as 52 (i.e., at the intersection of two curves) then 60 % of both low risk and high risk buildings would be correctly classified. If SD is selected as 65, then 80 % of high risk buildings and 40 % of low risk buildings would be correctly classified. Figure 2.3 shows comparison of calculated and observed performance scores through cumulative distribution function. A reasonably good match is observed.

2.2.5.2 Application to Existing Building Database

131 RC buildings located in different parts of Turkey were assessed using detailed assessment based mainly on the 1997 earthquake code (TEC 1997). Final decisions for the buildings after the detailed assessment revealed that 36 buildings were

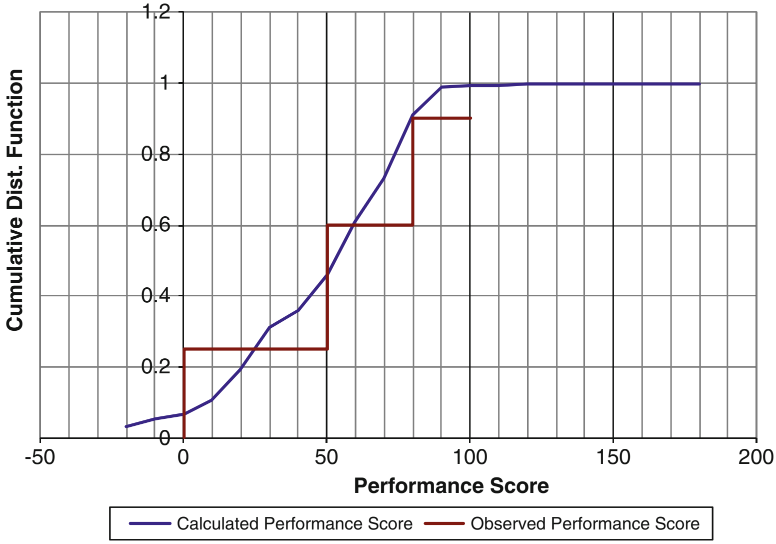


Fig. 2.3 Comparison of calculated and observed scores for Düzce database

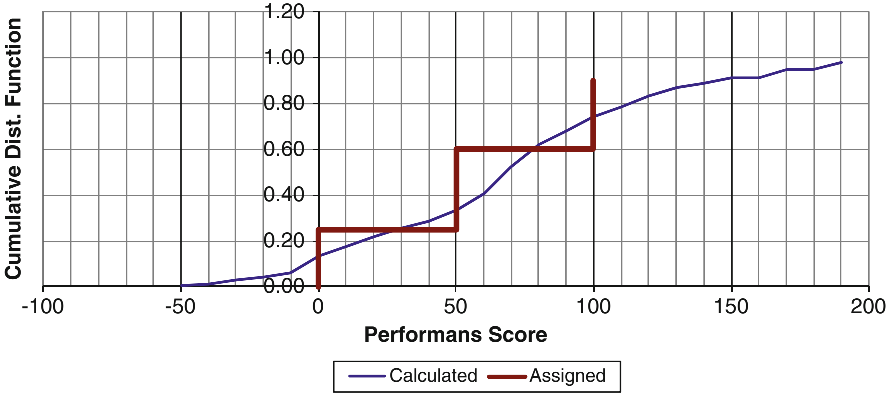


Fig. 2.4 Comparison of calculated and observed scores for the existing building database

sufficiently safe, 7 buildings were too weak to consider strengthening, and the remaining 88 buildings needed strengthening intervention to reach an acceptable safety level. Similar to observed performance scores for the Düzce database, GPS scores were also assigned to these buildings; GPS of 100 is assigned to safe buildings, 50 to buildings that needed strengthening, and 0 to the ones to be demolished (weakest 7 buildings). HPS scores have also been calculated for these buildings and are compared with GPS scores as shown in Fig. 2.4. As can be seen, the calculated and observed scores are in good agreement.

2.3 Proposed Procedure for Masonry Buildings

2.3.1 Data Collection Form and Methodology

The data collection form and seismic performance assessment methodology developed for masonry buildings is very similar to the one developed for reinforced concrete buildings. The structural parameters in the form, which provide the input to calculate the performance score of the surveyed building, have been selected in such a way that they can be obtained simply in a short period of time by street survey and without entering the building. There also exist some parameters in the form that cannot be obtained without entering the building, but these parameters are optional and the absence of these parameters does not prevent the calculation of the performance score of the building. The form is composed of two pages (see Fig. 2.5). The first page contains the structural parameters collected from the building. The second page acts as a commentary; providing simple and illustrative explanations for some of the parameters in the first page.

The first page of the form is composed of five sections: building ID info, type of masonry construction, observations from outside the building, observations from inside the building and general observations. The first section contains the parameters related with ID code, address, coordinates and construction year of the building. In the second section, type of masonry construction for the inspected building should be provided since it is an important parameter for the seismic safety evaluation of masonry buildings. There exist four options: unreinforced masonry, confined masonry, reinforced masonry and hybrid construction (masonry wall + RC frame). In the third section regarding the observations from outside the building, the parameters included can be listed as number of stories, plan geometry, vertical irregularity, position of the building (adjacency) and previous damage (if any). Section four is related to the observations from inside the building and it is optional. The parameters included are as follows: story height, wall thickness, unrestrained wall length, length of wall segment between openings, etc. The final section is composed of general parameters such as masonry unit type, mortar type, workmanship quality, floor type, presence of horizontal and vertical bond beams, weak/soft story, wall-to-wall and wall-to-floor connections.

In order to calculate the performance score (PS) of the inspected building some of the major parameters in the form are employed. First a base score (BS) is determined in accordance with the seismic zone and number of stories. Then the base score is reduced by the penalty scores (Pi) that reflect the structural deficiencies of the inspected building, as:

$$PS = BS + \sum w_i * P_i + R \tag{2.2}$$

a **SURVEY FORM FOR SEISMIC SAFETY ASSESSMENT OF MASONRY BUILDINGS**

Photo of the building

BUILDING ID INFO

BUILDING ID	
DATE OF SURVEY	
BUILDING ADRESS	
GPS COORDINATES (E/N)	
CONSTRUCTION YEAR	
TECHNICAL PERSON	

CONSTRUCTION TYPE (See -1-)

☐ UNREINFORCED	☐ CONFINED
☐ REINFORCED	☐ HYBRID (URM + RC)

OBSERVATIONS OUTSIDE THE BUILDING (See -2-)

NUMBER OF STORIES	..... (NUMBER)		
HIGH SLOPE ?	NO ( )	YES ( )	
BASEMENT FLOOR	NO ( )	YES ( )	N/A ( )
PLAN GEOMETRY	REGULAR ( )	IRREGULAR ( )	
FAÇADE LENGTH (FRONT) ..... Meters	CRITICAL STORY OPENING LENGTH (FRONT) ..... Metre		
FAÇADE LENGTH (SIDE) ..... Meters	CRITICAL STORY OPENING LENGTH (SIDE) ..... Metre		
VERTICAL OPENING LAYOUT	REGULAR ( )	F. REGULAR ( )	IRREGULAR ( )
LOCATION OF BUILDING	SEPARATED ( )	ADJ. MIDDLE ( )	ADJ. CORNER ( )
BUILDING HEIGHT DIFFERENCE	NO ( )	YES ( )	
FLOOR ELEVATION DIFFERENCE	NO ( )	YES ( )	
PREVIOUS DAMAGE	NO ( )	YES ( )	
ADJACENT TO HISTORICAL BUILDING	NO ( )	YES ( )	

OBSERVATIONS INSIDE THE BUILDING (See -3-)

TYPICAL STORY HEIGHT	..... Meters	
TYPICAL WALL THICKNESS	..... Meters	
UNCONSTRAINED WALL LENGTH (L_m) > 5.0 m ?	YES ( ) ..... TIMES	NO ( )
WALL LENGTH BTW TWO OPENINGS (L_b) < 1.0 m ?	YES ( ) ..... TIMES	NO ( )
WALL LENGTH BTW CORNER & OPENING (L_k) < 1.5 m ?	YES ( ) ..... TIMES	NO ( )

GENERAL OBSERVATIONS (See -4-)

MASONRY WALL TYPE	SOLID BRICK ( )	HOLLOW BRICK ( )	SOLID CMU ( )	
	HOLLOW CMU ( )	AAC ( )	CUT STONE ( )	
	RUBBLE STONE ( )	ADOBE ( )		
MORTAR TYPE	CEMENT ( )	LIME ( )	MUD ( )	NO ( )
WORKMANSHIP	GOOD ( )	MODERATE ( )	POOR ( )	
FLOOR TYPE	RC ( )	WOODEN ( )	ARCHED ( )	
HORIZONTAL BOND BEAM ?	OVER WINDOW ( )	FLOOR LEVEL ( )	NO ( )	
VERTICAL BOND BEAM ?	YES ( ) ..... metre interval	NO ( )		
LINTEL ?	YES ( )	NO ( )		
LINTEL/BEAM MATERIAL?	RC ( )	WOODEN ( )		
ROOF TYPE	FLAT ( )	SHED ( )	GABLE ( )	HIPPED ( )
ROOF MATERIAL	TILE ( )	RC ( )	METAL SHEET ( )	EARTHEN ( )
CONNECTIONS	GOOD ( )	POOR ( )		
SOFT/WEAK STORY	YES ( )	NO ( )		

Fig. 2.5 (**a**) First page of the proposed data collection form for masonry buildings. (**b**) Second page of the proposed data collection form for masonry buildings

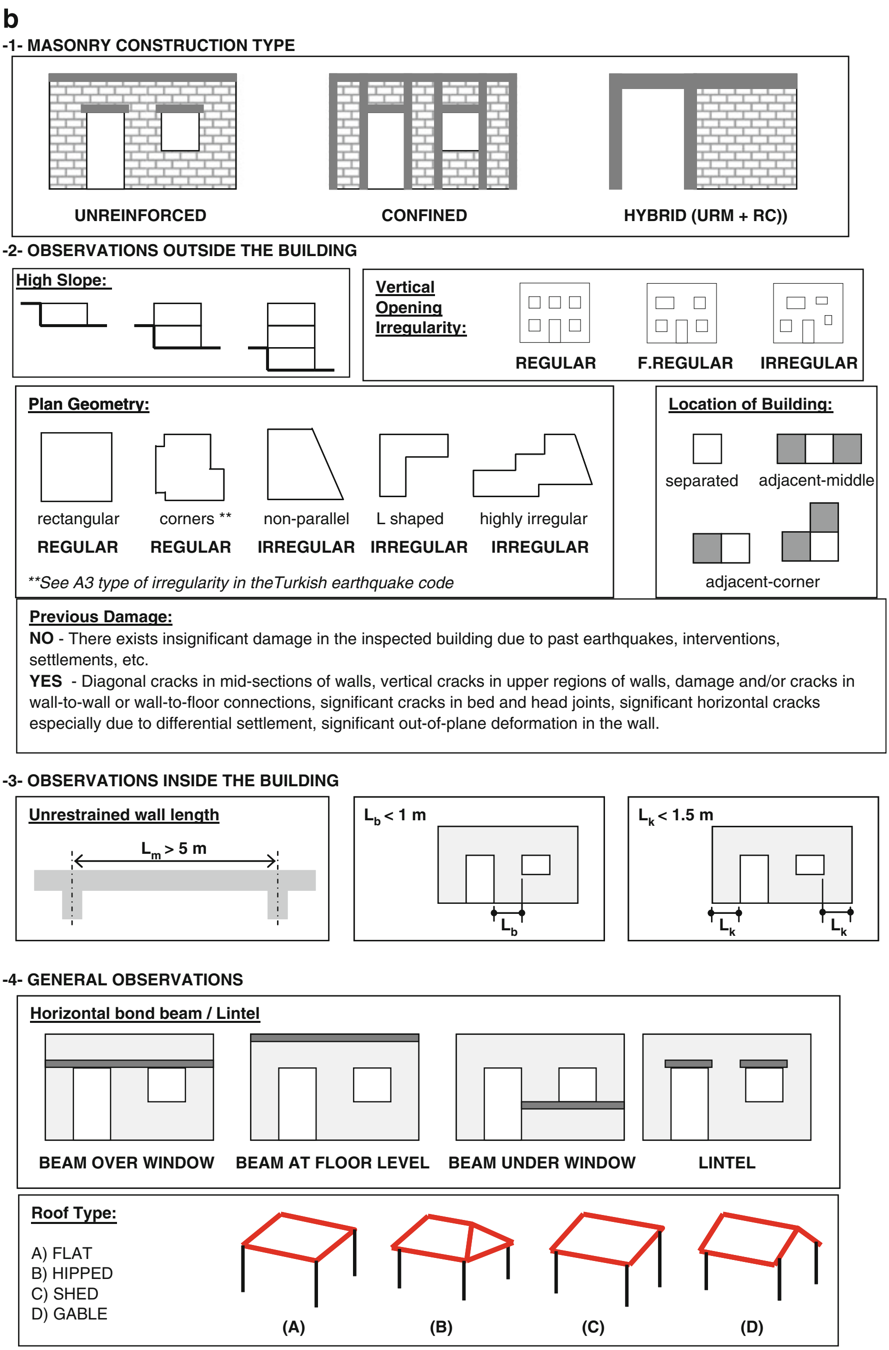


Fig. 2.5 (continued)

Table 2.7 Base scores for masonry buildings other than adobe

No. of stories	Zone-I (PGA≥0.4g)	Zone-II (0.2g ≤PGA<0.4g)	Zone-III (PGA<0.2g)
1	110	120	130
2	100	110	120
3	90	100	110
4	80	90	100
5	70	80	90

In Eq. (2.2), w_i stands for the weighing factor multiplied by the negative penalty score in order to reflect the negative effect of the corresponding structural deficiency on the potential performance of the inspected building and can take values of 0, 1, or 2. Parameter R represents the type of masonry construction and takes positive values in the case of confined (30 points) and reinforced masonry (60 points) buildings.

The base score is a function of seismic zone and number of stories. Masonry buildings are evaluated in three seismic zones in accordance with the peak ground acceleration (PGA) limits as presented in Table 2.7. The base scores are calculated by considering the maximum number of stories permitted by the code for masonry buildings according to the seismic zone that the buildings reside. For instance, the cells in gray color in Table 2.7 represent the maximum allowable number of stories for a specific seismic zone. The base score for these cases is considered as 100. Each additional story means violation of the code requirement and hence punished by a penalty score of 10 per story. On the other hand, if the number of stories of the inspected building is less than the number of stories allowed by the code, then the base score is increased by 10 per story. However, it should be noted that the scores in Table 2.7 are for masonry structures other than adobe. According to the earthquake code, adobe buildings are allowed to be constructed as a single story regardless of the seismic zone, since they are the most vulnerable type of masonry construction. Hence the scores for adobe construction are adjusted in such way that all scores in Table 2.7 are reduced by 30.

Penalty scores, which represent the structural deficiencies of masonry buildings, can be grouped as follows:

- Existing condition and apparent quality of the building
- Irregularities in plan
- Irregularities in elevation
- Location of the building (adjacency)
- Out-of-plane vulnerability of the masonry walls

Penalty scores for the parameters related to the existing condition and apparent quality of the building are presented in Table 2.8. These include the material quality (both masonry units and mortar), workmanship quality and existence of previous

Table 2.8 Penalty scores and weighing factors for the existing condition and apparent quality

No. of stories	Material quality (0/1/2)	Workmanship (0/1/2)	Previous damage (0/1)
1–5	−10	−5	−5

Table 2.9 Penalty scores for irregularities in plan and elevation

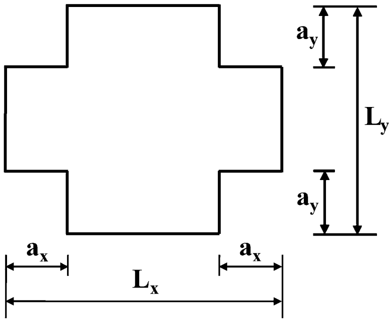
	Irregularities in plan			Irregularities in elevation		
No. of stories	Geometry (0/1)	Wall length (0/1/2)	Bond beams (0/1)	Openings (0/1/2)	High slope (0/1)	Soft/weak story (0/1)
1	−5	−5	−5	0	−5	0
2	−10	−5	−5	−5	−5	−5
3	−10	−10	−5	−5	−5	−5
4	−15	−10	−5	−10	−5	−10
5	−20	−15	−5	−10	−5	−10

damage or not. Penalty scores are assumed to be independent of the number of stories for the given parameters. Weighing factors for material quality are 0, 1 and 2, representing good, moderate and poor quality, respectively. The same weighing factors are also valid for the workmanship quality. For the previous damage parameter, the weighing factors take values of 0 or 1 for absence and presence of any significant damage.

The second and third groups of penalty scores include the parameters related to the irregularities in plan and elevation for masonry buildings. These parameters can be listed as plan geometry, load-bearing wall length, existence of horizontal and vertical bond beams, vertical arrangement of openings in walls, high slope and existence of soft/weak story. The penalty scores and the weighing factors of these two groups are presented in Table 2.9. Since the structural deficiencies in elevation become more pronounced with an increase in the number of stories, this should also be reflected in the penalty scores as given in Table 2.9. The most influential parameters seem to be the plan geometry and the total wall length, which is consistent with the observations during field studies on damaged buildings. In this methodology, plan geometry is classified as “regular” or “irregular” with weighing factors of 0 and 1, respectively. The definition of plan irregularity is based on the requirements of the current earthquake code. Accordingly, a building is irregular in plan if the projections (ax, ay in Fig. 2.6) beyond the re-entrant corners in both of the two principal directions exceed the total plan dimensions of the building (Lx, Ly in Fig. 2.6) in the respective plan directions by more than 20 %. In addition, buildings with L-shaped or U-shaped plans are also deemed as irregular.

The total length of the load-bearing walls in the critical story (generally the ground story) of the building in both principal directions can be roughly determined during the street survey. Accordingly, if the total length of the openings (door and window) is less than 1/3 of the total length of the walls on façade under consideration, the total length is considered as “adequate” with a weighing factor of 0. On the other hand, if the total length of the openings is more than 2/3 of the façade length, it is considered as “inadequate” with a weighing factor of 2. In between, the total length is considered as “fairly adequate” with a weighing factor of 1. If it is

Fig. 2.6 The definition of irregularity in plan according to the Turkish earthquake code



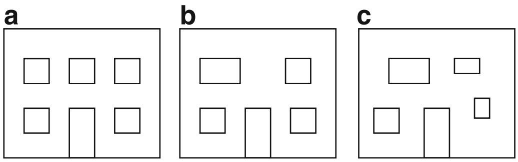


Fig. 2.7 The illustrations for classification of masonry buildings according to vertical arrangements of openings, (**a**) regular, (**b**) fairly regular, (**c**) irregular

possible to enter the building, a more precise evaluation can be performed regarding the total length of the load-bearing walls. The last parameter related with the irregularities in plan is the presence or absence of the horizontal and vertical bond beams with weighing factors of 0 and 1, respectively.

The buildings are classified according to the vertical arrangement of the openings in walls as "regular", "fairly regular" and "irregular" with weighing factors of 0, 1 and 2, respectively. The definitions used for this classification are illustrated in Fig. 2.7. Buildings on high slopes and having soft/weak stories are also considered as seen in Table 2.9 with weighing factors of 0 (absence) and 1 (presence).

The location of the building with respect to the adjacent buildings is also an important parameter. For adjacent buildings, if the floor levels are different, it is possible that the buildings get some damage during an earthquake because of the pounding effect. In this study, five different cases are considered for the location of the building and the floor levels of adjacent buildings:

1. Case A: Separated building
2. Case B: Adjacent building in the middle – floor levels at the same elevation
3. Case C: Adjacent building in the middle – floor levels at different elevations
4. Case D: Adjacent building in the corner – floor levels at the same elevation
5. Case E: Adjacent building in the corner – floor levels at different elevations

The penalty scores for these five different cases are listed in Table 2.10. The most critical case seems to be Case E, representing a building at the corner of a block with floor levels at different elevations with respect to the adjacent building.

Table 2.10 Penalty scores for location of the building and floor levels of adjacent buildings

No. of stories	Case A	Case B	Case C	Case D	Case E
1–5	0	0	−5	−5	−10

There exist some minor parameters which affect the seismic performance of masonry buildings so they should also be included into Eq. (2.1) as penalty scores. The first one is the existence of heavy earthen roofs, which is generally encountered in rural-type masonry construction. Masonry buildings with heavy earthen roofs usually become death traps during an earthquake and in most of the cases it is not possible to escape outside during an earthquake. This structural deficiency increases the final death toll significantly as experienced recently during the 2010 Elazığ (Turkey) earthquake (Akkar et al. 2011; Celep et al. 2011). Hence a penalty score of 10 is assigned to masonry buildings with earthen roof. Another important parameter in the seismic performance of masonry buildings is the out-of-plane capacity of load-bearing walls. In some cases, out-of-plane damage precedes in-plane damage in masonry buildings and causes the partial or total collapse of the building. The structural deficiencies that cause out-of-plane vulnerability can be listed as poor wall-to-wall and wall-to-floor connections, flexible floor diaphragm, having poor or no mortar (dry joint) in walls, existing out-of-plane deformations in the walls and unrestrained gable end walls. These are also the parameters that exist in the data collection form. If at least three of the aforementioned deficiencies are present in the inspected building, then a penalty score of 10 is assigned to that building.

2.3.2 Evaluation of Performance Scores Using Field Data

The scores in this methodology have been determined by considering previous experience from past earthquakes, expert opinion and the results of the analytical fragility functions for different types of masonry construction (Erberik 2008). However the reliability of the proposed methodology should be checked by using actual damage data. For this purpose, the damaged building data obtained after the 1995 Dinar (Turkey) earthquake has been employed. This includes 102 masonry buildings, for which the damage levels were determined by using the damage assessment form of the Ministry of Public Works and Settlement (METU-EERC 1996). According to this form, damage scores are assigned for the walls of the most damaged story of the masonry structure as well as for the stairs and roof. Damage is classified as undamaged (0–1), minor (1–3), moderate (4–6), severe (7–9) or collapse (>9). The numbers in parenthesis represent the score range for each damage state. The comparison of the inverse of the damage score with the performance score obtained by using the proposed methodology is presented in Fig. 2.8. There seems to be an increasing trend line for the scattered data. In other words, as expected, buildings with serious damage after the earthquake receive low

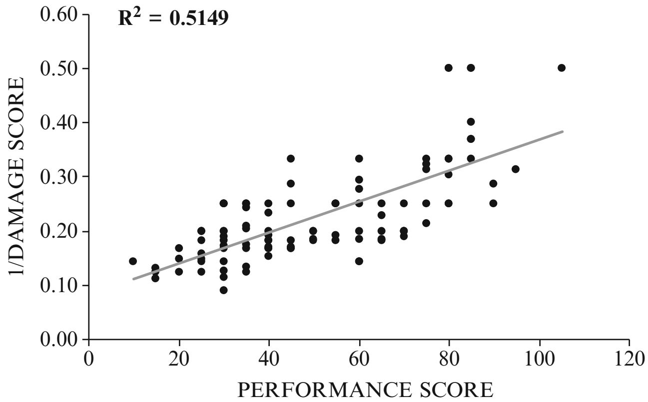


Fig. 2.8 Comparison of performance score with the inverse of the damage score obtained after the 1995 Dinar earthquake

performance points. The R^2 value is not sufficiently high since the damage score obtained after the earthquake does not contain many of the parameters used in calculating the performance score by the proposed methodology, so it is not possible to make a one-to-one comparison between these two measures.

Then the proposed methodology is applied to two different existing masonry building databases for comparison with the existing procedures. The first one is the Zeytinburnu (Istanbul) database, which is composed of 69 masonry buildings. The seismic safety of buildings in this database were examined by using a performance measure named as the "weighted shear strength factor (WSSF)", details of which are provided in the technical report by Sucuoğlu and Erberik (2005). The WSSF can take positive values, for which high values mean high seismic risk. The comparison of the inverse of the WSSF with the performance score is provided in Fig. 2.9a. The second database considered is the Fatih (Istanbul) database, composed of 9,457 masonry buildings. The seismic safety evaluation study carried out by using this database makes use of a vulnerability measure named as the "vulnerability score (VS)". This score is obtained by using analytical fragility curves and takes values between 0 (high risk) and 1 (low risk). The details of the procedure and the VS can be found elsewhere (Erberik 2008, 2010). The comparison of the VS with the performance score is shown in Fig. 2.9b.

The statistical comparisons in Fig. 2.9 reveal that there is a consistent trend but a low R^2 value in both cases. The dispersion in the results arises from the fact that each methodology uses different approaches with different parameters. The assumptions used are also different, so it is not possible to make a one-to-one comparison between different methodologies. Overall, the proposed procedure for masonry buildings is promising but it has to be calibrated further by using field data, which is not easy to find.

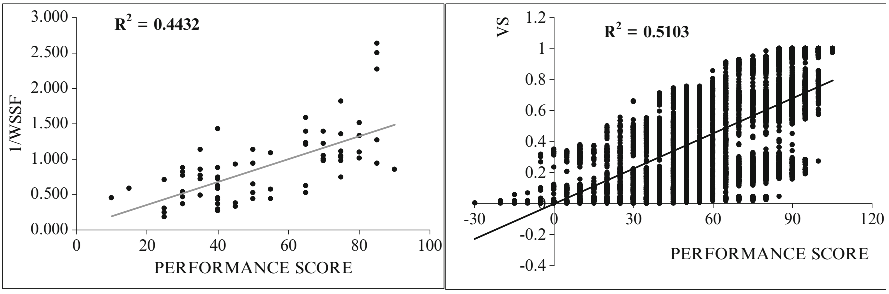


Fig. 2.9 Comparison of the performance measures obtained previously for two different building databases with the performance score developed in this study

2.4 Conclusions

Rapid assessment procedures have been developed for the two most common construction types in Turkey. The procedures reflect peculiarities of Turkish building stock and are believed to reflect their performance observed in recent earthquakes in Turkey. These procedures are applicable to a population of buildings to determine their seismic risk prioritization, but are not appropriate to determine seismic vulnerability of an individual building. Their validity has been tested using field data of existing building databases as well as past earthquake damage databases. The proposed procedures are expected to be used officially in Turkey for both risk prioritization and obtaining building inventory.

References

Akkar S, Aldemir A, Askan A, Bakır S, Canbay E, Demirel O, Erberik MA, Gülerce Z, Gülkan P, Kalkan E, Prakash S, Sandikkaya MA, Sevilgen V, Ugurhan B, Yenier E (2011) 8 March 2010 Elazığ-Kovancılar (Turkey) earthquake: observations on ground motions and building damage. Seismol Res Lett 82(1):42–58

Applied Technology Council (ATC) (2002) Rapid visual screening of buildings for potential seismic hazards: a handbook, 2nd edn, FEMA 154. Federal Emergency Management Agency, Washington, DC

Arya AS (2007) Rapid visual screening of masonry buildings. Technical report prepared under GoI – UNDP Disaster Risk Management Programme. National Disaster Management Division, New Delhi

Bal İE, Tezcan S, Gülay FG (2007) Betonarme binaların göçme riskinin belirlenmesi için P25 hızlı değerlendirme yöntemi. Altıncı Ulusal Deprem Mühendisliği Konferansı, 16–20 Ekim 2007, İstanbul

Celep Z, Erken A, Taskin B, Ilki A (2011) Failures of masonry and concrete buildings during the March 8, 2010 Kovancilar and Palu (Elazig) earthquakes in Turkey. Eng Fail Anal 18(3):868–889

Erberik MA (2008) Generation of fragility curves for Turkish masonry buildings considering in-plane failure modes. Earthq Eng Struct Dyn 37:387–405

Erberik MA (2010) Seismic risk assessment of masonry buildings in Istanbul for effective risk mitigation. Earthq Spectra 26:967–982

FEMA 154 (2002) Rapid visual screening of buildings for potential seismic hazards: a handbook, 2nd edn. Federal Emergency Management Agency; FEMA 500 C Street, SW Washington, DC

İlki A, Boduroğlu H, Özdemir P, Baysan F, Demir C, and Şirin S (2003) Mevcut ve güçlendirilmiş yapılar için sismik indeks yöntemi ve yapısal çözümleme sonuçlarının karşılaştırılması. Beşinci Ulusal Deprem Mühendisliği Konferansı, İstanbul

Kaminosono T (2002) Evaluation method for seismic capacity of existing reinforced concrete buildings in Japan. In: Proceedings of the international conference on earthquake loss estimation and risk reduction, Bucharest

Karbassi A, Nollet MJ (2008) Development of an index assignment procedure compatible with the regional seismicity in the province of Quebec for the rapid visual screening of existing buildings. Can J Civ Eng 35:925–937

Kocaman C, Kuran F, Demirok E, Avşar Ö (2009) Seismic safety evaluation studies in the province of Denizli. Technical report, Ministry of Public Works and Settlement, General Directorate of Disaster Affairs, Earthquake Research Division, Ankara

METU-EERC (1996) Repair and rehabilitation project for moderately damaged masonry structures after 1995 Dinar Earthquake. Earthquake Engineering Research Center, Civil Engineering Department, Middle East Technical University, Ankara

Ozcebe G, Yucemen MS, Aydogan V (2004) Statistical seismic vulnerability assessment of existing reinforced concrete buildings in Turkey on a regional scale. J Earthq Eng 8(5):749–773

SERU [Structural Engineering Research Unit] (2003) Middle East Technical University, Ankara, Turkey. http://www.seru.metu.edu.tr/archives/databases/Duzce_Database/

Sextos AG, Kappos AJ, Stylianidis KC (2008) Computer-aided pre- and post-earthquake assessment of buildings involving database compilation, GIS visualization, and mobile data transmission. Comput-Aided Civ Infrastruct Eng 23:59–73

Sucuoğlu H, Erberik MA (2005) Earthquake master plan for Istanbul, pilot study in Zeytinburnu sub-province: seismic safety evaluation of masonry and hybrid buildings. Technical report, Middle East Technical University, Ankara

Sucuoğlu H, Yazgan U (2003) Simple survey procedures for seismic risk assessment in urban building stocks. In: Wasti ST, Ozcebe G (eds) Seismic assessment and rehabilitation of existing buildings, vol 29, Earth and environmental sciences. Kluwer Academic, London, pp 97–118

Sucuoğlu H, Yazgan U, Yakut A (2007) A screening procedure for seismic risk assessment in urban building stocks. Earthq Spectra 23:441–458

Temür R (2006) Hızlı Durum Tespit (DURTES) yöntemi ve bilgisayar programının geliştirilmesi. Yüksek lisans tezi, İstanbul Üniversitesi, İstanbul

Turkish Earthquake Code (TEC) (1997, 2007) Specification for buildings to be built in seismic areas. Ministry of Public Works and Settlement, Ankara

Yakut A (2004) Preliminary seismic performance assessment procedure for existing RC buildings. Eng Struct 26(10):1447–1461

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http://www.springer.com/978-3-319-00458-7

Seismic Evaluation and Rehabilitation of Structures
Ilki, A.; Fardis, M.N. (Eds.)
2014, XIX, 497 p. 359 illus., 169 illus. in color.,
ISBN: 978-3-319-00458-7