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Research Article

Seismic Risk Assessment of Existing RC Buildings in Muğla

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ABSTRACT

Turkey is located in a highly seismic region and has experienced major earthquakes with substantial casualties and economic losses in the past two decades. The February 6, 2023, Mw 7.7 and 7.6 sequential earthquakes were catastrophic ones that affected eleven cities with many casualties and high economic losses. The increased financial burden would not be necessary if our building stock were in decent shape. Therefore, it is critical to assess the seismic vulnerability of existing buildings to be able to take precautions. Muğla is one of the high-seismic cities located in the western part of Türkiye. In this study, a walk-down survey method proposed by the code The Principles of Identifying Risky Buildings (RYTEIE, 2019), a simple and rapid method, is used to assess the risk levels of RC buildings in the Emirbeyazıt neighborhood of Menteşe, Muğla. 469 RC buildings are examined considering parameters such as age, number of stories, and technical deficiencies, including soft or weak stories. The performance score is calculated for each building and ranked in ascending order to decide the risk prioritization. 26 RC buildings were selected from a different range of performance scores to be able to evaluate the preliminary assessment method using the concrete compressive strength and confinement rebar searched by non-destructive testing methods. The blueprints were used to calculate the base shear capacities and assessed by a preliminary assessment method to observe the performance levels and relationship with performance score.

Introduction

Turkey is situated in a highly seismic region, where the active tectonic plates can cause major earthquakes. The February 6, 2023 Kahramanmaraş earthquake sequence was catastrophic and resulted in many casualties and high economic losses. It affected eleven cities and the building stock showed poor performance with heavy and collapse damage. The increased financial burden would not be necessary if our building stock were in decent shape. This situation initiates the urgent necessity for the risk assessment of the existing building stock [1]. Principles for Identifying Risky Structures (RYTEİE, [2]) introduce a walk-down survey and ranking system for the regional risk assessment for existing reinforced concrete and masonry buildings.

The risk assessment can be classified into three groups. The walk-down method is the simplest, requiring few queries to identify deficiencies and calculate a performance score, which is similar to the approach used by RYTEİE (2019) [2], [3] and Coskun et al. (2020) [4]. The second group includes more parameters and calculations to check the capacity or capacity-related parameters. Hassan and Sozen (1997) [5] studied seismic vulnerability assessment of low-rise buildings. They adapted the risk assessment method proposed by Shiga, Schibata, and Takahashi in Erzincan [6], which was developed after the 1968 Tokachi-Oki earthquake. Sucuoğlu et al. (2007) [7] developed a risk assessment method for reinforced concrete buildings in urban building stocks, and 16,523 reinforced concrete buildings in the Fatih district were examined using the walk-down survey procedure. Yakut (2004) [8] and Yakut et al.(2012) [9] used workmanship or capacity concepts to develop risk ranking methodologies. Coskun et al. (2020) [4] developed a preliminary assessment method using statistical methods for the walk-down assessment parameters for the 2020 Elazığ earthquake. The third group of the risk assessment is the detailed analysis, such proposed in RYTEİE (2019) [2] for risk assessment and Turkish Building Earthquake Code (TBEC 2018) [10] performance assessment.

This study aims to predict the vulnerability of existing RC buildings in Mugla, Emirbeyazıt Neighborhood, which is given in Fig.1, using the walkdown survey method according to RYTEİE (2019) and preliminary assessment technique (Yakut 2004) [8] to make a risk ranking and performance check to create a database for the existing buildings of Muğla Emirbeyazıt Neighborhood, since no similar research exists in this location. This study is focused on the parameters such as age of the buildings, the occupancy type, the number of stories, vertical and plan irregularities, seismic intensity, strength of the concrete, soil type, the apparent quality, and the construction quality. Approximately 469 buildings have been evaluated with a walk-down survey according to RYTEİE (2019) [2], and performance scores are evaluated, and 26 buildings have been examined from these rankings to investigate the performance according to the Yakut (2004) [8] procedure. The results are expressed separately for each building by calculating a performance score.

Figure 1 Muğla, Emirbeyazıt Neighborhood (The Survey Area)

The Methodology

Walk-Down Survey

Many risk assessment methods have been developed by researchers for reinforced concrete buildings in urban settlements as described above. A walk-down survey, which is the simplest method, is used to identify the risky RC buildings for regional risk assessment purposes. The analysis, data collection, and decision-making process are carried out in the field, and the average time spent per building is approximately 15 to 30 minutes. The main purpose is to create a ranking according to the evaluated performance score for each building and allow the decision makers to take precautions for potentially risky buildings via a more detailed performance assessment and retrofitting options.

The age of building, the occupancy type, the number of stories, the vertical and plan irregularities, seismic hazard, apparent quality, heavy overhangs, and structural system type are some of these parameters required for RYTEİE (2019) [2] walk-down survey method, which is given in Fig. 2. The stated parameters can be determined quite easily in site-investigation. The year of construction, or namely the age of the building, gives an idea about the seismic code in force during construction and can be observed on site if the structural member sizes are not suitable to the recent code in force. More details about the parameters used in the survey are given in Fig. 2.

Technical deficiencies such as soft story, overhang and apparent quality are described in detail with photos from the site investigation to clarify how the database is constructed.

Soft Story

Soft stories usually exist in buildings when the ground story has less stiffness and strength compared to upper stories [7], . Generally, it can be observed in buildings where the infill walls are removed or discontinuous vertically. Fig. 3 gives structure examples with the soft stories in the site investigation.

BUILDING ID FORM			Date:		
			No:		
Builidng ID			PHOTO		
City					
Sub-premises					
District					
Street					
Builidng No					
Block					
Lot					
Parcel					
UAVT Code					
Estimated Age of Building					
Coordinates	LATITUDE :		LONGITUDE :		
Occupancy Type	☐ Residential	☐ Commercial	☐ Industrial	☐Government	☐ Disused
Building Technical Details					
Structural System	☐ RC Frame		☐ RC Frame with Shear Wall		
Number of Stories					
Apparent Quality	☐ Good	☐ Modarate	☐ Bad		
Soft / Weak Story	☐ Yes	☐ No			
Vertical Irregularity	☐ Yes	☐ No			
Overhang	☐ Yes	☐ No			
Plan Irregularity	☐ Yes	☐ No			
Short Ccolumn	☐ Yes	☐ No			
Adjacency	☐ Seperate	☐ Adjacent	☐ Adjacent at corner		
Floor Level in Adjacent Buildings	☐ Same	☐ Different			
Elevation	☐ Straigth	☐ Slope (Slope > 30)			
Site Class	☐ ZA	☐ ZB	☐ ZC	☐ ZD	☐ ZE
NOTE :					

Figure 2 Data Collection Form for RC Buildings (RYTEİE 2019 *[2]*)

Figure 3 Soft Story Examples

Overhangs

This effect is related to the area changes in the plan between the ground story and the upper stories. According to the Construction Zoning Regulation, open and closed cantilevers can be made on each facade of the building, provided that it does not exceed the boundaries of their garden, except for the floor area. However, heavy overhangs cause mass and stiffness irregularity in the building. Fig. 4 gives examples of heavy overhangs.

Figure 4 Heavy Overhang Examples

Apparent Quality

The apparent quality is examined by observing the overall appearance of the structure in terms of maintenance and evaluations are classified into three levels: good, average, and poor as seen in Fig. 5.

Short Column

A short column is identified when change in floor levels or adjacent partial infill walls may result in a short column effect which makes the column stiffer than surrounding structural members and take more shear forces. Compared to long columns, the short columns are indeed stiffer therefore they take most of the earthquake forces acting on the building. One of the identified short column effect is given in Fig. 5 (c).

which varies with the number of stories for the buildings with shear wall. For frame system, YSP is equal to 0. TP and YSP values are given in Table 1.

$$PP = TP + \sum_{i=1}^{N}(O_i + OP_i) + YSP \qquad (1)$$

O_i is the penalty parameter coefficient and OP_i is the penalty parameter value. The penalty parameters are related to the existence of the situation. In example, if there exist soft story in the building, it is checked as “Yes” and O_i is “1”, else it is “0”. Similarly, for apparent quality, if it is in

Table 1 Base Score and Structural System Score (RBTEİE 2019 Table A.1)

	Base Score (TP)				Structural System Score (YSP)	
	Hazard Zone				Structural System	
	I	II	III	IV	RC Frame	RC Frame w/Shear Walls
1 and 2	90	120	160	195	0	100
3	80	100	140	170	0	85
4	70	90	130	160	0	75
5	60	80	110	135	0	65
6 and 7	50	65	90	110	0	55

Table 2 Technical Deficiencies and The Penalty Parameter Coefficients, O_i (RBTEİE 2019 Table A.3)

Parameter Number	Technical Deficiency	Situation 1		Situation 2	
		Parameter Existence	Parameter Coefficient	Parameter Existence	Parameter Coefficient
1	Apparent Quality	Good	0	Moderate (Bad)	1 (2)
2	Soft Story	No		Yes	1
3	Heavy Overhang	No		Yes	
4	Vertical Irregularity	No		Yes	
5	Plan Irregularity	No		Yes	
6	Short Column	No		Yes	
7	Adjacency	Separate		Adj. / Corner	
8	Slope	No		Yes	

Figure 5 Apparent Quality Evaluation (a, b, c) and Short Column Effect (c) Examples

Performance Score Calculation According to RYTEİE (2019) [2] *Walk-Down Survey Method*

In RYTEİE (2019) [2], Annex A is related a ranking method using the walk-down survey parameters. The performance score is calculated for each building according to Eq. 1. TP is the base score which varies depending on the number of stories and seismic zone. YSP is the structural system score

“Good” condition that is “0”, else if it is “Moderate”, that is “1” and else it is “2”. (Table 2)

According to the identified existence of the technical deficiency parameters, the penalty parameter score is chosen from Table 3 to multiply with the penalty parameter coefficients. Calculated performance scores (Eq.1) are ranked in ascending order. By using the ranked scores, the risk priority can be determined for the region and the decision makers such as municipalities can take precautions for probable casualty and economic loss.

Preliminary Assessment Method, Yakut (2004)

The preliminary assessment methods are varies depending on the purpose and the richness of the data availability. In this study Yakut (2004) [8] will be used to perform a second step detailed analysis to compare the capacity check of the buildings according to the regulations in force year built.

Table 3 The Penalty Parameter Score, OP_i (RBTEİE, 2019 Table A.4)

Number of Stories	Soft Story	Apparent Qualtiy	Heavy Overhang	Adjacency / Level of Floors				Vertical ırregularity	Plan Irregularity	Short Column	Slope
				Same		Different					
				Middle	Edge	Middle	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
6,7	-30	-30	-30	0	-10	-5	-15	-15	-10	-5	-3

The preliminary assessment methods need more variable most of the time. Yakut (2004) [8] needs extra variables such as sizes and dimensions of the structural components, material mechanical properties and blueprints for the plan layouts in addition to the walk-down survey parameters. In this method, comprehensive field studies are performed to collect the data relevant to building characteristics. The base shear capacity for each building is calculated by using the Eq. 2. "V_{ci}" represents the shear capacity of the rectangular reinforced concrete column in dimensions of b_w and h. "f_{ctk}" is the reinforced concrete tensile strength. "c" is taken as 2/3 in the considered direction and 1/3 for for the other one. The value of "a" is chosen as 0.65 which is as given by TS500 for RC buildings.

$$V_{ci} = caf_{ctk}b_wh \tag{2}$$

The recommended compressive strength of reinforced concrete values for the apparent quality technical deficiency parameters from site investigation are given in Table 4. The compressive strength of the concrete can also be determined using the non-destructive testing method such as Schmidt hammer test. The tensile strength of reinforced concrete is related to compressive strength directly.

Table 4 Recommended f_{ck} values by Yakut (2004), [8]

Apparent quality (from visual inspection)	Recommended compressive strength (f_{ck}) (MPa)
Poor	<10
Average	10-16
Good	>16

V_y, which represents yield base shear capacity without infill walls, is calculated by Eq. 3. In this equation, it is assumed that no infill walls contributing to the lateral load resistance [11]. If the infill walls included in the lateral resistance, then taken into account using the ratio of the total infill wall cross-sectional areas, A_w, to the total floor area, A_{tf}. V_{yw} which represents yield base shear capacity with infill wall can be determine by Eq. 4 as given.

$$V_y = \frac{V_c}{0.95^{0.125n}} \tag{3}$$

$$V_{yw} = V_y\left(46\frac{A_w}{A_{tf}} + 1\right) \tag{4}$$

Basic Capacity Index (BCPI) is computed from Eq. 5 by dividing V_{yw} to the code specified design base shear V_{code}.

$$BCPI = \frac{V_{yw}}{V_{CODE}} \tag{5}$$

In Eq. 6, Capacity Index (CPI) has been developed using the Basic Capacity Index (BCPI) in order to take into account the effects such as soft story, heavy overhangs, torsional irregularity. Two coefficients derived from visual inspection are used. C_A and C_M are coefficients that reflect the architectural features and construction quality, respectively.

$$CPI = C_AC_MBCPI \tag{6}$$

In Eq. 7, C_{AS} reflects the soft story and C_{ASC} takes into account the presence of short column effect. C_{AP} and C_{AF} stand for plan irregularity and frame discontinuity, respectively. In order to prevent relative values for the parameters used during the calculation of the C_A value, the Table 5 has been given.

$$C_A = 1.0 - (C_{AS} + C_{ASC} + C_{AP} + C_{AF}) \tag{7}$$

Table 5 Adapted from Yakut, 2004, *[8]*

	FEMA 154	GULKAN and Yakut	Sucuoğlu and Yazgan
C_{AS}	0.36	0.5	0.32
C_{ASC}	0.18	0.25	0.11
C_{AP}	0.19	0.125	0.19
C_{AF}	0.27	0.125	0.38

In Table 6, the suggested C_M, where it is defined for the material and workmanship quality, formulas are given [8]. In this study, Q_r value is considered as 0.55 for Turkey which is suggested by Yakut, 2004, [8]. The CPI is calculated for each building and it is decided whether the buildings are safe or not.

Table 6 Suggested C_M values (Yakut, 2004, *[8]*)

Poor	$1.0 - Q_r (1 - C_A)$
Average	$1.0 - Q_r (1 - C_A)/3$
Good	1

Results

The results are evaluated in two parts as the walk-down survey and preliminary analysis results.

The Walk-Down Survey Results

A total of 469 RC buildings were examined and walk-down survey parameters are collected. In buildings that do not have an earthquake design, the horizontal loads create a great risk with incomplete capacity design. The number of stories in a building is an essential parameter for earthquake design and Fig 6. displays the number of buildings for varying story numbers for the investigated database.

In Fig. 7, different classifications are displaced to observe the data. The buildings are classified according to their occupancy type as 93% residential, 5% government and 2% commercial buildings. 77% of the buildings are reinforced concrete frame system and the rest have a structural system type as reinforced concrete frame with shear walls. It has been determined that the apparent quality of 35% of the buildings is "Bad", 44% is "Medium" and 21% is "Good".

The majority of the buildings suffer from the heavy overhang effects. Heavy overhangs were observed in 82% of the buildings examined. Among all buildings, 27% of the buildings have a plan irregularity.

Another problem mostly observed in buildings was the irregularities in the vertical. The vertical irregularity caused by the discontinuity of the vertical elements of the structural system was found in 68% of the buildings examined. Among these buildings, the soft story was the most common problem encountered. Furthermore, gusset-supported cantilever beams or columns were also determined. Soft story irregularity was encountered in 65% of the total buildings. Short column effect, which is one of the other weaknesses that negatively affects the behavior of the buildings during earthquakes, is not common and the ratio is at the level of 22% in database.

Another important parameter is the floor level difference between adjacent buildings. Leveling differences of adjacent buildings can increase the failure during earthquake. Since 62% of the buildings are separate, the probability of collapse is less than the adjacent ones. The floor level of 25% of the adjacent buildings is at same level or critical and at different levels in 12% of adjacent buildings.

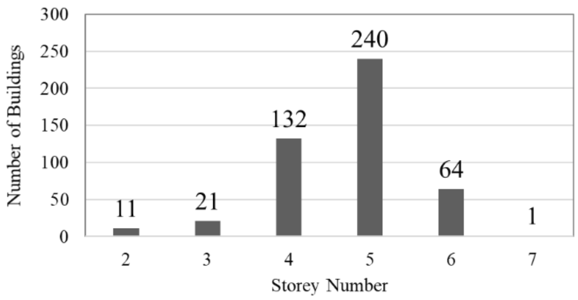

Figure 6 Distribution of the number of stories in the database

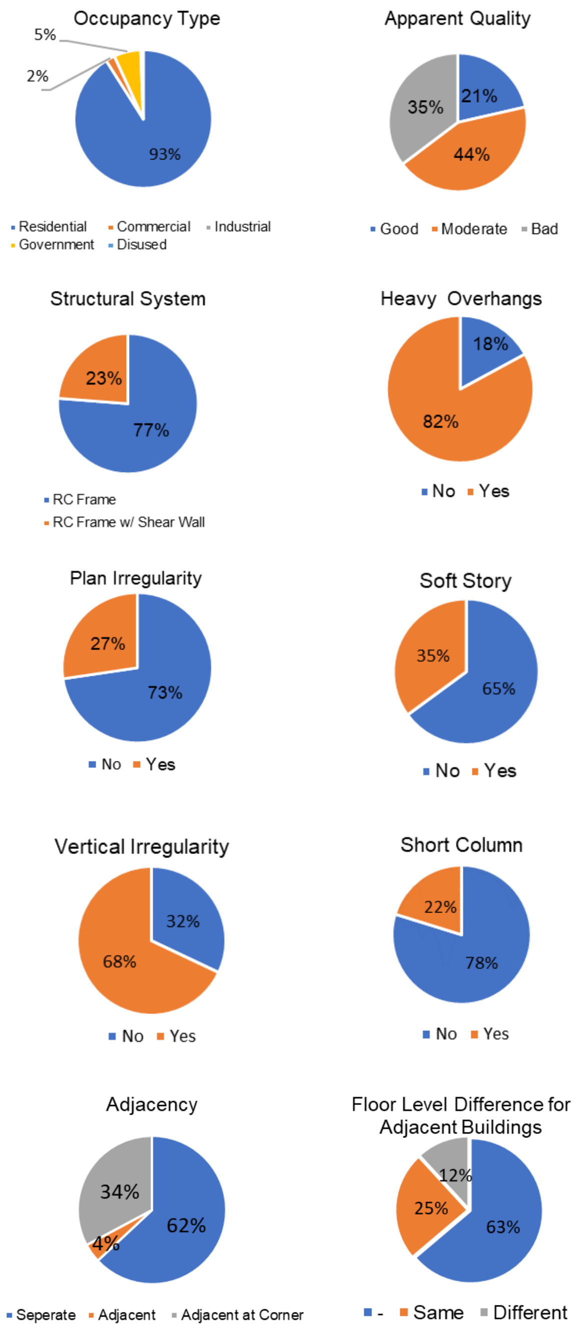

Figure 7 Classified Data for RYTEİE (2019) survey parameters

The performance score results of walk-down method according to RYTEİE (2019) [2] are given for all reinforced concrete buildings in Fig. 8. 249 buildings received less than zero performance score. The lowest performance score is -118. The performance score of 8 buildings is calculated as zero. The remaining reinforced concrete buildings score is higher than zero, but the highest performance score is 145. The walk-down survey method proposed by [2] is a ranking system there for the result given in Fig. 8 is ranked in an ascending order. There is no limit or threshold value for risk prioritization. The decision makers can use this data to create their risk mitigation plan.

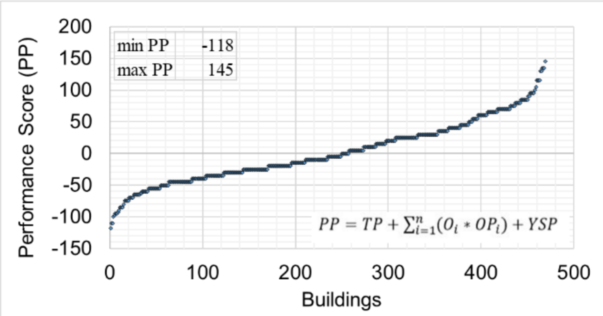

Figure 8 Performance Points calculated according to RYTEİE (2019) *[2]* of the buildings examined

Preliminary Assessment Results

In this study, Yakut (2004) [8] one of the preliminary methods which is derived using Türkiye database. There is no threshold limit for the performance scores obtained by the walk-down method [2] and it is a ranking system. Preliminary assessment methods are simpler than detailed performance analysis, but require more data than screening procedure. In this study, the geometrical properties of the structural elements, mechanical properties of the materials, and plan layouts were taken into account. The earthquake regulations in-force the year built for each building was considered to calculate base shear capacities [12] [13] [14] [15] [16] [17]. The earthquake regulations in-force for the selected buildings and corresponding base shear capacities were given in Table 7.

A building set consisting of 52 buildings was selected in order to make a preliminary assessment study among the dataset from the site investigation. A second field study was performed for this selected building set, to determine the concrete strength with the Schmidth hammer test and confinement rebar detection. The f_{ck} values in Fig. 9 were calculated from R values of Schmidth hammer test conversion curve. The existence of confinement rebar in the columns and shear walls also investigated.

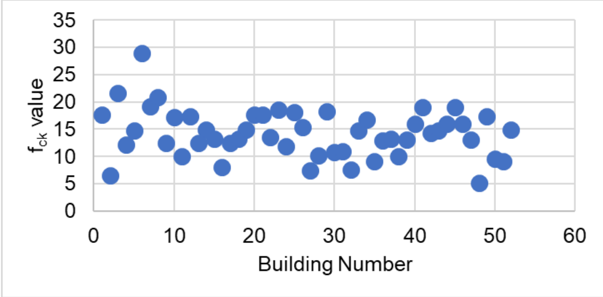

Figure 9 Schmidth test f_{ck} values of each building

The blueprints of the buildings were taken from the Menteşe Municipality. However, only 26 building blueprints could be used for being relevant with the existence ones. By using the blueprints and walk-down survey parameters, the selected building were investigated for the risk according to (Yakut 2004) [8]. BCPI refers to basic capacity index and CPI refers to the capacity index. The limit for CPI value is taken as 1.0 [8].

Table 7 The set created with the static projects and the calculations made according to *[8]*

Bldg. No	Design Code	RYTEİE (2019) PP	$V_{yw,X}$ (kN)	$V_{yw,Y}$ (kN)	V_{CODE} (kN)	BCPI	CPI
1	1975	-5	1985.0	3349.8	2414.6	0.82	0.64
2	1975	-25	2437.8	2353.7	2203.2	1.07	0.83
3	2007	95	952.7	1295.9	914.4	1.04	0.89
4	**2007**	75	1572.1	3095.5	1132.0	1.39	**1.08**
5	1975	55	1655.9	1698.1	2283.6	0.73	0.57
6	**1968**	-30	2328.7	1689.4	1153.0	1.47	**1.14**
7	1998	5	1149.8	1221.6	1374.9	0.84	0.65
8	**1998**	55	2576.3	2458.3	1341.2	1.83	**1.43**
9	**1975**	-20	3785.5	5435.2	1650.9	2.29	**1.79**
10	**1975**	-45	3216.5	4618.1	1650.9	1.95	**1.52**
11	**1975**	10	3216.5	4618.1	1650.9	1.95	**1.52**
12	1975	25	3016.5	2366.3	2869.1	0.82	0.64
13	1975	-25	3110.3	2440.0	2758.2	0.88	0.69
14	1975	25	3547.7	2783.1	2758.2	1.01	0.79
15	2007	75	924.2	1257.2	850.0	1.09	0.92
16	1975	-30	2738.8	2981.9	2740.0	1.00	0.78
17	1975	-25	3248.9	3537.3	2740.0	1.19	0.92
18	1975	45	3723.8	4382.5	4934.9	0.75	0.59
19	**2007**	65	6302.9	6133.2	4916.8	1.25	**1.06**
20	**2007**	65	7181.4	6988.0	4916.8	1.42	**1.21**
21	**2007**	65	6207.8	6040.7	4916.8	1.23	**1.04**
22	**2007**	65	6578.0	6400.8	4916.8	1.30	**1.11**

23	1998	95	4319.0	3164.0	3670.5	0.86	0.67
24	1975	15	2919.0	1759.6	2058.1	0.85	0.67
25	2007	-40	5321.4	2919.7	3348.0	0.87	0.74
26	2007	-45	1170.0	1295.3	1096.9	1.07	0.83

In Table 7 and Fig. 10-11, it can be observed that 9 of the buildings have a value less than one. 15 buildings are expected to be risky via CPI value. While calculating the CPI values, it is assumed that the ratio of the infilled wall area to the total construction area is 0.02. The soil class was assumed as ZC, reflecting Muğla in general. The buildings which were built according to the 1975 Earthquake Code [13] with large column sizes and good concrete quality are evaluated as non-risky.

In Fig. 12, the performance scores [2] and CPI [8] values are plotted. The number of buildings compared with preliminary analysis is for sure not enough to make a certain conclusion, however, even with good performance score the CPI values are below 1.0 even the proposed value for CPI is 1.2 [8].

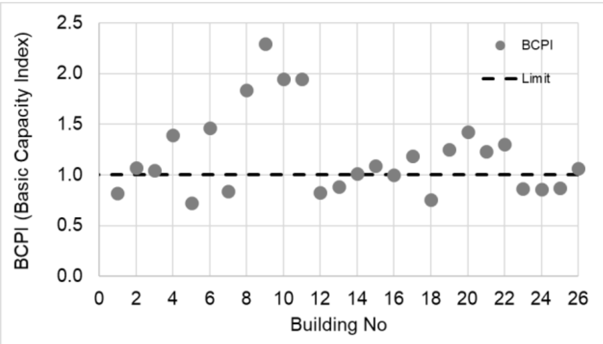

Figure 10 Basic Capacity Index Values (BCPI)

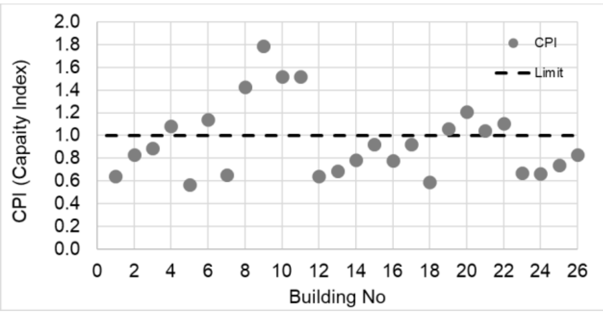

Figure 11 Capacity Index Values (CPI)

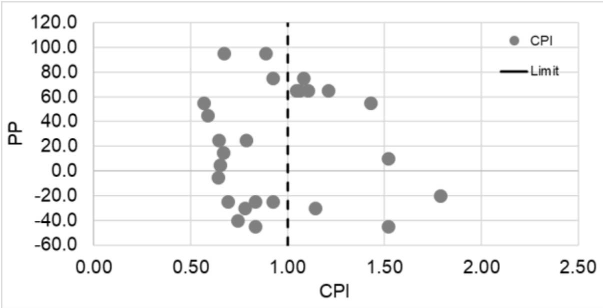

Figure 12 Capacity Index Values (CPI) [8] vs Performance Score [2]

Conclusion and Discussion

In this study, seismic risk assessment of existing RC building stock in Emirbeyazıt Neighborhood of Muğla investigated by using the walk-down survey method [2] and preliminary assessment method [8]. 461 RC buildings investigated and 26 RC buildings of them examined in detail. Based on the results of this research, the following key conclusions are derived and discussions come out:

- The main reason for using two methods for research is the determine the risk level of buildings that should be prioritized for a comprehensive risk mitigation plan.
- The majority of the buildings suffer from the heavy overhang and vertical irregularity deficiencies. The lowest performance score was calculated as -118 and the maximum as 145 according to [2].
- The ranking system [2] needs a threshold to differ the risky and non-risky buildings to make a risk mitigation plan in short budget, otherwise the decision makers such as municipalities cannot lose the focus on their risk mitigation plans.
- In preliminary assessment analysis 15 of 26 buildings are not passing the CPI threshold value and therefore they can be labeled as Risky.
- The buildings built according to the 1975 Earthquake Code [13] with large column sizes and good concrete quality are classified as non-Risky according to the preliminary risk assessment analysis [8].
- The results of the preliminary analysis showed that if the existing building is designed according to the specification [2], it may have bad performance score, however, the CPI value may become higher such as building 6 in Table7.
- The results of this study will provide a data source for future seismic risk mitigation plan for Muğla. The current study can be extended to a larger area also including masonry structures.

Ethics committee approval and conflict of interest statement

"There is no conflict of interest with any person / institution in the article prepared"

Authors' Contributions

-Study conception and design: Akansel, Baki
-Acquisition of data: Akansel and Baki
-Analysis and interpretation of data: Akansel and Baki
-Drafting of manuscript: Akansel and Baki
-Critical revision: Akansel
-Site Investigation: Baki

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