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Study on Effectiveness of Regional Risk Prioritisation in Reinforced Concrete Structures after Earthquakes

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Abstract: Depending on the characteristics of the existing buildings, earthquakes can cause damage at different levels and have a significant impact on the environment. The structural damages after the earthquakes have shown the importance of analysing both the existing and the damaged buildings. In this study, the Turkish rapid seismic assessment method, which was used for the existing building stock before a possible earthquake, was applied to the damaged reinforced concrete (RC) buildings after the 6 February earthquakes in Kahramanmaraş (Türkiye). The building data were used as a result of field observations in the provinces of Adıyaman, Hatay, and Kahramanmaraş, where the greatest destruction was caused by these earthquakes. Five RC buildings from each province were considered. The rapid assessment method was applied to a total of 15 buildings with different levels of damage. For this purpose, pre-earthquake images of the buildings were obtained, and an earthquake performance score was obtained for each building, taking into account the sustained damage during the earthquake. The primary aim of this study is to show the effects of structural irregularities on earthquake behaviour and to demonstrate the applicability of the rapid assessment methods used before the earthquake. The results obtained clearly demonstrate the effectiveness of rapid evaluation methods for existing building stock. Structural analyses were also carried out in this study to address the fact that the height of the ground storey is higher than the other storeys, which is one of the factors leading to a soft storey.

Keywords: earthquake; reinforced concrete; damage; rapid; irregularity; soft/weak story

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1. Introduction

Earthquakes are one of the natural disasters that are uncontrollable large-scale hazards that can cause loss of life and property. The destructive effects of earthquakes on structures make studies on earthquake–structure relationships important. Characteristics of the existing building stock in settlements, local ground conditions, and characteristics of the earthquake directly affect possible structural damage. Design and construction that do not comply with earthquake-resistant building design rules may cause increased possible damage. In addition to all of these, the presence of irregularities that will negatively affect the earthquake performance of buildings is one of the factors that cause damage [1–6]. In this context, earthquake damages can be reduced by studies taking into account the earthquake–structure relationship.

In order to reduce the effects of earthquakes on buildings, which are unlikely to be predicted with today's technology, earthquake-resistant building design rules must be fully implemented in new buildings, both during the design and in the construction phases. However, this is not valid for existing buildings. Demolition or reinforcement decisions can be made regarding buildings with inadequate earthquake performance through studies on the existing building stock. However, the large amount of existing building stock does not allow detailed earthquake performance analyses of all these structures in terms of expert personnel, financial resources, and time. At this point, rapid assessment methods can be developed on existing buildings and risk priorities can be determined among these structures [7–16]. Within the scope of this study, the rapid assessment method currently used in Türkiye was used to determine regional risk priorities for reinforced concrete (RC) structures. In general, rapid assessment methods take into account the structures' damage characteristics due to earthquake effects.

There are many studies in which risk priorities for existing structures are determined using different rapid assessment methods. Febriansyah et al. [17] applied the rapid assessment method for buildings affected by the earthquake in Aceh, Indonesia. Bektaş and Kegyes-Brassai [18] applied the rapid assessment method to 20 different unreinforced masonry buildings (URM) in the GYŐR region of Hungary and made risk prioritization among them. Shendkar et al. [19] used the EDRI rapid assessment method for RC structures for the existing building stock in the Koyna-Warna region of India. Aynur and Atalay [20] comparatively examined rapid evaluation methods for RC structures damaged in the 1999 Marmara earthquake. Başgöze and Güncü [21] determined the regional risk priorities for 490 existing RC buildings located in Erzincan Province, which has a high seismic risk in the eastern of Türkiye. Kassem et al. [22], used the rapid evaluation method to determine the behaviour of buildings in Malaysia under earthquake effects and made recommendations for these structures. Işık [23] applied different rapid assessment methods for RC buildings that suffered different levels of structural damage in the 2011 Van earthquake and tried to reveal the harmony between these methods. Ademović et al. [24] made a risk ranking by applying the rapid assessment method for the existing building stock in different regions of Bosnia-Herzegovina. Nemutlu et al. [25] applied the rapid assessment method for 1261 buildings in the Bingöl province in eastern Türkiye and performed detailed structural analyses on some buildings. Albayrak et al. [26] determined the earthquake risk priorities of 1643 buildings in Eskişehir (Türkiye) Province as high, medium, and low using the rapid assessment method. Using the rapid assessment method, Clemente et al. [27] determined the risk priorities of hospital-type buildings located in Manila (Philippines), a region with high seismic risk. Arkan et al. [28] determined regional risk priorities for 20 masonry buildings in Bitlis (Türkiye) Province using the 2019 Turkish rapid assessment method. Ruggieri et al. [29] proposed a method for the rapid assessment of earthquake risks in RC school buildings. Işık et al. [30] tried to determine the risk priority among the provinces by using the 2013 Turkish rapid assessment method for a total of 1620 RC buildings, 20 from each province in Türkiye. İlki et al. [31] proposed a performance-based rapid assessment method (PERA) for structures using data from 372 RC buildings. Büyüksaraç et al. [32] tried to determine the risk priorities in terms of both seismic and structural aspects among Van (Türkiye) Province and its districts with their study. Bülbül et al. [33] determined the risk priorities for 329 existing reinforced concrete buildings in Bitlis Province using the 2013 Turkish rapid assessment method using a Genetic Algorithm and Artificial Neural Network. Sucuoğlu et al. [34] proposed a new method for determining earthquake risk priorities of urban building stocks by street scanning.

An attempt was made to reveal the effects of parameters on seismic performance in the studies where structural irregularities included in rapid assessment methods were evaluated through numerical modelling. Ruggieri and Vukobratović [35] examined the torsion effect in eight low-rise reinforced concrete building models. Bilgin and Uruçi [36] tried to reveal the effects of short columns, heavy overhangs, and soft-storey irregularities in three and six-storey reinforced concrete buildings. Das et al. [37] compiled the studies on the earthquake performance of structures containing horizontal and vertical irregularities and made suggestions for completing the missing parts of these studies. Ruggieri and Uva [38] investigated the effect of increasing height irregularity on the seismic behaviour of the structures in the created numerical models for RC structures. Habib et al. [39] examined the results obtained for different PGA/PGV ratios in earthquake-isolated RC structures containing different irregularities. Işık et al. [40] evaluated the structural performance of short column formations in RC structures due to different reasons by different design criteria. Satheesh et al. [41] investigated the effect of plan eccentricity under earthquake loads in buildings with vertical rigidity irregularity using numerical models. Jara et al. [42] examined the structural damages caused by the 2017 Mexico earthquake and made reinforcement recommendations for the soft-storey problem that may occur on the critical ground storeys. Yu et al. [43] proposed a rapid assessment method for identifying soft-story irregularities in buildings using deep learning methods via street-view scanning. Athanassiadou [44] revealed the effects of such irregularities on the seismic performance of the structures using models with irregular elevation created for RC buildings. Nezhad and Poursha [45] compared the seismic behaviour of the structures with vertical irregularities on different result parameters. Özmen et al. [46] evaluated the effects of the main factors affecting the seismic performance of RC structures through structural models. Ulutaş [47] investigated the impact of soft/weak story formation on structural performance through different RC structure models.

Using these and similar rapid assessment methods, detailed studies on the existing building stock can be conducted before a possible earthquake. Within the scope of this study, reinforced concrete buildings located in Hatay, Kahramanmaraş, and Adıyaman, the three provinces most affected by the 6 February 2023 Kahramanmaraş earthquake, which were exposed to different levels of structural damage during the earthquakes, were taken into consideration. This earthquake, which caused more than 50,000 deaths, was the disaster of the century for Türkiye. Many studies have been conducted on the effects of these earthquakes on structures. Numerical analyses are also included in some of the studies in which structural damages in adobe, masonry, prefabricated, RC, mosque, and minaret-type structures located in the entire earthquake region or in any settlement affected by the Kahramanmaraş earthquakes are evaluated within the scope of civil and earthquake engineering [48–63].

Buildings built without complying with earthquake-resistant building design principles are the factors that cause the most loss of life and property in earthquakes. Studies to be carried out on the existing building stock before earthquakes can be used as an important support tool for decision makers. Within the scope of this study, rapid assessment methods used to determine risk priorities for detailed analyses of existing structures were used for reinforced concrete structures damaged at different earthquake levels. The aim of this study is to clearly reveal the pre- and post-earthquake effects of the parameters taken into account in the rapid evaluation method. The data obtained from buildings were subjected to a real test after the earthquake, hence representing, in a sense, a validation of rapid assessment methods. In this study, five RC buildings selected from each of the three provinces affected by the Kahramanmaraş earthquakes were considered. An attempt was made to determine regional risk priorities both within each province and among all RC structures taken into account in this study. For the buildings taken into consideration, the rapid evaluation method used for RC structures in Türkiye was used, which was updated in 2019. Building data obtained as a result of field investigations and other data required to use the method were obtained in the office environment and a structural system score was obtained for each building. Risk prioritization was made among these selected buildings using the obtained scores. Within the scope of this study, numerical analyses were carried out for the soft/weak storey, which causes the most damage and is one of the important parameters in the rapid evaluation method. Separate structural analyses were performed for two different RC structural models for each of the three provinces. In one of the models, all storeys were chosen to be of equal height, while in the other model, the ground story height was chosen to be higher than the other storeys.

This research addresses a critical topic in the field of civil engineering and emergency management, namely the assessment of RC structures after the 6 February 2023 Kahramanmaraş (Türkiye) earthquakes. In this study, first of all, the method considered and all the necessary details for using the method are given. Each irregularity parameter is supported by pre-earthquake images. An attempt has been made to show the importance of the factors taken into account in the rapid assessment methods that have a direct impact on earthquake damage to buildings. Unlike our other studies, the 2019 Turkish Rapid Assessment method is used for the first time for RC structures damaged after an earthquake. The unique originality of this research lies in the application of the Turkish rapid seismic assessment method to evaluate damaged buildings after the Kahramanmaraş earthquakes. By focusing on a specific geographical context and utilizing a systematic approach to assess structural integrity, this study presents a novel framework for risk prioritisation. The scientific validity of the findings is supported by a robust methodology that includes field observations and comparative data analyses in several affected provinces. Overall, the research highlights significant structural irregularities, such as soft or weak storeys, which contribute to heightened vulnerability during seismic events. Investigating the impact of different ground-storey heights provides valuable insights into design flaws that can exacerbate damage during earthquakes. This aspect emphasizes the need to adhere to the principles of earthquake-resistant design.

2. Materials and Methods

In this section of the study, detailed information is given about the Turkish Rapid assessment method used in determining the regional risk priorities of RC structures. In addition to detailed information for each parameter used in the evaluation method, these parameters are shown both on schematic representations and pre-earthquake building images.

Turkish Rapid Assessment Method for RC Structures-2019

It is not possible to determine earthquake performances using structural analyses recommended within the scope of performance-based earthquake engineering for existing buildings due to the large number of building stocks. Both public resources and a lack of expert personnel prevent the determination of the earthquake performance of all existing structures in a short time. Here, rapid evaluation methods have been developed in order to prioritize existing structures for detailed structural analysis. The main purpose of these methods is to make a risk ranking among the buildings that have risk priority within the existing building stock and will be subjected to detailed structural analysis. In this way, an important ranking will be made in the number of buildings for detailed structural analyses. In these methods, it is not determined whether the earthquake performance of the structures is sufficient or not [64–70]. Whether the earthquake performance of any existing structure is sufficient should be decided as a result of detailed structural analysis.

Similar to the rapid assessment methods used in different parts of the world, these methods are available for different structural systems in Türkiye. The method, which was first officially developed in 2013, was updated with the change in the earthquake regulations in the country in 2018 and started to be used in 2019.

This method is used to determine priorities in certain areas and the regional distribution of buildings that may be at risk. The methods to be used in defining the regional risk status can be applied to areas containing a statistically significant number of buildings as required by science and technique and are not used for risk assessment purposes in individual buildings. This method, specified under the title of "Simplified Methods for Determining Regional Earthquake Risk Distribution of Buildings", can be used for RC and masonry structures. A performance score is obtained for each structure by taking into account the adverse conditions that directly affect the seismic performance of RC and masonry structures and cause damage, especially in earthquakes. For these reasons, the parameters taken into consideration in masonry and RC structures differ. Regional risk prioritization can be made among the structures using this method for different structural types. In this study, risk prioritization was made by taking into account the methodology determined for RC structures, which are the dominant urban building stock in Türkiye. This method, which is used to determine regional risk priorities for RC structures in the

Turkish Rapid Assessment Method-2019, is limited to 1–7 storey RC structures [71]. The parameters taken into account in this method are shown in Figure 1.

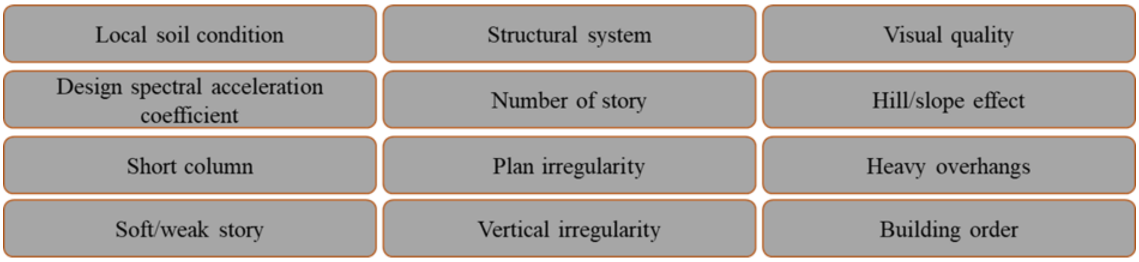

Figure 1. Parameters taken into account in the rapid evaluation method.

At the beginning of the method, the design spectral acceleration coefficient (S_{DS}) is determined using the Türkiye Earthquake Hazard Map, depending on the earthquake ground motion level. In this method, standard earthquake ground motion (*DD-2*) is taken into account, where the probability of exceedance in 50 years is 10%, with the corresponding recurrence intervals of 475 years. The earthquake hazard zone is determined according to the S_{DS} obtained by taking into account the geographical location of the building, local soil class and earthquake ground motion level. The determination of earthquake hazard zones according to this method is given in Table 1.

Table 1. Determination of earthquake hazard zone for RC structures [71].

Hazard Zone	S_{DS}	Local Soil Class
I	$S_{DS} \geq 1.0$	*ZC/ZD/ZE*
II	$S_{DS} \geq 1.0$	*ZA/ZB*
	$1.0 \geq S_{DS} \geq 0.75$	*ZC/ZD/ZE*
III	$1.0 \geq S_{DS} \geq 0.75$	*ZA/ZB*
	$0.75 \geq S_{DS} \geq 0.50$	*ZC/ZD/ZE*
IV	$0.75 \geq S_{DS} \geq 0.50$	*ZA/ZB*
	$0.50 \geq S_{DS}$	All kinds of soils

After determining the earthquake hazard zone based on the local soil class and S_{DS}, the base score should be determined by taking into account the total number of storeys in the building and the structural system. The base score values to be determined according to the hazard zone, number of storeys, and structural system are shown in Table 2.

Table 2. Base (TP) and structural system scores (YSP) for RC structures [71].

Total Number of Story	Base Score (*TP*)				Structural System Score (*YSP*)	
					Structural System	
	Hazard Zone				RCF	RCF + RC Shear Walls
	I	II	III	IV		
1–2	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
6–7	50	65	90	110	0	55

After these values are determined, a number of structural characteristics that affect the earthquake performance of buildings and cause damage are taken into account, as presented below.

Type of the structural system: It is the first parameter taken into consideration, and one of the reinforced concrete frame (RCF) and reinforced concrete frame + RC shear walls (RCF + RC Shear Walls) systems is selected as the load-bearing system of the building. Here, an additional structural system score is added, taking into account the effect of RC shear walls in resisting earthquake loads. If this situation cannot be detected, it would be appropriate to choose RCF. Schematic representations for these two different structural systems are shown in Figure 2.

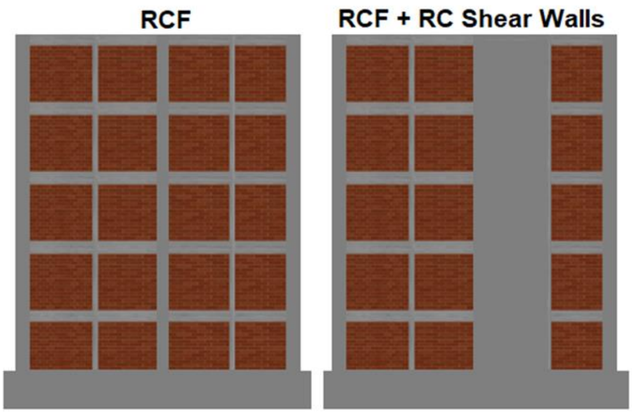

Figure 2. Types of the structural systems for the RC buildings.

Total number of storeys: It is the total number of storeys in a building, which is one of the causes of damage in earthquakes. In the method, the number of free storeya is determined in line with the principles given schematically in Figure 3.

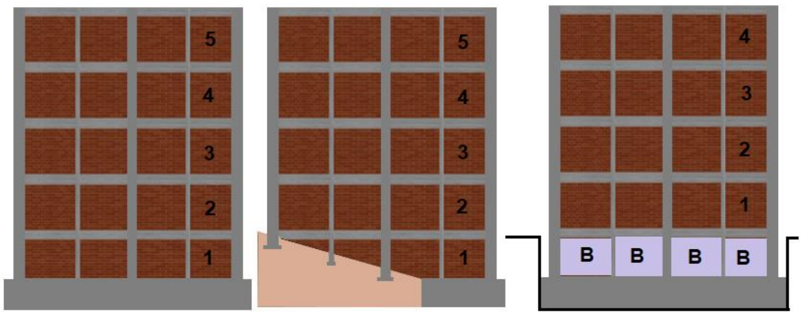

Figure 3. Determination of the number of storeys in RC structures.

Building visual quality: The apparent quality of the building reflects the importance given to the quality of materials and workmanship and the maintenance of the building. The apparent quality of the building is classified in three different ways: good, medium, and bad.

Soft/weak storey: It is determined observationally, taking into account the difference in storey height as well as the significant stiffness difference between storeys. Situations to be taken into account for determining the soft/weak-storey situation are shown in Figure 4. The concept of the relatively soft/weak storey is mentioned here. It should not be forgotten that detailed structural analyses are required to clearly reveal this situation in any structure.

Vertical irregularity: It is taken into account to reflect the effect of vertically discontinuous frames and changing storeys areas. Columns or shear walls that do not continue along the height of the building create vertical irregularities. The detection of vertical irregularity is shown in Figure 5.

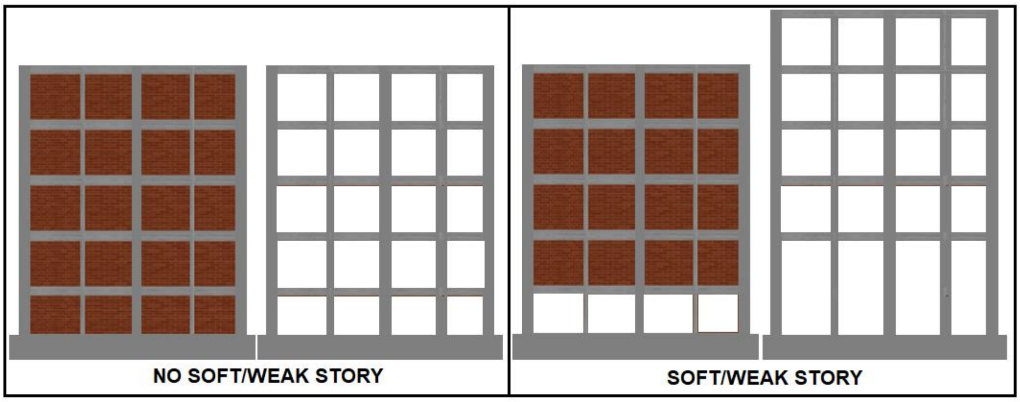

Figure 4. Detection of soft/weak storey in RC structures.

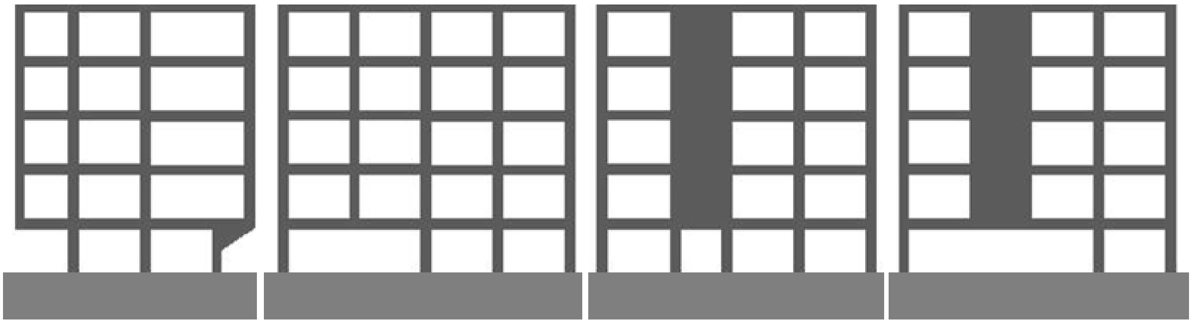

Figure 5. Vertical irregularities in RC structures.

Heavy overhangs: The difference between the floor area on the ground and the floor area above the ground will be determined. The detection of heavy overhang is shown in Figure 6.

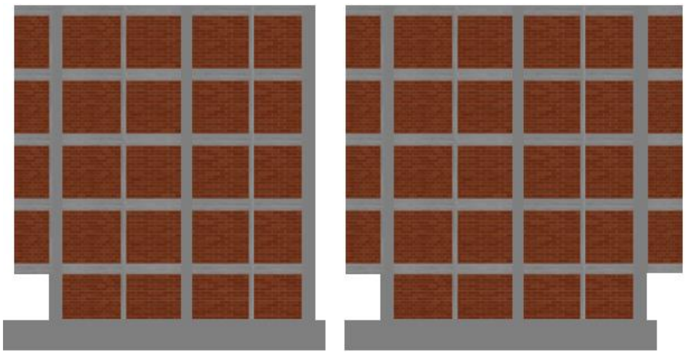

Figure 6. Detection of heavy overhangs in RC structures.

Irregularity in plan/torsion effect: It is defined as the plan not being geometrically symmetrical and the vertical structural elements being placed irregularly. Plan irregularities that may cause torsion in the building are taken into account. Detection of irregularity in the plan is shown in Figure 7.

Short column: At this stage, only short columns that can be observed from outside will be taken into account in the evaluation. The determination of the short column situation that may occur due to changing column heights for different reasons is shown schematically in Figure 8.

Building status/storey levels with adjacent buildings: The locations of adjacent buildings can affect earthquake performance due to collision. Buildings located on the edge are most negatively affected by this situation, and this negativity increases even more if the floor levels of the adjacent building are different. Situations where the impact of a collision occurs will be determined by external observations. The building order status and the floor level status of adjacent buildings will be evaluated together. Determination of the building order is shown in Figure 9.

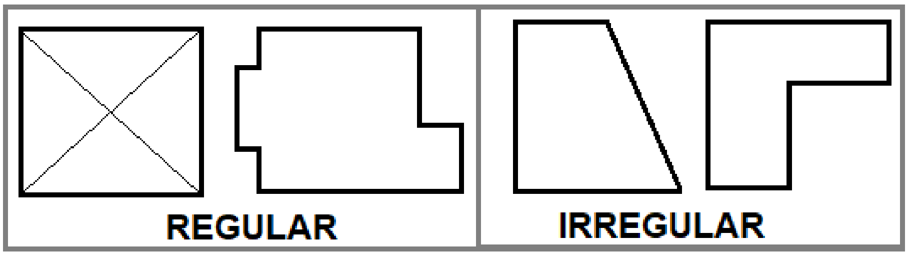

Figure 7. Determination of plan irregularities in RC structures.

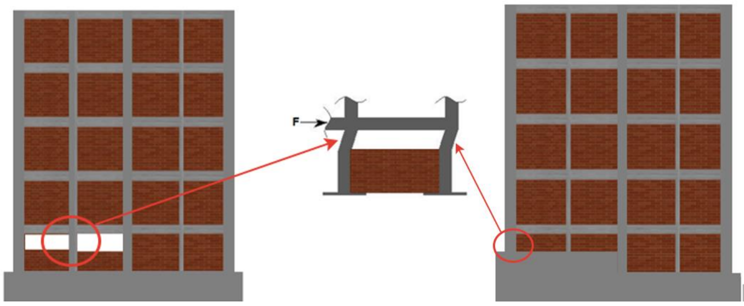

Figure 8. Short column effects in RC structures.

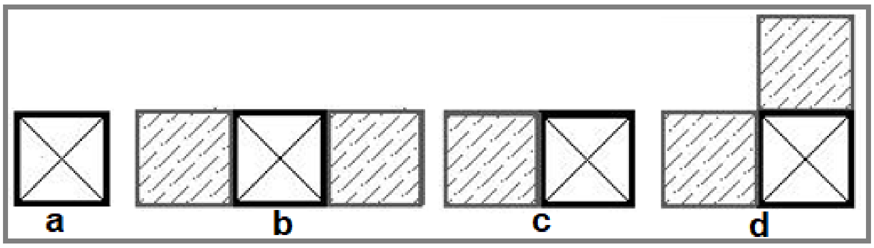

Figure 9. The status of adjacent buildings (**a**) isolated, (**b**) middle, (**c**) corner, (**d**) corner.

Since the impact of the collision will depend on the relationship of the floors of the neighbouring buildings to each other. The method also requires the determination of the floor levels of the adjacent buildings. Situations to be taken into account in the interaction of floors in adjacent buildings are shown in Figure 10.

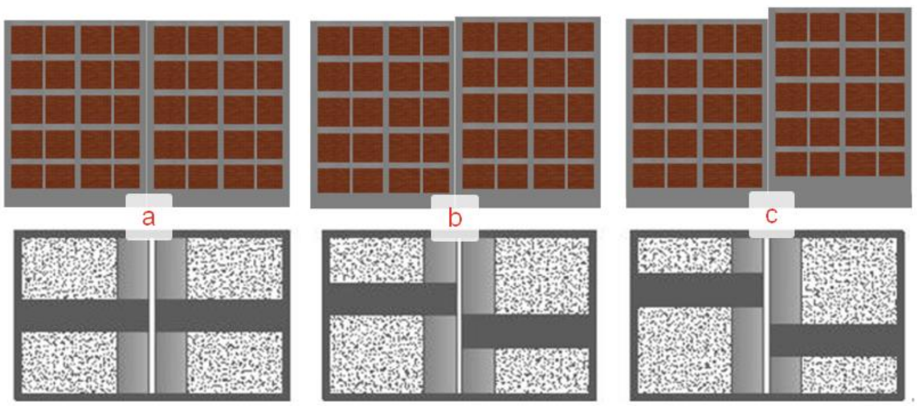

Figure 10. Detection of floor level change in adjacent buildings (**a**) same, (**b**) limit(same), (**c**) different.

Hill/slope effect: This effect will be taken into account in buildings built on slopes above a certain slope. If the natural ground slope is below 30°, there is no hill/slope effect; if the natural ground slope is above 30°, it is considered to have a hill/slope effect.

Earthquake hazard zones: When determining the earthquake hazard zone, the standard design ground motion level (repetition period of 475 years) is taken into account depending on the geographical location of the structure. By using the geographical location, earthquake ground motion level, and local soil classes together, the earthquake hazard zone is determined according to the limits given in Table 1.

Geographic coordinates: They should be determined in accordance with the Türkiye Earthquake Hazard Map coordinate system, which has been used since 2018. Since S_{DS} varies depending on geographical location, location information obtained from the field is used for the structure.

The stages taken into account when calculating the structural result score for each structure taken into account for the Turkish Rapid evaluation method used within the scope of this study are stated below.

- The collected data are evaluated and a performance score is calculated for each building. The results obtained can be used to determine the risk priorities of the regions.
- DD-2 earthquake ground motion level will be used and the parameter value (S_{DS}) will be taken from the current Türkiye Earthquake Hazard Map. Earthquake hazard zones given in Table 1 are determined by using the relationship between the parameter value and the defined soil classes.
- The effect of the structural system type is taken into account as a positive score. No additional points are given for buildings with the RCF system. For buildings with other load-bearing systems (RCF + RC shear walls), a Structural System Score (*YSP*) is obtained according to the number of storeys by using Table 2.
- Determinations are made as "Yes or No" for all negative parameters except the apparent quality and building status (Table 3). The negativity parameter values (O_i) corresponding to these determinations will be taken as 1 and 0 for the yes and no situations, respectively. If the apparent quality evaluation is Good, the negativity parameter value (O_i) will be taken as 0; if it is medium, it will be taken as 1; and if it is bad, it will be taken as 2. If the building order status is isolated, the negativity parameter value (O_i) is taken as 0, and if it is adjacent/adjacent at the corner, it is taken as 1.

Table 3. Negativity parameter values (O_i) [71].

No	Negativity Parameter	Situation 1		Situation 2	
		Yes/No	Value	Yes/No	Value
1	Visual quality	Good	0	Medium (Bad)	1 (2)
2	Soft/weak storey	No	0	Yes	1
3	Vertical irregularity	No	0	Yes	1
4	Heavy overhang	No	0	yes	1
5	Plan irregularity	No	0	Yes	1
6	Short column	No	0	Yes	1
7	Building status	Isolated	0	Middle/corner	1
8	Hill/slope effect	No	0	Yes	1

Application examples of the parameters considered in this study on the existing building stock in the earthquake region are shown in Figure 11. Google Street [72] was used to obtain images.

Figure 11. (**a**) Short column, (**b**) soft/weak storey, (**c**) plan irregularity, (**d**) hill/slope effect, (**e**) heavy overhang, (**f**) adjacent buildings.

In the method used, a reduction score is given for each negative parameter in reinforced concrete structures. The scores to be taken into account depending on each negative situation and number of storeys are given in Table 4.

Table 4. Negativity parameter scores (OP_i) [71].

Number of Storeys	Soft/Weak Storey	Visual Quality	Heavy Over-hang	Building and Floor Status				Vertical Irregu-larity	Plan Irregu-larity	Short Col-umn	Hill/Slope Effect
				Same		Different					
				Middle	Corner	Middle	Corner				
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 performance score of the structure is obtained by summing the base score obtained for each reinforced concrete structure and the score obtained for each negative parameter. These processes are determined with the help of the formula given below.

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

Here, PP denotes the performance score, TP denotes the base score, O_i denotes each negativity parameter, OP_i denotes the negativity parameter score, and YSP denotes the positive parameter score as the structural system score. The effect of the structural system type will be taken into account as a positive score. The Structural System Score (YSP) shows the parameter that reflects the effect of the building's structural system type on earthquake performance. Since all buildings examined were RCF, YSP was taken as 0. In this method, a base score is obtained and each negativity parameter is reduced from this base score. The building with a lower score has a higher risk priority. A flowchart of this method is shown in Figure 12.

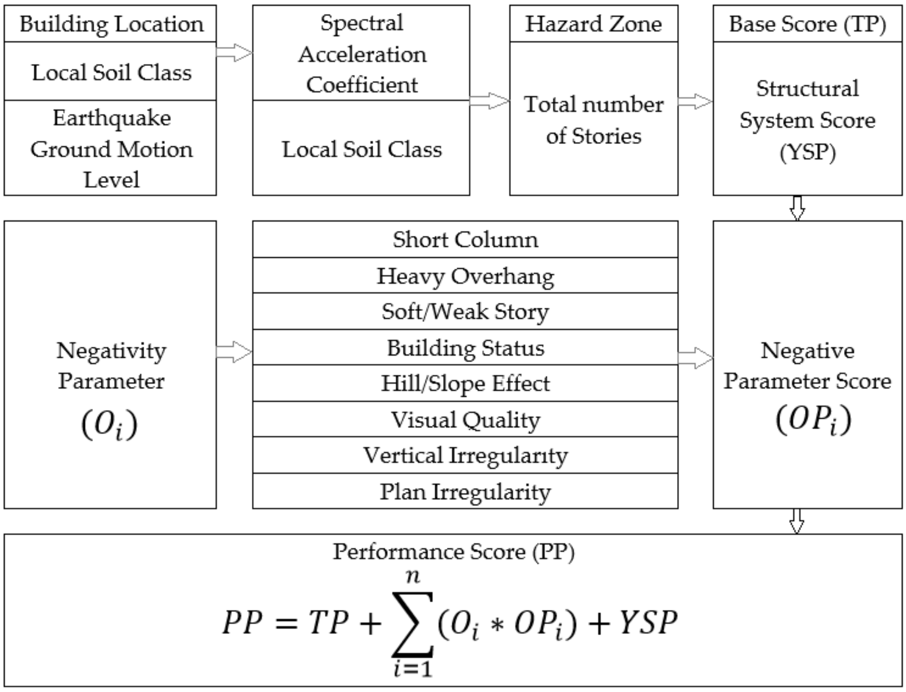

Figure 12. Flowchart of the rapid assessment method for RC buildings.

Examples of structural damage that occurred in RC structures as a result of the presence of one or more of these parameters as a result of field observations are shown in Figure 13.

Figure 13. (**a**) Soft/weak-storey damage caused by mezzanine, (**b**) structural damage caused by short column, (**c**) example of damage caused by irregularity in plan, (**d**) example of damage caused by collision, (**e**) example of damage caused by heavy overhangs, (**f**) soft/weak-storey damage example caused by ground story.

3. Results

In this section of the study, firstly the results of the rapid assessment method for RC structures with different levels of structural damage as a result of field observations are given. In addition, structural analyses carried out to reveal the change in the storey height within the structure are included.

3.1. Application of the Rapid Assessment Method to Damaged Buildings

Within the scope of the study, five RC building examples taken into consideration from Adıyaman, Hatay, and Kahramanmaraş, the three provinces most affected by earthquakes, are shown in Figure 14. To compare the damage conditions obtained as a result of field investigations, pre-earthquake images of these buildings were obtained with the help of the Google Street application [72].

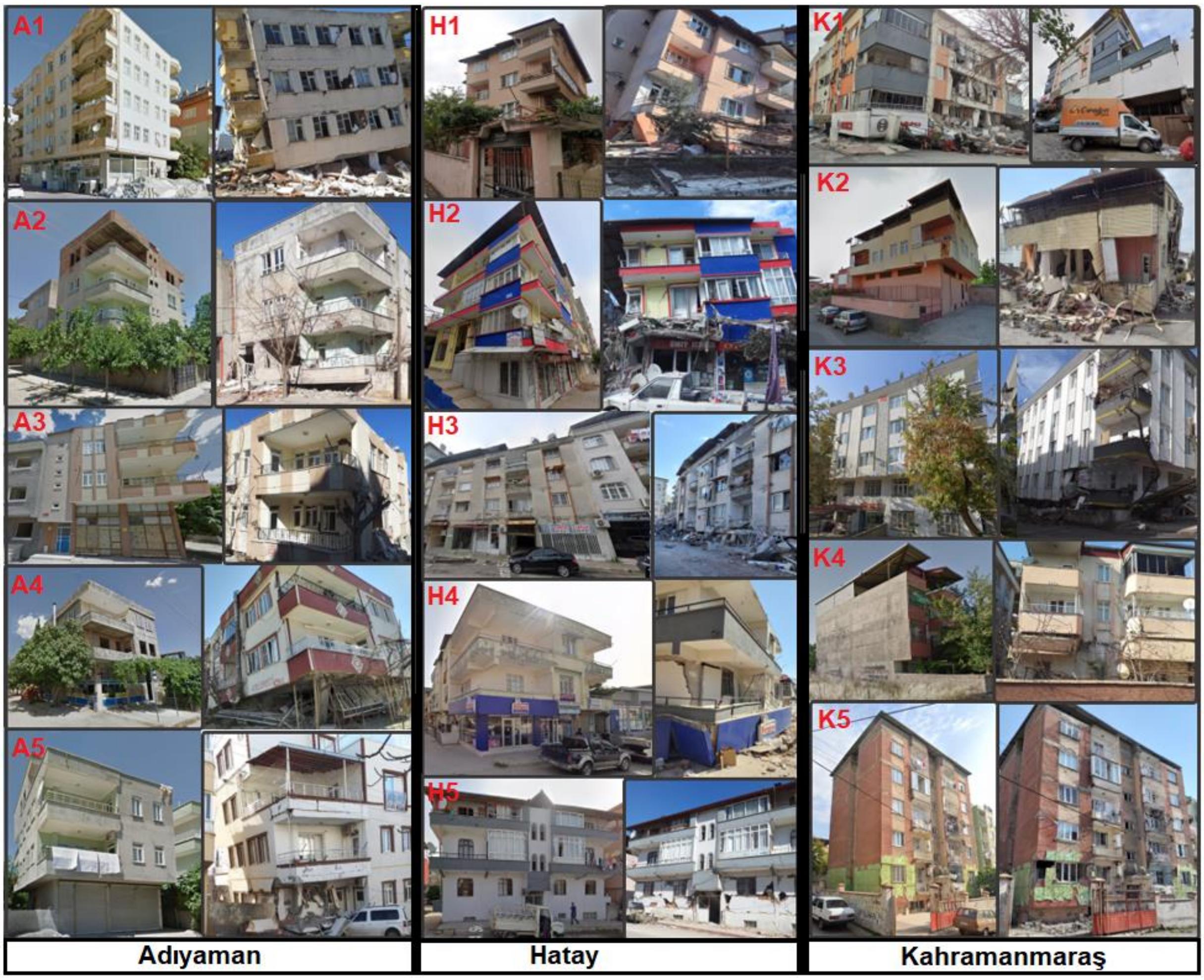

Figure 14. Before and after earthquake images of the RC structures. (RC structures examined in Adıyaman between A1–A5; in Hatay between H1–H5 and in Kahramanmaraş between K1–K5).

Taking into account the geographical location obtained for each structure as a result of field investigations, the design spectral acceleration coefficient that should be used in the rapid evaluation method is obtained with the help of the Türkiye Earthquake Hazard Map Interactive Web Earthquake Application [73]. These values are obtained by taking into account the standard design ground motion level, geographical location, and local soil class. Peak Ground Acceleration (*PGA*) and S_{DS} values obtained from the application for different exceedance probabilities in 50 years for each reinforced concrete structure in this study are shown in Table 5.

Table 5. *PGA* and S_{DS} values for different exceedance probabilities for RC structures.

No	*PGA (g)*				S_{DS}			
	2%	**10%**	**50%**	**68%**	**2%**	**10%**	**50%**	**68%**
A1	0.455	0.262	0.105	0.070	1.350	0.782	0.313	0.211
A2	0.442	0.254	0.102	0.068	1.310	0.763	0.302	0.203
A3	0.435	0.250	0.101	0.067	1.284	0.753	0.298	0.201
A4	0.429	0.247	0.100	0.066	1.264	0.744	0.295	0.200
A5	0.420	0.242	0.098	0.065	1.236	0.731	0.290	0.196
H1	0.891	0.453	0.148	0.100	2.605	1.279	0.433	0.291
H2	0.886	0.451	0.148	0.099	2.593	1.274	0.432	0.291
H3	0.880	0.449	0.148	0.100	2.576	1.268	0.432	0.291
H4	0.877	0.448	0.148	0.099	2.566	1.265	0.432	0.291
H5	0.876	0.447	0.148	0.100	2.563	1.265	0.433	0.291
K1	0.735	0.401	0.146	0.100	2.184	1.150	0.434	0.290
K2	0.711	0.387	0.143	0.098	2.108	1.109	0.425	0.289
K3	0.702	0.382	0.142	0.097	2.082	1.094	0.421	0.287
K4	0.699	0.380	0.142	0.097	2.071	1.088	0.420	0.287
K5	0.687	0.373	0.140	0.096	2.038	1.069	0.415	0.285

Regarding earthquake hazard, the highest *PGA* values among the three provinces were obtained for Hatay Province, while the lowest *PGA* value was obtained for Adıyaman. Hatay has *PGA* values approximately two times larger than Adıyaman Province. When instrumental and historical earthquake activities are examined, Hatay Province stands out among these provinces in terms of seismicity.

The values observed for each RC structure for the hazard zone obtained by taking into account the number of storeys, S_{DS}, local ground conditions, and the presence of parameters to be used in the rapid assessment method are shown in Table 6.

Table 6. Presence of negativity parameter in the RC structures examined.

No	S_{DS}	Number of Storeys	Hazard Zone	Visual Quality	Soft/Weak Storey	Heavy Overhang	Plan Irregularity	Short Column	Building Status	Hill/Slope Effect
A1	0.782	6	II	1	1	1	0	0	0	0
A2	0.763	4	II	1	1	1	0	0	0	0
A3	0.753	3	II	2	1	1	0	1	1	0
A4	0.744	4	III	1	1	1	0	0	1	0
A5	0.731	4	III	1	1	1	0	0	0	0
H1	1.279	4	I	2	1	1	1	1	0	1
H2	1.274	4	I	2	1	1	0	1	0	1
H3	1.268	4	I	2	1	0	0	0	1	0
H4	1.265	3	I	2	1	1	0	0	1	0
H5	1.265	4	I	2	0	0	0	0	0	0
K1	1.150	6	I	1	1	1	0	1	1	1
K2	1.109	4	I	2	1	1	1	1	0	0
K3	1.094	5	I	1	1	1	0	0	0	0
K4	1.088	4	I	1	1	1	0	0	0	0
K5	1.069	6	I	2	0	0	0	0	0	0

While there are one or more irregularities in the buildings examined, there is no structural irregularity in the building numbered K5 in Kahramanmaraş Province. In 87% of the buildings examined, the ground storeys are used for commercial purposes while the upper storeys are used as residences, and as a result, relatively soft/weak-storey irregularity is observed. This damage situation was observed in all of these structures after the earthquake. The classification of irregularities found in the examined reinforced concrete structures is given in Table 7.

Table 7. Total number of structural irregularities in the buildings examined.

Soft/Weak Storey	Heavy Overhang	Plan Irregularity	Short Column	Building Status	Hill/Slope Effect
13	12	2	5	5	3

The result performance scores obtained by taking into account the base score obtained as a result of the earthquake danger zone and the reduction scores corresponding to the negative parameters for each RC building, taking into account the number of storeys and S_{DS} value, are shown in Table 8.

Table 8. Obtaining performance scores for RC buildings.

No	Base Score	Soft/Weak Storey	Visual Quality	Heavy Overhang	Buildings Status	Plan Irregularity	Short Column	Hill/Slope	Performance Score
A1	65	−30	−30	−30	0	0	0	0	−25
A2	90	−30	−15	−30	0	0	0	0	15
A3	100	−20	−20	−20	−15	0	−5	0	20
A4	130	−30	−30	−30	−10	0	0	0	30
A5	130	−30	−30	−30	0	0	0	0	40
H1	70	−30	−30	−30	0	−10	−5	−3	−38
H2	70	−30	−30	−30	0	0	−5	−3	−28
H3	70	−30	−30	0	−15	0	0	0	−5
H4	80	−20	−20	−20	−15	0	0	0	5
H5	70	−30	−30	0	0	0	0	0	10
K1	50	−30	−30	−30	−10	0	−5	−3	−58
K2	70	−30	−30	−30	0	−10	−5	0	−35
K3	60	−30	−25	−30	0	0	0	0	−25
K4	70	−30	−30	−30	0	0	0	0	−20
K5	50	0	−60	0	0	0	0	0	−10

The performance scores obtained for all buildings are shown in Figure 15. The average performance score of the RC structures considered was obtained as −8.2. The scores of a total of seven buildings are above this score and the others are below the average value. While the building with the highest risk is K1 in Kahramanmaraş Province, the building with the lowest risk priority is A5 in Adıyaman Province. The fact that the building with the most different structural irregularities is K1 reveals the accuracy of the results obtained. The fact that performance scores in Adıyaman Province are higher than in other provinces is due to the earthquake hazard of the province. While the buildings in Hatay and Kahramanmaraş Provinces are in the I earthquake hazard zone, the buildings in Adıyaman Province are in the II earthquake hazard zone.

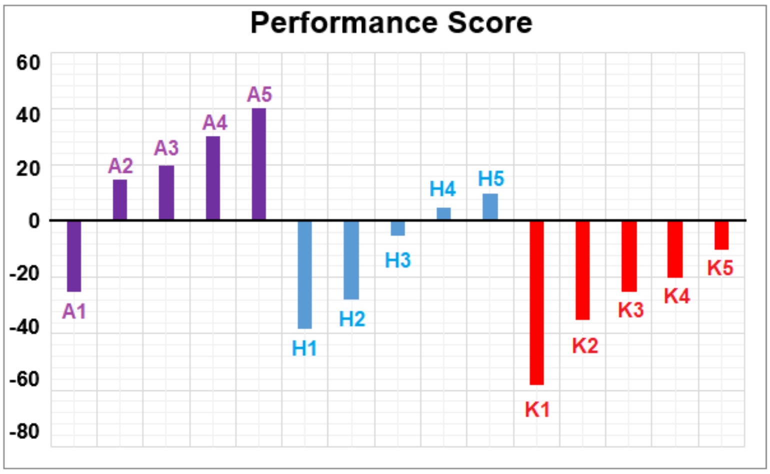

Figure 15. Performance scores of the RC buildings.

One of the parameters that is taken into consideration and has a high impact in this rapid assessment method is the visual quality of the structure. Therefore, the correct determination of the visual quality of the structure is directly related to the education and experience of the decision makers. Poor material quality directly affects the structural capacity and as a result, damage levels can increase. Another important parameter is the soft/weak storey that will arise from the difference in stiffness and strength between the storeys of the structure. The effect of this parameter was clearly evident in the examined structures. Partial or total collapses occurred on the ground storeys of the examined buildings due to the soft/weak storey. The effects of both cases were clearly observed in the examined structures, revealing how accurate the effects of these two parameters are in the rapid evaluation method.

Another important parameter is the heavy overhangs in the structure. The number of facades where heavy overhangs are located directly affects the seismic performance of the structure. In addition, the length of the heavy overhang is another factor that should be taken into consideration. Therefore, it is recommended to add the number of facades with heavy overhangs to the method in accordance with the rapid evaluation method. This situation can be determined quickly and practically by observing the building.

In many urban settlements in Türkiye, buildings are constructed adjacent to each other. Lack of sufficient distance between buildings creates a pounding effect during an earthquake and as a result, creates additional shear forces on the columns. Damage occurring in RC columns whose shear force capacity is exceeded may cause greater damage to the structure than can be compensated for.

It has once again been demonstrated that prioritizing the existing building stock using rapid assessment methods is one of the measures that can be taken before an earthquake. Images before and after the earthquake show that there should be no irregularities. In this context, it is necessary to avoid these irregularities in building design as much as possible. If necessary, the necessary precautions should be taken to ensure that the structures achieve adequate earthquake performance during an earthquake. The results are well documented and demonstrate a good correlation between the characteristics of structures and their behaviour during earthquakes.

It cannot be said with certainty whether the buildings that are found to be low risk comply with the seismic design codes. As stated above, this is only the first stage of the assessment. Therefore, definitive results will only emerge as a result of advanced analysis methods. This method only aims to determine the priority of the buildings to be examined in the second stage assessment method.

As stated in the rapid assessment method, an additional base score is added for RC shear wall structures. In Türkiye, the current seismic design code requires the use of RC shear walls only in basements. Therefore, it is thought that it might be beneficial to require the use of RC shear walls at certain rates for other storeys.

In the rapid assessment method used in this study, there is no reduction coefficient related to the effect of the earthquake code used in the design/construction of the building. However, changes and developments in civil engineering, earthquake engineering, and software have led to differences in the design and evaluation of structures. In this context, the minimum concrete grade in the last four seismic design codes used in Türkiye has changed to C14, C16, C20, and C25, respectively. It is recommended to add a reduction factor for this parameter.

As a limitation, the fact that this study mainly focuses on immediate post-earthquake assessments, which may not take into account the long-term behaviour of structures and the impact of subsequent ground motions or other abnormal effects, can be discussed. The results emphasize the importance of systematic evaluations and point to critical areas for further developments in seismic safety.

3.2. Structural Analysis for Different Height of Ground Storey

In the 12 reinforced concrete buildings taken into account in the field observations, great destruction occurred as a result of the complete collapse of the ground storey. This situation, which is called relatively soft-storey damage, can generally occur for different reasons. One of the reasons for such damage is that the ground storey height is higher than the other storeys. In this part of the study, separate structural analyses were carried out for the sample RC building model for all three provinces, in case the storey height was the same throughout the entire building. Afterwards, the structural analyses were performed for the three provinces by selecting the ground storey height as higher than the other storeys, respectively. Structural analyses were carried out separately for each city and different storey heights with Seismostruct software [74]. Pushover analyses were performed by averaging the *PGA*'s obtained for five different locations for each province. The *PGA* was 0.436 g for Adıyaman, 0.882 g for Hatay, and 0.707 g for Kahramanmaraş. The reference RC building model is five storeys and the story heights are equal and 3 m. The building model consists of four openings, chosen symmetrically in both directions. Each span was chosen as 5 m in both directions. The 2D models obtained for the sample RC structure are shown in Figure 16. In order to make comparisons, in the other RC building model, the ground story height was chosen as 4 m, and the other storey heights were equal and 3 m.

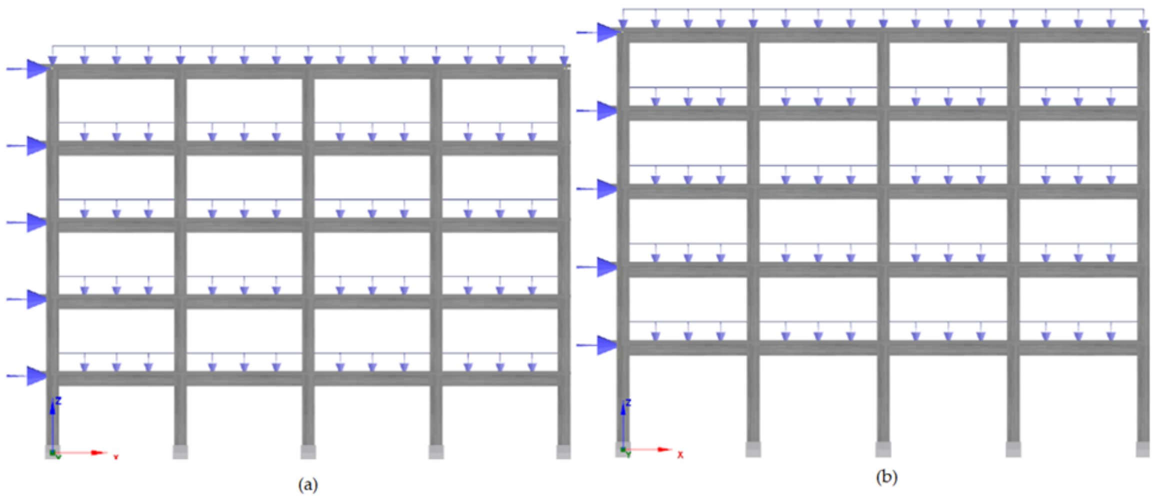

Figure 16. Two-dimensional models of sample RC buildings. (**a**) Same storey height, (**b**) different ground storey height.

In all structural analyses, the target displacement value was selected as 0.30 m and the local soil class was chosen as *ZC*, which is the average soil class in Eurocode-8. The infrmFBPH (force-based plastic hinge frame elements) were used for structural elements such as beams and columns in all structural models. Plastic-hinge length (*Lp/L*) was selected as 16.67%. The boundary conditions of the column were set in accordance with the cantilever boundary conditions, which resulted in a fully fixed column footing and a free top end. The boundary condition of the footings was fixed on the ground. The blueprint of the sample RC building model is shown in Figure 17. Building storey plans were taken using the same method from all structural analyses. There are two different variables in the analysis: storey height and *PGA*. All other chosen structural characteristics are the same. The axes in the X and Y directions are shown as 1–5 and A–E.

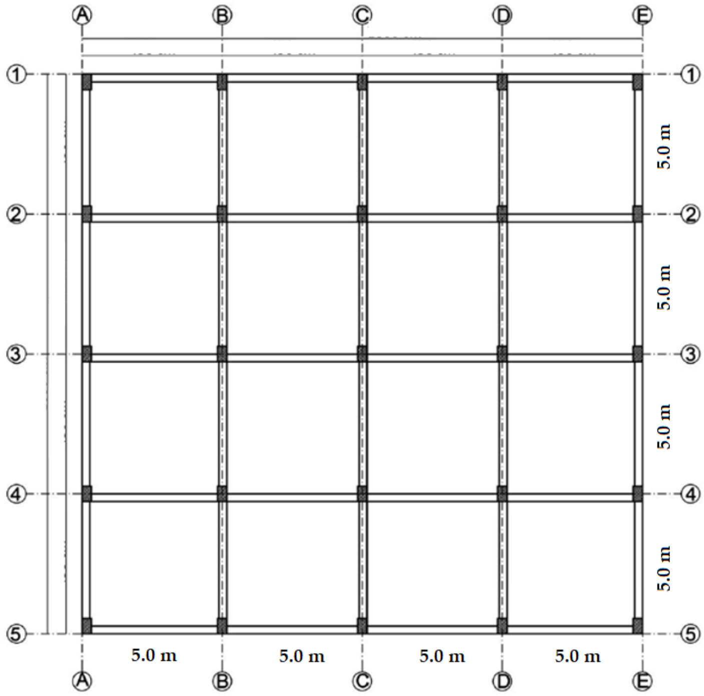

Figure 17. The blueprint of the sample RC building model.

It is crucial to determine the target displacements for damage estimation when certain performance limits of structural elements are reached in performance-based earthquake engineering [75]. In Eurocode-8 (Part 3), which is much more widely used worldwide, target displacements are obtained by taking into account limit states [76–78]. Detailed explanations of the limit state values taken into account in this study are shown in Table 9. All results from numerical analyses are shown in Table 10.

Table 9. Limit states in Eurocode 8 (Part 3) [76–78].

Limit State	Description	Return Period (Year)	Probability of Exceedance (in 50 Years)
Limit state of damage limitation (DL)	Only lightly damaged, damage to non-structural components economically repairable	225	0.20
Limit state of significant damage (SD)	Significantly damaged, some residual strength and stiffness, non-structural components damaged, uneconomic to repair	475	0.10
Limit state of near collapse (NC)	Heavily damaged, very low residual strength and stiffness, large permanent drift but still standing	2475	0.02

Table 10. Results obtained from numerical analysis.

Parameter	Same Storey Height			Different Ground Storey Height		
	Adıyaman	Hatay	Kahramanmaraş	Adıyaman	Hatay	Kahramanmaraş
Period (s)	0.499	0.499	0.499	0.586	0.586	0.586
K_elas (kN/m)	185,372.9	185,372.9	185,372.86	151,841	151,841	151,841.01
K_eff (kN/m)	86,587.67	86,587.67	86,587.67	69,283.45	69,283.45	69,283.45
DL (m)	0.118	0.239	0.191	0.136	0.275	0.220
SD (m)	0.151	0.306	0.246	0.174	0.352	0.282
NC (m)	0.263	0.531	0.426	0.302	0.611	0.490

In this study, the period value of the soft-storey model increased relatively with the change in the ground storey height and there was a significant decrease in the total stiffness. This is sufficient to clearly demonstrate the effect of the change in storey height within the building.

Period and stiffness values are the same for all provinces. As the ground storey height increased, the total building height increased accordingly. The building rigidity decreased and the period increased. Target displacements had different values in all provinces for both building models. Earthquake hazards specific to geographical location directly affect target displacements. Among three different provinces with different earthquake hazards, the lowest values were obtained for Adıyaman, which has the lowest earthquake hazard. The highest target displacements were obtained for Hatay Province, which has the greatest earthquake hazard. With the increase in ground storey height, target displacement values also increased. All results show that the change in storey height within the building negatively affects the building's performance.

4. Conclusions

Detailed earthquake performances on existing structures in order to minimize the effects of a possible earthquake are not possible in many respects. Rapid evaluation methods have been developed to facilitate and accelerate detailed earthquake performances of existing structures. Using these methods of assessment, it can easily be determined which buildings need to be examined in detail, thus prioritising the evaluation. Using these methods, it cannot be determined whether the earthquake performance of the structures is sufficient or not, but these methods are used only for regional risk prioritisation.

The rapid assessment method chosen in this study was applied to damaged buildings. Regional risk priorities have been determined for five RC buildings from each of the three provinces most affected by the 6 February 2023 Kahramanmaraş earthquakes, which caused great destruction to the constructed environment with great loss of life. In addition to the building examples in which the parameters in the rapid evaluation method are applied, examples of the damage caused during the earthquake were added to the study.

The presence of one or more of the parameters that will negatively affect the earthquake behaviour of structures directly increases the amount of possible damage. The earthquake hazard of the region where the buildings are located is one of the main parameters taken into consideration in the design and evaluation of buildings. This was directly reflected in the results. For RC structures with the same irregularities, the risk priorities of buildings in Adıyaman Province were lower than in other provinces. This is directly related to the danger of the earthquakes. Another factor is the total number of storeys in the building. As the number of storeys increases, the vulnerability of the structure increases. In the rapid evaluation method, this situation is directly reflected in the base score. As the number of storeys increases, the effect of irregularities also increases. It has been observed that the irregularities taken into account in the rapid assessment method are factors in post-earthquake damages.

It has once again been demonstrated that prioritizing the existing building stock using rapid assessment methods is one of the measures that can be taken before an earthquake. Images before and after the earthquake show that there should be no irregularities. In this context, it is necessary to avoid these irregularities in building design as much as possible. If necessary, the necessary precautions should be taken to ensure that the structures achieve adequate earthquake performance during an earthquake. The results are well documented and demonstrate a good correlation between the characteristics of structures and their behaviour during earthquakes.

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