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Investigation of the contribution of the reinforcement tie to the seismic behavior of reinforced-concrete columns

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ABSTRACT

In seismic design codes it is obligatory to use special earthquake reinforcement ties in reinforced-concrete structural columns. Lack of special earthquake reinforcement ties or any deficiency in arrangement or amount of these reinforcements can cause different levels of damage to the reinforced-concrete structural elements after the earthquake. Within the scope of this study, a total of eight different structural models were created in order to determine the effect of the reinforcement-ties on the shear capacity of reinforced-concrete columns, considering four different reinforcement-tie models and two different reinforcement materials. The period, seismic capacity and target displacement values were obtained for each structural model. In addition, demand, limit and capacity values for shear force were obtained and compared. Significant contribution to the seismic behaviour of the structure with use of reinforcement ties was observed. Material strength and the amount of reinforcement ties used significantly contributing to the seismic behaviour of the structure.

1. Introduction

Earthquakes cause different levels of destructive damages in engineering structures. The magnitude of the earthquake and structural characteristics of the building stock affect the amount of damage. In this context, determining the existing building stock characteristics before a possible earthquake is a part of modern disaster management (Shendkar et al., 2021; Işık et al., 2018; Harirchian et al., 2020; Arslan, 2010). In addition, collapsed and heavily damaged structures after the earthquake reveal the importance of earthquake resistant structure design. (Tabrizikahou et al., 2021; Bilgin et al., 2021; Harirchian et al., 2021). Particularly, the damages that occur in reinforced-concrete (RC) structures, which constitute a large part of the existing building stock, add a special importance to the studies on the earthquake performance of such structures (Doğan et al., 2021; Büyüksaraç et al., 2021 Hadzima-Nyarko and Šipoš, 2017).

Reinforced-concrete structural system that constitutes a large part of the existing building stock is preferred due to its properties. RC is a composite building material formed by the combination of two different materials namely reinforcement and concrete. In RC structures, insufficient reinforcement and concrete properties significantly affect the behavior of the structure under the influence of earthquakes (İnel et al. ,2008; Işık et al., 2021; Arslan ve Korkmaz, 2007). The deficiencies of the transverse and longitudinal reinforcements are one of the causes of structural damage in RC structures as a result of destructive earthquakes. Reinforcement defects can increase the degree of damage in structures especially in vertical load-

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bearing elements such as columns and shear walls. Choosing the placement and numbers of the transverse and longitudinal reinforcements to be used in the columns in accordance with the relevant regulations and standards and placing them as in the project during the construction phase are important in fulfilling the functions expected from the reinforcements. Reinforcement arrangement details in columns, shear walls, beams, slabs and foundation elements that make up RC frames directly affect the strength, ductility and rigidity of RC structure (Stepinac et al., 2021; Yakut et al., 2021; Işık, 2014; Doğangün, 2004; Çelebi et al., 2013; Işık et al, 2020; Erdil, 2017; Tapan et al., 2013; Pekgokgoz and Avcil, 2021). Many studies have been carried out to determine the effect of transverse and longitudinal reinforcements on structural properties of RC columns.

Çolakoğlu (2020) investigated the effect of transverse reinforcement spacing change, which is an important effect that determines the earthquake performance of RC column, on its trans linear behavior. Taşkın and Okay (2019) investigated the effect of transverse reinforcement type on column behavior in their study. Merter and Uçar (2015) investigated the effects of longitudinal reinforcement ratio, transverse reinforcement pitch spacing and axial load on the energy consumption and cross-section energy consumption of reinforced concrete sections under monotonic loading in nonlinear behavior. İnel et al., (2007) investigated the seismic performance of mid-height RC buildings with different story numbers, as well as the transverse reinforcement spacing, as well as different parameters. On the other hand, Meral (2018) investigated the effects of parameters such as axial load, concrete compressive strength, longitudinal reinforcement ratio, longitudinal reinforcement yield strength, transverse reinforcement spacing, transverse reinforcement diameter, transverse reinforcement yield strength and volumetric ratio of transverse reinforcement on the curvature ductility of column sections. İnel et al., (2008), while determining the behavior of fourteen RC buildings under earthquake effects, also took into account the variation of transverse reinforcement spacing, along with other variables. Foroughi et al., (2020) investigated the effect of material model, axial load and transverse reinforcement ratio on the behavior of RC columns in their study. Aydemir et al., (2009) derived analytical relations for realistic and practical calculation of Mp in rectangular reinforced concrete columns. Hasgül et al., (2016) tested four RC cantilever column elements with low concrete strength and insufficient transverse reinforcement in their study.

One or more of the effects such as bending, shear, torsion may cause damage to the columns at the same time. If there is not enough transverse reinforcement at the joints and in the column enclosing area, the core concrete is easily crushed and fractured, the longitudinal column reinforcements are buckled. One of the reinforcements used in the columns is the reinforcement ties that keep the opposing reinforcements or rows of reinforcements at the same distance by connecting them to each other. These ties are used in RC shear walls and columns, which are vertical load-bearing elements. In addition to ensuring that both longitudinal and transverse reinforcements work together by clamping each other, it also works as a distance protector between the reinforcements. Especially in seismic design codes, it is called special earthquake reinforcement tie and its use is important. The crossties can clamp the reinforcements together and prevent the reinforcements from moving under the effect of concrete casting and earthquake. It can prevent the buckling of the transverse reinforcements as well as helping to the transverse reinforcements that meet the shear force in the vertical structural elements. Reinforcement ties can be seen as a type of transverse reinforcement and can contribute to the fulfillment of the functions of these reinforcements. These ties can also be used to maintain the cover spacing. When all these features are taken into consideration, the reinforcement ties used properly will increase the strength and ductility of the columns. The diameter and spacing of special earthquake reinforcement ties are the same as the diameter and spacing of stirrups. The reinforcement ties must be applied separately at both ends so as to wrap the longitudinal reinforcements and outer stirrups. Stirrups and reinforcement ties are applied by being firmly attached to the longitudinal reinforcements so that they do not slip from their places while concrete is poured.

Although the contribution of reinforcement ties to the earthquake behavior of the building is known, there is limited number of experimental and analytical studies that investigated the effect of reinforcement ties on seismic behaviour of RC structural elements. Within the scope of this study, the contribution of different reinforcement ties arrangements to the seismic behavior of the structure was analytically determined using eigenvalue and pushover analysis. In this context, a total of eight different structural models were created. For each model, limit values for shear force, demand, capacity and limit values, as well as period, seismic capacity, target displacement values were obtained.

2. Structural Analysis

A 7-storey RC building was chosen as an example in order to demonstrate the cross-ties effect. The floor plan of the selected RC building is shown in Figure 1. Analyzes were performed using Seismostruct software (Seismosoft, 2022).

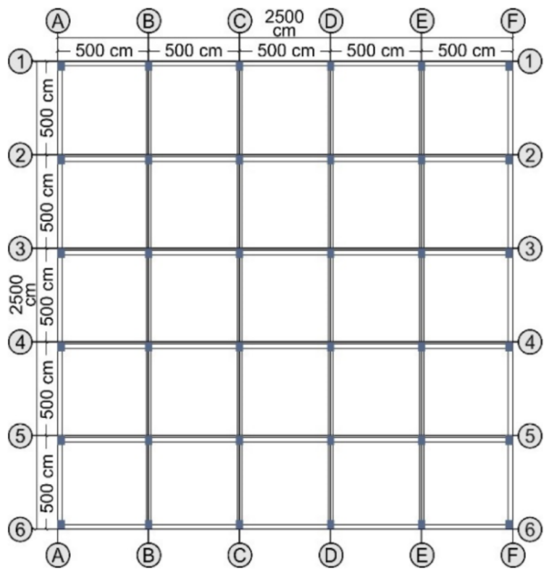


Figure 1. Floor plan of the RC building selected as an example

The 2 and 3 dimensional structural models of the RC building chosen as an example and the representation of the applied loads are given in Figure 2.

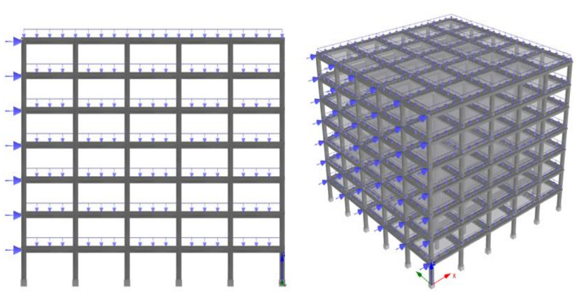


Figure 2. 2 and 3 dimensional structural models and applied loads of the RC structure analyzed

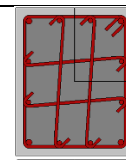
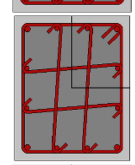
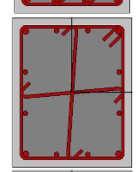
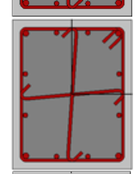
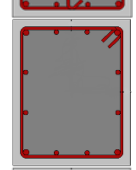
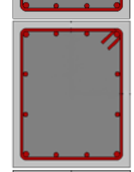
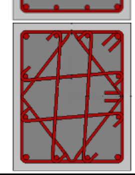
The material and dimensional properties of the structure as well as the parameters used in the series of the analysis are shown in Table 1.

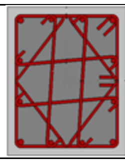
Table 1. Analysis input values considered for the sample RC structure

Parameter		Value
Concrete grade		C25
Reinforcement grade		S220 and S420
Beams		250*600mm
Height of floor		120 mm
Cover thickness		25 mm
Columns		400*500mm
Longitudinal Reinforcement	Corners	4Φ20
	Top bottom side	4Φ16
	Left right side	4Φ16
Transverse reinforcement		Φ10/100
Steel material Model		Menegotto-Pinto
Concrete material model		Mander et al. nonlinear
Constraint type		Rigid diaphragm
Incremental load		2,38 kN
Permanent Load		5 kN/m
Target Displacement		0.42m
PGA		0.654g
Ground Type		C
Importance Class		II
Damping		5%

Structural models used to consider the effect of reinforcement ties are shown in Table 2. While creating the models, two different types of reinforcement (S220 and S420), were taken into account. In addition, four different types of cross-ties were chosen as the other variable as shown in Table 2.

Table 2. Considered cross-sections and their description

Model No	Section	Material	Description
Model I		S220	Double
Model II		S420	Double
Model III		S220	Single
Model IV		S420	Single
Model V		S220	None
Model VI		S420	None
Model VII		S220	Diamond

Model VIII		S420	Diamond

In the structural analysis, the limit states given in Eurocode-8 (Part 3) and used worldwide were taken into consideration for damage estimation. Three performance limit states, namely Near Collapse (NC), Significant Damage (SD) and Damage Limitation (DL) were obtained for all structural models respectively. The period, base shear capacity and performance limit states values obtained as a result of the structural analysis are given in Table 3 for S220; and in Table 4 for S420 reinforcement.

Table 3. Comparison of the analysis results for S220

Model No	Period (s)	Base Shear (kN)	DL (m)	SD (m)	NC (m)
Model I	0.699	6758. 33	0.222	0.284	0.492
Model III	0.699	6752.07	0.221	0.283	0.491
Model V	0.699	6733.28	0.220	0.283	0.49
Model VII	0.699	6767.02	0.222	0.284	0.493

Table 4. Comparison of the analysis results for S420

Model No	Period (s)	Base Shear (kN)	DL (m)	SD (m)	NC (m)
Model I	0.699	9550.29	0.238	0.305	0.529
Model III	0.699	9508.26	0.237	0.304	0.527
Model V	0.699	9437. 49	0.236	0.303	0.525
Model VII	0.699	9593.55	0.238	0.305	0.529

The load factor continued until the 51st step in all models, except for Model 5 (S220 without reinforcement ties). In Model 5, after 29th load step, the phase was terminated and the entire load could not be applied. There was no change in the natural vibration period of the structure due to the presence and different arrangements of reinforcement-ties. With the increase of reinforcement ties in cross-section, there was an increase, in seismic capacity for both S220 and S420. The reinforcement ties were found to be more effective in Model VII and Model VIII. The least effect was obtained for Model V and Model VI, which are models with no reinforcement ties. The grade of the reinforcement ties has caused significant changes in the performance of the columns and structure. The change in the transverse and longitudinal reinforcement materials grades used in all columns caused very significant changes in the seismic capacity. From this point of view, use of S420 and equivalent reinforcements contributed approximately 50% in the base shear. The target displacement values decreased with the decrease in the amount of reinforcement ties for both reinforcement grades.

The main purpose of performance-based engineering, is is to determine the performance of structure at different limit states. This can be accomplished efficiently in SeismoStruct software through the definition of Performance Criteria. The comparison of the demand and limit values obtained for Column 111 and Column 163 located on the ground story as a result of the structural analysis is given as an example in Table 5. PR means performance ratio.

Table 5. The comparison of demand and limit shear values

Model	Col 111			Col 163		
	Demand	Limit	PR	Demand	Limit	PR
Model I	174.01	381.3	0.456	221.02	449.47	0.492
Model II	217.51	558.2	0.390	321.92	690.51	0.466
Model III	165.91	317.5	0.522	202.14	379.50	0.533
Model IV	220.45	444.38	0.496	304.92	565.94	0.539
Model V	150.93	245.43	0.615	176.59	306.15	0.577
Model VI	237.48	354.71	0.670	257.58	430.36	0.599
Model VII	168.42	497.06	0.339	236.10	579.54	0.407
Model VIII	214.48	791.72	0.271	342.58	940.41	0.364

Shear capacity of the columns were determined using code-based check in the software used was used. The main difference between the Code-based Checks and the Performance Criteria is that the latter are checks against the 'expected' values of the response quantities, whereas the former follow the conservative assessment methodologies as defined by the corresponding Codes and Standards (Antoniou and Pinto, 2003). The shear capacity of the Sections module was calculated using the expression of EC8-Part 3. The comparison of demand and capacity shear values is given in Table 6.

Table 6. The comparison of demand and capacity shear values

Model	Col 111			Col 163		
	Demand	Capacity	PR	Demand	Capacity	PR
Model I	174.01	255.07	0.682	221.05	313.67	0.705
Model II	217.51	361.38	0.602	321.86	475.71	0.677
Model III	165.91	211.33	0.785	202.14	265.92	0.760
Model IV	220.45	287.31	0.767	304.93	392.31	0.777
Model V	150.93	162.75	0.927	176.59	215.29	0.820
Model VI	237.48	233.91	1.015	257.58	299.36	0.860
Model VII	168.42	329.56	0.511	236.10	400.59	0.589
Model VIII	214.48	514.46	0.417	342.58	642.98	0.533

In Model 6, shear capacity has been exceeded in a total of four columns. On the other hand, in Model 5, since the analysis could not be completed shear capacity values were not obtained. For all other structural models, no shear force capacity is exceeded.

The shear capacity of each column increased significantly with increasing number of reinforcement ties in the cross section. The lowest shear capacities were obtained for Model V and Model VI, in which no reinforcement ties were used, while the highest values were obtained for Model VII and Model VIII, in which diamond type reinforcement ties were used.

The nonlinear behavior of the structures is assessed based on the material strains implemented in the SeismoStruct (2022). For this, purpose strains were respectively taken as–0.0035, –0.008, and +0.10, for spalling of cover concrete (crush_unc), crushing of core concrete (crush_conf), and fracture of steel (fracture). The number of elements exceeding these strain limit states for the 36 columns on the ground floor in all structural models are given in Table 7. Only one column fracture was observed in Model 5, in which is no reinforcement ties were used. With increasing the usage of reinforcement ties, the number of damaged elements were decreased.

Table 7. The comparison of material strain

Model No	Number of columns is ground story		
	Crush-conf	Fracture	Crush-unc
Model I	36/36	0/36	36/36
Model II	30/36	0/36	36/36
Model III	36/36	0/36	36/36
Model IV	30/36	0/36	36/36
Model V	36/36	1/36	36/36
Model VI	36/36	0/36	36/36
Model VII	30/36	0/36	36/36
Model VIII	30/36	0/36	36/36

5. Results and Conclusions

It is possible to ensure that the structure exhibits ductile behavior in order to minimize the level of damage of the structures in possible earthquakes, if the structural elements have sufficient and necessary strength at the same time. Use of reinforcement ties in reinforced concrete columns provides important contributions to the ductility and strength properties of RC structural elements. The transverse and longitudinal reinforcements used in RC columns directly affect the seismic behavior of the structures. The amount of reinforcement ties to be used provides significant positive contributions. However, providing this contribution in practice will only be possible if it is made in accordance with the reinforcement arrangement and placement rules.

In the current seismic design codes used in Turkey, stirrups are used in all earthquake zones, in columns of all RC systems with normal ductility level, column-beam junction areas, shear end zones and beam wrapping zones are 'special earthquake stirrups', and reinforcement ties are 'special earthquake reinforcement tie'. will be arranged. The diameter and spacing of special earthquake reinforcement ties will be the same as the diameter and spacing of stirrups. The reinforcement ties will definitely wrap the longitudinal reinforcements at both ends. The operations to be carried out in accordance with this and similar equipment regulation rules are important for the fulfillment of the functions expected from the equipment.

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