

The Effect Of Column Cross-Section Shape On Structural Behavior In Reinforced Concrete Structures With Beamless Slabs (Flat Slab)

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Abstract:

Reinforced concrete framed systems are building systems in which horizontal and vertical loads are supported by the structural system formed by the combination of columns and beams. According to the Turkish Building Earthquake Code-2018, the maximum height of reinforced concrete frame buildings is determined depending on the ductility level. It is limited to 17.5 m for the case of limited ductility and to 91.0 m for the case of high ductility. Therefore, reinforced concrete framed structural system is the most preferred building structural system in Turkey. Considering Turkey's location on major fault lines and past losses of life and property from earthquakes, it is of great importance to investigate the structural behavior of reinforced concrete frame structures. In this context, the main objective of this study is to investigate whether the cross-sectional shape of the columns, square or rectangular, affects the structural behavior of reinforced concrete structures with unbroken slabs. The study considers the case of a square (710 mm x 710 mm) and a rectangular (500 mm x 1000 mm) column cross-sectional shape in a symmetrical framed reinforced concrete structure. In both models, column dimensions were determined by keeping the total column cross-sectional area equal. Five-story buildings used for residential and commercial purposes were analyzed and five different ground floor heights (2 m - 2.5 m - 3.0 m - 4.0 m and 5.0 m) were considered for the possibility of using the ground floor for different purposes. Within the scope of the study, ten different types of structures were modeled three-dimensionally in CSI-SAP2000 program and dynamic analyses were performed by Equivalent Earthquake Load Method. Using the data obtained from the analysis results, the behavior of reinforced concrete frame structures is evaluated and interpreted.

1. Introduction

Flat slabs are a prevalent form of slab, following solid and ribbed floor systems in buildings. This type of reinforced concrete slab, which is directly supported by columns without beams, has a flat surface and can be designed with or without drop panels and column heads. In this study, the design was without drop panels and column heads. This flooring system eliminates intermediate load-transfer elements such as beams, allowing loads exerted on the slabs to be transferred directly to the columns, their primary support. Flat panels are favored in many buildings due to their advantages, including lower floor height, faster construction, layout flexibility, and lower construction cost

compared to other panel categories [7]. The research topic of this study is the effect of column cross-section shape on the structural behavior of reinforced concrete flat slab structures. The study examined the impact of different column shapes on the performance of these structures under various loading conditions. A symmetrical frame reinforced concrete building, consisting of 5 stories (ground + 4 regular floors), was designed to serve both residential and business functions [1]. The study focused on the effects of the column cross-sectional shape of the structure being square (710 mm x 710 mm) and rectangular (500 mm x 1000 mm). A balance was achieved between models where the column cross-sectional areas were equal. Columns, beams, and floors were specified in accordance with

the Turkish Reinforced Concrete Structures Design Regulation (TBDY 2018) and the TS500 standards [4]. To represent different usage scenarios, five different values for the height of the ground floor were considered (2.0m - 2.5m - 3.0m - 4.0m and 5.0m), taking into account the possibility of using the ground floor for different purposes (such as a garage, a residence, or a commercial store). Modeling and analysis were performed using the equivalent earthquake load method with SAP2000 software [2]. At the end of the study, the behavior of reinforced concrete structures was compared and interpreted based on values such as period, basic shear strength, maximum displacement at the top, torsional irregularity, and smooth floor irregularity coefficient obtained from the analysis results. This rephrasing maintains the original meaning while presenting the information in a different structure.

2. Literature Review Methods

In the literature, some of the studies on various frame models for buildings to evaluate the parametric effects of column shapes such as Square, and Rectangular Column on the response of flat slabs. **Akinpelu, M.A. et al.** They used Finite Element modelling software Abaqus in the development of a numerical model capable of predicting punching shear features of flat slabs, considering the use of various Column shapes such as L, T, and Cruciform as support. **Borkar, S., Khedikar, I., Dabhekar, K.** They studied the seismic response of flat-slab multi-storey structures across different elevations and layouts, and compared it with conventional two-way slab systems across different seismic zones. Comparison parameters include maximum bending moment, story shear, base shear, and story drift. The analysis is performed using software tools such as ETAB, STAAD PRO and SAP 2000. **Hukre, M., Harne, V. R.** They designed a building with a ground floor and eight additional floors. The height of the top floor exceeds the permissible limit, and the construction must be completed within a set timeframe. The design process uses STAAD.pro for 3D finite element analysis to understand stress behavior in flat slabs and to design for safe shear. Additional reinforcement is provided for shear resistance. **Wiley, J., Sons, Ltd.** They studied the effect of shear strength of two-way panels on flat panels. Panels without and with shear reinforcement are discussed. With an explanation of the importance of shear reinforcement in transforming the failure mode of the slab from brittle to ductile. **Husain, B.,**

Siddiqui, B., Khan, F. They studied the comparative analysis of reinforced concrete (RCC) frame structures with different types of slabs and column cross-section shapes in seismic zone 5, India. The analysis is performed using ETABS 2016 software. Evaluation parameters include maximum and minimum displacement, storey drift, storey shear, and storey stiffness. **J. Sagaseta et al.** They studied the structural behavior of RC flat slabs supported on rectangular internal columns and the effect of loading conditions (bending in one or two directions) on the punching shear strength. Explaining the possibility of rectangular columns in RC flat panels leading to concentration of shear forces, which may reduce the perforated shear force compared to square columns of similar length to the control perimeter. **Isufi, B., Ramos, A.P.** They highlighted gaps in the published literature for tests of plate-column connections (for high-strength concrete (HSC), fiber-reinforced concrete (FRC), and ultra-high-performance fiber-reinforced concrete (UHPFRC)) in both non-seismic and seismic loading conditions to understand the behavior and performance of these advanced materials under different stress conditions.

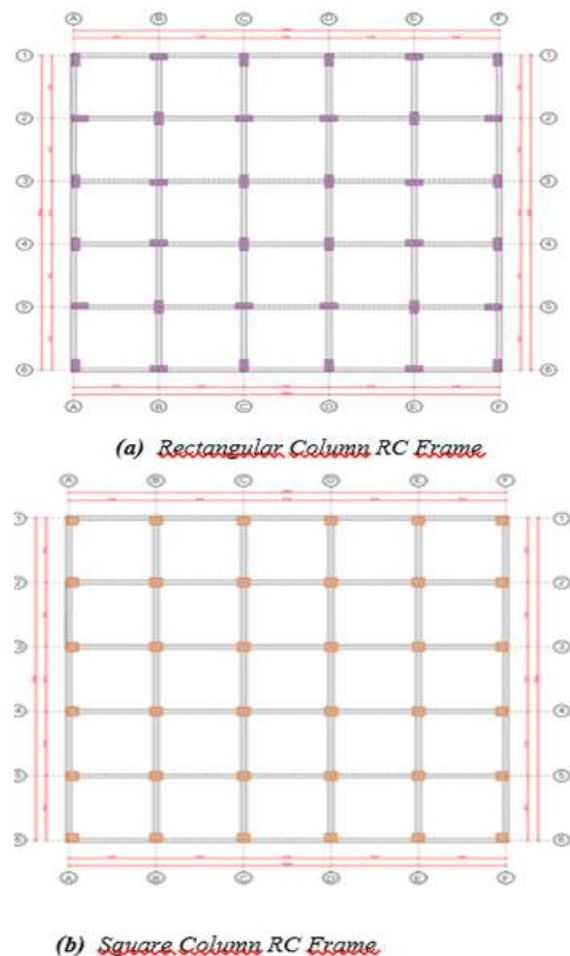


Fig. 1. X-Y Floor Plan of the Square and Rectangular Column

Table 2 The parameters of the different model types that were used in the numerical analysis:

Floor to floor height	4.0 m
No of stories	G+4
Beam	300x500 mm
Beam Reinforcement	3 Ø 12 (Bottom), 2 Ø 12 (Top), Stirrups: Ø 8 / 20 / 10
Square Column	710x710 mm
Rectangular Column	500x1000 mm
Column Reinforcement	Longitudinal reinforcement: 10 Ø 18, Stirrups: Ø 8 / 20 / 10 / 10
Thickness of flat slab	200 mm
Live Load	3.50 KN/m ²
Wall Load	6.474 KN/m ²
Floor finish	1.46 KN/m ²

Table 3. The numerical study established the material properties, which are shown in:

Grade of concrete for building	C25/30
Grade of steel	B420C
Unit weight of reinforcement	w _s = 76.9729 KN/m ³
Modulus of elasticity of reinforcement	E _s = 200 Gpa
Unit weight of concrete	w _c = 24.9926 KN/m ³
Modulus of elasticity of concrete	E _c = 31 Gpa
Poisson's ratio	v _c = 0.2

Table 4 The analysis parameters obtained in the numerical study.

Intended Use	Konut + İşyeri
Importance factor	I=1
Location	Serdivan Belediyesi
Local Soil Class	ZD
Ductility Level soil site	High
Knowledge Level	Limited
Seismic Zone	DD-2
Moving Load Coefficient	n=0.3
Structural behaviour coefficient	R= 8
Strength excess coefficient	D=3
Short period map spectral acceleration coefficient	S _s =1.598
Map spectral acceleration coefficient for 1.0 second period	S ₁ = 0.438
Long Period	6 s
Time Period Ct (m)	0.10– 0.75

3. Variable And Fixed Parameters

3.1. Fixed parameters

Table 1. The following common features apply to each model:

Model Feature	Value
Floor Height	3 M
X Axis Length	5.1 M
Y Axis Length	5.1 M
Reinforcement Type	B420C

3.2. Variable parameters

The study considers two different frame models for buildings: Square Column (S) and Rectangular Column (R). These models take into account various ground floor heights and total building heights

- Frame Models: The study uses two types of column shapes for the building frames: Square and Rectangular.
- Ground Floor Heights: Five different ground floor heights are considered in these models: 2.0, 2.5, 3.0, 4.0, and 5.0 metres.
- Total Building Height: The total height of the building, denoted as H (m), includes five different values: 14, 14.5, 15, 16, and 17 metres.

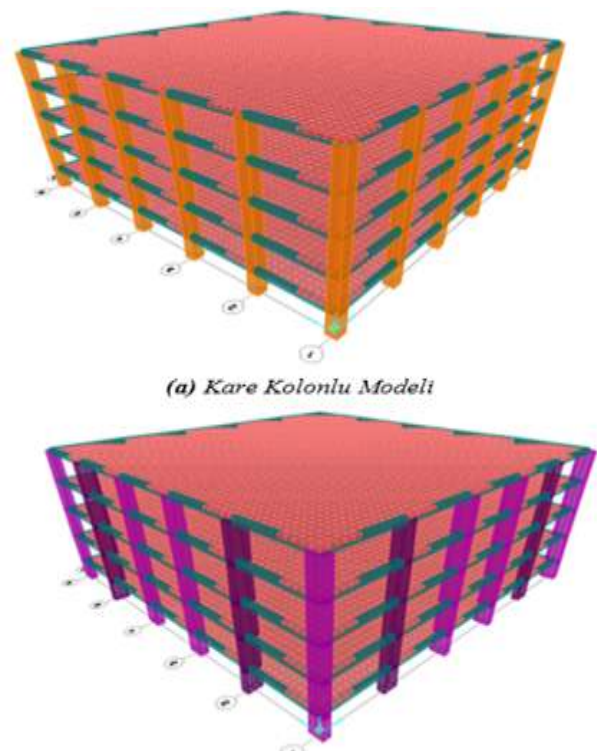


Figure. 2. 3D models have been crafted using the Sap2000 software

4. Design Models

4.1. Turkish code

In the study, the loads on the structure were determined in accordance with TS 498, a Turkish standard that provides guidelines for calculating the loads to be considered when designing structural elements. These loads include both vertical, and horizontal loads (due to forces such as earthquakes). An additional eccentricity of ± 0.05 in the X direction was applied to the structure. Eccentricity in this context refers to the offset of the center of mass from the center of stiffness, which can lead to rotation (torsion) when the structure is subjected to lateral loads. The Equivalent Earthquake Load Method, as outlined in the Turkey Building Earthquake Regulation-2018, was used to calculate the earthquake loads. In this method, the total equivalent earthquake load (or base shear force) $V_{te}^{(X)}$ affecting the building in the X direction is calculated. The base shear force is a measure of the total lateral (horizontal) force that the structure needs to withstand during an earthquake. The calculation of $V_{te}^{(X)}$ involves certain relations. These relations are used in the Equivalent Earthquake Load Method to calculate the earthquake loads on a structure. The aim is to ensure that the structure can safely withstand the forces generated by an earthquake.

$$V_{te}^{(X)} = m_t S_{ar} (T_p^{(X)}) \geq 0,04 m_t I S_{DS} g \quad (1)$$

- m_t : the total seismic mass of the structure,
- $S_{ar} (T_p^{(X)})$: the reduced design spectral acceleration at the period $(T_p^{(X)})$,
- I : the importance factor,
- S_{DS} : the design spectral response acceleration parameter in the short period range, and

g : the acceleration due to gravity.

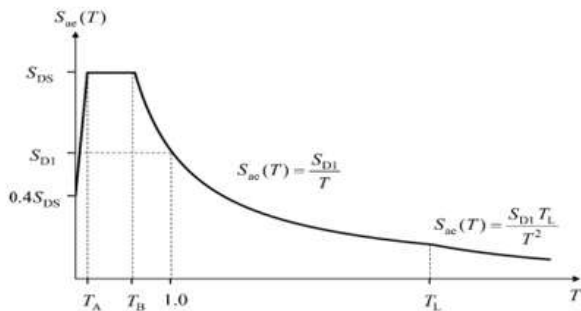


Fig. 4. Horizontal Elastic Design Spectrum Curve

the variable T is defined as $T_p^{(X)}$. This represents the natural vibration period in the considered earthquake direction, denoted as X. The value of T is determined using equation (2) in this method.

$$T_p^{(X)} = 2\pi \left(\frac{\sum_{i=1}^N m_i d_{fi}^{(X)2}}{\sum_{i=1}^N F_{fi}^{(X)} d_{fi}^{(X)}} \right)^{1/2} \quad (2)$$

4.2. Irregularity Controls

Irregularity Checks During the design and construction process, irregular buildings that may exhibit adverse behaviors against earthquakes are identified. For this, calculations have been made for A1 - Torsional Irregularity and B2 - Inter-Story Stiffness Irregularity (Soft Story) located in Table 3.6 of Section 3.6 of the 2018 Turkey Building Earthquake Regulation, both in plan and vertical direction. Other irregularities have not been checked due to their absence in the models.

A1. Torsional Irregularity:

Table 5. Irregularity in Plan - A1. Torsional Irregularity

A - PLANDA DÜZENSİZLİK DURUMLARI	İlgili Maddeler
A1 - Burulma Düzensizliği: Birbirine dik iki deprem doğrultusunun herhangi biri için, herhangi bir katta en büyük göreceli kat ötelemesinin o katta aynı doğrultudaki ortalama göreceli ötelemeye oranını ifade eden <i>Burulma Düzensizliği Katsayısı</i> η_u 'nin 1.2'den büyük olması durumu (Şekil 3.1). $ \eta_u = (\Delta_i^{(0)})_{\max} / (\Delta_o^{(0)})_{\text{ort}} > 1.2$. Göreceli kat ötelemelerinin hesabı, $\pm 5\%$ ek düzmerkezlilik etkileri de gözönüne alınarak, 4.7'ye göre yapılacaktır.	3.6.2.1

B2. Stiffness Irregularity Between Adjacent Floors (Soft Story):

Table 6. Irregularity in Plan – B2. Soft Story Irregularity

B2 - Komşu Katlar Arası Rijitlik Düzensizliği (Yumuşak Kat): Birbirine dik iki deprem doğrultusunun herhangi biri için, bodrum katlar dışında, herhangi bir i'inci kattaki ortalama göreceli kat ötelemesi oranının bir üst veya bir alt kattaki ortalama göreceli kat ötelemesi oranına bölünmesi ile tanımlanan <i>Rijitlik Düzensizliği Katsayısı</i> η_u 'nin 2.0'den fazla olması durumu. $ \eta_u = (\Delta_i^{(0)} / h_i)_{\text{ort}} / (\Delta_{i-1}^{(0)} / h_{i-1})_{\text{ort}} > 2.0$ veya $ \eta_u = (\Delta_i^{(0)} / h_i)_{\text{ort}} / (\Delta_{i+1}^{(0)} / h_{i+1})_{\text{ort}} > 2.0$ Göreceli kat ötelemelerinin hesabı, $\pm 5\%$ ek düzmerkezlilik etkileri de gözönüne alınarak 4.7'ye göre yapılacaktır.	3.6.2.1
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5. Analysis

The study models have been defined using the data from Table 1, Table 2, and Table 3. Modeling and analyses were carried out with the CSI-SAP2000 software. Columns and beams have been defined as bar elements. A rigid diaphragm has been assumed for all floors of the models. Equivalent Seismic Load calculations were performed within the program.

6. Discussion Of Results

The table compares two models that in the study applied to the structures. The models used the CSI-SAP2000 software to assess the structures' reliability and perform structural analyses. These parameters describe the structures' characteristics. The table displays the analysis outcomes using these parameters: Building total height (H), Base shear force (V_{te}), Peak maximum displacement (d), Building total weight (W),

Torsional irregularity (η_{bi}), and Soft story irregularity coefficients (η_{ki}).

Table 6. Presents the data obtained for the models with the assistance of the SAP 2000 software

Parameters	Square				
H_{Ground} (m)	2	2,5	3	4	5
V (kN)	2442.738	2426.813	2395.297	2347.735	2246.22
d (m)	0.02623	0.02742	0.028497	0.03127	0.03379
H (m)	14	14,5	15	16	17
W (kN)	24513.169	24739.947	24966.73	25420.281	25873.837
η_{bi}	1.00924	1.00955	1.00951	1.00988	1.01009
η_{ki}	2.71113	2.42989	2.22603	1.93864	1.73727
T (s)	0.90548	0.94711	0.99007	1.08099	1.17975
V / W	0.09965	0.09809	0.0959	0.09236	0.08681
d / H	0.001874	0.001891	0.0019	0.001954	0.001988

Rectangular				
2	2,5	3	4	5
2483.981	2470.845	2442.455	2381.959	2287.745
0.02569	0.02694	0.02808	0.03068	0.033296
14	14,5	15	16	17
24461.525	24686.458	24911.392	25361.259	25811.126
1.00888	1.00921	1.00919	1.00950	1.00977
2.72586	2.44979	2.2502	1.96927	1.77324
0.88466	0.92592	0.96839	1.05782	1.15429
0.10155	0.10009	0.09805	0.09392	0.08863
0.001835	0.001858	0.001872	0.001918	0.00196

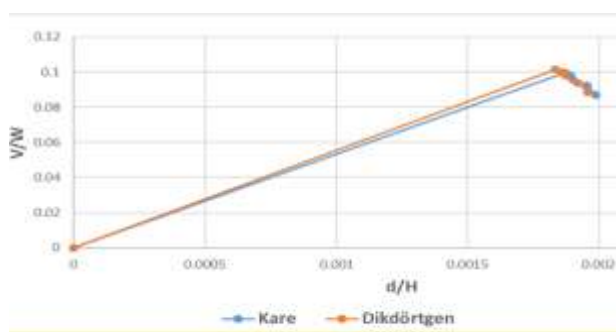


Fig. 5. Change in Shear Force Carrying Capacity of the Models.

- Carrying Capacity of Rectangular and Square Columns:

The model with rectangular columns always has a higher carrying capacity in all types. Even if they are the same size, models with rectangular columns can withstand more shear force.

- Effect of Ground Floor Height:

In both models, as the ground floor height increases, the shear force carrying capacity decreases.

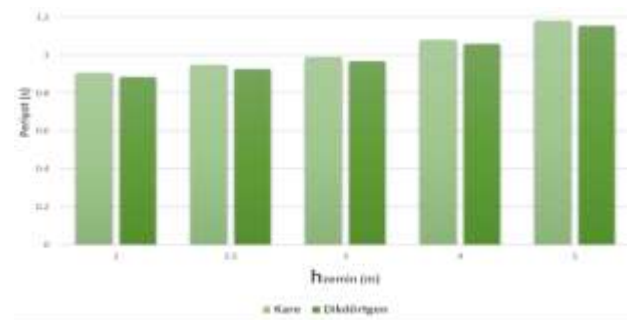


Fig. 6. Alteration in Period with Respect to Ground Floor Height.

- Dominant Period Values:

The dominant period values between the Square and Rectangular column models are generally close to each other.

- Effect of Ground Floor Height:

In both models as the ground floor height increases, an increase in periods is observed. Specifically, when the ground floor height increases by 0.5 meters, the period in the ‘Square’ column model has increased by approximately 4.53%, while the period in the ‘Rectangular’ column model has increased by 4.59%.

Similarly, when the ground floor height increases by 1 meter, the period in the ‘Square’ column model has increased by approximately 9.14%, while the period in the ‘Rectangular’ column models has increased by 9.12%. This situation indicates that an increase in ground floor height increases the periods in both models.

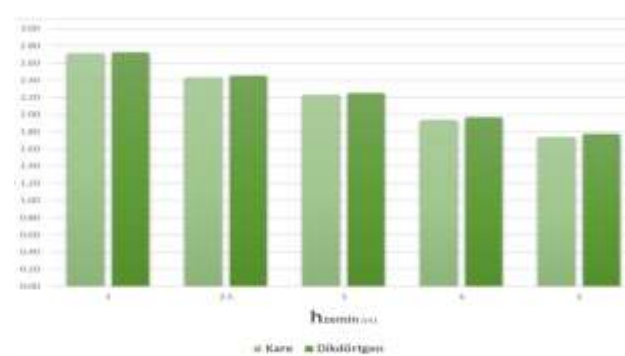


Fig. 7. Ground Floor Height – Soft Floor Irregularity Change

- “soft floor irregularity” :

The values between the models are quite close to each other. However, the value of the model with ‘Rectangle’ columns is observed to be slightly higher.

It has been found that as the height of the ground floor increases, the coefficient of soft floor irregularity decreases.

For instance, when the height of the ground floor increases by 0.5 meters, it is observed that the soft floor irregularity increases by approximately 9.16% in the model with 'Square' columns and by 9.18% in the model with 'Rectangle' columns.

Similarly, when the height of the ground floor increases by 1 meter, an increase of approximately 13.21% occurs in the model with 'Square' columns, and an increase of 12.64% occurs in the model with 'Rectangle' columns.

The results suggest that changes in the height of the ground floor can significantly impact the stability of the floor structure.

7. Conclusion

- According to the findings of the study, as the height of the ground floor increases in both models, the following results are observed:
- The natural vibration period and the value of peak point displacement increase.
- The coefficient of soft floor irregularity and the base shear force decrease.
- The increase in periods causes a decrease in the shear forces affecting both models.
- There is a decrease in the shear force carrying capacity.
- Additionally, while the dominant period values in the models are close to each other, it has been found that the model with 'Square' columns has a slightly larger dominant period.
- When the ground floor height is 2 m and 5 m, the dominant period value of the model with 'Rectangle' columns has decreased by 2.35% compared to the model with 'Square' columns.
- Peak point displacements are always smaller in the model with 'Rectangle' columns. The base shear forces affecting the structure with 'Rectangle' columns are generally larger compared to the model with 'Square' columns.
- Soft floor irregularity is always smaller in the model with 'Square' columns. When the ground floor height is 2 m, the value of soft floor irregularity in the model with 'Rectangle' columns has increased by 0.55% compared to the model with 'Square' columns; at a ground floor height of 5 m, this increase is observed as 2.15%. In both

models, the maximum value of soft floor irregularity is generally observed on the ground floor.

Lastly, the torsional irregularity in both models has not exceeded the limits allowed in the TBDY 218 regulation.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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