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Research Article

Effect of eccentricity on the internal forces on the columns of a reinforced concrete building

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ABSTRACT

In this study, a five-storey reinforced concrete building was modeled with the IdeCAD V10 program, and the internal force changes in the columns were examined by creating different eccentricity states. While creating the eccentricity, the center of rigidity was moved away from the center of mass by changing the size of one of the corner columns. The columns whose internal strength is examined are the corner, edge and interior columns on the ground, third and fifth floors of the building. As a result of the analysis, the bending moment and shear force values in the ground floor columns have the highest values, while the torsional moment values are higher at the third floor.

1. Introduction

In a reinforced concrete structure, the earthquake performance of the building depends on the strength of the load-bearing elements as well as the distribution of the load-bearing elements in the plan. In structures which is not symmetrical, there is an eccentricity between the center of rigidity and the center of mass. With the earthquake force acting on the center of mass of the building horizontally, the structure is forced to rotate around the center of rigidity. According to Turkish Building Earthquake Code 2018 (TBDY-2018), torsional irregularity coefficient (η_{bi}) expresses the ratio of the largest relative story drift occurring at any floor because of rotational and translational movements in the building. Torsional irregularity is defined as the relative drift in the same direction at that floor [1].

The experiences with past earthquakes have shown that the columns of the structures with torsional irregularity have more damage than the regular structures [2-6]. The energy absorption capacity of reinforced concrete columns decreases significantly with increasing amount of torsion. [7]. In structures, which has different degrees of torsional irregularity, could collapse depending on the degree of irregularity [8].

It was reported that the torsion effect is a function of the eccentricity between the center of mass and stiffness in structures [9]. In studies on torsional irregularity, the behavior of reinforced concrete has been emphasized and it has been determined that eccentricity, which is caused by the change of the vertical carriers in the structure and the formation of the carrier system in various ways, changes the behavior of the structure [10-11]. In order to reduce the torsion effect in the structure and to limit the relative storey drifts, the center of mass and stiffness should be close to each other [12]. To reduce the torsion effect, the strength of the carrier elements in the weak direction of the structure should be increased and the eccentricity should be reduced [13]. However, even in symmetrical structures designed according to earthquake regulations which the center of mass and stiffness overlap, torsional irregularity can be observed when the horizontal stiffness is not sufficient [14-15]. Although, the effects of torsion on the behavior of the structure are known, it has to determine how the irregularity change in the structure affects the torsional moment in the columns.

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In this study, a 5-storey reinforced concrete structure was modeled with the IdeCAD V10 program. The structural system is arranged in such a way that the center of rigidity and mass center coincide. By changing the b/h ratio of the corner column in the building, different eccentricities were created between the center of rigidity and the center of mass. The variation of the shear force, bending and torsion moment in the side, middle and corner columns on the ground floor, third and fifth floors were investigated. As the eccentricity between the mass and the center of rigidity of the structure increases, the torsional moment occurring in all columns in the structure changes. Corner columns in the structure are forced more than other columns under the effect of torsion.

2. Material and Method

In this study, a 5-storey symmetrical building with each floor 3 meters high was created and analyzed using the IdeCAD V10 program. Then, by keeping the b dimension of one of the corner columns of the building constant, the h dimension was increased, and eccentricity was created in the structure. In each case of eccentricity, the building was re-analyzed and the torsional moment, bending moment and shear force values in the corner, edge and interior columns of the ground, third and fifth floors were investigated.

For the building to be symmetrical, in other words, the center of rigidity and the center of mass coincide, there are no elements such as stairwells, recesses, protrusions at the floor level. The b dimension of all columns was determined as 30 cm and the h dimension as 60 cm. For beams, the b dimension is 25 cm and the h dimension is 60 cm. The floor thickness is adjusted to be 12 cm. The dead load on the floors is 4.48 kN/m^2 (marley coating is selected), the live load is 2.00 kN/m^2. Concrete compressive strength was chosen as C25, reinforcement as S420 and soil class as ZA.

The structure is arranged in such a way that the center of rigidity and mass center coincide. By changing the b/h ratio of the corner column in the building, different eccentricities were created between the center of rigidity and the center of mass. The variation of the shear force, bending and torsion moment in the side, middle and corner columns on the ground floor, third and fifth floors were investigated. As the eccentricity between the mass and the center of rigidity of the structure increases, the torsional moment occurring in all columns in the structure changes. Corner columns in the structure are forced more than other columns under the effect of torsion.

The 3D model of the building is shown in Figure 1, and the floor plan is shown in Figure 2.

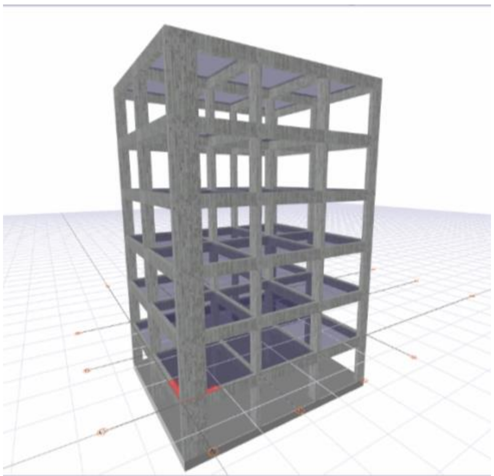

Figure 1. 3D model of the building

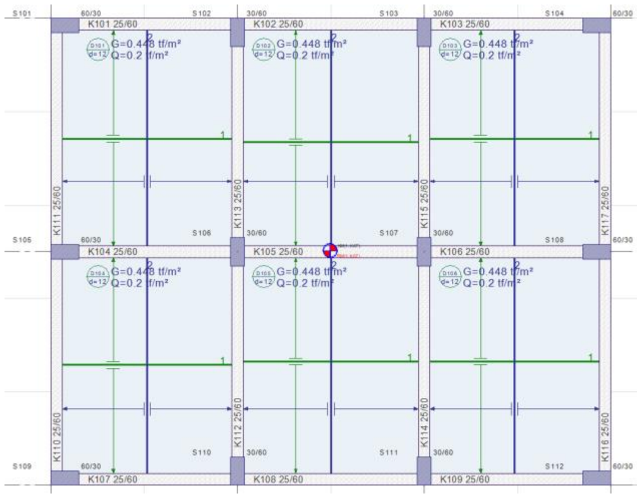

Figure 2. Floor plan of the building

In order to understand the torsion effects on the building better, it would be appropriate to choose a location where the earthquake effect is great. For this, earthquake data belonging to Sisli district of Istanbul province were used for analysis (Figure 3).

Information about the design spectra is shown in Figure 4. The ductility level of the building was chosen as high.

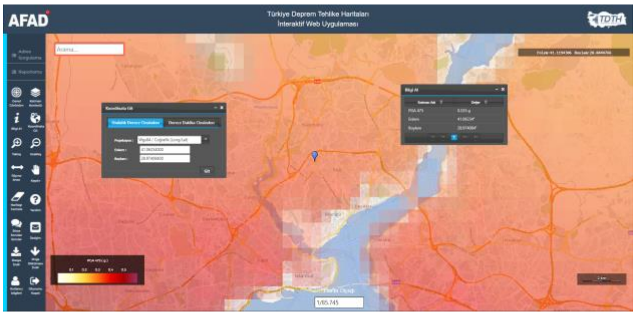

Figure 3. The location where the earthquake data of the building will be taken, Sisli/Istanbul

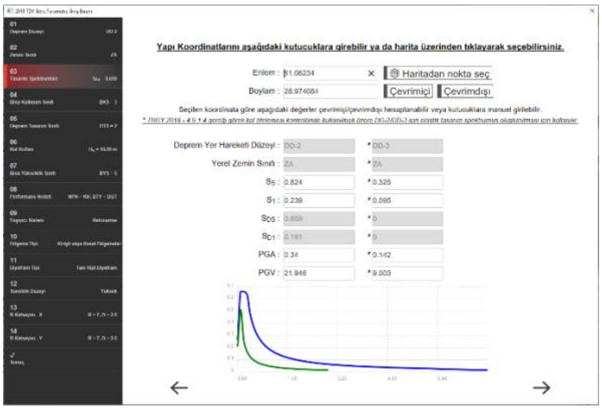

Figure 4. Design spectrums

To create the eccentricity in the building, the dimension h of the lower left corner column shown as S109 in Figure 2 has been increased to 70 cm, 90 cm and 120 cm, respectively, for the whole building height. The corners, edges and interior columns with which the section effects will be compared are given in Figure 5.

Figure 5. Corner, edge and interior column

3. Conclusions

The building model to be used in the study was analyzed according to TBDY-2018 and the variation of the cross-sectional effects in the columns depending on the eccentricity was investigated. In the results, the cross-sectional effects on the corners, edges and inner columns at the ground, third and fifth floors of the building were examined at each eccentricity state. For cross-section effects, the load combination G+Q+E_x+0.3E_y was used. Torsional moment values of the columns in question are given in Table 1, bending moment values are given in Table 2, and shear force values are given in Table 3. Structure type A with 30x60 columns, structure type B with 30x70 columns, structure type C with 30x90 columns, and structure type D with 30x120 columns.

The coefficients of center of mass, center of rigidity and torsional irregularity occurring in the structures are given in Table 4.

3.1. Comparison of Torsional Moments

When the torsional moment values in Table 1 are examined, it is seen that generally the lowest torsional moments occur at the fifth floor and the highest ones at the third floor.

Columns with the highest torsional moment in case A; corner and interior columns on the ground floor and corner columns on the third and fifth floors.

Columns with the highest torsional moment in types of B, C and D; corner columns on the ground floor and corner columns on the third and fifth floors.

When all cases are compared, the highest torsional moment occurred with 17.2x10^{-2} kNm in the ground floor side column in D state.

3.2. Comparison of Bending Moments

When the bending moment values in Table 2 are examined, it is seen that the bending moment values in the ground floors are quite high compared to the other floors. Although the structural types vary, there is no significant difference in bending moments. The highest bending moment occurred in the ground floor corner column of the D type building with 124 kNm.

3.3. Comparison of Shear Force

When Table 3 is examined, it is seen that the shear force values give similar results with the bending moment values. The most stressed columns were formed on the ground floors and no significant difference was observed between the building types. Among all the building types, the column with the highest shear force occurred in the ground floor corner column with 59 kN.

Table1. Torsional moment values of columns (kNm x 10^{-1})

Floor	A (30x60)			B (30x70)			C (30x90)			D (30x120)		
	Corner	*Edge*	*Int.*	*Corner*	*Edge*	*Int.*	*Corner*	*Edge*	*Int.*	*Corner*	*Edge*	*Int.*
5	4.8	2.2	2.3	5.8	2.7	4.5	7.6	3.8	4.7	7.6	4.7	6.2
3	5.0	4.8	4.8	6.8	6.5	10.4	9.8	9.5	9.6	12.7	12.3	12.5
Ground	0.1	4.9	4.9	1.8	7.3	6.6	5.1	11.9	9.8	8.3	17.2	13.3

Table 2. Bending moment values of columns (kNm)

Floor	A (30x60)			B (30x70)			C (30x90)			D (30x120)		
	Corner	*Edge*	*Int.*	*Corner*	*Edge*	*Int.*	*Corner*	*Edge*	*Int.*	*Corner*	*Edge*	*Int.*
5	2	2	1	2	2	6	2	2	4	1	3	7
3	16	12	3	16	12	15	17	12	14	17	12	16
Ground	120	47	24	121	46	19	122	100	28	124	46	30

Table 3. Shear force values of columns (kN)

Floor	A (30x60)			B (30x70)			C (30x90)			D (30x120)		
	Corner	*Edge*	*Int.*	*Corner*	*Edge*	*Int.*	*Corner*	*Edge*	*Int.*	*Corner*	*Edge*	*Int.*
5	2	3	3	2	3	5	2	3	5	2	4	6
3	11	9	8	12	9	10	12	9	10	12	9	13
Ground	56	20	13	57	20	14	58	20	15	59	20	16

Table 4. Centers of mass, center of stiffness and torsional irregularity coefficients in the structures

Structure Type	Center of Mass		Center of Stiffness		Irregularity Coefficients (η_{bi})	
	X_m (m)	Y_m (m)	X_r (m)	Y_r (m)	X Direction	Y Direction
A (30x60)	6.00	5.00	6.00	5.00	1.076	1.107
B (30x70)	5.97	4.97	6.00	5.01	1.068	1.106
C (30x90)	5.97	4.97	6.01	5.04	1.051	1.111
D (30x120)	5.97	4.97	6.02	5.07	1.032	1.115

3.4. Comparison of Torsional Irregularity

When the torsional irregularity coefficients in Table 4 are examined, as one goes from state A to state D, the torsional irregularity coefficient decreases in the X direction and increases in the Y direction. The largest η_{bi} in the X direction was formed in case A with 1.079, while η_{bi} in the Y direction was formed in case D with 1.115.

4. Result and Discussion

In this study, different eccentricities were created in a five-storey reinforced concrete building. The torsional moment, bending moment and shear force values occurring in the corner, edge and interior columns of the ground, third and fifth floors of the building were investigated.

Torsional moment values formed in the columns of the buildings did not show a distribution in a certain order. The greatest torsional moments occurred in the columns on the third floor in case A, and in the ground floor in cases B, C and D. Therefore, in the building type with low eccentricity, the torsional moment value is higher in the middle floors. The reason for this situation is thought to be due to the fact that the relative floor rotation in the middle floors is higher than the other floors when the eccentricity is low.

Torsional moments have also occurred in the columns of the A-type structure, which has a symmetrical arrangement. It is thought that this situation arises from the different movements of the floors relative to each other, since the earthquake forces acting on the floors are different from each other.

As the structure type goes from A to D, in other words, as the eccentricity increases in the structure, the torsional moment values increase significantly. The highest increase rate occurred in the ground floor corner column.

The most critical floor in terms of torsion was the third floor. In general, the torsional moments of the third floor were higher than the other two floors.

The bending moment and shear forces reached the highest values in the ground floors of the buildings. The most critical column for these effects was the ground floor corner column.

Since the torsional irregularity coefficient η_{bi} is less than 2 for all cases, torsional irregularity did not occur in any case. Although it is seen that torsional irregularity does not occur according to the TBDY-2018 regulation, it should be noted that as the eccentricity increases, the torsional moment values occurring in the columns of the structure can reach critical levels. In the study of Attarchian et al. (2020), it is seen that reinforced concrete columns reach torsional cracking at 2.0 kNm. In this study, it is seen that the torsional moment value of the D type structure on the ground floor side column is close to the critical value in this study with 1.72 kNm. Column dimensions in this study are the same as in this study; but the axial load ratio on the columns is 0.07. This value is quite low. The axial load ratio on reinforced concrete columns in practice is well above these levels. Therefore, considering that the behavior of the columns will change with the increase in the axial load level, the critical torsional moment values of reinforced concrete columns should be investigated in detail depending on the axial load level.

If studies on the design of torsion-resistant reinforced concrete columns develop, architecturally more diverse, in other words, more asymmetrical and design structures may emerge.

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Author contributions

Conceptualization: [Salih Cengiz]; Methodology: [Alptug Unal]; Formal analysis and investigation: [Salih Cengiz]; Writing - original draft preparation: [Salih Cengiz], [Abdulkadir Solak]; Writing - review and editing: [Mehmet Kamanli]; Resources: [Salih Cengiz]; Supervision: [Mehmet Kamanli, Alptug Unal]

Conflicts of interest/Competing interests

There is no conflict of interest or common interest with any institution or person that we know that could affect our work.

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