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Investigation Of Relative Story Shifts In Buildings With Projection Irregularities At Different Ratios

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Abstract: There are 3 major fault lines in our country, which are exposed to thousands of earthquakes every year, namely the North Anatolian Fault Zone and the East Anatolian Fault Zone. Therefore, earthquake effects are more important in terms of the structural behavior of the buildings built in our country. It is very important for building safety to design buildings as regularly as possible during the design phase. However, sometimes this is not possible for reasons such as architectural designs. In the study, 6 different models with the irregularity type of A3-Existence of Projections in the Plane and the symmetric reference model were analyzed according to Mode Superposition Method. The models analyzed in the study were modeled with the SAP2000 program. As a result of the analysis, the interstory drift performances of the models under the effect of earthquakes were examined. Comparisons were made in line with the results obtained from the analyzes and comments were made on the effect of structures with A3 irregularity type on the interstory drifts.

Farklı Oranlarda Planda Çıkıntı Düzensizliğinine Sahip Yapılarda Göreli Kat Ötelemelerinin İncelenmesi

Anahtar Kelimeler
Düzensizlik Türleri,
Mod Birleştirme Yöntemi,
Göreli Kat Ötelemeleri

Öz: Her yıl binlerce deprem etkisine maruz kalan ülkemizde Kuzey Anadolu Fay Zonu ve Doğu Anadolu Fay Zonu olmak üzere 2 büyük fay zonu bulunmaktadır. Dolayısıyla ülkemizde yapılan yapıların yapısal davranışı açısından deprem etkilerinin önemi daha fazladır. Yapıların tasarım aşamasında olabildiğince düzenli olarak tasarlanması yapı güvenliği açısından çok önemlidir. Fakat bazen mimari tasarımlar gibi sebeplerle bu mümkün olmamaktadır. Çalışmada 2018 Türkiye Bina Deprem Yönetmeliğince açıklanan A3-Planda Çıkıntılar Bulunması düzensizlik türüne sahip 6 farklı modeli ve simetrik referans modeli mod birleştirme yöntemi ile analizi yapılmıştır. Çalışmada analizi yapılan modeller SAP2000 programından üç boyutlu olarak modellenmiştir. Analizler sonucu modellerin deprem etkisi altında yapılan göreli kat ötelemeleri performansları incelenmiştir. Analizlerden elde edilen sonuçlar doğrultusunda karşılaştırmalar yapılıp A3 düzensizlik türüne sahip yapıların göreli kat ötelemeleri üzerindeki etkisi hakkında yorum yapılmıştır.

1. INTRODUCTION

Due to the location of Turkey, the damage to the buildings are mainly due to earthquakes. The effect of earthquake forces varies according to the characteristics of the structure. Therefore, while the structures are being designed, the regularity of the structural carrier system is of great importance in terms of any load transfer. For this reason, the issue of irregularities is discussed in the relevant section of TBDY-2018 (Turkish Building Earthquake Code).These irregularities are examined under two headings as plan and vertical irregularities. In the models examined in the study, the presence of protrusions in the A3 plan, which is explained under the title of irregularity type in the plan, the effect of the irregularity type on the structure was examined.

In the study, 7 different models were designed as R (reference), A, B, C, D, E and F type. The reference model, the R-type model, has a symmetrical form, and the other 6 models have projections in the plan. In all models, ground story height is 5 m and normal story height is 3 m. The local soil class is taken from ZC.

In order to increase the building safety in earthquake resistant building design, some limitations were introduced in TBDY-2018 (2018 Turkish Building Earthquake Code). If there is no flexible joint or any connection between the column and the wall, the relative storey drift value cannot be greater than 0.008κ. If the column and wall are independent of the frame, this value cannot be greater than 0.016κ. Since the structural system examined in the study is reinforced concrete, the value of κ is taken as 1. [1]

2. PROJECTIONS IN THE PLAN

The structures in which the horizontal and vertical load effects on the structure are not transferred to the foundation through the carrier system in a regular manner are called irregular structures. As a result of the studies, it has been seen that regular structures are more effective than irregular structures under the effect of earthquakes. For this reason, some restrictions have been introduced for irregular structures in the regulation. These limitations were first defined in DBYBHY-2007 (Regulation on Buildings to be Constructed in Earthquake Zones) and entered into force. In TBDY-2018 (Turkish Building Earthquake Code), the regulation updated in 2018, no changes were made regarding irregularities. It is defined under the title of Irregular Buildings Under the Effect of Earthquake in Section 3.6 of TBDY-2018 (Turkish Building Earthquake Code). It has been examined under two sub-headings as irregularities in the plan and irregularities in the vertical. Within the scope of this study, A1 and A3, which are irregularities in the plan, only B2 irregularities among vertical irregularities will be examined. [2] [3][4]

2.1. Irregularities In The Plan

According to TBDY-2018 (2018 Turkish Building Earthquake Code), plan irregularities consist of 3 types: A1 torsional irregularity, A2 slab discontinuities, and A3 projections.

2.1.1. A1 Torsional Irregularity

If the load-bearing system of the buildings is not made symmetrical, it will cause the rigidity center of the structure and the center of gravity not to coincide. Therefore, while the horizontal earthquake forces act on the rhythm center of the structure, torsion occurs around the vertical axis passing through the center of gravity of the structure. Torsion condition causes serious damage to structures under the effect of earthquake. The regulation brought limitations in these cases and enabled the buildings to be designed more safely. [3][5]

In the 2018 Turkish Building Earthquake Code, it is defined as "The case where the Torsional Irregularity Coefficient ηbi, which expresses the ratio of the maximum relative story drift at any story to the average relative drift in the same direction at that story, is greater than 1.2 for any of the two perpendicular earthquake directions".[1]

$$\eta bi \;=\; (\Delta i^{(X)})\mathrm{max} / \;(\Delta i^{(X)})avr \;>\; 1.2 \qquad (1)$$

At the same time, it was emphasized that the calculation of the relative storey drifts, ± 5% additional eccentricity effects should be taken into account in the regulation. [3] In Figure 1, "The torsional irregularity situation" in TBDY 2018 is expressed.

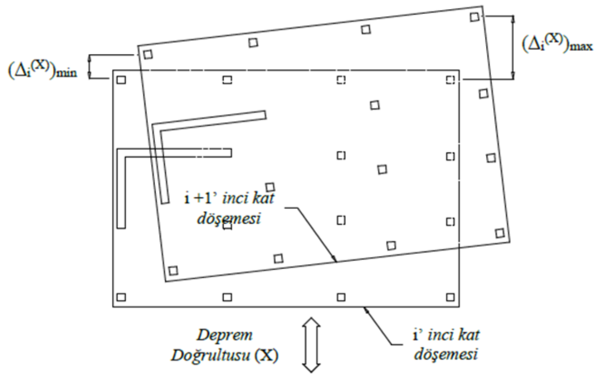

Figure 1. Torsional irregularity condition

$$(\Delta i^{(X)})avr = 1/2[(\Delta i^{(X)}))max + (\Delta i^{(X)})min \qquad (2)$$

$$\eta bi = (\Delta i^{(X)})max/(\Delta i^{(X)})avr \qquad (3)$$

$$\eta bi > 1.2 \qquad (4)$$

2.1.2 A3 Irregularities In The Plan

In TBDY-2018 (Turkish Building Earthquake Code), it is defined as "the situation where both the dimensions of the protruding parts in the two perpendicular directions in the building story plans are greater than 20% of the total plan dimensions of the building in the same directions". [1] In Figure 2, "The case of protrusions in the A3 plan" in TBDY 2018 is shown.

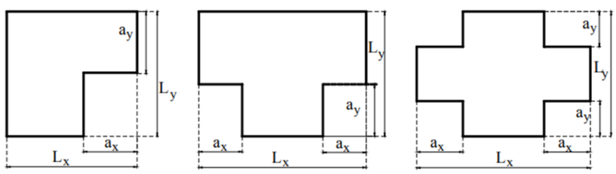

Figure 2. A3 case of protrusions in the plan

There may sometimes be protrusions in the building story plans due to the land form on which the buildings sit or due to the architectural design. These protrusions cause irregularities in the structure. In order to prevent such irregularities, the building form can be made more suitable by arranging the joints appropriately. [6] [7] [8]

2.2 Vertical Irregularities

According to TBDY-2018 (Turkish Building Earthquake Code), vertical irregularities consist of 3 types: B1 strength irregularity between adjacent stories, B2 stiffness irregularity between adjacent stories and B3 discontinuity of vertical elements of the carrier system.

2.2.1 B2 Stiffness Irregularity Between Adjacent Stories (Soft Story)

In TBDY-2018 (Turkish Building Earthquake Code), “For either of two perpendicular earthquake directions, excluding basement stories, the mean relative story drift ratio at any ith story is divided by the average relative story drift ratio at an upper or a lower storey, the Stiffness Irregularity Coefficient ηki". It is defined as “the condition of more than 2.0”.[1]

$$\eta ki = (\Delta i^{(X)}/hi)avr/(\Delta i + 1^{(X)})/hi + 1)avr > 2.0 \quad (5)$$

or

$$\eta ki = (\Delta i^{(X)}/hi)avr/(\Delta i - 1^{(X)})/hi - 1)avr > 2.0$$

For this type of irregularity, the maximum height of the structure in the regulation. 28 m is allowed. In cases where this limit value is exceeded, it is not allowed to use the equivalent earthquake load method as the calculation method. [2]

3. MATERIALS AND METHOD

3.1 Mod Superposition Method

According to TBDY-2018 (Turkish Building Earthquake Code), the maximum values of the response magnitudes in each vibration mode taken into consideration are calculated by the modal calculation method by using the earthquake design spectrum for a given earthquake direction in the mode coupling method. The largest modal behavior magnitudes calculated for enough vibration modes but not simultaneous are then statistically combined to obtain approximate values of the largest behavior sizes. There are two types of mod merge rules. These are Perfect Quadratic Combination (TKB – CQC) and Square Root of Sum of Squares (KTKK – SRSS).

The sum of the base shear force modal effective masses calculated for all modes in both earthquake directions shall not be less than 95% of the total mass of the building. Mods that contribute less than 3% to the build will not be considered. In the three-dimensional calculation, the direction with a sufficient number of vibration modes will be taken into account. [1]

3.2 Displacement and Interstorey Drift

The movement of vertical carrier systems in the x or y direction is called displacement. The displacement of a vertical carrier system element at any Story relative to the vertical carrier system element at an upper or a lower story is called the relative storey drift. In this study, the relative storey drifts of the structures in the x and y directions will be examined separately. In Figure 3, the interstorey drifts occurring at each storey are expressed visually.

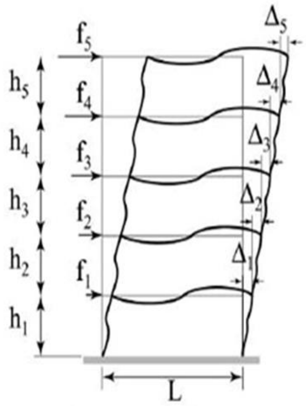

Figure 3. Relative story drift on each story

Earthquake resistant building design is of serious importance for countries like our country, which are affected by thousands of earthquakes every year. Limitations are defined in the 2018 Turkish Building Earthquake Code, which is used in our country, for the relative story offsets. These limitations are of vital importance in terms of protecting the safety of the building. [9]

It is limited to $\Delta \leq 0.02$ in TDY-2007 (Turkish Earthquake Code). However, changes were made in the regulation that entered into force in 2018. In TBDY-2018 (Turkish Building Earthquake Code), these limitations were examined for two different situations, depending on whether the wall is adjacent to the column and whether it is separate. If the walls are adjacent to the column, the limit value has been reduced since it will prevent the vertical carrier systems from making any drifts. The ratio of the structural system behavior coefficient to the building importance factor multiplied by the relative storey drift is called the effective relative storey drift (δ).

$$\delta = (R/I) \times \Delta \quad (6)$$

$$\lambda = DD3 / DD2 \quad (7)$$

Flexible joint between the column and wall;

$$\lambda \times \delta i / hi \leq 0{,}016\, \kappa \quad (8)$$

Lack of flexible joint between the column and wall;

$$\lambda \times \delta i / hi \leq 0{,}008\, \kappa \quad (9)$$

κ value is taken as 1 for reinforced concrete structures and 0,5 for steel structures [1] [4] [10]. In Figure 4, the flexible joint application between the vertical carrier systems and the wall is expressed visually.

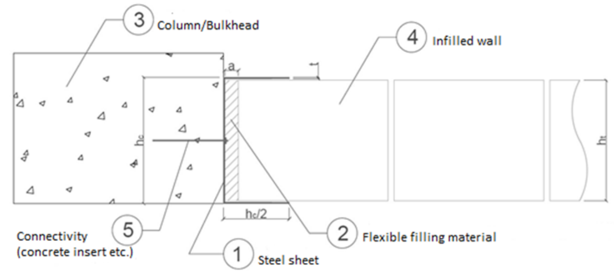

Figure 4. Flexible joint application between vertical carrier systems and the wall [10]

4. NUMERICAL STUDY

The structure examined in the study consists of a reinforced concrete frame system with a total of 5 stories consisting of ground floor and 4 normal stories. The purpose of use of the building is office and residence, and the number of stories has been chosen as 5, since such structures are built with a maximum of 5 stories in Turkey. In the study, a total of 7 different models, namely R type (reference), A type, B type, C type, D type, E type and F type, were examined. At the same time, since it is the most common situation in workplace and residential type buildings, the ground story height of the examined buildings was chosen as 5 m and the other story heights as 3 m. In the study, analyzes were made by choosing the most common ZC soil class in our country. The distances between the axles are 5 m and the width and length of the structure is 30 m. The story system is beamed story running in two directions. Beams are designed as 300mm x 500mm columns 600mm x 60mm. Story thickness is 120mm. C30/37 concrete class was used as concrete material. The structure is in the Izmit region, at latitude 40,760019° and longitude 29,934446°. In this study, the projection ratio in the X-direction plane is shown as Ox, and the projection ratio in the Y-direction plane is shown as Oy. The earthquake level of the building was taken as DD-2. Modeling and analyzes in the study were made with the help of the SAP2000 program. [11] [12] The xy plane view of the analyzed models are given in Figure 5a-5g.

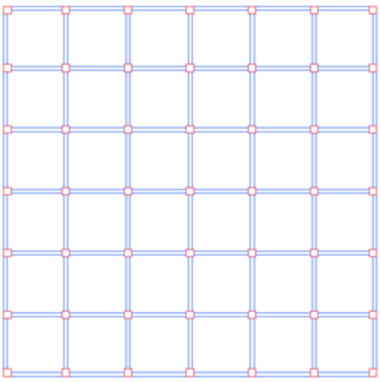

Figure 5a. Type R (Reference) Story Plan
Ox = 0 / Oy = 0

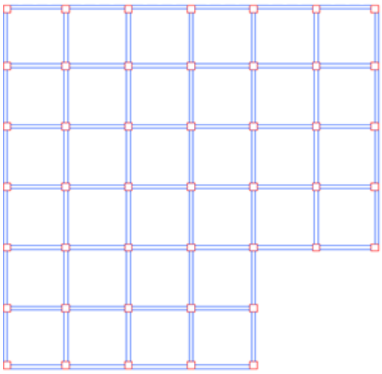

Figure 5b. Type A Story Plan
Ox = 0,33 / Oy = 0,33

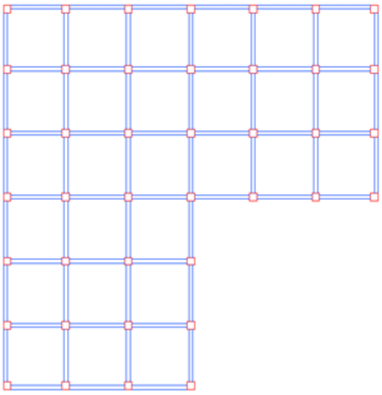

Figure 5c. Type B Story Plan
Ox = 0,50 / Oy = 0,50

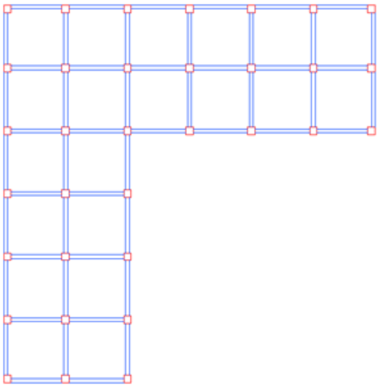

Figure 5d. Type C Story Plan
Ox = 0,67 / Oy = 0,67

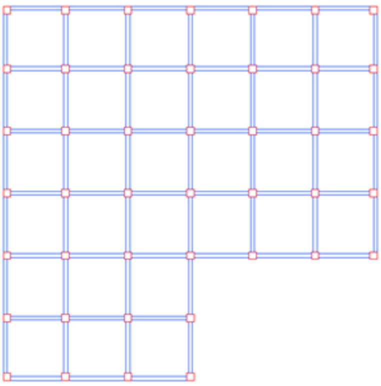

Figure 5e. Type D Story Plan
Ox = 0,50 / Oy = 0,33

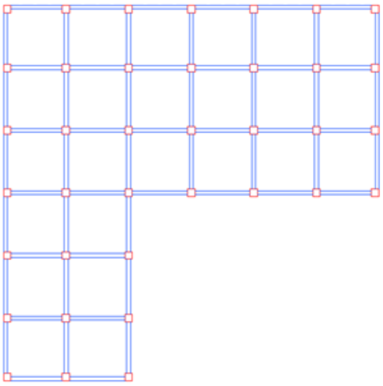

Figure 5f. Type E Story Plan
Ox = 0,67 / Oy = 0,50

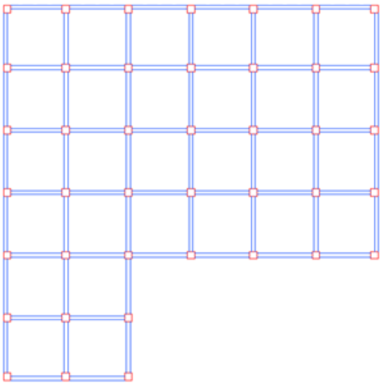

Figure 5g. Type F Story Plan
Ox = 0,67 / Oy = 0,33

5. RESULTS

In Table 1, the drifts made at each story for the 1st and the 2nd mode in the x and y directions of the 7 models analyzed are shown. Ux represents the displacements in the x direction, Uy represents the displacements in the y direction. Units are taken in mm.[13] [14] [15]

Table 1. Displacement of the buildings on each story

		Type R	Type R	Type A	Type A	Type B	Type B	Type C	Type C	Type D	Type D	Type E	Type E	Type F	Type F
	Stories	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy
RX	5	45,61	18,0	44,57	17,35	43,21	16,73	40,16	16,02	44,24	17,10	42,43	16,12	43,95	16,81
RX	4	40,61	16,0	39,67	15,46	38,43	14,90	35,67	14,23	39,37	15,24	37,73	14,34	39,11	14,97
RX	3	33,50	13,2	32,70	12,77	31,66	12,30	29,33	11,71	32,45	12,58	31,07	11,82	32,23	12,36
RX	2	24,31	9,67	23,71	9,29	22,94	8,93	21,2	8,46	23,53	9,15	22,51	8,57	23,37	8,98
RX	1	13,67	5,46	13,31	5,23	12,86	5,01	11,85	4,72	13,21	5,14	12,61	4,8	13,12	5,04
RX	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
RY	5	18,0	45,6	17,35	44,57	16,73	43,21	16,02	40,16	17,14	43,89	16,58	41,35	17,05	42,87
RY	4	16,06	40,6	15,46	39,67	14,9	38,43	14,23	35,67	15,27	39,05	14,76	36,76	15,19	38,12
RY	3	13,28	33,5	12,7	32,7	12,3	31,66	11,71	29,33	12,61	32,18	12,17	30,25	12,55	31,4
RY	2	9,67	24,3	9,29	23,7	8,93	22,94	8,46	21,2	9,17	23,33	8,83	21,89	9,11	22,74
RY	1	5,46	13,6	5,23	13,31	5,01	12,86	4,72	11,85	5,16	13,09	4,94	12,25	5,12	12,74
RY	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

In Figure 6-7, the story drifts of the analyzed models are shown graphically.

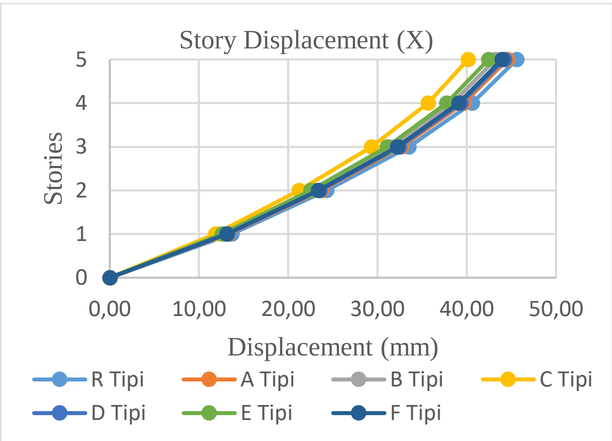

Figure 6. Story drifts of the analyzed seven models (X)

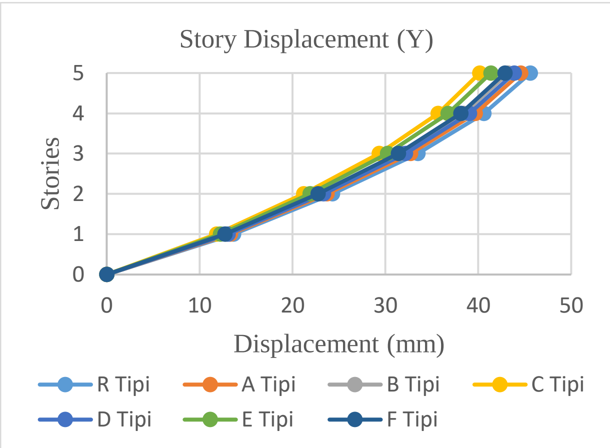

Figure 7. Story drifts of the seven models (Y)

The results of the relative story drifts obtained as a result of the analyzes made with the Mode Combination Method are shown in Table 2. [15] [16]

Table 2. Relative story drifts of the analyzed seven models

		Type R	Type R	Type A	Type A	Type B	Type B	Type C	Type C	Type D	Type D	Type E	Type E	Type F	Type F
	Stories	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy
RX	5	5,00	1,94	4,9	1,89	4,78	1,83	4,49	1,79	4,87	1,86	4,70	1,78	4,84	1,84
RX	4	7,11	2,78	6,97	2,69	6,77	2,60	6,34	2,52	6,92	2,66	6,66	2,52	6,88	2,61
RX	3	9,19	3,61	8,99	3,48	8,72	3,37	8,13	3,25	8,92	3,43	8,56	3,25	8,86	3,38
RX	2	10,64	4,21	10,4	4,06	10,08	3,92	9,35	3,74	10,32	4,01	9,90	3,77	10,25	3,94
RX	1	13,67	5,46	13,31	5,23	12,86	5,01	11,85	4,72	13,21	5,14	12,61	4,80	13,12	5,04
RX	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
RY	5	1,94	5,00	1,89	4,9	1,83	4,78	1,79	4,49	1,87	4,84	1,82	4,59	1,86	4,75
RY	4	2,78	7,11	2,69	6,97	2,60	6,77	2,52	6,34	2,66	6,87	2,59	6,51	2,64	6,72
RY	3	3,61	9,19	3,48	8,99	3,37	8,72	3,25	8,13	3,44	8,85	3,34	8,36	3,44	8,66
RY	2	4,21	10,64	4,06	10,4	3,92	10,08	3,74	9,35	4,01	10,24	3,89	9,64	3,99	10,00
RY	1	5,46	13,67	5,23	13,31	5,01	12,86	4,72	11,85	5,16	13,09	4,94	12,25	5,12	12,74
RY	0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

In Figure 8-9, the interstorey drifts of the seven models analyzed according to the storeys are given in a table.

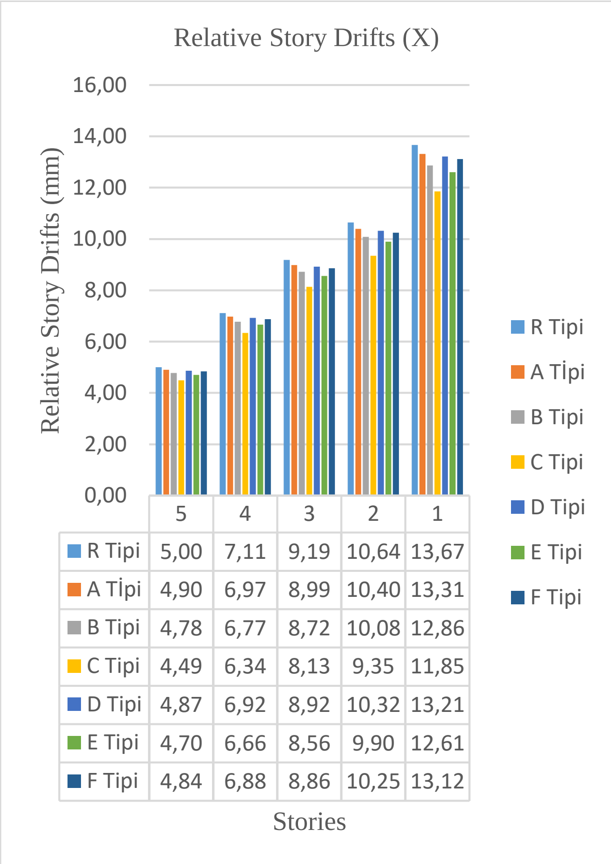

Figure 8. Interstorey drifts of the seven models (X)

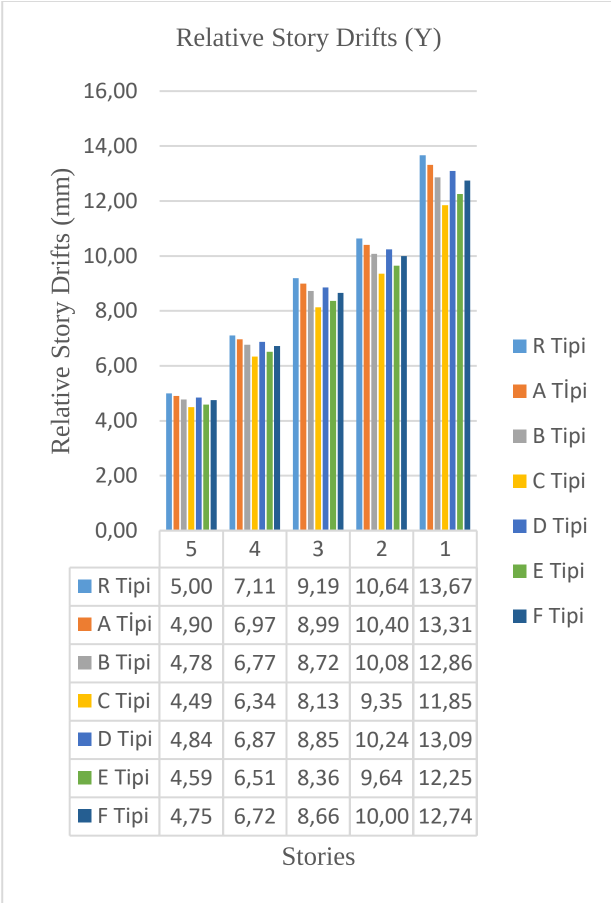

Figure 9. Interstorey drifts of the seven models (Y)

4. CONCLUSION

Since the R, A, B and C type models are symmetrical in plan in x and y directions in terms of projection ratio, it is observed that the storey drifts occurring in the x and y directions are the same.

In the R, A, B and C type models, it was observed that the peak displacement decreases due to the decrease in the structure weight as the A3 irregularity type coefficients Ox (ax/Lx) and Oy (ay/Ly) increase. It is seen that the coefficient of irregularity increased by 50 % between the type A model and the type B model, while the story drift decreased by 3.14 %. Similarly, between the A type and C type models, although the irregularity coefficient increased by 100 %, the story drift decreased by 9.9 %.

When the E and F type models are compared, the coefficient of A3 irregularity type in the x direction is the same, and the A3 irregularity type coefficient in the y direction Oy Considering that it is 0.50 in the E type and 0,33 in the F type, it is seen that the peak displacement in the F type model is higher than the peak displacement in the E type model has been observed. It is seen that while the irregularity coefficient decreased by 34% between the type E model and the type F model, the story drift decreased by 2.45%.

When the D and F type models are compared, the coefficient of irregularity type Oy in the y direction is the same for both models, and the coefficient of irregularity type Oy in the x direction is Ox, 0.50 in the D type model and 0.67 in the F type model, the displacement value at the apex is in the F type observed to be less. It is seen that the coefficient of irregularity between the type D model and the type F model increased by 34%, while the story drift decreased by 2.32%.

When the results obtained in the study are examined, it is observed that the structure period decreases as the A3 type irregularity coefficient increases. It is seen that the period value decreased by 1.05% despite the 50% increase in the irregularity coefficient between the type A model and the type B model. Moreover; It is seen that the period value decreased by 2.84%, despite the 100% increase in the irregularity coefficient between the type A and type C models.

On the other hand; As the structure weight decreases, the result is that the structure period decreases. For example, between the type R model and the type A model, although the structure weight decreases by 11.11%, the period value decreases by 0.73%. Similarly; Between type R and type A models, the structure weight decreases by 16.67%, whereas the period value decreases by 1.05%.

Regardless of whether the structure is symmetrical or asymmetrical in terms of projection ratio in plan, it is understood that the apex displacement of the structure decreases due to the increase in the A3 type irregularity coefficient (Ox and Oy) and accordingly the decrease in the weight of the structure. In this respect, it was seen that the decrease in the weight of the structures over the displacements of the structures was more decisive than the increase in the A3 type irregularity coefficient (Ox and Oy). It has been observed that the increase in the A3 type irregularity coefficient and the decrease in the structure weight are serious factors in the decrease in the structure period.

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