Dicle University
Journal of Engineering
https://dergipark.org.tr/tr/pub/dumf
duje.dicle.edu.tr

Araştırma Makalesi / Research Article

Asma katın neden olduğu döşeme süreksizliklerinin yapısal performans üzerine etkisi

The effect of slab discontınuıtıes on structural performance caused by mezzanine

Ercan IŞIK[1], İbrahim Baran KARAŞİN[2*], Mehmet Emin ÖNCÜ[2]

[1] Bitlis Eren University, Department of Civil Engineering, Bitlis, eisik@beu.edu.tr, ORCID ID: 0000-0001-8057-065X
[2] Dicle University, Department of Civil Engineering, Diyarbakır, baran.karasin@dicle.edu.tr, ORCID ID: 0000-0001-5990-1215
[3] Dicle University, Deparment of Civil Engineering, Diyarbakır, oncume@dicle.edu.tr, ORCID ID: 0000-0001-6434-293X

MAKALE BİLGİLERİ

Makale Geçmişi:
Geliş 10 Aralık 2021
Revizyon 20 Ocak 2022
Kabul 3 Mart 2022
Online 30 Mart 2022

Anahtar kelimeler: Asma kat; pushover; öz değer; döşeme süreksizliği; düzensizlik

ÖZ

Döşemelerde, asma kat gibi çeşitli nedenlerden dolayı süreksizlik oluşabilir. Ülkemizde asma kat yaygın olarak kullanılmaktadır. Bu çalışmada, tek ve iki yönde oluşturulan asma kat için öz değer ve statik itme analizleri yapılmıştır. Toplam altı farklı bina modeli hem X hem de Y yönü için ayrı ayrı analizler yapılmıştır. Tüm yapısal modellerde farklı performans seviyeleri için; periyotlar, etkili kütle katılım oranları, taban kesme kuvveti, elastik ve etkili rijitlik ve hedef yer değiştirme elde edilmiştir. Tüm değerlerin karşılaştırılması ve sonuçların yorumlanmasından sonra öneriler yapılmıştır. Yapıda kullanılacak asma kat nedeniyle döşeme süreksizlikleri ve yapı içerisinde kat yüksekliklerinin farklılaşması, bina savunma mekanizmasını zayıflatan riskler olarak ortaya çıkmaktadır. Çalışma, İki farklı olumsuzluk değişkeninin etkileşimini ortaya koymak ve yaygın olarak kullanılan asma kat seviyelerinin yapısal deprem davranışı üzerindeki etkisini ortaya koymak adına önemlidir.

ARTICLE INFO

Article history:
Received 10 December 2021
Revised 20 January 2022
Accepted 3 March 2022
Available Online 30 March 2022

Keywords:Mezzanine; pushover; eigen value; slab discontinuity; irregularity

Doi: 10.24012/dumf.1080070

* Sorumlu yazar / Correspondence

ABSTRACT

Slabs may contain discontinuity due to various reasons such as mezzanine. Mezzanine are widely used in our country. In this study, eigen value and static pushover analyses were made for mezzanine formed by one and two direction. Totally six different structural models were analysed separately for both X and Y direction. The periods, effective mass participation ratios, base shear force, elastic and effective rigidity and target displacement for different performance level were obtained for all structural models. Suggestions were made after comparison of all values and the interpretation of the results. The slab discontinuities and the differentiation of story heights in the building due to the mezzanine appear as risks that weaken the building defence mechanism. The study is important on behalf of asserting the interaction of two different negativity variables and revealing the effect of commonly used mezzanine levels on the structural earthquake behaviour.

1 Introduction

Earthquake performance can be defined as "building safety status determined according to the level and distribution of potential damages in a building under the influence of a certain earthquake" [1-3]. There are many parameters that may affect the earthquake performance of buildings negatively. These parameters are also found in the seismic design codes. The damage caused by the past earthquakes reveals the importance of the unfavourable parameters of the buildings. Parameters such as vertical/horizontal discontinuity, irregularity in plan, material quality, short column, stiffness/strength difference between stories and hill/slope effects weaken the earthquake defence mechanisms and decrease the earthquake performance of the structures [4-13]. These parameters in the structure should be avoided as much as possible. For this reason, if these parameters are required, special measures should be taken to improve the performance of the structure. Knowing the parameters that reduce the earthquake performances in the structural analysis will gain meaning in the operations that will be carried out at the design stage. Buildings that have been inattentive during the design and construction will naturally increase the amount of damage if combined with negativity parameters. Sufficient stiffness, strength, continuity, and ductility are the leading principles considered in the design of buildings under earthquake impact. The continuity of the structural system elements in the buildings is one of the general principles of earthquake-resistant building design. The continuity of the structural system elements provides the loads affecting the structures to transfer easily and without entanglement within the structure. In the case of discontinuity, the loads enter a difficult transfer process up to the ground by finding their way through the labyrinth shape. Nevertheless, because of several reasons, there may be interruptions in the structural elements. In such cases, it is not possible to refer to continuity. The discontinuity of the structural elements is one of the factors that will negatively affect the earthquake performance of the structure. This discontinuity is observed in the horizontal and/or vertical elements. One of these discontinuities is slab discontinuity. Slabs can be interrupted in any floor for different reasons. One of the factors causing the discontinuity of the slab is the mezzanine.

In the studies on slab discontinuity, different structural models and different gaps were taken into account and the results were compared. Khurram (2018), examined the effect of beam and slab discontinuity on structural behavior in reinforced-concrete (RC) buildings on ten different structural models for a 5-storey RC structure [14]. Tekdal (2008), investigated the effects of slab discontinuities on RC framed structures with different types of discontinuities under earthquake loads. The models have changed according to the void ratio in the slabs and whether the voids are symmetrical in the plan or not [15]. Ayrancı (2004), carried out earthquake structural analyzes of 2 types of building samples with 3 different computer modelling approaches for the case of large slab irregularities [16]. Yedikardeş (2010), investigated the case of A2 irregularity (slab discontinuity) with sheared structures and the effect of shear placement to correct this situation [17]. Özdemir (2005), made structural analyzes by changing the gap rate and their location in RC buildings with A2-slab discontinuity [18]. Öztürk (2013), compared the behavior of RC buildings with slab gaps at certain rates under earthquake loads, taking into account the earthquake codes of Turkey and different countries [19]. Terzi and Elçi (2006), compared the effect of slab discontinuity on section effects in RC structures under different slab assumptions [20]. Sağlıyan and Yön (2018), examined the effect of multi-story RC structures with slab discontinuity in plan on earthquake behavior for six different structural models using incremental dynamic analysis method [21].

In this study, the discontinuity of the slab due to the mezzanine was examined. A reference RC building was selected to determine the effects of slab discontinuity. Earthquake performances of all models were obtained by considering six different structural models. The existing structures with mezzanine were examined on-site and models were created. The mezzanine models which cause discontinuity of single or double sides are considered principally. The heights of the stories can be different or have same values in buildings with mezzanines. As part of this study, the first group models were selected by taking the story height equal in buildings model. In the second group models, we selected the ground and mezzanine story height was different and the other story heights were equal. Since the mezzanine are generally used in commercial buildings, the height of the ground story can be different from the mezzanine height. For this reason, the analyses for the second group of models were carried out separately for both directions in order to reflect the results more accurately. All calculated values related to earthquake performance were compared. The obtained results were compared with the building values chosen as reference without any mezzanine and the suggestions were made. In addition, information about the concept of mezzanine is also given in the study. The fact that the models considered in the study were made in practice increases the value of the study. In addition, the differentiation of the story heights and the presence of the mezzanine together develop as a difference from the other studies.

2 Mezzanine and Slab Discontinuities

The two main components of the studies conducted to estimate the impact of earthquake disaster are the determination of earthquake hazard and determination of the vulnerability of the building systems. Vulnerability of structural systems is generally possible by examining the existing building stock and other construction structures, classifying them and obtaining the damage potential curves [22-28]. In some regions, mezzanine has an extensive usage and is one of the building stock properties for the region. Mezzanines are commonly used in the ground stories that are used especially for commercial purposes. Mezzanine is formed as a result of the differences of the story dimensions in the plan for two adjacent stories. It is generally used between the ground story and an upper story. In some cases, it may take smaller values than other story heights. A connection is made between two stories with the usage of a stair. It can be used in different models, areas and for purposes. Mezzanine, half story or penthouse is used for different purposes. In general, it is thought to obtain efficiency by using the available space in the most optimum way. The area of use is highly increased in commercial enterprises especially. The use of mezzanine causes discontinuity of the slab in the structure. The discontinuity of the slab on any story for various reasons within the structural system is caused by the discontinuity of the slab. Slab discontinuities are expressed as A2 irregularity situation in Turkey Building Earthquake Code (TBEC-2018) [29]. In this case three different situations are taken into consideration. Slab discontinuity patterns of these three cases are shown in Figure 1.

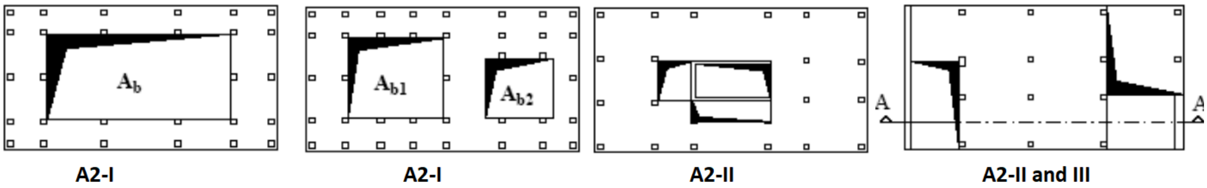

Figure 1. Slab discontinuity patterns [29]

In this study, a mezzanine was formed between the ground story and an upper story of the building. Some of the slabs in the story were removed from the structural system. Two different types of mezzanine were selected, and story height irregularity was revealed. Single and double-sided slab discontinuities due to the mezzanine are considered separately. Eigenvalue analysis and pushover analysis were performed separately for all structural models considered in this study.

Eigen Value Analysis

Mode shapes and natural frequency for any kind of structure can be obtained by eigenvalue analysis. Material properties remain constant throughout the calculation. Briefly, it can be evaluated as pure elastic structure analysis. It can be expressed by material cross-sectional properties such as cross-section, torsion constant, and moment of inertia, module of elasticity and module of stiffness. Structure-related modal period, frequency, modal participation factors, effective modal masses and their percentage values can be achieved by eigenvalue analysis [30-35].

Static Pushover Analysis

Pushover analysis is a common approach for determining seismic demand in building designs and evaluations. The pushover curve is evaluated from the static multiplier obtained by the application of the theorem of virtual works while considering kinematic varied configurations of the mechanism under study in large displacements. The contribution of links is taken into account along this incremental kinematic analysis until the ultimate equilibrium condition. The displacement capacity for each contribution is a threshold considered as a performance level of the system. Pushover analysis is frequently utilized to predict nonlinear behavior of structural systems. In addition to this it is a static-nonlinear analysis method where a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern that continuously increases through elastic and inelastic behavior so that an ultimate condition is reached. Lateral load may represent the range of base shear induced by earthquake loading and its configuration may be proportional to the distribution of mass along building height, mode shapes or other practical effects. A capacity curve obtained from pushover analysis represents the relationship between the base shear force and the displacement of the roof. The base shear is normalized by building seismic weight while the roof level displacement is normalized by building height to represent the shear strength coefficient and roof displacement drift respectively [36-43].

Properties of the Sample Building Models

As part of this study, a 5-story RC building was selected. Seismostruct software was used for the numerical analysis in this study for all models [32]. The importance class of building was selected as II and damping ratio of 5% value was taken into consideration in all building models. C25 was used for concrete grade and for rebars S420 grade was used as material for all structural models. All columns were selected as 300*400 mm and all beams were selected as 250*500 mm. The transverse reinforcements were used in both elements as Φ10/100. The cross secitons of columns and beams used in the sample RC building are shown in Figure 2. These values are taken as constant in the analyses of all structural models.

Figure 2. The cross-sections of columns and beams

Force-based plastic hinge frame elements (infrmFBPH) were selected for columns and beams in all structural models. These frame elements model the spread inelasticity based on force and only limit the plasticity to a finite length. The ideal number of fibers in the cross section should be sufficient to model the stress–strain distribution in the cross section [30, 32]. In total, 100 fiber elements are defined for the selected sections. This value is sufficient for such sections. Plastic-hinge length (Lp/L) was selected as 16.67%. Permanent and incremental loads were applied to the building model. The target displacement was selected as 0.50 m. All these values were taken as the same in all models. The target displacement was selected as 0.50 m. All these values were taken as the same in all structural models.

The first variable was the presence of the mezzanine. Separate models were created for slab discontinuity due to the single or double direction mezzanine. In order to practice necessary controls a building which shows discontinuity was chosen. Slab discontinuities considered for single or double directions are shown in Figure 3.

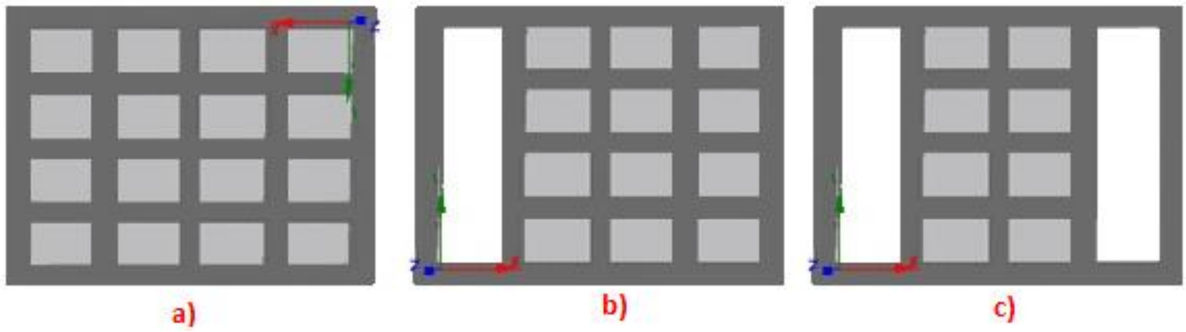

Figure 3. Slab discontinuities; a) No discontinuities, b) unidirectional discontinuity, c) bidirectional discontinuity

The 3D models obtained by the software within the study are given in Figure 4.

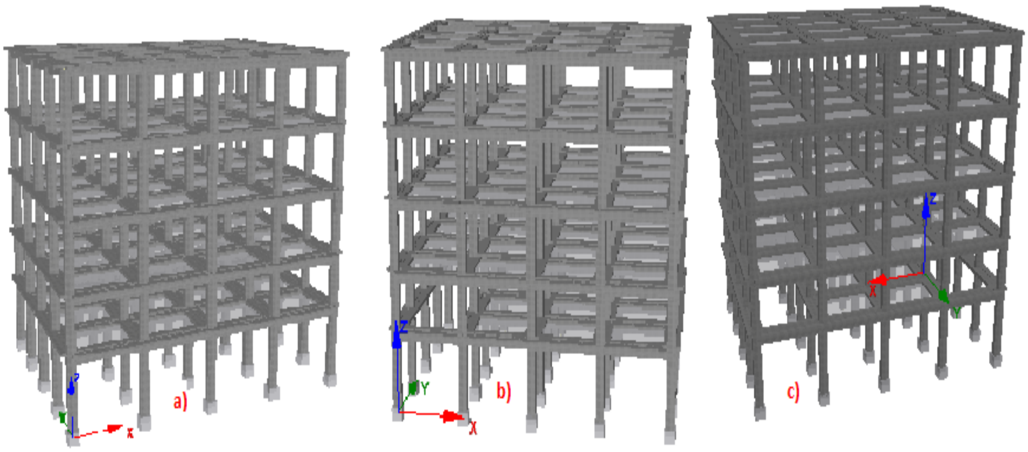

Figure 4. 3D structural models a) reference, b) unidirectional discontinuity, c) bidirectional discontinuity

The blueprint of the reference building model that does not include any slab discontinuity is shown in Figure 5.

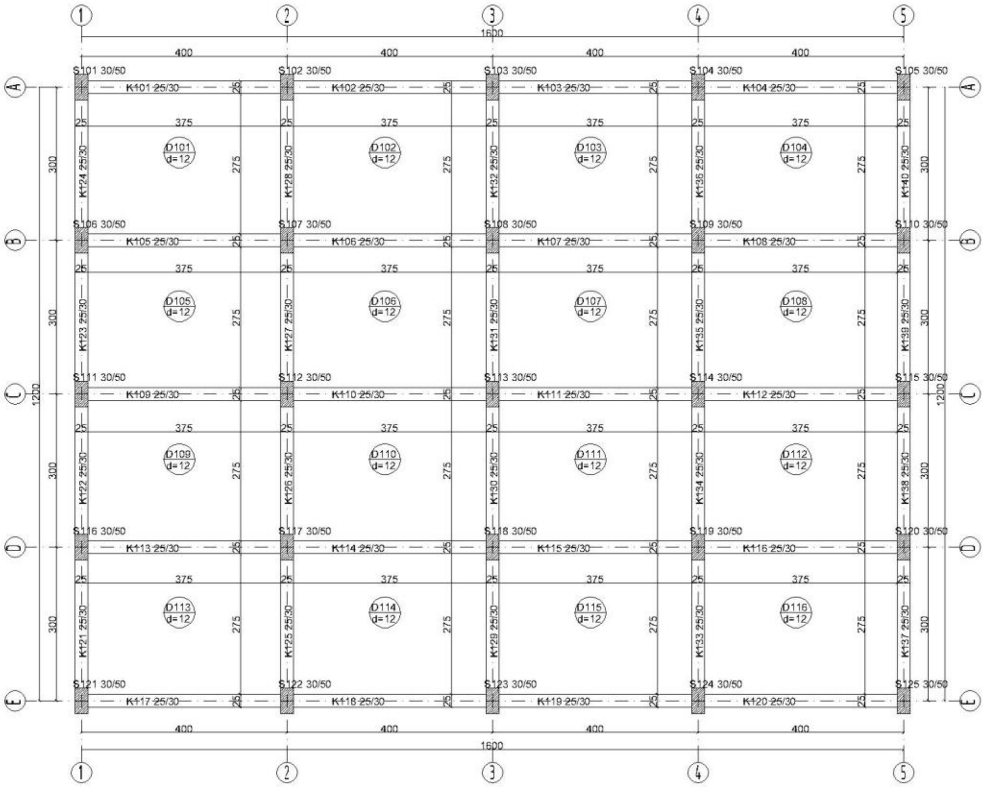

Figure 5. The blueprint of the reference building without slab discontinuity

The blueprint of the model used in case of a discontinuity of slab on one side of the building on the gorund story due to the mezzanine is shown in Figure 6.

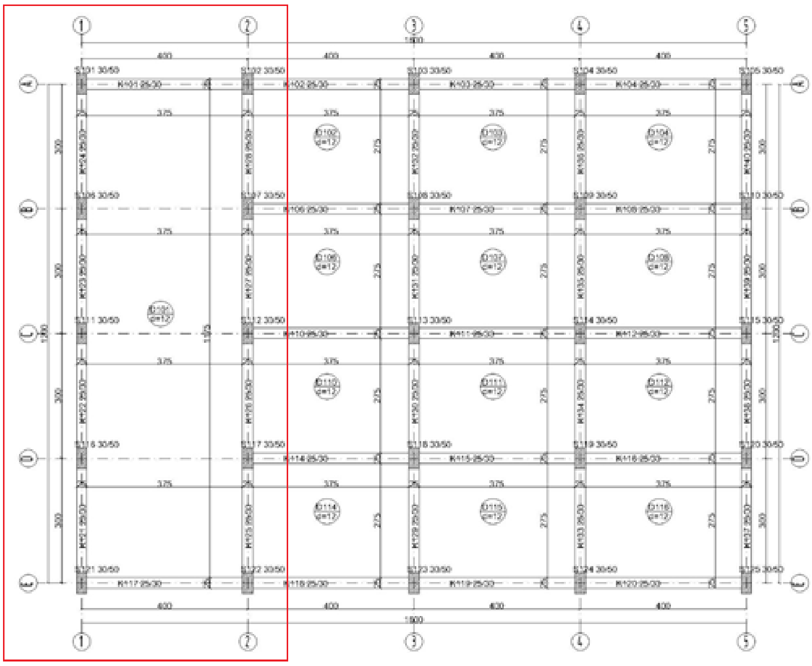

Figure 6. The blueprint of model for single-sided slab discontinuity in case of mezzanine

There is a discontinuity of slab in double-sided due to the mezzanine level in the third case of the study. The blueprint of the model for this situation is given in Figure 7.

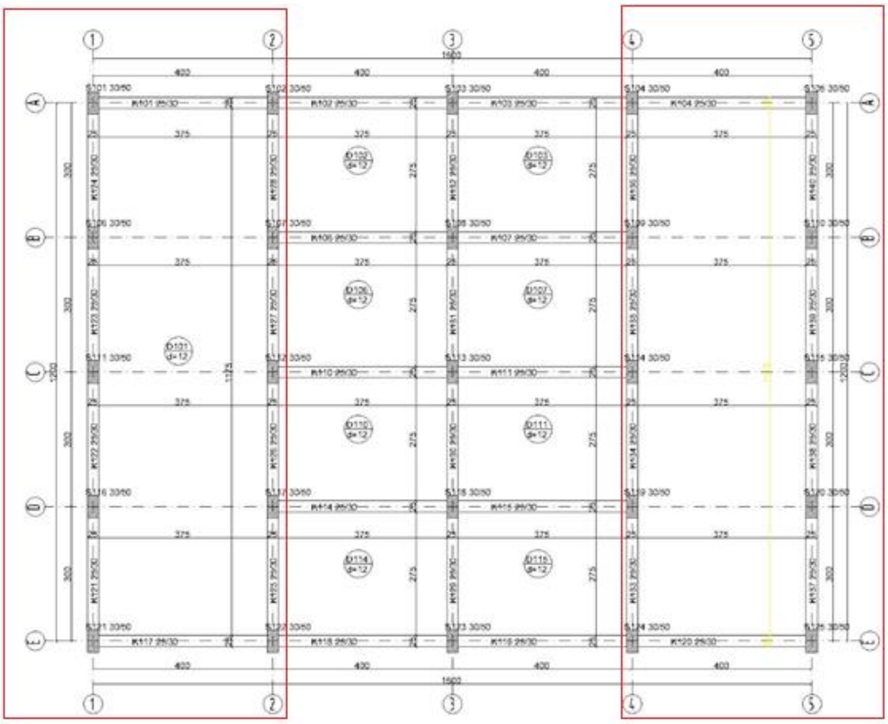

Figure 7 The blueprint of the model which discontinuity of double-sided slab

One of the variable parameters within the scope of the study in order to assert this difference is the height of the ground story. 2D models of the buildings in which the ground and other story heights are measured as 3m and equally in the entire structure are given in Figure 8.

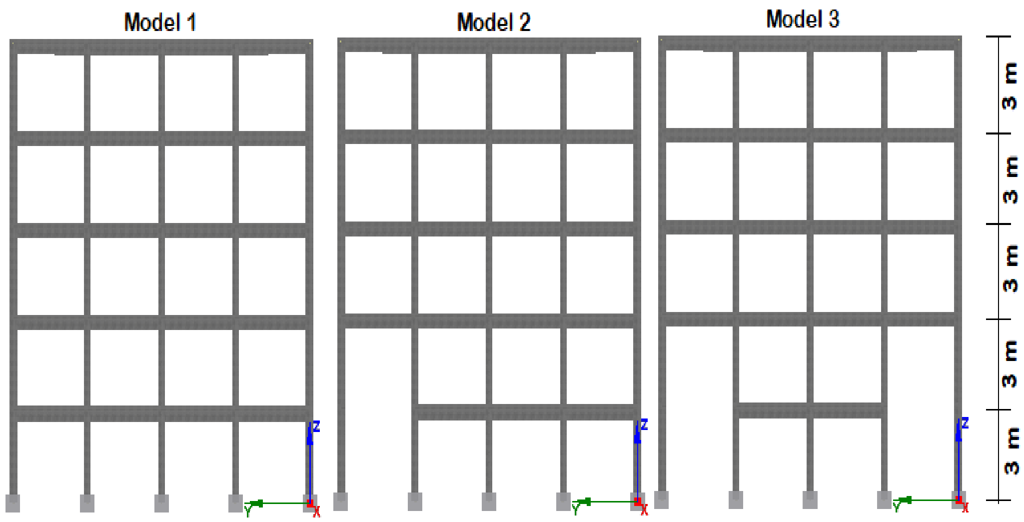

Figure 8. 2D models where all story heights are equal

The 2D models obtained in case the ground story height is 3.5m and the mezzanine height is 2.5m are given in Figure 9.

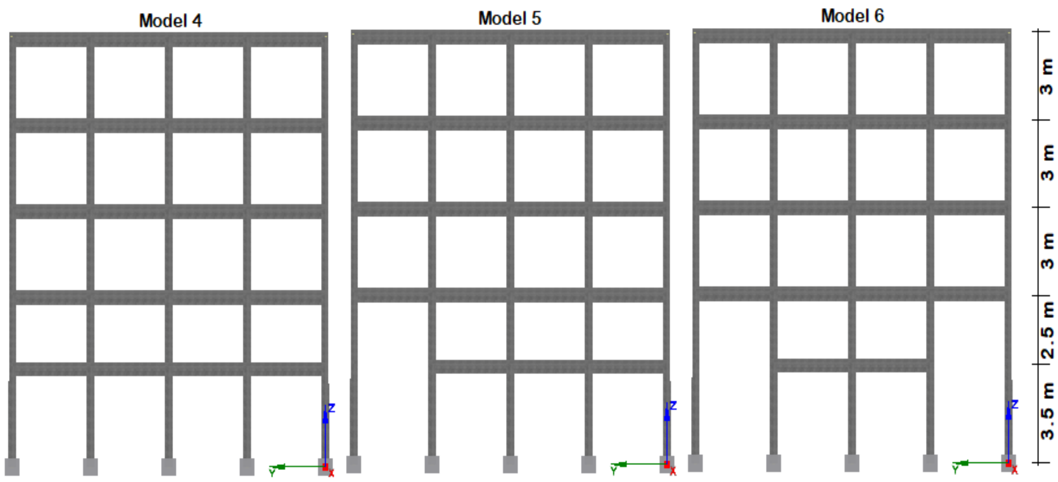

Figure 9. 2D models for different ground and mezzanine heights

Totally six structural models were considered in this study. Single and double-sided slab discontinuity due to the mezzanine, and ground story and mezzanine heights were taken into account for the variables. Information on all models considered in this study is shown in the Table 1. Apart from that all other parameters are kept constant for all structural models.

Table 1 The variables in structure models considered in the study

Model No	Discontinuity	Story Height (m)		
		Ground Story	Mezzanine	Other Stories
1	None	3	3	3
2	Unidirectional	3	3	3
3	Bidirectional	3	3	3
4	None	3.5	2.5	3
5	Unidirectional	3.5	2.5	3
6	Bidirectional	3.5	2.5	3

Analysis Results

The natural fundamental periods of structural models were obtained from the eigenvalue analysis and comparisons of these are shown in the Table 2.

Table 2 Comparison of natural fundamental periods of structural models

Model	Period (sec)					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	0.441	0.4415	0.4411	0.4536	0.4528	0.4521
2	0.355	0.3568	0.3582	0.3605	0.3620	0.3635
3	0.319	0.3274	0.3372	0.3215	0.3300	0.3401
4	0.148	0.1479	0.1471	0.1587	0.1573	0.1559
5	0.118	0.1177	0.1175	0.1248	0.1242	0.1235
6	0.104	0.1051	0.1063	0.1095	0.1101	0.1108
7	0.091	0.0901	0.0892	0.0920	0.0914	0.0908
8	0.068	0.0707	0.0698	0.0653	0.0717	0.0712
9	0.060	0.0679	0.0680	0.0618	0.0651	0.0650
10	0.058	0.0598	0.0594	0.0534	0.0614	0.0609

As the amount of gap in the story increased, the natural fundamental period of the structure increased and this reduces the rigidity of the structure. At the same time, when the story height is different in the building, the rigidity of the building decreases and the period of the building is obtained higher according to this. These two main factors are an indicator that these irregularities in the structure will negatively affect the earthquake performance of the structure. The comparison of the cumulative effective mass participation ratios obtained for the first ten modes for the structural models where all the heights are the same in the building is given in Table 3.

Table 3 Cumulative effective mass participation ratios (%)

Mod	UX			UY			RX			RY		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
1	0.00	0.00	0.00	86.14	86.54	86.95	9.35	9.09	8.83	0.00	0.00	0.00
2	0.00	0.00	0.00	86.14	86.54	86.95	9.35	9.09	8.83	0.00	0.00	0.00
3	84.09	85.46	86.85	86.14	86.54	86.95	9.35	9.09	8.83	8.10	7.46	6.80
4	84.09	85.46	86.85	95.84	95.87	95.90	48.05	47.41	46.71	8.10	7.46	6.80
5	84.09	85.46	86.85	95.84	95.87	95.90	48.05	47.41	46.71	8.10	7.46	6.80
6	94.38	94.65	94.94	95.84	95.87	95.90	48.05	47.41	46.71	36.28	36.16	36.04
7	94.38	94.65	94.94	98.73	98.64	98.54	50.93	50.20	49.40	36.28	36.16	36.04
8	94.38	94.65	94.94	99.76	98.76	98.54	54.32	50.63	49.40	36.28	36.16	36.04
9	97.99	94.65	94.94	99.76	99.67	99.56	54.32	53.63	52.86	38.39	36.16	36.04
10	97.99	97.83	97.68	100.0	99.67	99.56	54.58	53.63	52.86	38.39	38.04	37.67

The comparison of cumulative effective mass participation ratios obtained where the height of the ground story and mezzanine is different from the other stories in the building is given in Table 4.

Table 4. Cumulative effective mass participation ratios where stories heights are different

Mod	UX			UY			RX			RY		
	Model 4	Model 5	Model 6	Model 4	Model 5	Model 6	Model 4	Model 5	Model 6	Model 4	Model 5	Model 6
1	0.00	0.00	0.00	90.60	90.78	90.96	7.03	6.92	6.81	0.00	0.00	0.00
2	0.00	0.00	0.00	90.60	90.78	90.96	7.03	6.93	6.81	0.00	0.00	0.00
3	87.72	88.81	89.90	90.60	90.78	90.96	7.03	6.93	6.81	6.68	6.19	5.68
4	87.72	88.81	89.90	98.78	98.76	98.73	50.32	49.75	49.17	6.68	6.19	5.68
5	87.72	88.81	89.90	98.78	98.76	98.73	50.32	49.77	49.17	6.68	6.19	5.68
6	97.74	97.72	97.71	98.78	98.76	98.73	50.32	49.77	49.17	38.06	37.86	37.64
7	97.74	97.72	97.71	99.66	99.64	99.62	51.03	50.50	49.93	38.06	37.86	37.64
8	97.74	97.72	97.71	99.81	99.64	99.62	52.52	50.51	49.93	38.06	37.86	37.64
9	99.33	97.72	97.71	99.81	99.80	99.78	52.52	51.99	51.43	38.78	37.86	37.64
10	99.33	99.22	99.12	100.00	99.80	99.78	53.43	51.99	51.43	38.78	38.57	38.32

Base shear forces for each structural model were obtained separately for both directions. Values were obtained for three different points on the idealized curve as displacement values. Eurocode-8 [44] was used to obtain these values. The first value refers to displacement at the moment of yield (d_y), the second value refers to intermediate (d_{int}) and the third value refers to the target displacement. Elastic stiffness

($K_{\_elas}$) and effective stiffness ($K_{\_eff}$) values were also calculated separately for all models directly using the stiffness reduction coefficients predicted in the software according to Eurocode-8. In the structural analysis, the limit states given in Eurocode-8 (Part 3) [44, 45] were taken into consideration for damage estimation used worldwide. The limit states for damage estimation are presented in Figure 10, according to Eurocode-8.

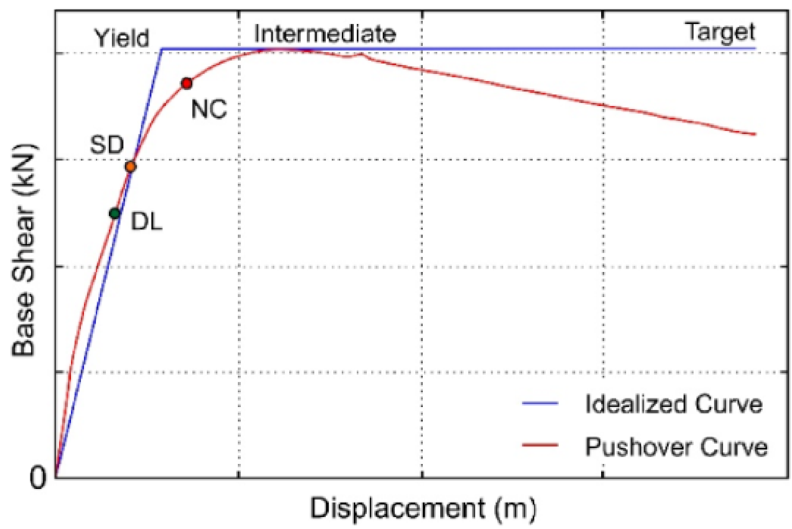

Figure 10. Limit states in Eurocode 8.

Three different cases are stated for the damage cases in the software. These are considered as near collapse (NC), significant damage (SD) and damage limitation (DL). These values are calculated for all the structural models. The comparison of all values obtained in X direction as a result of structural analyses is given in the Table 5. The comparison of the values obtained for Y direction is given in the Table 6.

Table 5 Comparison of values obtained in X direction

Model	Base Shear (kN)	Displacement (m)	K_elas	K-eff	DL	SD	NC
1	5785.73	0.0865 0.1500 0.4908	115972.02	66898.56	0.0274	0.0352	0.0609
2	5574.43	0.0898 0.2001 0.4983	109779.06	62078.1	0.0283	0.0364	0.0631
3	5198.32	0.0900 0.1901 0.0500	101700.05	57772.62	0.0293	0.0376	0.0652
4	4938.45	0.0732 0.1400 0.5005	113070.61	67491.03	0.0279	0.0358	0.062
5	4905.19	0.0779 0.1500 0.5007	106654.05	60942.61	0.0287363	0.0368638	0.0639089
6	4778.16	0.0843 0.1900 0.5001	99158.61	56671.62	0.0300913	0.0386021	0.0669224

Table 6 Comparison of values obtained in Y direction

Model	Base Shear (kN)	Displacement (m)	K_elas	K-eff	DL	SD	NC
1	2956.02	0.0838 0.1300 0.5000	69963.64	35283.14	0.0381	0.0488	0.0847
2	2949.56	0.0841 0.1397 0.5007	69789.2	35072.9	0.038	0.0488	0.0846
3	2943.64	0.0844 0.1400 0.5008	69482.88	34858.26	0.0378	0.0486	0.0842
4	2486.51	0.0717 0.12 0.5	64064.81	34660.94	0.0393	0.0504	0.0875
5	2481.9	0.0721 0.1198 0.5007	63952.97	34445.71	0.0393	0.0504	0.0873
6	2477.23	0.0724 0.12 0.5000	63466.31	34232.76	0.039	0.05	0.0867

In addition, load factors for X and Y directions were obtained for each model in the study. The load factor λ cannot be controlled by the user directly. Instead it is automatically calculated by the program. $P_i = \lambda_i P_0$ is applied in a certain "i" increment and at the same time the load vector corresponding to the controlled joint reaching the target displacement in that increment. The comparison of the load factors obtained is given in the Table 7.

Table 7 Comparison of maximum load factors

Model	Load Factor	
	X	Y
1	578.573	295.601
2	557.577	294.956
3	519.832	294.364
4	493.847	248.652
5	490.520	248.190
6	474.820	247.724

The comparison of the pushover curves obtained in X direction is shown in Figure 11 and in Y direction is shown in Figure 12.

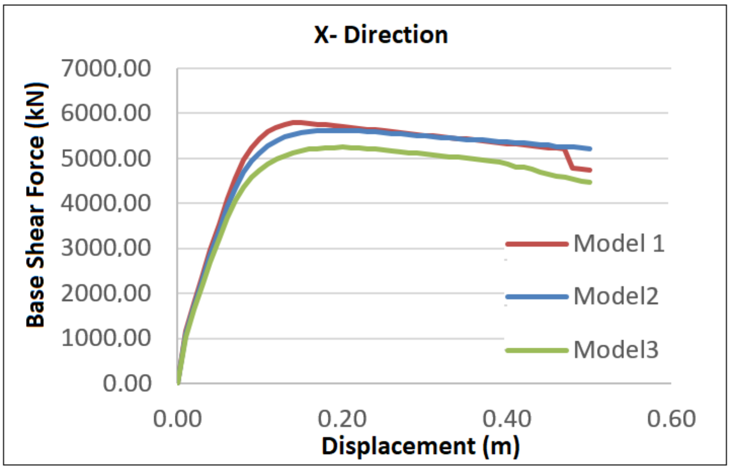

Figure 11 Comparison of pushover curves in X direction

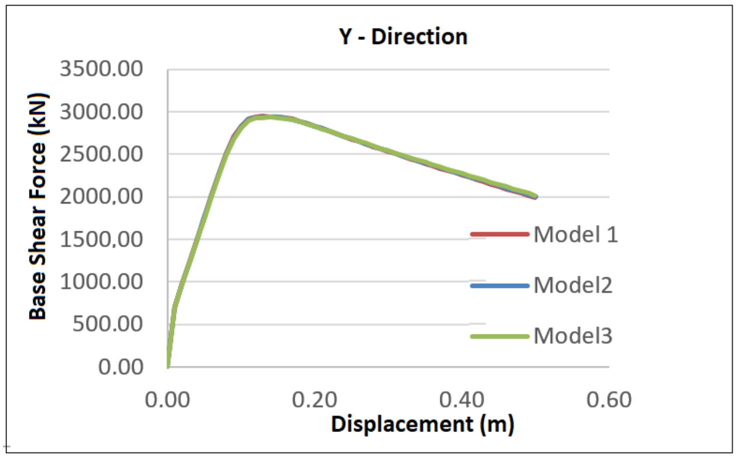

Figure 12 Comparison of pushover curves in Y direction

The comparison of the results where the heights of the story's in the building are the same and different is also obtained. In this comparison, the models created for none-discontinuity, unidirectional and bidirectional discontinuity were compared among themselves. Model 1 and Model 4 that were selected as reference; Model 2 with single-sided slab discontinuity due to mezzanine, and Model 3 with double-sided slab discontinuity cases due to mezzanine were compared between each other. X and Y directions were taken into consideration separately while making these comparisons. The comparison of the pushover curves obtained for X direction is shown in Figure 13. The comparison of the pushover curves obtained for the models between each other in the Y direction is shown in Figure 14.

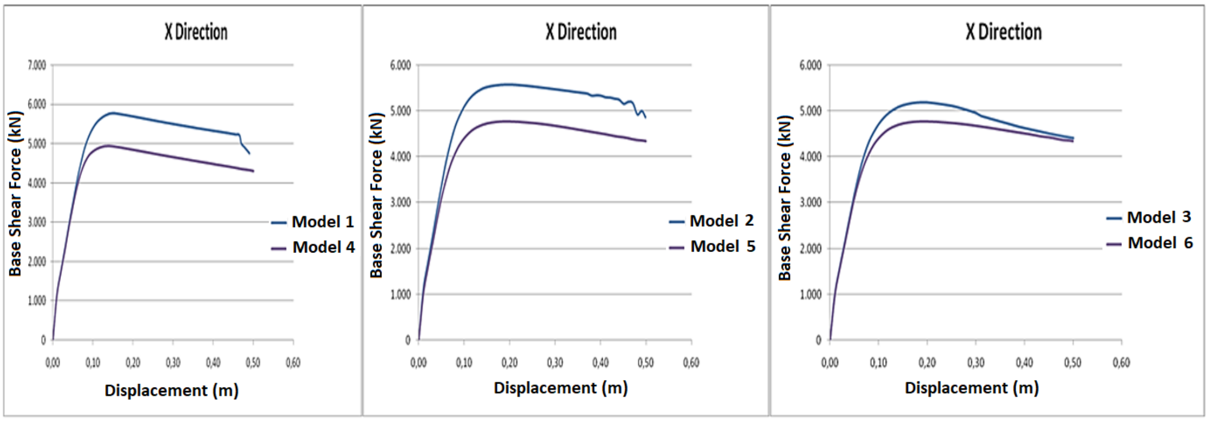

Figure 13. The comparison of models between each other in X-direction

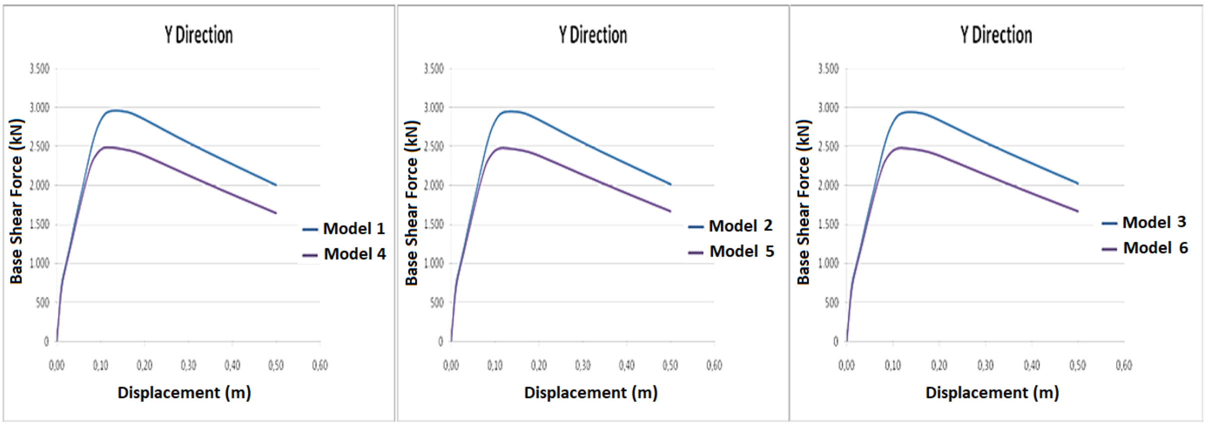

Figure 14. The comparison of models between each other in Y-direction

The comparison of the first damage occurring obtained for X direction is shown in Figure 15. The comparison of the firs damage occurring obtained for the models between each other in the Y direction is shown in Figure 16.

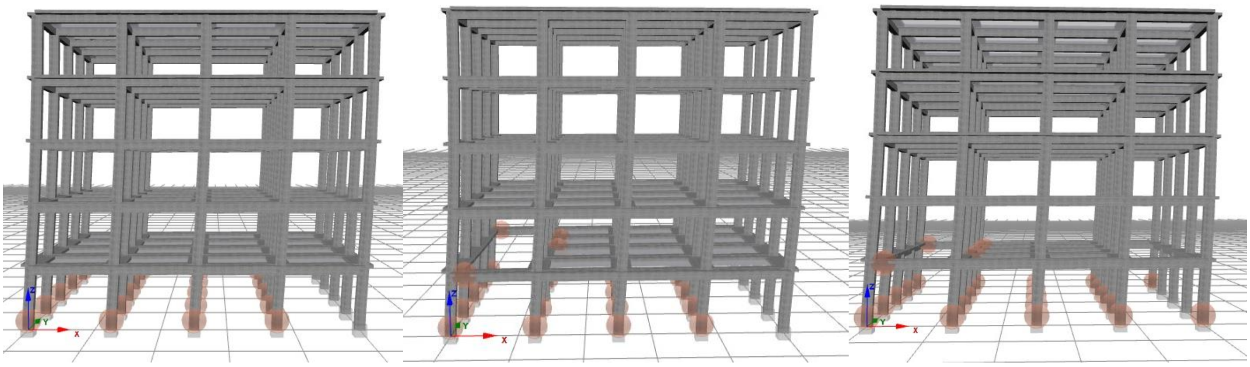

Figure 15. Plastic hinges at load factors 40.89-39.17-36.80 in X-direction for Model 1-2-3

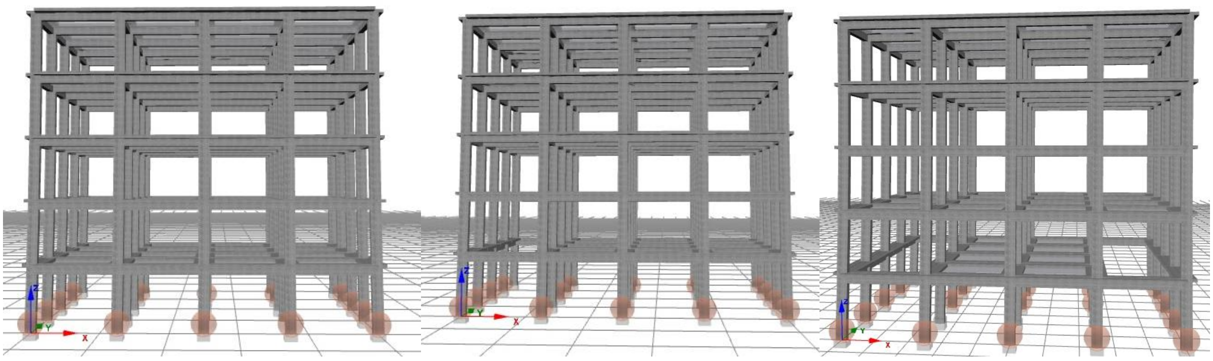

Figure 16. Plastic hinges at load factors 25.13-24.96-24.91 in Y-direction for Model 1-2-3

Comparisons were made for the first 3 models in order to reveal the effect of the mezzanine on the chord rotation in this study. The selected column in the ground story is shown in Figure 17.

Figure 17. Demonstration of selected column

The comparison of the chord rotation values obtained for the selected column for the first 3 models is made in the Table 8.

Table 8. Chord rotation values of selected column (Col123)

Element	Demand (X Direction)			Demand (Y Direction)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
col123 - End(A) - axis(2)	0.13588013	0.0808491	0.07929223	3.04E-08	5.32E-06	3.22E-07
col123 - End(A) - axis(3)	5.46E-06	3.47E-05	5.05E-05	0.1488093	0.1487721	0.1484661
col123 - End(B) - axis(2)	0.1300697	0.013335	0.0080529	3.08E-05	0.000102	0.000104
col123 - End(B) - axis(3)	7.84E-06	1.39E-04	4.94E-05	0.14732	0.147281	0.14697

In the first group (Model 1, Model 2 and Model 3) where all story heights are equal, period values are decreased with the increase of slab gap amount. The second group (Model 4, Model 5 and Model 6) where the story and mezzanine heights were different; period values were also decreased. The decrease in the mass of the building due to the absence of slab reduces the period values. While translational freedom mass participation rates increased in both X and Y directions in both group structure models; rotation translational freedom mass participation rates are decreased. In both groups, base shear forces are decreased for both directions. Three different displacement values calculated due to the idealized curve are increased with the amount of slab discontinuity. Both the elastic and the effective stiffness values have taken lower readings with the slab discontinuity. As the slab discontinuity increases, target displacement values are also increased for damage cases in both groups of building models. Comparisons have been made between similar building models (Model 1-Model 4; Model 2-Model 5; Model 3 - Model 6) in case of a change in the heights of the ground and mezzanine levels are also taken into consideration. In the case of building models where ground and mezzanine height values are different from other stories, increase in translational freedom mass participation rates and decrease in rotation freedom mass participation rates have been observed. The base shear force values obtained in the construction models where the story heights were the same have been higher than the structural models where the story heights were different. The three different displacement values calculated in the idealized curve have given lower values in the building models where the story heights are different. Both elastic and effective stiffness values were decreased in the groups where the story heights are different. An increase was observed in the target displacement values calculation done for the building models in which story height is changed. The period values in the building model groups in which the mezzanine and ground story heights are different were obtained as higher values. The increase in the period value shows that the stiffness value is low. Variation of the story heights within the structure is one of the factors decreasing the stiffness of the structure. The load factor values calculated within the scope of the study also took lower values with the increase of negativity parameter. The amount of first plastic hinge increased as the amount of gap in the slab increased. The amount of first plastic hinge increased as the amount of gap in the slab increased. The pushover curves on Y direction are almost same. This shows that the importance of the lack of beam elements in Y direction. This result shows that if designer wants to remove slab, shouldn’t remove the beam elements. Chord rotation values differed according to the section position taken from the column.

3 Results

Factors in structures that reduce the defence mechanism of the structure can refer to the negativity parameter. The negativity parameters in the structures can be formed differently. Within the scope of this study, structural analyses were made for the structures such as a RC building where the continuity of the slab in the structure changes and expressed as mezzanine, penthouse and half storey. In general, a mezzanine is commonly used in order to maximize the usage of the construction area in the buildings that carry out commercial activities on the ground stories. These can be built in different shapes and models. This study aims to reveal the effects of the presence of mezzanine on the structures under earthquake impact.

As part of the study, a 5-storey RC building was selected as reference building model. The mezzanine was formed without making any change in the structural size and properties of the reference structure. A mezzanine is formed between the ground and an upper story. The analyses were made to make the ground and mezzanine heights different from other heights in this study. The presence of the mezzanine and the fact that the story height values differ within the structure are some of the parameters that weaken the defence mechanism of the structures against earthquake effects.

In this study, it was observed that the discontinuity of the slab caused by partial mezzanine caused negativity in the transfer of earthquake forces to vertical structural elements and reduced the lateral stiffness of the structure in an irregular way. It has occurred that the confidence in transferring lateral loads of the slabs which are rigid in the plane to vertical structural elements has given way to uncertainties with such irregularities.

Structural properties, type of structural system, characteristics of structural system elements, ratio of mezzanine area to normal story area, mezzanine height and mezzanine support situation may interchange mostly. The weakening of the defence mechanism was observed in all values if there is a mezzanine in the building. If there is a necessity for making a mezzanine, then measures should be taken to increase the stiffness of the structure. The aim of the study is to analyse that the presence of mezzanine has a negative effect on the defence mechanism of the building against earthquake effects. However, more dramatic results can be obtained by examining the subject with more analysis by considering the structures that have different geometries. Considering the effects of the irregularities observed in the structures on the earthquake behaviour and taking precautions accordingly are part of the earthquake resistant structure design. The study occupies an important position from this standpoint.

In future studies, it will be beneficial to analyse different structural systems, regular/irregular buildings in plan, different gaps rates and locations in different software programs in different analysis types

.

References

[1] Krawinkler H.; Seneviratna G.D.P.K., ‘’Pros and cons of a pushover analysis of seismic performance evaluation’’ *Engineering Structures*, 20(4-6), pp.452-464, 1998 https://doi.org/10.1016/S0141-0296(97)00092-8

[2] Chopra A.K., Goel R.K., ‘’A modal pushover analysis procedure for estimating seismic demands for buildings’’ *Earthquake Engineering and Structural Dynamics*, 31(3), pp.561-582, 2002 https://doi.org/10.1002/eqe.144

[3] Yakut A, ‘’Preliminary seismic performance assessment procedure for existing RC buildings’’ *Engineering Structures*, 26(10), pp.1447-1461,2004 https://doi.org/10.1016/j.engstruct.2004.05.011

[4] Isik E, ‘’Consistency of the rapid assessment method for reinforced concrete buildings’’ *Earthquakes and Structures*, 11(5), pp.873-885, 2016http://dx.doi.org/10.12989/eas.2016.11.5.873

[5] Šipoš T.K.; Hadzima-Nyarko M. ‘’Rapid seismic risk assessment’’ *International Journal of Disaster Risk Reduction*, 24, pp.348-360, 2017. https://doi.org/10.1016/j.ijdrr.2017.06.025

[6] Ozmen H.B.; Inel, M. ‘’Effect of rapid screening parameters on seismic performance of RC buildings’’ *Structural Engineering Mechanics*, 62(4), pp.391-399, 2017. https://doi.org/10.12989/sem.2017.62.4.391

[7] Işık E.; Özdemir M.; Karaşin İ.B. ‘’Performance analysis of steel structures with A3 irregularities’’ *International Journal of Steel Structures*, 18(3), pp.1083-1094, 2018. https://doi.org/10.1007/s13296-018-0046-6

[8] Isik E.; Isik M.F.; Bulbul M.A. ''Web based evaluation of earthquake damages for reinforced concrete buildings'' *Earthquake and Structures*, 13(4), pp.387-396, 2017. https://doi.org/10.12989/eas.2017.13.4.387

[9] Hadzima-Nyarko M., Kalman Sipos T., ''Insights from existing earthquake loss assessment research in Croatia'' *Earthquakes and Structures*, 13(4), pp.365-375,2017. https://doi.org/10.12989/eas.2017.13.4.401.

[10] Atalić J.; Šavor Novak M.; Uroš M., ''Seismic risk for Croatia: overview of research activities and present assessments with guidelines for the future'' *Građevinar,* 71(10), pp.923-947, 2019. https://doi.org/10.14256/JCE.2732.2019.

[11] Harirchian E.; Hosseini S.E.A.; Jadhav K.; Kumari V.; Rasulzade S.; Işık E.; Lahmer T., ''A review on application of soft computing techniques for the rapid visual safety evaluation and damage classification of existing buildings.'' *Journal of Building Engineering*, 43, 102536,2021. https://doi.org/10.1016/j.jobe.2021.102536.

[12] Akdoğan R.; Karaşin, A.H., ''Effects of near-fault and far-fault ground motions on seismic performance of 5-story r/c building.'' *European Journal of Technique*, 7(1), pp60-68. 2017.

[13] Dogan G.; Ecemis A.S.; Korkmaz S.Z.; Arslan M.H.; Korkmaz, H.H., "Buildings damages after Elazığ, Turkey earthquake on January 24, 2020." Natural Hazards, 109(1), pp.161-200. 2021. https://doi.org/10.1007/s11069-021-04831-5.

[14] Khurram M.K., ''Betonarme binalarda kiriş ve döşeme süreksizliğinin yapısal davranışa etkisinin incelenmesi,'' Yüksek Lisans Tezi, Sakarya Üniversitesi, Sakarya, Türkiye. 2018.

[15] Tekdal E., ''Döşeme süreksizliklerinin betonarme çerçeveli binaların davranışına etkisi,'' Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, İstanbul, Türkiye. 2008.

[16] Ayrancı M.M., ''Döşeme süreksizliği olan BA yapı sistemlerinin farklı bilgisayar modelleri ile analizi ve karşılaştırması'' Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi, İstanbul, Türkiye. 2010.

[17] Yedikardeş U., ''Deprem yönetmeliğine göre yapılardaki A2 düzensizlik durumunun incelenmesi ve perde yerleşiminin düzensizliğe etkisi.'' Yüksek Lisans Tezi, Çukurova Üniversitesi, Adana, Türkiye. 2010.

[18] Özdemir M.Y., ''Yapıların deprem hesabında A2 düzensizlik durumunun incelenmesi.'' Yüksek Lisans Tezi, Çukurova Üniversitesi, Adana, Türkiye. 2005.

[19] Öztürk T., ''Binalarda döşeme boşluklarının taşıyıcı sistem davranışına etkisi.'' *Teknik Dergi,* 24(116), pp.6233-6256. 2013.

[20] Terzi M.; Elçi H., "Çerçeve tipi betonarme yapılarda döşeme süreksizliklerinin kesit tesirlerine etkisi." *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, 12(3), pp.341-349. 2006.

[21] Sağlıyan S.; Yön B. "Assessment of earthquake behavior of reinforced concrete buildings with slab discontinuity." *Turkish Journal of Science and Technology*, 13(1), pp.87-92. 2018.

[22] Bilgin H.; Shkodrani N.; Hysenlliu M.; Ozmen H. B.; Isik E.; Harirchian, E. ''Damage and performance evaluation of masonry buildings constructed in 1970s during the 2019 Albania earthquakes.'' *Engineering Failure Analysis*, 131, 105824.2022. https://doi.org/10.1016/j.engfailanal.2021.105824.

[23] Göker Ş.; Karaşin A. ''Depremde hasar gören kırsal yapılar için bir yapısal hasar değerlendirmesi.'' *Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi*, 6(1), pp.31-38. 2015.

[24] Işık M.F.; Işık E.; Bülbül M.A., ''Application of iOS/Android based assessment and monitoring system for building inventory under seismic impact,'' *Građevinar,* 70(12), pp.1043-1056, . 2018: https://doi.org/10.14256/JCE.1522.2015.

[25] Yön B.; Onat O.; Öncü, M. E.'' Earthquake damage to nonstructural elements of reinforced concrete buildings during 2011 Van seismic sequence.'' *Journal of Performance of Constructed Facilities,* 33(6),04019075.2019. https://doi.org/10.1061/(ASCE)CF.1943-5509.0001341

[26] Kalman Šipoš T.; Hadzima-Nyarko M. ''Seismic risk of Croatian cities based on building's vulnerability,'' *Tehnički Vjesnik,* 25(4), pp.1088-1094, 2018. https://doi.org/10.17559/TV-20170708190145.

[27] Yön, B., Onat, O., Öncü, M. E., & Karaşin, A. ''Failures of masonry dwelling triggered by East

Anatolian Fault earthquakes in Turkey.'' *Soil Dynamics and Earthquake Engineering*, 133, 106126. 2020.

[28] Pavić G.; Hadzima-Nyarko M.; Bulajić B. ''A Contribution to a UHS-based seismic risk assessment in Croatia— A case study for the City of Osijek,'' *Sustainability*, 12(5), pp.1796, 2020. https://doi.org/10.3390/su12051796

[29] TBEC-2018. Turkey Building Earthquake Code; Disaster and Emergency Management Presidency of Turkey: Ankara, Turkey, 2018.

[30] Antoniou S.; Pinho R. ''Seismostruct–Seismic Analysis Program by Seismosoft,'' Technical Manual and User Manual. 2003.

[31] Ordu E.; Özkan M.T. ''Three-dimensional finite element analysis of the seismic behaviour of pile foundations'' *İtü Dergisi/d,* 5(2), pp.27-34. 2006.

[32] SeismoStruct v6.5: A computer program for static and dynamic nonlinear analysis of framed structures". Seismosoft. 2013.

[33] Kutanis M.; Boru E.O.; Işık E. ''Alternative instrumentation schemes for the structural identification of the reinforced concrete field test structure by ambient vibration measurements'' *KSCE Journal of Civil Engineering*, 21(5), pp.1793-1801, 2017. https://doi.org/10.1007/s12205-016-0758-0

[34] Nikoo M.; Hadzima-Nyarko M.; Khademi F.; Mohasseb S. ''Estimation of fundamental period of reinforced concrete shear wall buildings using self organization feature map'' *Structural Engineering Mechanics*, 63(2), pp.237-249, 2017. https://doi.org/10.12989/sem.2017.63.2.237.

[35] Aksoylu C.; Arslan M.H. "Çerçeve türü betonarme binaların periyod hesaplarının farklı ampirik bağıntılara göre irdelenmesi." *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi*, 8(2), pp.569-581. 2019.

[36] Hsiao F.P.; Oktavianus Y., Ou Y.C. ''A pushover seismic analysis method for asymmetric and tall buildings'' *Journal of Chinese Institute of Engineers*, 38(8), pp.991-1001., 2015. https://doi.org/10.1080/02533839.2015.1056553

[37] Estêvão J.M.; Oliveira C.S. ''A new analysis method for structural failure evaluation'' *Engineering Failure Analysis*, 56, pp.573-584,2015. https://doi.org/10.1016/j.engfailanal.2014.08.009

[38] Casapulla C.; Argiento L.U. ''The comparative role of friction in local out-of-plane mechanisms of masonry buildings.'' *Pushover analysis and experimental investigation, Engineering Structures*, 126, pp.158-173, 2016. https://doi.org/10.1016/j.engstruct.2016.07.036

[39] Ademovic N.; Hrasnica M.; Oliveira D.V. ''Pushover analysis and failure pattern of a typical masonry residential building in Bosnia and Herzegovina'' *Engineering Structures*, 50, pp.13-29,2013. https://doi.org/10.1016/j.engstruct.2012.11.031

[40] Ademović N.; Hrasnica M. ''Capacity degradation and crack pattern development in a multi-storey unreinforced masonry building'' *Građevinar,* 67(04.), pp.351-361, 2015. https://doi.org/10.14256/JCE.1191.2014

[41] Işık E.; Özdemir M. ''Performance based assessment of steel frame structures by different material models'' *International Journal of Steel Structures*, 17(3), pp.1021-1031, 2017. https://doi.org/10.1007/s13296-017-9013-x

[42] Isik E.; Kutanis M. ''Performance based assessment for existing residential buildings in Lake Van basin and seismicity of the region'' *Earthquake and Structures*, 9(4), pp.893-910.2015. https://doi.org/10.12989/eas.2015.9.4.893

[43] Salihovic A.; Ademovic N. 2018: Nonlinear analysis of reinforced concrete frame under lateral load, Coupled System Mechanics, 7(3), pp.281-295, https://doi.org/10.12989/csm.2018.7.3.281.

[44] EN 1998-3 2005: Eurocode-8: Design of Structures for Earthquake Resistance-Part 3: Assessment and Retrofitting of Buildings; European Committee for Standardization: Bruxelles, Belgium, 2005.

[45] Pinto P.E.; Franchin P. "Eurocode 8-Part 3: Assessment and retrofitting of buildings." In Proceedings of the Eurocode 8 Background and Applications, Dissemination of Information for Training, Lisbon, Portugal, 10–11 February 2011.