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Research Article

Evaluating the effects of different slab types on static and dynamic characteristics of structures

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ABSTRACT

In this study, the effect of different types of slabs on dynamic characteristics of structures under the lateral loading was investigated. For this purpose, four different types of slabs namely, beamed slab, flat slab, one way ribbed (hollow core) slab and waffle slab have been modeled in buildings having 3, 4 and 5 storeys with the same geometric dimensions, in accordance to design and construction requirements (TS 500) and Turkish building seismic codes (TBDY, 2018). Seismic analysis calculations of the modeled buildings were done using the equivalent seismic load method. The assumed local soil class was taken from the geotechnical report as ZD. As a result of the analysis, natural periods, base shear forces, maximum horizontal displacements and relative storey drifts of the buildings were compared. Seismic analysis and calculations of the buildings were completed using SAP2000 finite element software.

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1. Introduction

Due to the fact that our country has active fault line lines, there have been many casualties of life and properties in the structures that have been destroyed or damaged by the earthquake. Reducing damages and destructions caused by earthquake can only be achieved by designing and constructing structures with high resistance to loads caused by earthquake. Design codes and specifications are set in order to prevent or reduce the loss of lives and assets due to the frequent occurrence of earthquake in our country. In spite of the frequent revisions of the Seismic design codes that are mandatory part of constructing new buildings, unfortunately, there has been no effective result that will significantly reduce the loss of life and property in case of an earthquake disaster. The Turkish Building Seismic Codes (TBDY, 2018) which was prepared by the commission created by AFAD was published as a draft in 2016. Following some arrangements in its contents, was published in the Official Gazette on March 18, 2018 and subsequently enforced as of January 1, 2019. TBDY (2018) has been prepared in line with the developments in earthquake engineering, taking into account the increasing and/or changing needs of our country. The most common and preferred types of structures in our country are reinforced concrete structures. The reason why reinforced concrete structures are preferred compared to other types of buildings is their longer useful life, the availability of concrete raw material, and higher resistance to earthquake loads. Structural members such as columns, beams, slabs and walls act as load bearing elements in reinforced concrete structures. The slab being one of the main load bearings in the structure is important in determining static and dynamic characteristics of the structure.

Different methods are used to find the optimum solution in building design. Shake tables and finite element modeling are two of the main solutions in determining dynamic characteristics (Ağcakoca, 2019; Sümer and Aktaş, 2015). Different methods are used in literature to properly understand the dynamic behavior of the building (Bilgin and Uruçi, 2018; Paripour et al., 2018; Martinez and Ventura, 2016). The characteristic behavior of the structure can be determined by estimation methods such as Arma-Arx (Uyar and Ağcakoca, 2020a, 2020b)

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and Artificial Neural Networks (Çağlar et al., 2008). In this study, the effects of different slab types on dynamic characteristics of the building is evaluated using finite element modeling method.

By using different slab types in the design of reinforced concrete structures, alternative design options can be considered for the same building system. Different slab types transfer the vertical and horizontal loads to the members differently. In addition, changing the slab type will cause changes in the earthquake parameters affecting the load bearing system. The most important factor in dissipating earthquake energy is the ductility capacity of the load bearing system.

During the design phase, it is important to maintain level of ductility of the building between the boundary values allowed by the design codes while determining the type of slab to be used in the structure. Moreover, slab type selection is important in determining the safety level of the load bearing system according to the Turkish seismic codes TBDY (2018). Therefore the slab types to be used in the load bearing systems and their performance mechanism should be correctly defined by the design engineers.

1.1. Previous research

Bansal and Patidar (2016) used beam slab and waffle slab in their work. They designed 4, 8 and 12 story buildings with a floor height of 3.6 m and building floor area of 20x20 m. The structures that were subjected to seismic load were examined for the changes in base shear forces, storey drift and maximum displacements using static pushover analysis. Bhina et al. (2013) compared the costs of flat slabs and beam slabs and their behavior under lateral load. They used static pushover analysis, time history and response spectrum analysis in order to assess the performance of both structures.

A study by Çağlarım (2002), has examined the effect of different types of slabs on structural behavior of rigid and ductile slab diaphragms. Rigid and ductile diaphragm were examined considering A2 and A3 modelling. Demirok (2009) investigated the effects of three different types of slab on the bearing system in a 10 storey building with the architectural features designed according to DBYBHY-2007 and compared the results. With regards to the periods in both directions, the largest period values were seen in the building model with flat slab. As for the displacements, the building model with ribbed slab had 32% more displacement in X direction and 38% more displacement in Y direction comparing to building models with beam slab.

El-Shaer (2013), has modelled a 30-storey building having concrete load bearing system with different slab systems namely, beam slab, flat slab and ribbed slabs in order to compare the storey drift, building overturning moments and base shear forces. Moreover, Özlü (2015) has evaluated a building consisting of three different bearing systems (frame, shear wall frame and shear wall) which was designed according to the Turkish seismic codes (DBYBHY-2007). They used traditional slab, filled beam slab and flat slab with different floors as 10, 15, 20, 25, 30, 35, 40 and 50. Different loading and different concrete classes were evaluated according to different floor classes in the designed structures. The load bearing system behaviors were examined by comparing the maximum displacements and maximum storey drift in both directions, secondary moment values, natural periods, and torsional and stiffness irregularity coefficients.

In a study conducted by Yaşaroğlu (2015) in which they designed an architectural plan with different slabs and different bearing systems according to Turkish seismic codes (DBYBHY, 2007). The 6 storey building was designed with frame and shear wall frame and the 12 storey building was designed with shear wall frame using the ETABS finite element analysis package. Structure weight, natural period and base shear forces were compared in the study. In all models, the largest base shear force, structure weight and natural period was obtained in buildings modeled with flat slab.

Yeşilyurt (2016); in his thesis study looked into 18 different multi-storey reinforced concrete structures with different bearing and slab systems under seismic loading using ETABS finite element program. The structural behaviors of these buildings were examined using mode superposition and design spectrum methods. The selected bearing systems were frame, tube and shear wall-frame systems, and slab systems were determined as beam slab and Ribbed (hollow core) slabs. The obtained base shear forces, maximum displacements, maximum bending moments, maximum shear forces and natural periods were compared.

The bending behavior of different slab types such as ribbed slabs has been examined. Using such slabs decreases material consumption and improve the insulation properties which enhances the sustainability of the structures (Alfeehan et al., 2017). Lastly, a parametric study has been done for the optimum solution of cantilever retaining walls such as slab (Uray, 2019), earth-retaining walls (Yepes et al., 2008), and reinforced concrete columns (Bektaş and Nigdeli, 2016).

2. Reinforced Concrete Slabs

Slabs are two-dimensional structural elements which have a considerably smaller thickness compared to the other two dimensions. The main role of slabs is to absorb the vertical loads and transfer them to the beams, columns and shear walls by which these slabs are supported. Additionally, slabs are responsible for transferring their own weights and the loads perpendicular to their planes to the beams or bearing members such as columns and/or shear walls by which are supported. The loads on the slabs vary a lot according to the usage purpose of the building. Therefore, considering the difficulties in calculating the loads affecting the slabs, it is assumed that the loads act uniformly on the slab. In addition, the change in the span of the slab will change the amount of load the slab is exposed to as a structural element. For small spans, simple slab types are generally used, while for large spans, more complicated systems and slab types are used (Topcu, 2019).

Slabs are mainly classified as beamed slabs, flat slabs, ribbed slab and waffle slabs according to their performance principles and supporting connections. In this study, the effect of different slab types such as flat slabs, beam slabs and ribbed slabs on the dynamic behavior of the building has been evaluated. According to TBDY (2018) Article 4.5.6.3, reinforced concrete slabs can be modeled with assumed rigid diaphragm in building plans where there are no A2 and A3 type irregularities and significant deflection in the plane will not occur. In addition to rigid diaphragm, the effect of eccentricity should also be taken into consideration during the analysis as per TBDY (2018).

Beam slabs are often preferred in residential buildings. They can be attached to the beam at least on one side (for example balcony slab) and can be supported by the beams on all four sides. Generally, the thickness of the beam slab is from 12 to 20 cm. Beam slabs are divided into two types namely one way slab and two way slabs based on the ratio of long span to the short span. If the ratio of the length of the slab (long span) to the width of the slab (short span) is equal to or more than 2, then it is called One way slabs. If that ratio is smaller than 2, then it is called two way slab. While one way slab are cost effective if span is short and the beam goes in one direction, but are not cost effective if the span is large. Additionally, in one way slabs, reinforcement calculations are made for only short spans, and these reinforcements are placed in the short span direction. For the long span, reinforcements are placed as per the design codes without any calculation. The main reason of placing these reinforcements is to absorb the additional stresses caused by freeze and thaw action as well as shrinkage (Topcu, 2019).

The ribbed (hollow core) slabs are formed by placing ribs parallel to each other which are then connected to main beam and have a thin plate over the ribs. Ribbed slabs can be considered as an alternative due to the fact that beamed slabs are not economical in structures with large spans. Practically, the thickness of the plate over ribbed slabs is generally 7-10 cm. The rib width is 10-20 cm and rib height is 32-50 cm. The space between each rib according to TS 500 is usually 40-70 cm. Dead and live loads on the thin plate are transferred to the ribs which then transfer them to the main beams. The most important point to consider is the direction of the ribs. If the ribs are arranged in the direction of the short span then the rib opening becomes small which is not a problem for the ribs but will cause big shear force and moment on the main beams. However, if the ribs are arranged in the direction of the long span, the ribs will be long in length causing to produce big shear force and moment in them and will not affect the main beams. Since the stiffness of the main beams, is already low in practice, it is not desirable to force the main beams too much, so ribs are generally arranged in long span direction in practice.

Ribbed slabs running in one direction are called one way ribbed slab. Ribbed slabs running in two directions are also referred to as waffle/grid slabs in practice. In ribbed slabs, the ribs are usually filled with filling material. The most commonly used filling materials in practice are: hollow concrete blocks, hollow brick, aerated concrete and foam. These filling materials do not have any load carrying capacity, and they are only considered as a dead load in the calculations. In cases where filling material is not necessary, the spaces between the ribs can be used for installation of utilities such as HVAC or mechanical pipes. According to Topcu (2019), in systems with ribbed slabs, normal beams on outer axes with a wall under them are more suitable in terms of seismic performance

Ribbed slab with ribs in both directions carrying the load are called waffle slabs. All the principles designated for one way ribbed slabs are applicable to waffle slabs as well. Waffle slabs are often used for large spans and large spaces where columns are undesirable (parking lot, Movie Theater, etc.). Waffle slabs can be thought of as beamed slabs running in two directions, which have voids in between. In this context, it can be said that the methods valid for beamed slabs will be valid for waffle slabs as well (Doğangün, 2018).

There are no restrictions on constructing waffle slabs in TBDY (2018). Same solutions and analysis that are used for one way ribbed slabs are applicable for waffle slabs as well. Since one way ribbed slabs perform poorly when exposed to earthquake load, therefore TBDY (2018) has put quite strict restrictions on using one way ribbed slabs in order to increase its performance against seismic loading. According to TBDY (2018), it is not allowed to design one way ribbed (hollow core) slab systems for high ductility. If a one way ribbed slab systems are to be created, then a shear wall needs to be included in order to increase the system ductility and can be designed as a mixed system. A system of one way ribbed slab can only be created with columns when the ductility level can be designed normally. According to TBDY (2018), one way ribbed slab systems without using shear walls are used only in buildings that are in earthquake design classes DTS = 3 and DTS = 4, and in building usage classes, BKS = 2 and BKS = 3. In other words, they can be used in building with an importance factor 1 and 1.2. In buildings with BKS = 1, (importance factor 1.5) it is not allowed to create a ribbed slab system without including shear walls. If it is to be constructed without a shear wall, then the maximum height of the building should not exceed 17.5 meters from the top of foundation elevation (if there is a basement, the height is calculated over the shear wall upper elevation). According to TBDY (2018), the maximum building height can be up to 17.5 meters from the foundation upper elevation for the earthquake design buildings with earthquake design classes DTS = 1, 1a, 2, 2a TBDY (2018). It is recommended to fill the gaps between the ribs with lightweight filling materials instead of heavy filling materials in one way ribbed slabs in order to reduce the overall weight of the structure.

Flat slabs are the structural elements that allow the loads acting on them to be transferred directly to the columns and/or shear walls since there are no surrounding beams. The most important problem in flat slabs is the risk of punching shear around the column. To prevent this, caps (column heads) are used between the column and the slab. In tensile-free slabs, the prime tensile stresses in the column- slab connection areas can exceed the tensile strength of concrete and cracks occur in the direction perpendicular to these stresses. Since the principal tensile stresses are at an angle of 45° with the slab plane, the cracks are formed at an angle of 45°. As a result, the column drills the slab by punching it in a sudden and brittle manner. Formulas are given in TS500 for controlling punching shear. If punching resistance is not achieved, then, increasing slab thickness, column/shear wall dimensions, concrete quality or using punching reinforcement can be the solution (Doğangün, 2018).

According to TBDY (2018), it has become mandatory to create shear walls in buildings with flat slabs. The shear walls should be placed as symmetrical and close to the outer axes in the X and Y direction as possible in the plan. Bearing systems of buildings with flat slabs can be arranged together with columns and shear walls. There is no obligation to create it with only shear walls. However, according to TBDY (2018), in buildings with flat slabs, shear walls have to meet the capacity of overturning moments caused by seismic loads TBDY (2018). Great effects can occur in areas where the flat slabs is supported directly by shear walls. If the shear walls are arranged on the outer axes, it is recommended to connect the columns and shear walls on the outer periphery with a beam. Thus, lateral loads are transferred to the shear wall through beams. Stiffness can be increased by placing beams on the outer axes of the systems with flat slabs.

3. Modeling by TBDY-2018

The models we have developed are to be constructed in Erenler district of Sakarya province (latitude=40.7°, longitude=30.3°). At DD-2 Earthquake Motion Level, the short period map spectral acceleration coefficient required to obtain the Horizontal Elastic Spectrum is S_S and the map spectral S_1 values for 1.0 second period (Afad, 2019).

Horizontal elastic design spectral accelerations $S_{ae}(T)$, which are the ordinates of the horizontal elastic design acceleration spectrum for any earthquake ground motion level, are defined by Eqs. (1-4) in terms of gravity acceleration (g) depending on the natural period (Fig. 1). In the equations below, S_{DS} and S_{D1} are design spectral acceleration coefficients, T is the natural period, T_A and T_B are horizontal design spectrum corner periods and T_L indicates transition period to the constant velocity zone. The value for T_L = 6 in Eq. (5) which is taken from TBDY (2018).

$$0 \leq T \leq T_A \quad \Rightarrow \quad S_{ae}(T) = \left(0.4 + 0.6\frac{T}{T_A}\right) \tag{1}$$

$$T_A \leq T \leq T_B \quad \Rightarrow \quad S_{ae}(T) = S_{DS} \tag{2}$$

$$T_B \leq T \leq T_L \quad \Rightarrow \quad S_{ae}(T) = \frac{S_{D1}}{T} \tag{3}$$

$$T_L \leq T \Rightarrow S_{ae}(T) = \frac{S_{D1}T_L}{T^2} \tag{4}$$

$$T_A = 0.2\frac{S_{D1}}{S_{DS}} \;\; ; \; T_B = \frac{S_{D1}}{S_{DS}} \;\; ; \; T_L = 6 \text{ s} \tag{5}$$

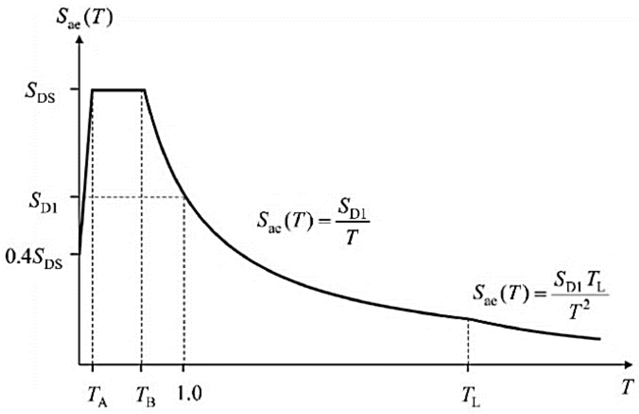


Fig. 1. Horizontal elastic design spectrum (TBDY, 2018).

The S_S and S_1 values are as follows S_S = 1.62 and S_1 = 0.444 which are mentioned in a report from Earthquake Hazard Map of Turkey. The Local Ground Impact coefficients F_S and F_1 values are obtained from assumed values in the geotechnical report for ground class ZD in the Table 2.1 of TBDY which are F_S = 1, F_1 = 1.856 respectively. In addition, design spectral acceleration coefficients: S_{DS} = 1.622, and S_{D1} = 0.824. Horizontal design spectrum corner periods T_A = 0.1202 sec and T_B = 0.508 sec. Spectral values for the locations in the vicinity of Erenler district of Sakarya province are given in Table 1. The ground class at the location where the models will be built is assumed to be ZD. The spectrum graphs obtained from the numerical data in Table 1 are shown in Fig. 2.

$$E_d^{(Z)} \cong \frac{2}{3}S_{DS}G \tag{6}$$

The BKS = 3 which is for the buildings used for residential / business purposes was taken from Table 3.1 of TBDY (2018). The Building Importance Factor (I) in the calculations used was I = 1 for the building belonging to this usage class. Short Period, Spectral Acceleration Coefficient for DD-2 earthquake level of building models was S_{DS} = 1.622. When BKS = 3 is taken into consideration, DTS = 1 as per TBDY (2018) Table 3.2. Since the building models are without basements, building heights have been determined from the foundation's upper elevation. There are different floors in building models. Building Height Class BYS for DTS = 1 and the building height HN of the relevant building model was determined. According to TBDY, the normal performance target for DTS = 1 and cast concrete buildings in the new building is Critic Controlled Damage (CCP) and the design approach is DD-2 earthquake ground motion Design by Strength (DGT).

Load-bearing system behavior coefficient (R) and strength excess coefficient (D) within the framework of DGT are shown in Table 4.1 of TBDY (2018). According to TBDY (2018), reinforced concrete bearing systems are divided into three classes as high ductility level bearing systems, limited ductility level bearing systems and mixed ductility level bearing systems. The reduced internal forces acting in the plane of the building floors are applied strength surplus coefficient specified in TBDY Table 4.1 for the relevant bearing systems TBDY (2018).

According to Article 4.5.8.3 of the TBDY, effective cross-sectional stiffness factors are applied only under seismic effective load combinations and under the loads entering these combinations TBDY (2018).

Table 1. Earthquake parameters for DD-3 and DD-2 earthquake level.

Earthquake Level	Spectral Parameters							
	S_S	S_1	F_s	F_1	S_{DS}	S_{D1}	T_A	T_B
DD-2	1.622	0.444	1	1.856	1.622	0.824	0.102	0.508
DD-3	0.643	0.156	1.256	2.288	0.827	0.327	0.086	0.432

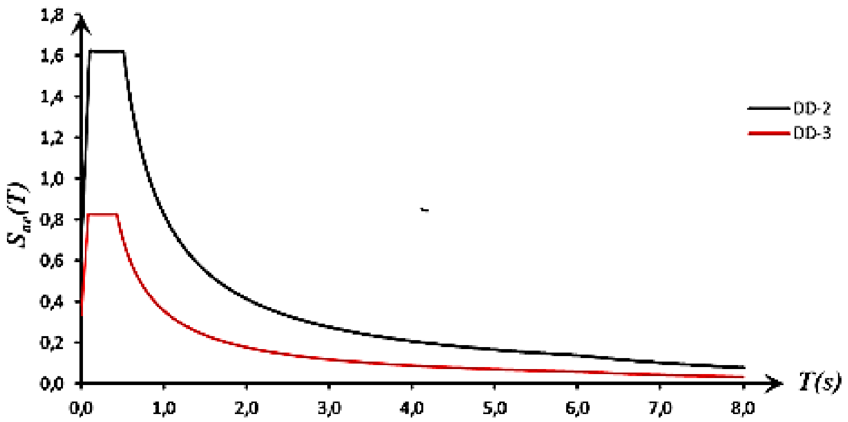


Fig. 2. Design acceleration response spectra for DD-3 and DD-2 earthquake level.

3.1. Equivalent seismic load method and floor earthquake loads

The earthquake in the X direction, the total equivalent earthquake load (base shear force), $V_{tE}^{(X)}$ is calculated as given in Eq. (7) as per TBDY (2018).

$$V_{tE}^{(X)} = m_t \cdot S_{aR}\left(T_p^{(X)}\right) \geq 0.04 \cdot S_{DS} \cdot I \cdot m_t \cdot g \qquad (7)$$

The additional equivalent earthquake load on the top floor of the building having *N* floors, is calculated by Eq. (8).

$$\Delta F_{NE}^{(X)} = 0.0075 \cdot N \cdot V_{tE}^{(X)} \qquad (8)$$

Earthquake loads affecting floor levels are calculated by Eq. (9).

$$F_{iE}^{(X)} = (V_{tE}^{(X)} - \Delta F_{NE}^{(X)}) \frac{m_i * H_i}{\Sigma_{j=1}^{N}(m_j * H_j)} \qquad (9)$$

The total overturning moment at the base of the building occurring from the seismic loads is calculated by Eq. (10).

$$M_O^{(X)} = \Sigma_{i=1}^{N} \cdot F_{iE}^{(X)} \cdot H_i \qquad (10)$$

Similarly, there are equivalent earthquake forces in the Y direction.

3.2. Control of effective relative storey drifts

The control of effective relative storey drift is in accordance with section 4.9.1 of the TBDY (2018). For equivalent earthquake loads in the X and Y direction, the reduced relative storey drift (Δ_i) and effective relative storey drift ($\delta_{\max}$) on all floors of the building, corner points and/or columns are calculated by Eqs. (11) and (12), respectively (TBDY, 2018).

$$\Delta_i^{(X)} = u_i^{(X)} - u_{i-1}^{(X)} \qquad (11)$$

$$\delta_i^{(X)} = \frac{R}{I} \Delta_i^{(X)} \qquad (12)$$

The control of relative storey drift is made according to Eq. (13) of Article 4.9.1.3.a of TBDY (2018).

$$\lambda \frac{\delta_{i,\max}^{(X)}}{h_i} \leq 0.008\kappa \qquad (13)$$

In the equations: h_i = height of *i*th storey of building (m.), $\delta_i^{(X)}$= effective storey drift of *i*th floor of building column and wall for earthquake in X direction, $\delta_{i,\max}^{(X)}$= maximum effective storey drift of *i*th floor of building column or walls for earthquake in X direction, κ = allowable relative floor displacements coefficient used for reinforced concrete systems, R = structural system behavior factor, I = building importance factor, λ = empirical coefficient for limiting storey drifts. $u_i^{(X)}$= horizontal displacement at the *i*th floor for any column or wall in the X earthquake direction, and $\Delta_i^{(X)}$= reduced storey drift of ith floor of building column or walls in X direction.

Our building models comply with the article 4.9.1.a of the TBDY that the filler walls and facade elements made of brittle material are completely adjacent to the frame elements, without any joints between them. The value for coefficient κ is taken as 1 for reinforced concrete buildings. The λ coefficient was obtained by dividing the elastic design spectral acceleration of the DD-3 earthquake ground motion by the elastic design spectral acceleration of the DD-2 earthquake ground motion. Elastic spectral acceleration values for DD-3 earthquake ground motion were obtained by entering the same latitude and longitude values as shown in Table 2.

Table 2. Earthquake parameters for DD-3 earthquake level.

Earthquake Level	S_{ae} (T^X)	S_{ae} (T^Y)	$\lambda^{(X)}$	$\lambda^{(Y)}$	κ	I
DD-3	0.827g	0.827g	1.256	2.288	1	1

4. Finite Element Models

In this study, a structure 18 m wide and 30 m long was designed with different slab types and different number of floors. The plan consists of 6 axes in the X-X direction and 4 axes in the Y-Y direction. The lengths of all models in the plan are 30 m in the X-X direction, 18 m in the Y-Y direction and between axes distance 6 m in both directions. Plan geometry is orthogonal and symmetrical in both directions. Since the columns and shear walls are symmetrically and uniformly placed on the X and Y axes in the plan, the center of mass and the center of stiffness are coincide. The shear walls are arranged in outer plan axes to increase the torsional stiffness.

C30 concrete with a 28-day cylindrical compressive strength of 30 MPa and B420C steel with a minimum yield strength of 420 MPa were selected for all building models. In order to pre-dimension the load bearing elements of all building models, it was manually calculated under axial loads in accordance with TS 500 and TBDY (2018) codes and controlled with ideCAD-Static V10 package program.

The bearing systems of the designed models have been economically considered and have been chosen in the sizes that are frequently used in the application considering the regulations. Rules for the modeling of load carrier systems for linear calculations have been taken into consideration. The calculation models of the structures are created in three dimensions and the earthquake effect in two horizontal directions perpendicular to each other is taken into consideration. The damping ratio is taken as 5%. Earthquake calculations of all structures in the study were done with SAP2000 finite element software. Columns, beams, rib beams and waffle beams in the building models are modeled as a frame element in the SAP2000 finite element program. The slabs and walls are modeled as shell elements in the SAP2000 finite element program. Since the finite element method is an approximate method, the wall and slab elements are divided into a number of rectangular and square mesh that can be sensitive to solution. In order to ensure a healthy load flow during the modeling phase, attention has been paid to overlap the joints of the axes where the walls and columns meet the slabs. Columns and shear walls at ± 0.00 level are supported in the SAP2000 program as built-in foundation. Rules for the modeling of load bearing systems for linear calculations have been taken into consideration. The names of the buildings corresponding to the slab types are shown in Table 3.

The load-bearing system behavior coefficients of beamed slab Type A buildings, waffle slab Type C buildings and flat slab Type B buildings were taken as R = 6 by performing the relevant controls in the earthquake regulation. As for ribbed (hollow core) slab Type D buildings the coefficient R = 5 was taken according to the earthquake codes of the one way ribbed slab. The dimensions of the bearing elements of the buildings with respect to the slab types are shown in Table 4.

4.1. Design based loads and load calculations

4.1.1. Fixed loads

Structures are under the influence of fixed and dynamic (live) loads throughout their lifetime. However, structures can be exposed to different loading conditions such as impact load as well (Nasery et al., 2020; Ağcakoca et al., 2018; Al Munifi and Alameri, 2019; Al-Safi et. al., 2020). Fixed loads affecting all building models are shown in Table 5. Wall loads are given for the unit area by converting them to distributed loads in order to simplify the calculations.

Table 3. Building names according to their slab types.

Number of Floors	Slab Type			
	Beam Slab (Type A)	Flat Slab (Type B)	Waffle Slab (Type C)	Ribbed (Hollow Block) Slab (Type D)
3	Type 3A	Type 3B	Type 3C	Type 3D
4	Type 4A	Type 4B	Type 4C	Type 4D
5	Type 5A	Type 5B	Type 5C	Type 5D

Table 4. The dimensions of the bearing elements of the buildings with respect to the slab types.

Number of Floors	Building Name	Beam (cm)	Slab (cm)	Wide Beam (cm)	Rib (cm)	Column (cm)	Wall (cm)
3	Type 3A	25/60	15	-	-	50/50	650/25
	Type 3B	25/60	26	-	-		
	Type 3C	25/60	10	50/35	15/35		
	Type 3D	25/60	10	50/35	15/35		
4	Type 4A	25/60	15	-	-		
	Type 4B	25/60	26	-	-		
	Type 4C	25/60	10	50/35	15/35		
	Type 4D	25/60	10	50/35	15/35		
5	Type 5A	25/60	15	-	-		
	Type 5B	25/60	26	-	-		
	Type 5C	25/60	10	50/35	15/35		
	Type 5D	25/60	10	50/35	15/35		

Table 5. Constant load values.

Unit volume weight of reinforced concrete elements	25 kN / m^3
Plaster + Coating (normal floors)	1.5 kN / m^2
Suspended Ceiling + Installation (on normal floors)	0.5 kN / m^2
Wall Load (normal floors)	2.8 kN / m^2
Plaster + Coating (on the roof)	1.0 kN / m^2
Suspended Ceiling + Installation (on the roof)	0.5 kN / m^2

4.2. Live loads

Live loads and snow loads are determined in accordance with TS 498. All live loads and snow loads affecting building models are presented in Table 6.

Table 6. Dynamic and snow load values.

Normal floor moving load	3.5 kN / m^2
Penthouse moving load	1.5 kN / m^2
Roof snow load	1.0 kN / m^2

The ground properties of the building models are shown in Table 7. Normal floor formwork plans based on their slab types are illustrated in Fig. 3. Three-dimensional calculation models of only 4-storey buildings by slab types are shown in Fig. 4.

Table 7. Soil information of the buildings.

Soil Class	S_s	S_1	S_{DS}	S_{D1}	PGA	PGV
ZD	1.622	0.444	1.622	0.444	0.659	53.480

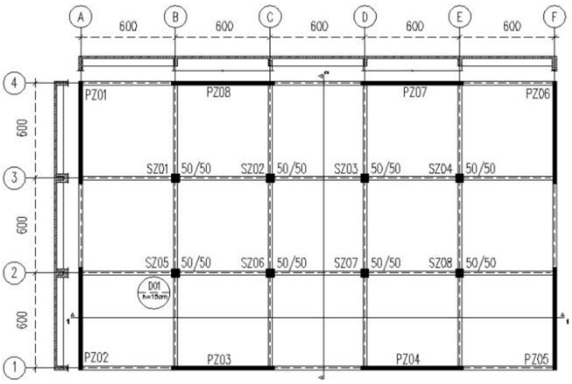
5. Comparison of Analysis Results

The building periods, base shear forces, maximum displacements and relative storey drifts obtained from the analyses are compared below. Earthquake load reduction coefficients in the X and Y direction used directly in the calculation of reduced design spectral accelerations corresponding to 4 different slab types are shown in Table 8.

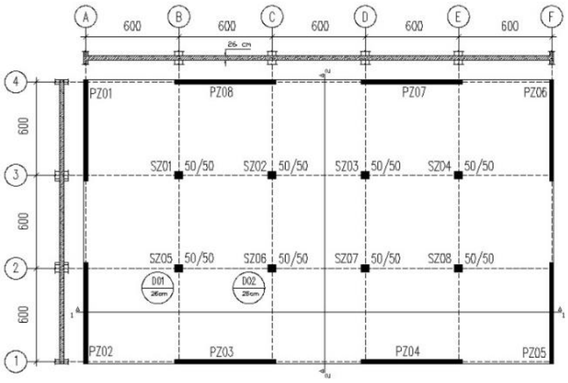
Table 8. Earthquake load reduction coefficients.

Slab Type	3 storey		4 storey		5 storey	
	$R_a(T_X)$	$R_a(T_Y)$	$R_a(T_X)$	$R_a(T_Y)$	$R_a(T_X)$	$R_a(T_Y)$
Type A	3.678	3.678	4.340	4.35	5.146	5.173
Type B	3.823	3.940	4.539	4.629	5.428	5.511
Type C	3.699	3.706	4.367	4.381	5.166	5.208
Type D	3.420	3.519	3.903	3.952	4.493	4.503

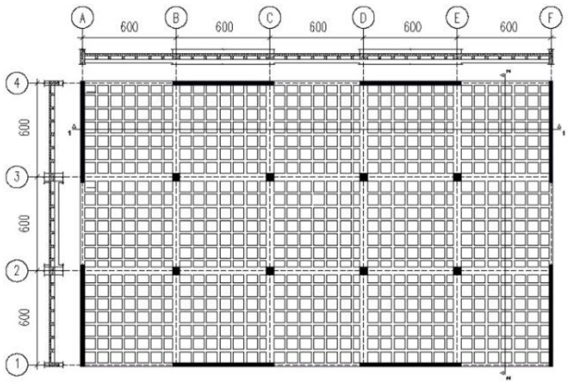
When the slab types are compared, it can be seen from Table 9 that the earthquake load reduction coefficients increase as the number of floors increases. It is known that natural periods increase with increasing number of floors. In this context, it can be said that earthquake load reduction coefficients are directly proportional to the period. Reduced design spectral accelerations of Type A, Type B, Type C and Type D structures designed according to 4 different slab types are shown in Table 9.



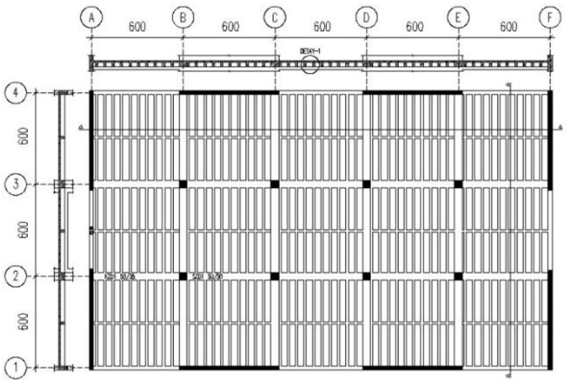
Type A



Type B

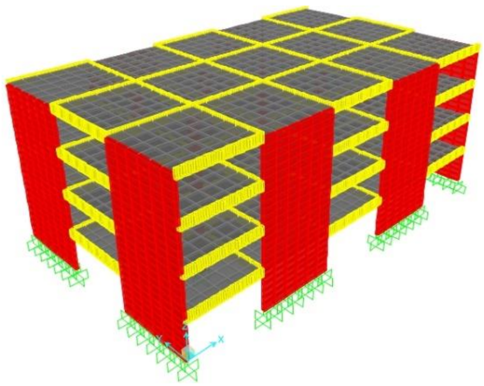


Type C

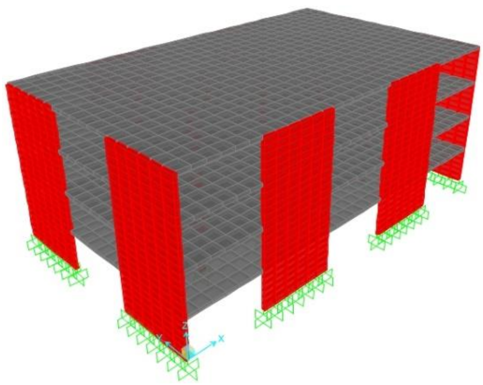


Type D

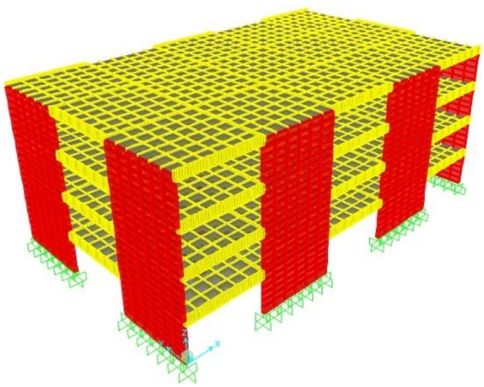
Fig. 3. Formwork plan.



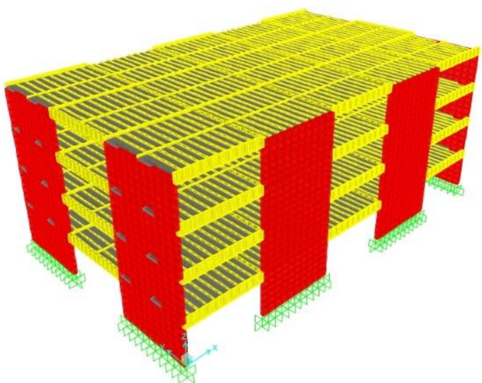
3D calculation model of the Type 4A building



3D calculation model of the Type 4B building



3D calculation model of the Type 4C building



3D calculation model of the Type 4D building

Fig. 4. Finite element models of buildings with different types of slabs.

Table 9. Reduced design spectral accelerations

Slab Type	3 storey		4 storey		5 storey	
	$SaR(T_X)$	$SaR(T_Y)$	$SaR(T_X)$	$SaR(T_Y)$	$SaR(T_X)$	$SaR(T_Y)$
Type A	0.441	0.441	0.374	0.373	0.315	0.314
Type B	0.424	0.412	0.357	0.350	0.299	0.294
Type C	0.439	0.438	0.371	0.370	0.314	0.311
Type D	0.474	0.461	0.416	0.410	0.361	0.360

When the slab types are compared among themselves, it is seen that the reduced design spectral accelerations decrease as the number of floors increases. The building weights of Type A, Type B, Type C and Type D building models are given in Table 10.

Table 10. Weights of structures.

Slab Type	Weights (kN)		
	3 storey	4 storey	5 storey
Type A	18403	25085	31766
Type B	21136	28778	36421
Type C	19409	26468	33527
Type D	19409	26468	33527

When the building weights given in Table 10 are compared, it can be seen that the flat slab Type B building models are the heaviest and the beam slab Type A building models are the lightest. Weights of ribbed slabs Type D buildings and waffle slab Type C buildings are almost the same. Comparing the building weights in percentage, Type B buildings with flat slabs was 13% heavier than beamed slab Type A buildings, 8% heavier compared to waffle slab Type C buildings and 8% heavier than one way ribbed slab Type D buildings. The natural vibration periods in the X and Y directions of the buildings modeled based on 4 different slab types and the number of floors are provided in Table 11.

Table 11. Natural vibration periods (sec) in X and Y directions.

Slab Type	X direction			Y direction		
	3 storey	4 storey	5 storey	3 storey	4 storey	5 storey
Type A	0.171	0.267	0.384	0.171	0.269	0.388
Type B	0.192	0.296	0.425	0.209	0.309	0.437
Type C	0.174	0.271	0.387	0.175	0.273	0.393
Type D	0.187	0.285	0.405	0.207	0.295	0.407

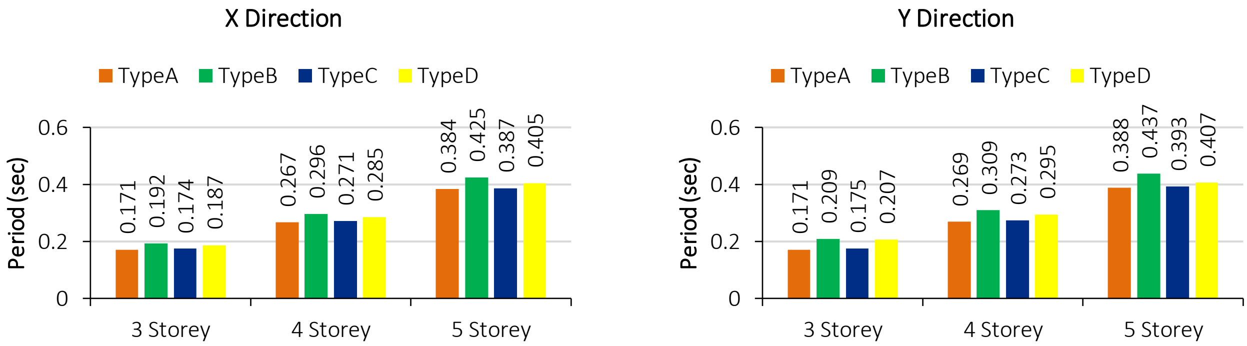


Fig. 5. Natural periods in X and Y directions.

Fig. 5 shows the comparison of natural periods in X and Y directions. Initially we compared the periods in the X direction of Type 3B (3-storey model) with different building models. We have observed that it had an 11% larger period compared to Type 3A building, 9% larger than the Type 3C and 3% larger than the Type 3D building models. Similarly, the natural periods in X direction of Type 4B building had a 10% larger period compared to Type 4A building, 8% larger than the Type 4C building and 4% larger than the Type 4D building. Finally, the natural vibration periods in the X direction of Type 5B building had a 10% larger period compared to Type 5A building, 9% larger than the Type5C building and 5% larger than Type5D building. The period of Type B building was the largest followed by type D building models in all three different storeys. Type A buildings had the smallest period in all three storeys. Next we compared the natural vibration periods in Y direction of Type 3B building with the remaining three building types. It could be seen that Type 3B had an 18% larger period compared to Type 3A building, 16% larger than the Type 3C and 1% larger than the Type 3D building models. Additionally, the natural periods in Y direction Type 4B building had a 13% larger period compared to Type 4A building, 12% larger than the Type 4C building and 5% larger than the Type 4D building. Lastly, the natural vibration periods in the Y direction of Type 5B building had an 11% larger period compared to Type 5A building, 10% larger than the Type 5C building and 7% larger than Type 5D building. Similar to the X direction, the period of Type B building in the Y direction was the largest followed by type D building models in all three different storeys. Type A buildings had the smallest period in all three storeys.

Total base shear force values in the X and Y directions, which are modeled with respect to 4 different slab types and floor volumes, are different from the horizontal earthquake forces (EXP and EYP) of Type A, Type B, Type C and Type D buildings as presented in Table 12.

Table 12. Base shear forces (kN) in X and Y directions.

Slab Type	X direction			Y direction		
	3 storey	4 storey	5 storey	3 storey	4 storey	5 storey
Type A	8115	9374	10013	8115	9354	9960
Type B	8968	10283	10883	8701	10084	10720
Type C	8511	9831	10526	8495	9800	10442
Type D	9204	11001	12103	8947	10864	12077

As it can be seen that in both X and Y directions, the largest base share forces values are in ribbed (hollow core) slab Type D building models, Followed by flat slab Type B, waffle slab Type C and beam slab Type A building models,

The lowest base shear force values can be found in the Type A building models with beam slabs, Although the building weights of Type C and Type D building models were the same, the base shear force values yielded different results (Fig. 6), This is due to the direct change of periods because of the arrangement of ribs in two directions in the plan in waffle slab systems,

Fig. 6 shows the comparison of base shear forces in X and Y directions of different types of building and with three different storeys. Initially, we compared the base shear force of Type 4D (4-storey model) with different building models. We have observed that Type 4D had a 15% bigger base shear force compared to Type 4A building, 11% bigger than the Type 4C and 7% bigger than the Type 4B building models. In addition, the base shear force in X direction of Type 5D building had a 17% larger base shear force compared to Type 5A building, 13% larger than the Type 5C building and 10% bigger than the Type 5B building. Next, we compared the base shear forces in Y direction of Type 3D building with the remaining three building types. It could be seen that Type 3D had a 9% bigger shear force compared to Type 3A building, 5% larger than the Type 3C and 3% bigger than the Type 3B building models. Additionally, the base shear force in Y direction Type 4D building had a 14% bigger base shear force compared to Type 4A building, 10% bigger than the Type 4C building and 7% larger than the Type 4B building. Lastly, the base shear forces in the Y direction of Type 5B building had a 18% bigger base shear force compared to Type 5A building, 14% larger than the Type 5C building and 11% larger than Type 5B building.

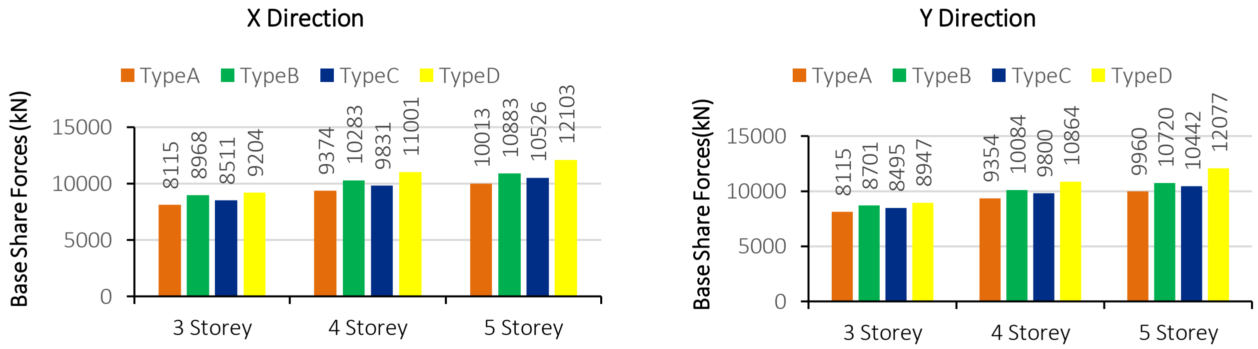


Fig. 6. Base shear forces in X and Y directions.

Maximum horizontal displacements consisting of EXP and EYP earthquake loads in X and Y directions are shown in Table 13. As seen in Table 13, the largest displacement values in the direction of X and Y are seen in the Type D building models with ribbed slabs while the smallest displacement values are in the Type A building models with beam slabs. The displacement values of the flat slab Type B and ribbed (hollow block) slab Type D buildings are close to each other as can be seen in Table 13.

Fig. 6 compares the maximum displacements in X and Y directions of the top floor of different types of building and with three different storeys. Initially, we compared the maximum displacement in X direction of top floor of Type 3D (3-storey model) with different building models. We have observed that the Type 3D had a 32% bigger maximum displacement compared to Type 3A building, 30% larger than the Type 3C and 1% bigger than the Type 3B building models. In addition, the top floor of Type 4D had a 25% bigger maximum displacement compared to Type 4A building, 24% larger than the Type 4C and 5% bigger than the Type 4B building models. Finally, the maximum displacement in X direction of top floor of Type 5D building had a 18% larger maximum displacement compared to Type 5A building, 23% larger than the Type 5C building and 8% bigger than the Type 5B building. Next we compared the maximum displacement in Y direction of top floor of Type 3D (3-storey model) with different building models. We have observed that the top floor of Type 3D building had a 9% bigger maximum displacement compared to Type 3A building and 6% larger than the Type 3C. The maximum displacements of Type 3B and Type 3D were close to each other. In addition, the top floor of Type 4D had a 10% bigger maximum displacement compared to Type 4A building and 8% larger than the Type 4C. The maximum displacements of top floor of Type 4B and Type 4D were close to each other. Finally, the maximum displacement in Y direction of top floor of Type 5D building had a 13% larger maximum displacement compared to Type 5A building, 11% larger than the Type 5C building and 3% bigger than the Type 5B building.

Control values of effective relative storey drift of the top floors of buildings in X and Y directions are shown in

Table 14. The values of relative storey drifts are compared to each other (Fig. 7). For all the building models, the ratio of effective relative storey drifts in both directions to the height of the floor was found below the limit value of 0,008 which is permitted by the design codes.

Table 13. Maximum horizontal displacements (mm) in X and Y directions.

Slab Type	X direction			Y direction		
	3 storey	4 storey	5 storey	3 storey	4 storey	5 storey
Type A	5,75	12,89	25,54	6,08	13,68	25,09
Type B	8,36	16,38	28,33	6,58	14,99	27,74
Type C	5,92	13,12	23,71	6,28	14,03	25,52
Type D	8,42	17,18	30,96	6,70	15,19	28,69

Table 14. Control of effective relative story drift in X and Y directions.

Slab Type	X direction			Y direction		
	3 storey	4 storey	5 storey	3 storey	4 storey	5 storey
Type A	0.00227	0.00399	0.00595	0.00242	0.00425	0.00638
Type B	0.00292	0.00478	0.00695	0.00262	0.00468	0.00712
Type C	0.00234	0.00403	0.00593	0.00249	0.00434	0.00644
Type D	0.00275	0.00437	0.00649	0.00219	0.00395	0.00607

Fig 8. illustrates the relative storey drifts of the top floors of all the building models in X and Y directions. Initially, we compared the storey drifts in the X direction of Type 3B (3-storey model) with different building models. We have observed that it had 22% larger storey drift compared to Type 3A building, 20% larger than the Type 3C and 6% larger than the Type 3D building models. Similarly, the storey drift in X direction of the top floor of Type 4B building had a 17% larger drift compared to Type 4A building, 16% larger than the Type 4C building and 9% larger than the Type 4D building. Finally, the storey drift in the X direction of the top floor of Type 5B building had a 14% larger storey drift compared to Type 5A building, 15% larger than the Type 5C building and 7% larger than Type 5D building. The storey drift of Type B building was the largest followed by type D building models in all three different storeys, Next, we compared the storey drifts in the Y direction of the top floor of Type 3B (3-storey model) with different building models. We have observed that it had 8% larger storey drift compared to Type 3A building, 5% larger than the Type 3C and 16% larger than the Type 3D building models. Similarly, the storey drift in Y direction of the top floor of Type 4B building had a 9% larger drift compared to Type 4A building, 7% larger than the Type 4C building and 16% larger than the Type 4D building. Finally, the storey drift in the Y direction of Type 5B building had a 10% larger storey drift compared to Type 5A building, 10% larger than the Type 5C building and 15% larger than Type 5D building. The storey drifts of Type B building were the largest and the storey drift of Type D building models were the smallest in all three different storeys,

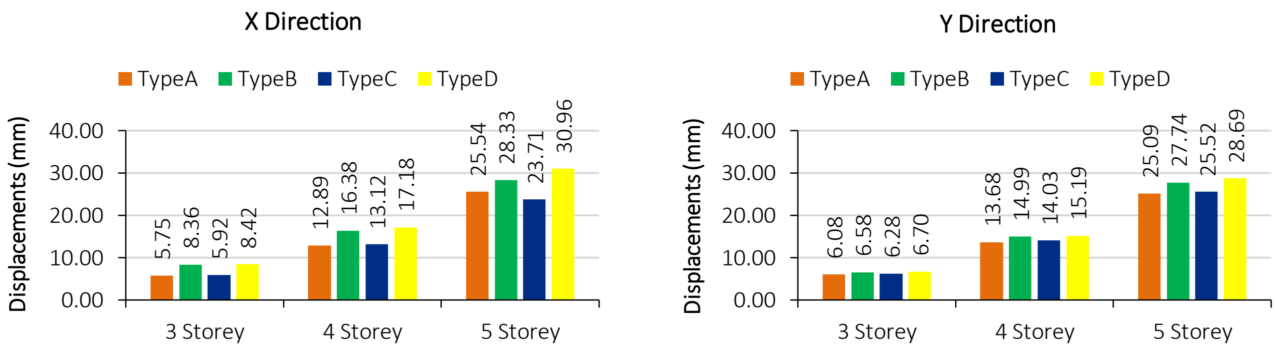


Fig. 7. Maximum lateral displacements in X and Y directions.

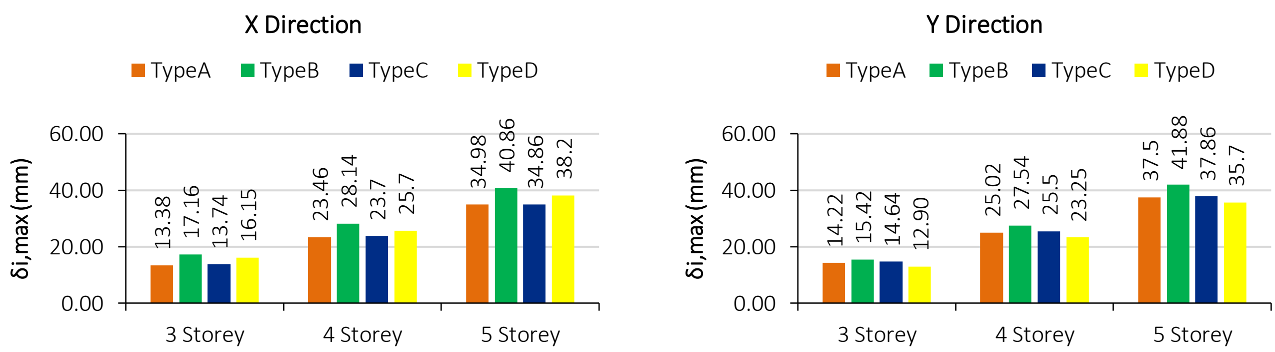


Fig. 8. Relative storey drifts in X and Y directions.

6. Conclusions

The horizontal loads that will affect the structure due to the earthquake are transferred to the carrier system elements by means of floors. During the transfer of these loads, the floor does not wrinkle and the loads can be transported properly only if the rigidity of the flooring is high. Thus, a true diaphragm behavior can be mentioned.

In the study, Earthquake calculations of model builds were analyzed by assuming full rigid diaphragm with beamed slab and waffle slab structures. Flat slab models and one way ribbed (hollow core) slab models were analyzed by assuming semi-rigid diaphragm. Rigid diaphragm behavior can be assumed in the direction of ribs in one way ribbed (hollow) slab systems. But assuming full rigid diaphragm behavior in the direction perpendicular to the ribs will give incorrect results. Therefore it is recommended to calculate such slab systems by assuming semi rigid diaphragm as a whole. Building systems can easily change shape during an earthquake as the beams is not embedded in slab, it is recommended to assume a semi-rigid diaphragm the calculations.

As we evaluated the effect of changing slab types on building natural periods, it was observed that the biggest periods in the X and Y direction were in flat slab Type B building models. The fact that the buildings with flat slabs have a big natural period is because their horizontal stiffness is less compared to other slab types. One way ribbed slabs Type D had the second biggest natural period followed by waffle slab Type C. The beam slab Type A buildings had the smallest period in all three storeys among all building models. The periods of beam slab Type A and waffle slab Type C buildings were very close to each other,

When the effect of the changing slab types on base shear forces was examined, it could be seen that the biggest base shear force values in the X and Y direction are in the Type D building models. Type B building models had the second and Type C building had the third biggest base shear forces. Type A building had the smallest base shear force,

The largest displacement values in the X and Y directions were obtained in one way ribbed slab Type D building models and the smallest displacement values were in the beamed slab Type A building models. The maximum displacement in Type B and Type D were close to each other while the maximum displacements of Type A and Type C were closes to each other.

All building models in the study were analyzed with the SAP2000 V20 finite element program according to TBDY (2018). C30/37 concrete and B420C reinforcement steel were used as materials in all analyzes. It has been accepted that the buildings will be built in Sakarya -Erenler district and the ground classes are ZD. It is assumed that all building models in the study are fixed to the foundation and foundation calculations are excluded. The effect of different slab type on the dynamic characteristics of the building can be re-examined by changing all these assumptions as material and soil type.

The buildings seismic analyzed in the study have a symmetrical plan, shear walls on the outer axes and coincide the center of mass and the center of rigidity . They have no irregularities specified in TBDY (2018). In other words, the most favorable situations have been considered. It is certain that different results will be obtained in different design styles.

The study has concluded that it is recommended to use beamed slab systems in areas with high risk of earthquakes. Frames formed by beams, columns and walls created in beamed slab, hollow slab and waffle slab systems are of great importance in terms of the horizontal rigidity of the system.

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