THE EFFECTS OF THE TYPE OF SLAB ON STRUCTURAL SYSTEM IN THE MULTI-STOREY REINFORCED CONCRETE BUILDINGS

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ABSTRACT :

It becomes so important to know the behaviour of reinforced concrete, determine all possible earthquake loading effects on reinforced concrete buildings correctly and design the structural system so as to resist seismic effects. Correct determination of seismic load effects on the structural system is important not only in multi-storey buildings but also in general residential buildings. In this study, the effects of slab types on the behaviour of load carrying systems are analysed on multi-storey reinforced concrete buildings under seismic loads according to the rules and regulations of the current Turkish Earthquake Code (TEC). Slab openings in floor systems may cause irregularities in the horizontal plane according to the earthquake code. Analysis of the case in which the slab openings are formed very close to the vertical load carrying elements is also included in this study. The results obtained from all the analyses carried out and all the works done in this study are explained and summarized with diagrams.

KEYWORDS : Slabs, R/C building, earthquake code, seismic analysis

1. INTRODUCTION

In last 30 years the decrease in living areas, the purpose of using remaining spaces in most efficient ways and the wishes of big companies to build big prestigious buildings for their owns resulted in a considerable increase in the number of multi-storey buildings in our big cities together with other countries. In developed countries multi-storey buildings are generally constructed with steel. However, in our country the use of structural steel in multi-storey buildings has not been yet started due to both economical reasons and the lack of skilled labour and special equipments. For these reasons it becomes so important to know the behaviour of reinforced concrete, determine all possible earthquake loading effects on reinforced concrete buildings correctly and design the structural system so as to resist seismic effects. Correct determination of seismic load effects on the structural system is important not only in multi-storey buildings but also in general residential buildings.

In this study, the effects of slab types on the behaviour of load carrying systems are analysed on multi-storey reinforced concrete buildings under seismic loads according to the rules and regulations of the current Turkish Earthquake Code (TEC) namely, specification for structures to be built in disaster areas. Slab openings in floor systems may cause irregularities in the horizontal plane according to the earthquake code. Analysis of the case in which the slab openings are formed very close to the vertical load carrying elements is also included in this study.

The scope and the main idea of this study are explained in detail in the first part. The slab systems are explained and the roles of slabs among the whole load carrying systems are examined. The buildings having floor irregularities are explained and the earthquake regulations related to the construction of these buildings are mentioned. The rigid diaphragm and flexible slab modelling are explained and compared. A 17-storey building is choosen as an example and on that building the structural system elements are designed with three different slab systems. Moreover, the modal analysis results are examined. In order to understand the differences between rigid diaphragm and flexible slab modelling, a number of same buildings are analysed and the results are interpreted. Also, A2 and A3 type irregularities in TEC are examined both modelling methods. In the conclusion part, the results obtained from all the analyses carried out and all the works done in this study are explained and summarized with diagrams.

2. TURKISH EARTHQUAKE CODE, TEC 2007

The Turkish Code for the structures in disaster regions which came into operation in 1975, has become inadequate due to advancements in structural technology and earthquake engineering over the years. Aiming at improving the code, a code more consistent with the current requirements took effect in 1997 and 2007. The base shear force is computed by using Eqns. 1.1 and 1.4 as

$$A(T)=A_0 IS(T) \quad (1.1)$$

$$S(T)=1+1.5\ T/T_A \quad (0=T=T_A)\ , \quad S(T)=2.5 \quad (T_A<T=T_B)\ , S(T)=2.5(\ T_B/T)0.8 \quad (T>T_B) \quad (1.2)$$

$$R_a(T)=1.5+(R-1.5)\ T/T_A \quad (0=T=T_A) \quad , \quad R_a(T)\ =R \quad (T>T_A) \quad (1.3)$$

$$V_t=W.A(T_1)/R_a(T_1) \qquad A(T_1)/R_a(T_1)=C \quad (1.4)$$

with respect to the TEC 98 and TEC 07. Here, A_0, denoting the effective ground acceleration coefficient, takes the values 0.10g for the 4th and 0.40g for the 1st degree seismic risk zones, respectively. I, the structural importance factor, takes values varying in between 1 and 1.5 and takes 1 for a conventional reinforced concrete structure. S(T), the spectrum coefficient, is represented by a curve which gives the values of design acceleration spectrum varying with the natural period, T, of the structure. The type of the curve differs depending on the ground characteristics and each curve type gives a value of 2.5 at maximum. T_B, in Eqn. 1.3, is the corner period appointed regarding the ground type R_a, defined as the earthquake reduction or behavioural coefficient, is the indicator of the structural ductility adopting values varying between 3 and 8. For frame and frame-shearwall structures, the coefficient becomes 8 and 7, respectively. One of the fundamental changes in the 1998 Code is the dual classification of the structural systems namely those with high ductility and normal ductility. With regulations on detailing given in the Code, structural systems possessing high ductility values can be designed. With higher ductility values, conditions given in the Code for detailing, which are directly in correlation with the structural ductility, such as the stirrup spacing, calculations of column-beam intersection zones, arrangement of the compression reinforcement in the cross-section, and concrete quality have been becoming rigorous to satisfy the reduction of the C coefficient in the earthquake load computation. Thus the structure has been rewarded for ductile behaviour. The converse holds true for systems, in which ductility levels are normal. Under intensive seismic motions, due to the elasto-plastic deformation owing to ductility, large lateral displacements form, resulting in the formation of secondary moments. To keep secondary moments at a minimum, inter-storey drifts, in other words, the relative storey displacements, have been limited in the Code.

Structural systems are classified as;

a) Frame systems with slab-beam and grid slabs,
b) Shear-wall systems,
c) Flat plate slab systems.

The ductility levels of these systems may be high, normal and mixed. Building structural systems and structural behaviour factors R are given in Table 2.1 according to TEC 98-07.

Table 2.1 Building structural systems and structural behaviour factors (R)

System	Shear wall	Ductility level	R	Conditions	
Frame Systems	No	High	8	Usable in all cases	
		Normal	4	I<1.4	No usable in 1.° - 2.° region For 3.°- 4.° , $H_n \leq$ 25 m,13 m ***
	Yes	High	6-7 *	Usable in all cases	
		Normal	4	I<1.4	$\alpha_M > 0.75$
		Mixed	5.2-7 **	$\alpha_M \geq 0.40$	
Solid structural walls	Yes	High	6	Usable in all cases	
		Normal	4	I<1.4	
Coupled structural walls	Yes	High	7	Usable in all cases	
		Normal	4	I<1.4	
With flat slab systems	No	Normal	4	I<1.4	No usable in 1.° - 2.° region For 3.° - 4.° , $H_n \leq$ 13 m
	Yes	Normal	4	I<1.4	$\alpha_M > 0.75$
		Mixed	5.2-7 **	$\alpha_M \geq 0.40$	

* If $\alpha_M < 0.75$, R = 7
** If $0.75 < \alpha_M < 1.00$, $R = 10 - 4\alpha_M$
*** For slab-beam systems, 25 m. and for grid slab systems, 13 m.

3. NUMERICAL EXAMPLES

3.1. The Effect of Slab System on Structural Behaviour

For this purpose, a structural model having 3-18 storey is choosen. According to slab types, three building systems occur; Building 1 (Bina-1, slab-beam system), Building 2 (Bina-2, grid slab system), Building 3 (Bina-3, flat plate slab system). Consisting of 1 basement story, 1 ground story and 1-16 normal stories the building is a 3-18-story reinforced concrete structure. Structural system of the building is formed with rectangular columns, polygon shaped shear walls and beams. The structural system is symmetrical in two direction. Structural system is modeled as high ductility moment resisting frame system. Building is in the 1st degree earthquake zone and Z2 local site class is assumed. Material types used in the project are C25 and S420. In seismic analysis of the sample structure, equivalent earthquake force method and mode superposition method are used. In structural analysis, SAP2000 Structural Analysis Program is used.

The following results are obtained from these calculations;

- The frames are very important for lateral rigidity of three building systems.
- In high seismic risk regions, beam-slab systems having high lateral rigidity shouls be preferred.
- The grid slab systems provide a rigid diaphragm behaviour. The structures with these slabs have very important lateral displacements and structural periods.
- In flat plate slabs systrems, all of the earthquake loads should be carried with shear-walls in two directions.
- The slab type is very important for choosing of ductility level and structural behaviour coefficient.
- System lateral rigidity is bigest in beam-slab systems. Lateral displacements and structural periods increase in the flat plate slab systems (Fig 1).
- Structural periods increase with storey number and high of building. The relative storey

displacements have been limited in the Code (Fig 2).

- In the varying of base shear load V_t, the first natural period of structure T_1 and the spectrum characteristic periods T_A and T_B are very important (Fig 3).

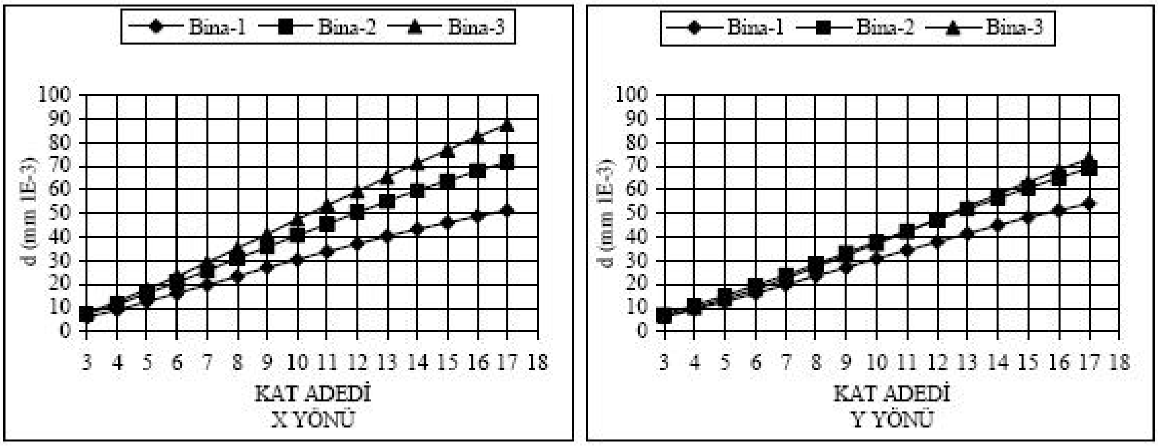


Figure 1 Displacements of S1 column in x and y directions
(Kat adedi=story number; x yönü=x direction; Bina=building)

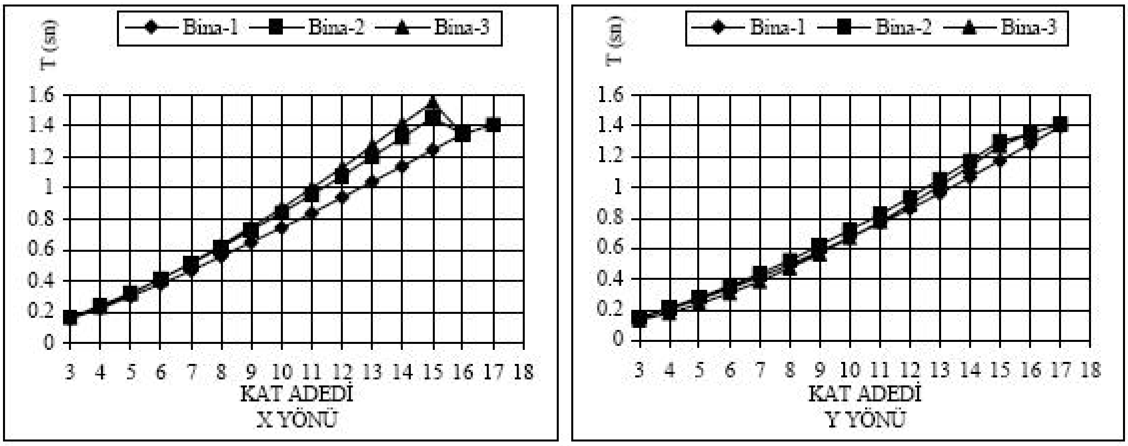


Figure 2 Natural periods in x and y directions
(Kat adedi=story number; x yönü=x direction; Bina=building)

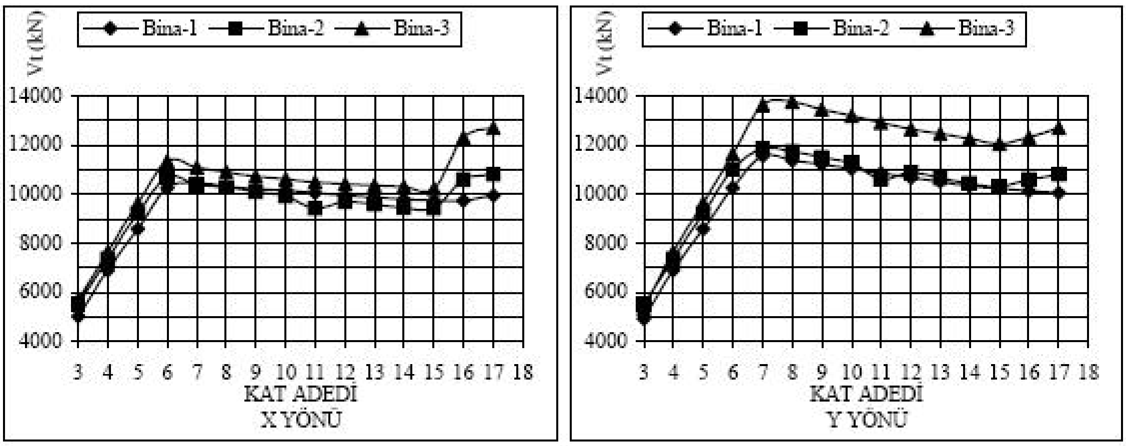


Figure 3 Base shear loads in x and y directions
(Kat adedi=story number; x yönü=x direction; Bina=building)

- In structure with low period and little storey number, the effect of soil type on base shear load V_t is not very much. In multi-storey structures, this load takes very big values for poor soils (Fig 4).
- The effect of shear-wall behaviour increase on low-storey structures.

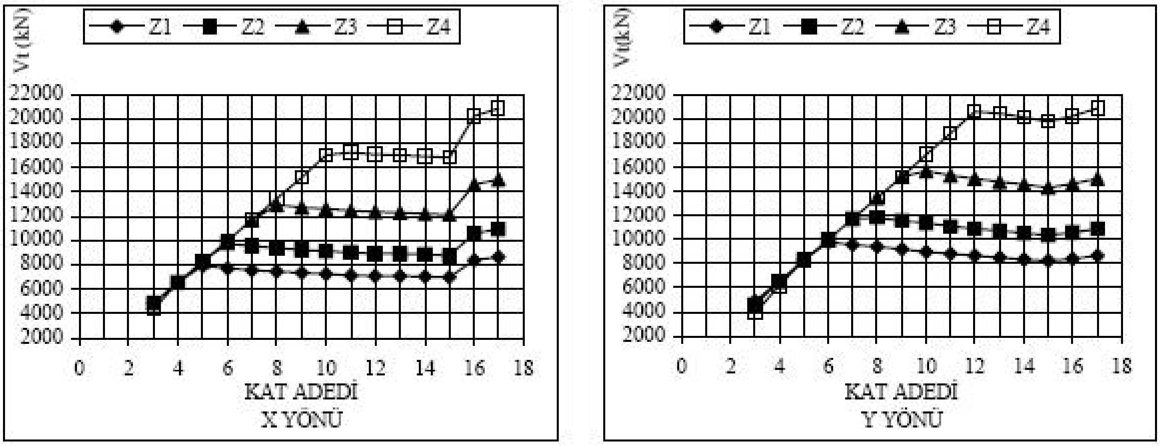


Figure 4 Base shear loads of Building3 in x and y directions (according to soil type)
(Kat adedi=story number; x yönü=x direction; Bina=building)

3.2. The Effect of Rigid Diaphragm and Flexible Slab Modelling on Structural Behaviour

The five sample structures are examined as an example. For this purpose, structures are analyzed under the assumption of the rigid diaphragm and flexible behavior of floor slabs.

3.2.1 Example 1

Building has a rectangular area of 30m x 12m in plan. Spans are 6.00m in two directions. The height of storey is 3.00m. The structural system is frame and shearwall-frame system in x and y direction, recpectively (Fig 5).

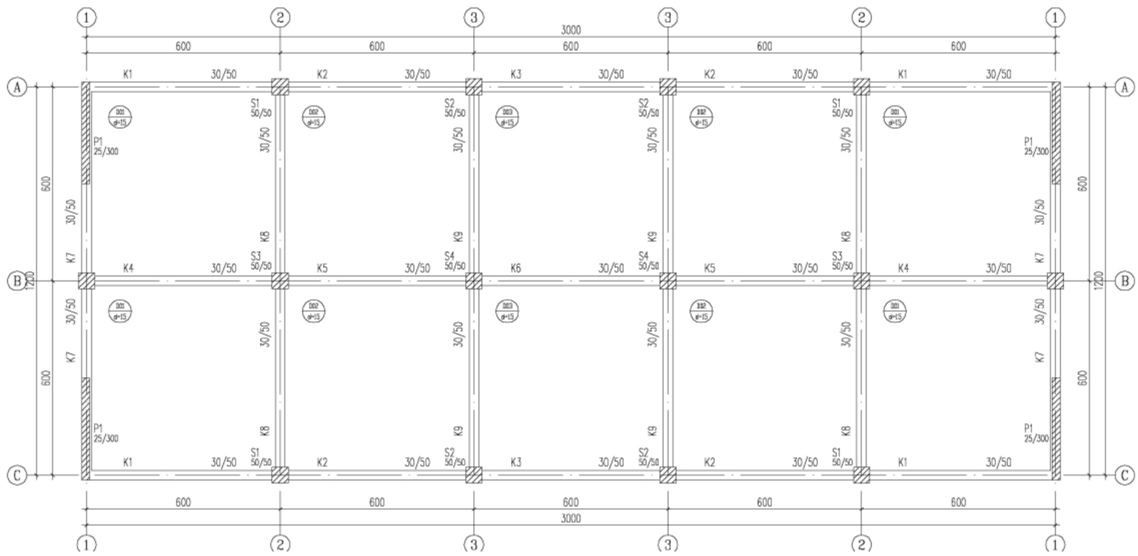


Figure 5 Building storey plan of example 1

The following results are obtained from calculations of example 1;

- In multi-storey structure, the structural periods obtained for rigid diaphragm and flexible slab modelling approach together, and in low-storey structures, the periods of two modellings leave from each other as shown in Table 3.1.

Table 3.1 Building periods of example 1 (1–9 story) (kat sayisi=storey number)

KAT SAYISI	1. MOD		2. MOD		3. MOD	
	R.D.	E.D.	R.D.	E.D.	R.D.	E.D.
1	0.21438	0.19922	0.05452	0.09143	0.03445	0.04311
2	0.36740	0.36766	0.13128	0.14861	0.11516	0.11582
3	0.54277	0.54294	0.23398	0.24293	0.17024	0.17068
4	0.61332	0.61345	0.33955	0.34460	0.22687	0.22789
5	0.78261	0.78276	0.46599	0.47003	0.31497	0.31576
6	0.95608	0.95621	0.60035	0.60374	0.40946	0.41011
7	1.00593	1.00604	0.69716	0.69951	0.48441	0.48495
8	1.16852	1.16864	0.83600	0.83862	0.58359	0.58418
9	1.33550	1.33563	0.98014	0.98270	0.68635	0.68693

- In multi-storey structure, the structural periods obtained for rigid diaphragm and flexible slab modelling approach together, and in low-storey structures, the periods of two modellings leave from each other as shown in Table 3.1.
- The differences of modellings occur in one storey model. Increasing the storey number, results of two medellings approach to each other. The displacement forms of one and nine storey flexible slab model in y direction are shown in Fig 6a and Fig 6b, respectively.

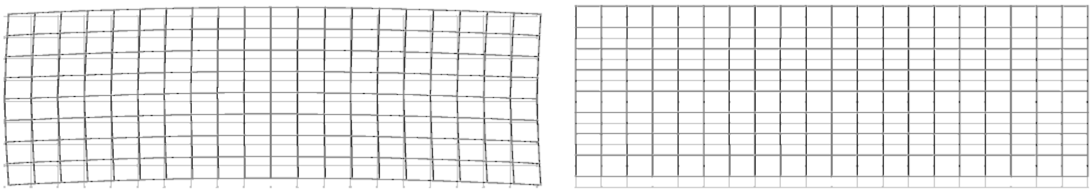


Figure 6 Deformation forms of flexible slab model in y direction; (a) One storey, (b) Nine storey

- The ratios of total shear loads of column and shear-wall to total base shear load are shown in Fig 7 for two modellings. The ratios of flexible slab model are always greater than the other modelling.

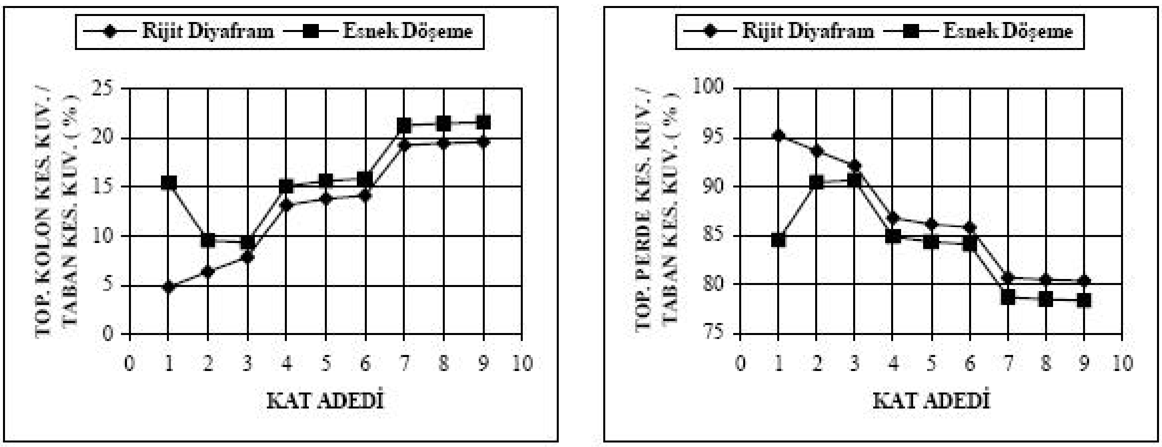


Figure 7 Base shear loads of columns and shear-walls
(Kat adedi=story number; top. kolon kes. kuv.=total column shear load; taban kes. kuv.=base shear load; top. perde kes. kuv.=total shearwall shear load; rijit diyafram=rigid diaphragm; esnek döseme=flexible slab)

3.2.2 Example 2

Building given in Fig 8 is calculated as example 1. Four different plans (example 2a, b, c, d) are formed by slab hollows in several regions. In example 2a, the ratios of total shear loads of shear-walls to total base shear load are shown in Fig 9 for two modellings.

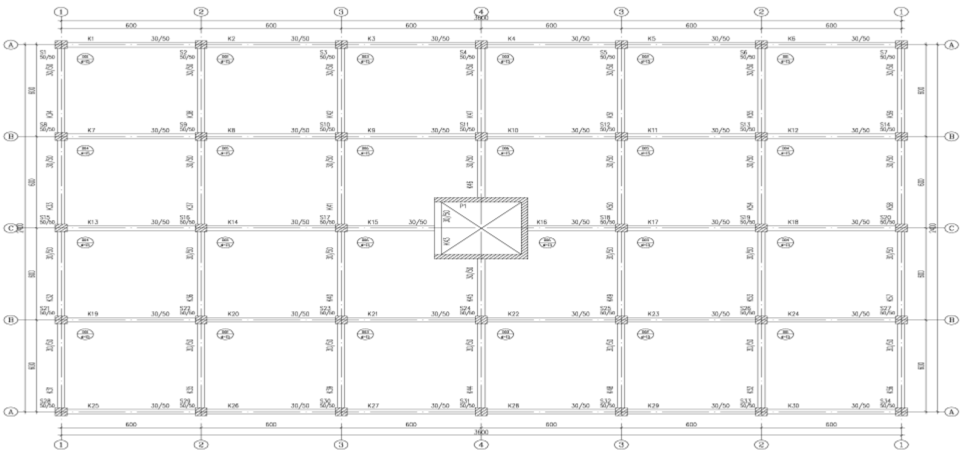


Figure 8 Storey plans of example 2a

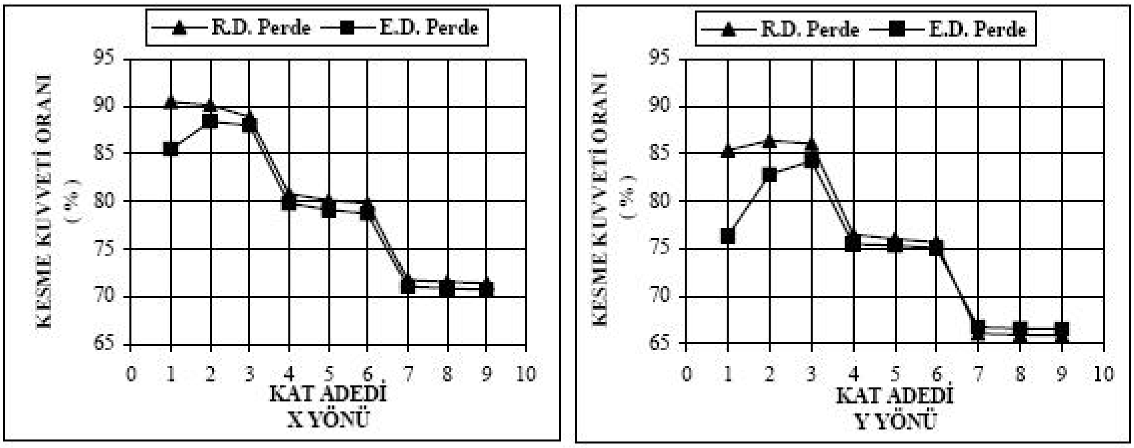
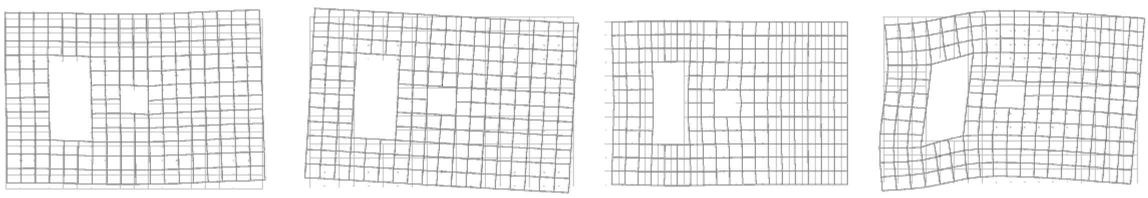


Figure 9 Shear load ratio of shear-walls of example 2a in x and y directions
(Kat adedi=story number; x yönü=x direction; y yönü=y direction; kesme kuvveti orani=shear load ratio; R.D.perde=rigid diaphragm shear-wall; E.D. perde=flexible slab shear-wall)

The following results are obtained from calculations of example 1;

- The rigid diaphragm model is usable in general for structural design. In some cases, it may be necessary to use the flexible slab modelling (Fig 10 and Fig 11).
- In multi-storey buildings, the two modellings are given same results.



Mode 1 Mode 2 Mode 3 Mode 4

Figure 10 The first four mode shapes of one story model of example 2b

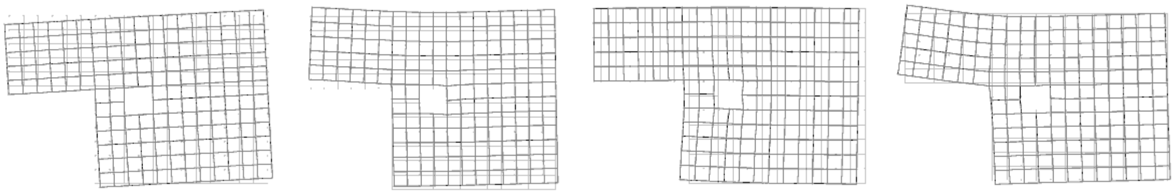


Figure 11 The first four mode shapes of one story model of example 2d

4. CONCLUSIONS

In this study, the effects of slab types on the behaviour of load carrying systems are analysed on multi-storey reinforced concrete buildings under seismic loads according to the rules and regulations of the current Turkish Earthquake Code (TEC). Slab openings in floor systems may cause irregularities in the horizontal plane according to the earthquake code. Analysis of the case in which the slab openings are formed very close to the vertical load carrying elements is also included in this study. The results obtained from all the analyses carried out and all the works done in this study are explained and summarized with diagrams.

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