

# Structural Analyses With Flexibility Effect Of The Floor Slabs

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## ABSTRACT

In general, the structure of a building can be regarded as composed of several vertical systems bounded by horizontal diaphragms. The analysis is faster if the diaphragms are assumed to be rigid.

The software analysis of the structures, assumes a rigid diaphragm for the modelling of floor slab. The floor slab flexibility is generally ignored. This assumption can be reasonable for the analysis of some types of structures. However, the floor can have a significant influence on the lateral response of the structures, if the flexibility of the floor slab is completely ignored, and lateral rigidity can be appreciably underestimated.

Within the framework of this study, the deformability of the floor in their plan is examined, under the effect of horizontal seismic actions.

The results obtained such as the seismic response as well as displacements, periods of vibrations and shear forces show the difference of assumed type of diaphragm floor.

*Key words: diaphragm, rigid floor, flexible floor, flexibility of the floor slab, rigidity.*

## 1. INTRODUCTION

The Evolution of the computation software's of these last years has put the availability of the engineers the instruments which allow the development of the projects with reduced periods and costs. The finite element method and codes of calculation provided to the engineers possibilities of modelling and analysis, as well as the ability to control the model of calculation and to interpret the results.

It is generally, the modelling of the behaviour of the no rigid floors is much more complex than the rigid floors.

Since many years, simplified elastic methods of calculation were systematically used in dimensioning structures based on stick model (Figure.1.1), with concentrated masses and equivalent stiffness's, because they are easy to put and well comparable by engineer.

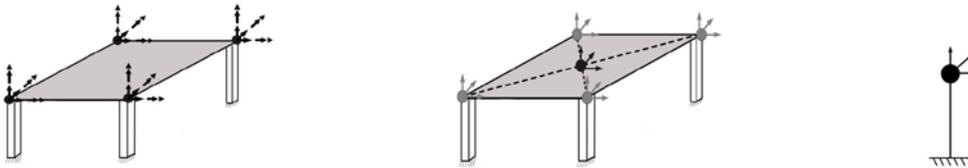
However, this approach cannot provide that limited comprehension of the real seismic behaviour, the linear response of the structure with flexible floors under seismic forces in terms of displacement, being largely unexplored.

Using codes of calculation based on the finite element methods ,thus, imposes in our work to try to approach the real behaviour of the no rigid diaphragms.

To reduce these disadvantages, some seismic regulations (European or American), recommend using specific methods based on the principle of finite elements which could give good indications on the seismic behaviour of the structure.

In the structural analysis of buildings, floor slabs are usually assumed to be rigid in their planes. At the mass centre of each rigid floor, there is a master node having three degrees of freedom to represent the two in-plane translations and one out-of-plane rotation of all the other nodes or so-called slaved nodes in this floor. These slaved nodes contain three degrees of freedom two in-plane rotations and one out-of-plane translation. This assumption, no deformation in the plane of building floors, is used widely in the structural analysis of building systems (MacLeod 1970; Wilson et al. 1975). Muto (1974) used a beam with bending and shear deformation effects to simulate the behaviour of flexible floors in buildings.

Jain (1984) also used this beam including flexible and shear deformation effects to generate a solution to find the flexible floor effect under the dynamic analysis. In recent years, due to the great improvement of computer speed and memory, simulations of building floors with flexible elements, such as plate and membrane elements, have been performed. Saffarini and Qudaimat (1992) analyzed 37 reinforced concrete buildings to compare the difference between static rigid-floor and flexible floor analyses. They found that the rigid-floor assumption is accurate for buildings without shear walls, but it can cause errors for building systems with shear walls.



**Figure 1.1.** Stick model

## 2. MODELS OF BUILDING ANALYSES

For building analyses under the rigid-floor assumption, master and slaved nodes are used (Bathe et al. 1973; Ju 1997).

Each rigid floor contains a master node with three degrees of freedom at the mass center of the floor to control the two inplane translations and one out-of-plane rotation of all the slaved nodes in this rigid floor. The slaved nodes include three additional degrees of freedom-two in-plane rotations and one out-of-plane translation. Thus, the total number of degrees of freedom is equal to three times the total number of slaved nodes and master nodes in the mesh for a three-dimensional (3D) building analysis. The numerical model of the masterslaved- node algorithm can be performed using a constraint matrix (Ju 1997).

For building analyses under the flexible-floor assumption, each node contains six degrees of freedom-three translations and three rotations. Thus, the number of degrees of freedom for the flexible-floor mesh is about twice as large as that for the rigid-floor mesh. In addition to using 3D beam elements to model the members in the building, four-node membrane elements with incompatible modes (Cook et al. 1989) and plate elements (Clough and Felippa 1968) were used to model the floor slabs. The membrane elements were also used to model the shear walls of the buildings under the rigid- or flexible- floor assumption.

In the analysis of building structures, the stick model which has 3 in-plane DOF's per floor is usually used in commercial software, such as ETABS, by applying the rigid diaphragm assumption. But if the rigid diaphragm assumption is applied, the story shear forces in the basement may be significantly overestimated since the flexibility of the floor systems is ignored.

## 2. EFFECT OF FLOOR SLABS ON SEISMIC RESPONSE

Plan types were analyzed with 5, 10 and 15 story structures. In order to emphasize the differences, the gross section of the slab was used for slab stiffness in this comparison.

Equivalent static analysis and response spectrum analysis were performed with the framed structures and the shearwall structures to investigate the effect of floor slabs on seismic response. In these analyses, two models were used for each plan type (frame and shearwall buildings). Model R uses rigid diaphragms (conventional procedure) not including the flexural stiffness of slabs as shown in Figure.2.2 and 2.4 while model F is using plate elements to introduce the flexural stiffness of slabs as shown in Figure.2.2 and 2.4.

### 2.1. Analyses of frame buildings

Dimensions frame buildings shown in figure.2.1. are 23,48m in length and 10,06m in width with 5, 10, and 15 stories defined in Table 2.1. were analyzed. These buildings contain 8 by 3 column lines, the height of story is 3.06m.

For each structure, the slabs were modeled using different methods: the rigid diaphragm method and, the refined mesh method figure 2.2.

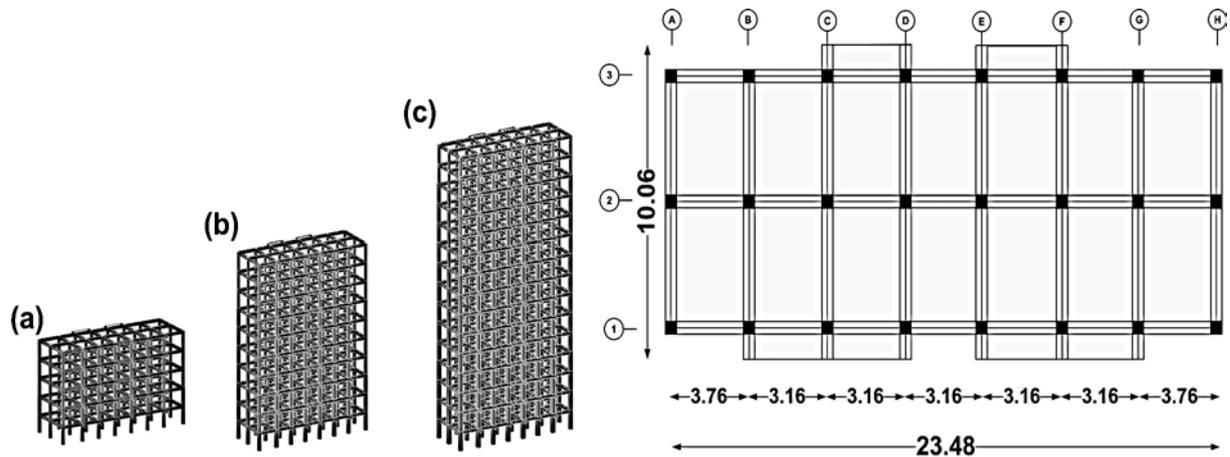


Figure 2.1. Plan view of frame buildings.

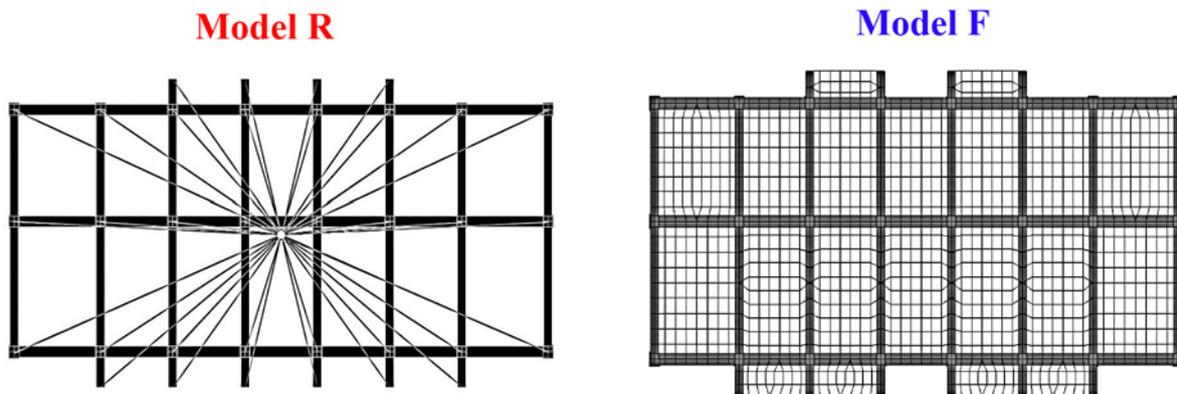


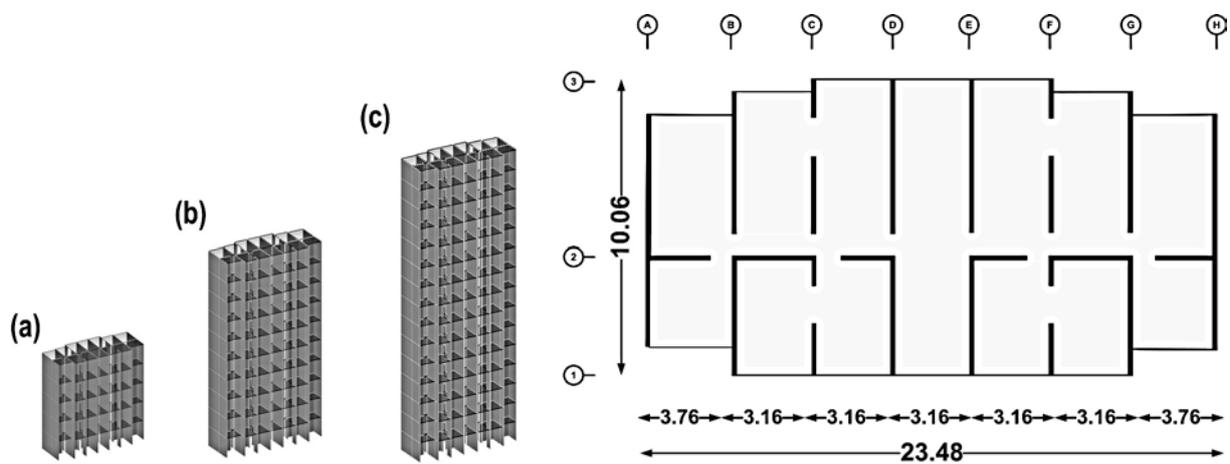
Figure 2.2 Rigid and flexible diaphragm of frame buildings.

**Table 2.1.** List of Member Sizes in Building Analyses

(a) 5-story building			
Floor	Column size (cm)	Beam size (cm)	Slab (cm)
1-3	45×45	35×45	20
4-5	35×45	35×45	20
(b) 10-story building			
Floor	Column size (cm)	Beam size (cm)	Slab (cm)
1-3	60×60	35×45	20
4-7	50×50	35×45	20
8-10	40×40	35×45	20
(c) 15-story building			
Floor	Column size (cm)	Beam size (cm)	Slab (cm)
1-4	70×70	35×45	20
5-8	60×60	35×45	20
9-12	50×50	35×45	20
13-15	40×40	35×45	20

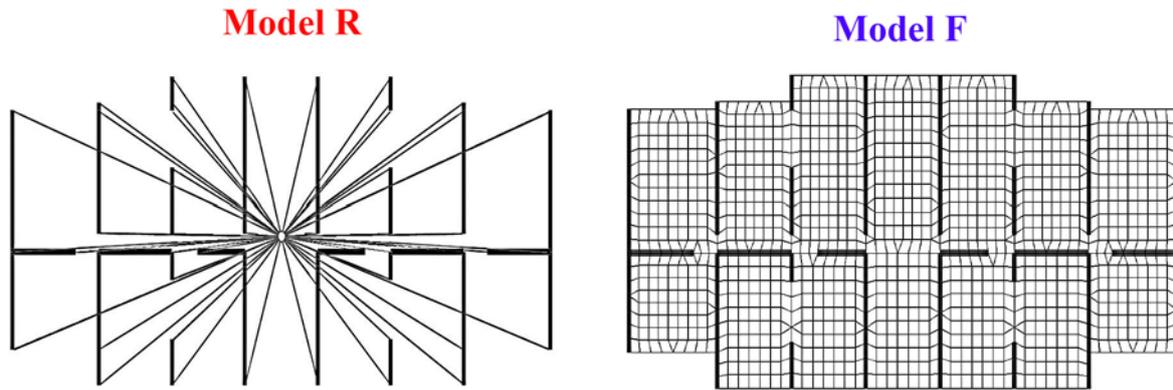
## 2.2. Analyses of shear walls buildings

A computer program ETABS was used for the analysis of those structures. With the same plan, three different structures were analyzed: Shear wall buildings with 5, 10, and 15 stories, as shown in figure 2.3. with a dimension of 23,48m in length and 10,06m in width. The thickness of the longitudinal shear wall is 16cm and transverse is 20cm.



**Figure 2.3.** plan view of shearwall buildings.

For each structure, the slabs were modeled using different methods: the rigid diaphragm method, the refined mesh method figure 2.4.



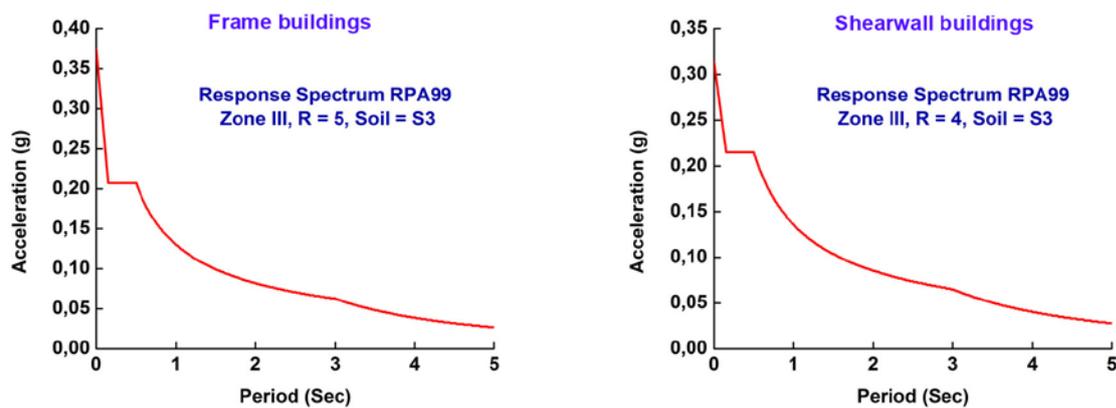
**Figure 2.4.** Rigid and flexible diaphragm of shearwall buildings.

### 3. SEISMIC RESPONSE OF DIFFERENT BUILDING SYSTEMS

Response spectrum analysis were performed with framed structures to investigate the effect of floor slabs on seismic response. In these analyses, two models were used for each plan type. Model uses rigid diaphragms, while model using plate elements to introduce the flexural stiffness of slabs. Three plan types were analyzed with 5,10, and 15 story structures.

#### 3.1. Response spectrum analysis results

The different natural periods result in different seismic responses of the structures. The design response spectrum from Algerian Seismic Code (RPA 99 version 2003) shown on figure 3.1 was used in this study. In the design of those structures the seismic zone, soil type, Behaviour factor were assumed to be III, S3, and (5 for frame structure, 4 for shearwall structure) respectively.



**Figure 3.1.** Response spectrum from Algerian Seismic Code (RPA 99 version 2003).

Model R has longer natural periods and thus less spectral accelerations than those of model F, and may be used as shown in figure 3.2. Therefore, if the flexural stiffness of the floor slab is ignored, seismic loads scaled to the code base shear may be underestimated. Even though, the difference in periods is small, the difference in the spectral acceleration becomes large in the shorter period region, because the slope of the response spectrum is steep in that region. As listed in table 3.1, the base shears of model R are less than those of model F. Therefore, in order to obtain more accurate results, it is important to include the flexural stiffness of slabs adequately based on the actual behavior of a building.

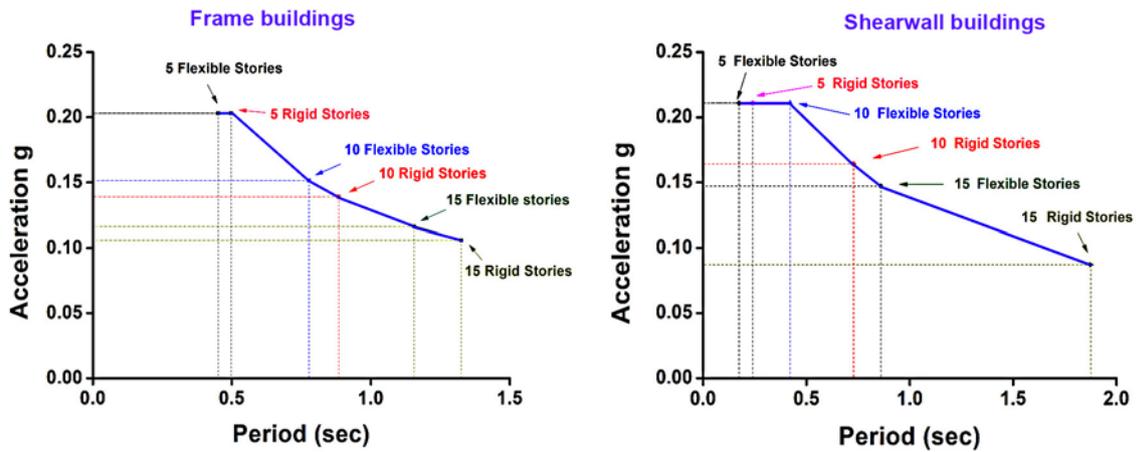


Figure 3.2. Difference of acceleration caused by modeling technique

Table 3.1. Base shear calculated from response spectrum (unit: kN)

Plan Type	Frame		Shearwall	
	Rigid	Flexible	Rigid	Flexible
5-Story	1352,27	1433.36	1552.01	1655.26
10-Story	1853.54	2210.52	2135.2	3069.23
15-Story	2452.85	3128.71	2879.27	3876.08

### 3.2. Lateral displacements

Lateral displacements for equivalent static analysis are plotted in figure 3.3 and figure 3.4 for 5 story, 10 story and 15 story structures respectively. In all cases, the lateral displacements are reduced when the flexural stiffness of slabs is included in the analysis. In the framed structures, the effects of the floor slabs are similar for 5 story, 10 story and 20 story structures as illustrated in figure 3.3. The effects are more significant, however, in 5, 10 and 15 story shearwall structures. The displacements of plan (c) show the most significant influence of the floor slabs as expected from the assumption of the strain energy stored in the slabs. The roof displacement of the 15 story framed structure with plan (a) was reduced by only 13% when the flexural stiffness of slabs is considered. The roof displacements of shearwall structures were reduced, however, by 67% and 72% with plan (b) and (c) respectively.

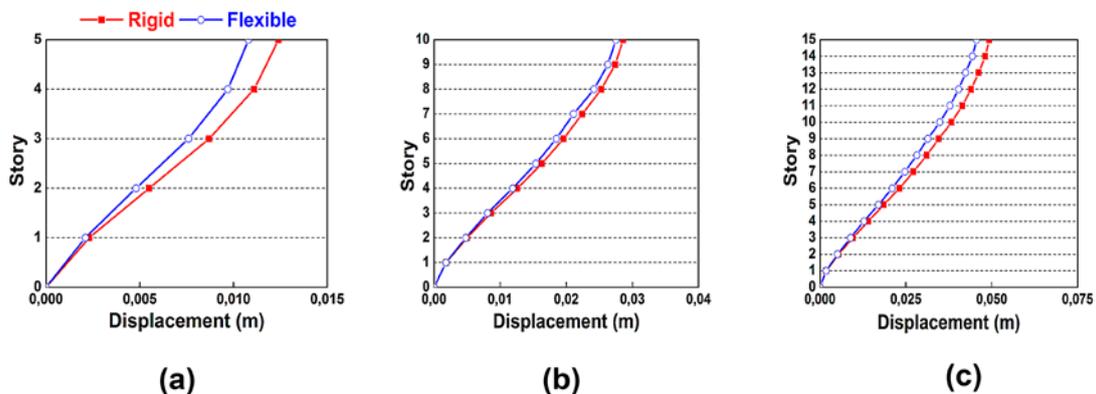


Figure 3.3. Displacements of frame story structures. (a) 5 story, (b) 10 story, (c) 15 story.

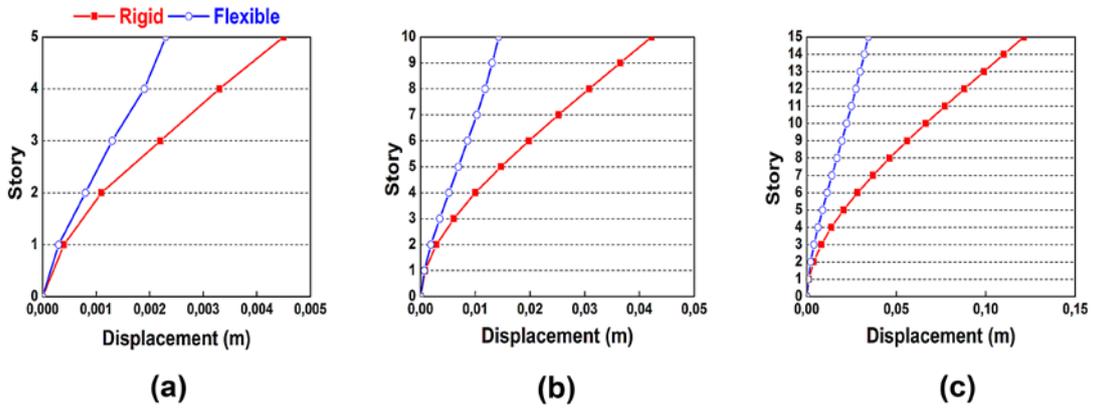


Figure 3.4. Displacements of shearwall story structures. (a) 5 story, (b) 10 story, (c) 15 story.

### 3.3. Natural periods of vibration

Natural periods of vibration for the example structures are shown in figure 3.5. and figure 3.6. for 5 story, 10 story and 15 story structures respectively. They showed that in all cases, the natural period is shorter when the flexural stiffness of the slab is included. The floor slab effects are more noticeable in shearwall structures. Differences in natural periods are more significant in the first mode which is the most important mode for the seismic response of a structure.

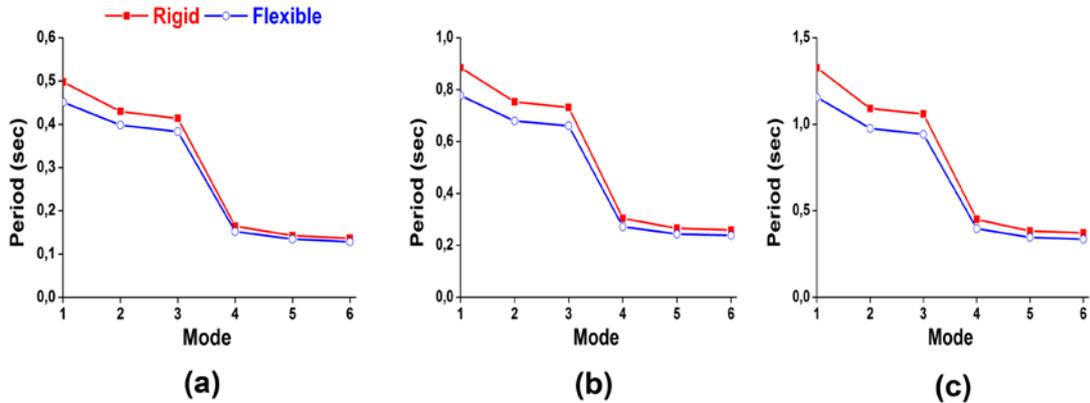


Figure 3.5. Natural periods of vibration of frame structures. (a) 5 story, (b) 10 story, (c) 15 story.

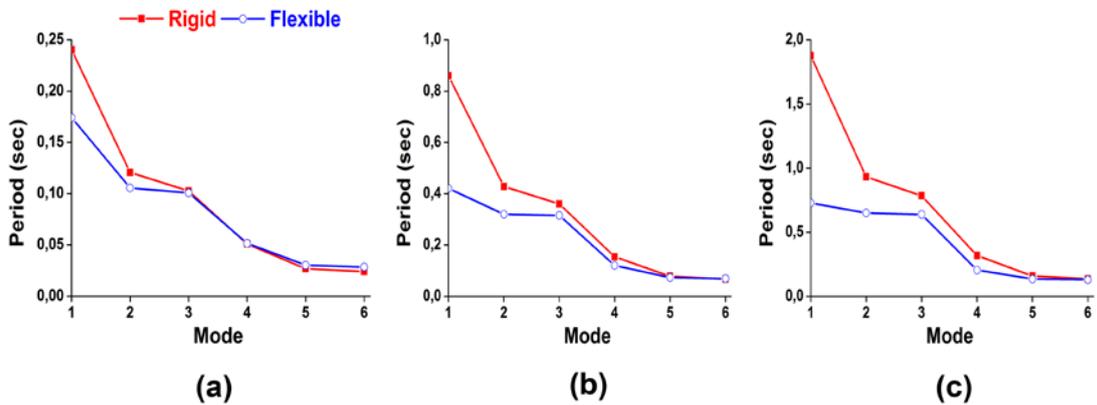


Figure 3.6. Natural periods of vibration of shearwall structures. (a) 5 story, (b) 10 story, (c) 15 story.

## 4. CONCLUSION

The work presented in this study provides the basis for numerical modeling of a rather complex structure as a floor diaphragm. Many factors that influence the mechanical behavior of the floor, make their inclusion practice difficult to implement.

The numerical model that considers the flexural stiffness of the floors of a building allows to obtain more accurate results of the real behavior of the structure. Degree and level of accuracy depend, as seen in the examples, on the structural typology of the building.

For buildings with shearwall, the effect of the flexural stiffness of slabs is relatively significant, especially in taller buildings. If the flexural stiffness of the slabs is totally ignored, the lateral displacements may be overestimated and the seismic loads per the building code base shear may be significantly underestimated. It is recommended that the flexural stiffness of slabs is adequately included in the analysis of shearwall structures.

Because of the non-uniform distribution of lateral stiffness and masses, the effects of flexible diaphragms in the typical building structure are complicated. The flexible diaphragms reduce the natural frequencies of the global structural modes.

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