INVESTIGATION OF FLOOR RIGIDITY EFFECT ON BEHAVIOR OF STEEL BRACED FRAMES

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ABSTRACT:

One of the most important assumptions for analysis and design of building against lateral force is rigidity of floor diaphragms. The rigid floor assumption distributes forces between lateral resistant elements according to the proportion of elements rigidity. In addition, this assumption decreases the degrees of freedom and makes the analysis simpler. But the application of this assumption to the seismic analysis of building structures may be not valid in many cases and make the design not safe and economical. In this study, to investigate the effect of floor rigidity, one type of steel frame including simple frame with X-braces was considered. The linear static analysis and spectral dynamic analysis both was used to investigate the flexibility of diaphragm in each case via Variables such as thickness of diaphragm, plan dimensions ratio and number of stories. This study shows that the lower three stories of the building are sensitive to the amount of floor rigidity. So some part of structure may be subjected to increased stress due to shear force redistribution caused by the large in-plane deformation of floor diaphragms.

KEYWORDS: Rigid Diaphragm, Flexible Diaphragm, Steel Braced Frame, Linear Static Analysis, Spectral Dynamic Analysis

1. INTRODUCTION

Structures with flexible floor systems behave differently under dynamic lateral loading than structures with rigid diaphragms. The rigid floor assumption distributes forces between lateral resistant elements according to the proportion of elements rigidity. In addition, this assumption decreases the degrees of freedom and makes the analysis simpler. Several codes, for instance Iranian code of practice for seismic resistance of buildings (Standard 2800) present some criterions for the diaphragm. According to the mentioned standard, diaphragm is to be considered flexible when the diaphragm deflection exceeds twice the story drift. However, flexible diaphragm systems are still analyzed with criteria and recommendation developed for structure with rigid diaphragms. Variables such as thickness of diaphragm and plan dimension ratio can affect diaphragm behavior and causes rigid diaphragm treatment was not accurate. For these structures, diaphragm flexibility can modify dynamic behavior. In this study analysis was performed in a linear mode and for each structures, modeling was performed considering both real rigidity and rigid diaphragm assumption. Values of period of vibration, force in braces and story shear was compared in models with various length-to-width ratios and height.

2. ANALYSIS OF SUNJECT BUILDINGS

The difference between rigid floor and flexible floor building with X-braced frame was examined. Rectangular shaped buildings with 2, 5 and 10 stories and various plan dimension ratio (2, 3 and 4) defined in table 1, were analyzed.

Table 1. Analyses information of buildings

Case	No of Stories	Analysis model	Length-to-Width ratio	Slab Thickness (Cm)
1-36	2,5,10	Rigid	2,3,4	5,10,15,20
36-72	2,5,10	Flexible	2,3,4	5,10,15,20

These buildings contain 4 by7, 10 and 13 column lines and spaced 5 m in both x and y directions. Fig. 1 displays the plan with various plan dimension ratio and location of X-braced frame in each model.

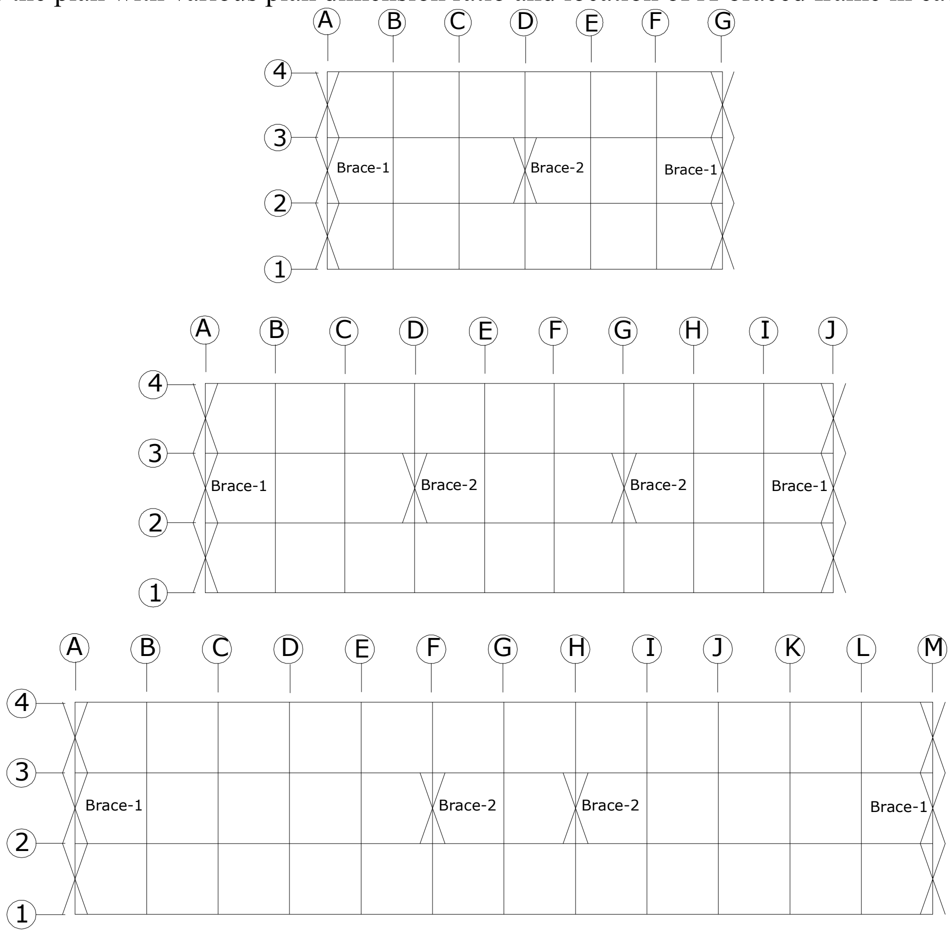

Figure 1 Rectangular buildings with different ratio of length over width.

First, each model was designed according to Iranian seismic code BHRC. Minimum base shear, based on this code, can be obtained as follows:

$$V=CW \tag{2.1}$$

Where V: shear force, W: total weight of building plus 20% live load and C: seismic coefficient as C=ABI/R. A: design base acceleration ratio=0.35 for high seismic potential zone, I: building important factor =1. R: building behavior factor which for simple frame with X-braced frame R=6, B: building response factor obtained from a design response spectrum. It can be obtained from the following equation:

$$B = 2.5 \times \left(\frac{T_0}{T}\right)^{2/3} <= 2.5 \tag{2.2}$$

Where, T_0: a value selected by soil type, assuming soil type II. T_0 = 0.5, T= building fundamental period; $T=.05H^{3/4}$ and varies for each building.

Based on the above, the base shear force was obtained and the buildings were designed according to AISC-ASD89. The member size of each building in case of Length-to-Width 2, 3 and 4 is given in tables 2 to 4.

Table 2 Information of 2, 5 and 10 story building (Length- to- width ratio= 2)

No. of Story	Story	Column	Beam	Brace
2	1-2	2IPE14	IPE 270	2UNP 8
5	1-2	2IPE20	IPE 270	2UNP 8
	3-5	2IPE16	IPE 270	2UNP 10
10	1-4	Box 30x30x1	IPE 270	2UNP 16
	5-10	Box 15x15x1	IPE 270	2UNP 12

Table 3 Information of 2, 5 and 10 story building (Length- to- width ratio= 3)

No. of Story	Story	Column	Beam	Brace
2	1-2	2IPE14	IPE 270	2UNP 10
5	1-3	2IPE20	IPE 270	2UNP 12
	4-5	2IPE14	IPE 270	2UNP 8
10	1-3	Box 20x20x1	IPE 270	2UNP 12
	4-6	Box 15x15x1	IPE 270	2UNP 10
	7-10	Box 10x10x1	IPE 270	2UNP 8

Table 4 Information of 2, 5 and 10 story building (Length- to- width ratio= 4)

No. of Story	Story	Column	Beam	Brace
2	1-2	2IPE16	IPE 270	2UNP 8
5	1-2	Box 15x15x1	IPE 270	2UNP 12
	3-5	Box 10x10x1	IPE 270	2UNP 10
10	1-3	Box 30x30x1	IPE 270	2UNP 12
	4-6	Box 20x20x1	IPE 270	2UNP 12
	7-10	Box 15x15x1	IPE 270	2UNP 10

For spectral analysis, based on Iranian seismic code, the building response factor according with soil type II was obtained. Then spectral acceleration values calculated which shown in the figure 2.

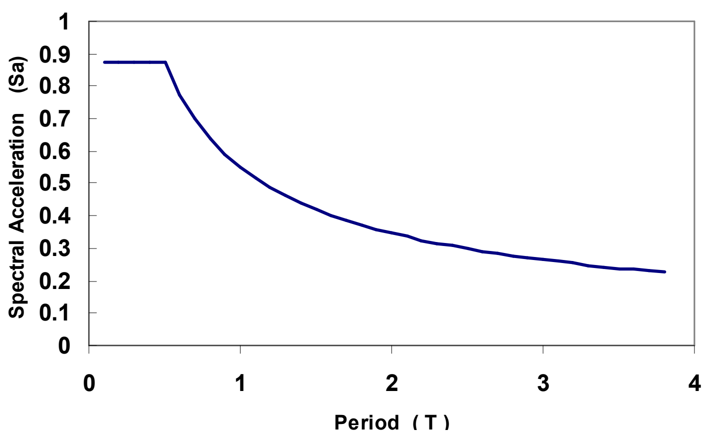

Figure 2 Spectral acceleration of soil type II

3. RESULT OF ANALYSIS

The linear static and response spectrum analysis both was used to investigate the difference between rigid floor and flexible floor buildings. A formula to estimate the error of the structural analysis of a building when the rigid floor assumption is used can obtain as:

$$\Lambda_{fi} = {(f_{fi} - f_{ri})}/{f_{fi}} \times 100 \tag{4.1}$$

Where f_{fi} = action in flexible floor assumption, f_{ri} = action in rigid floor assumption. Based on above formula, the error which comes from rigid floor assumption for axial force is shown in interior and exterior X-braces. Diagrams in left side shows error in linear static analysis while in right side correspond to spectral analysis. Comparison of result discussed in the following sections. It must be noted that only values of error was depicted in story which maximum error occurs.

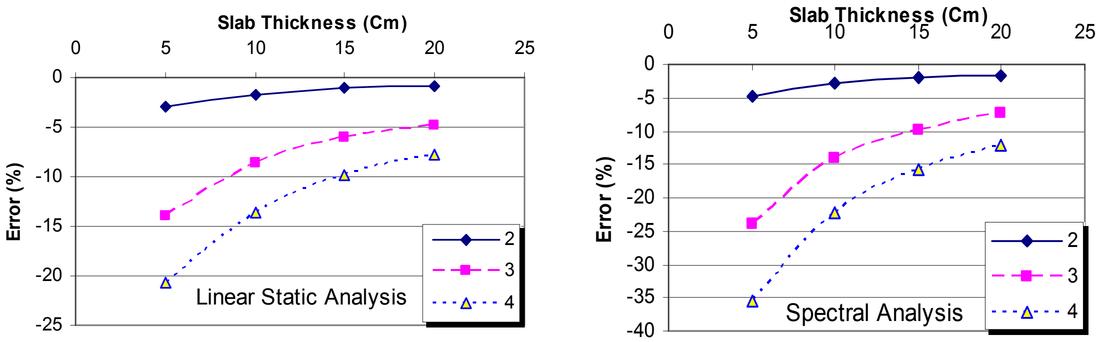

Figure 3 Estimation of error due to rigid floor assumption in exterior braces

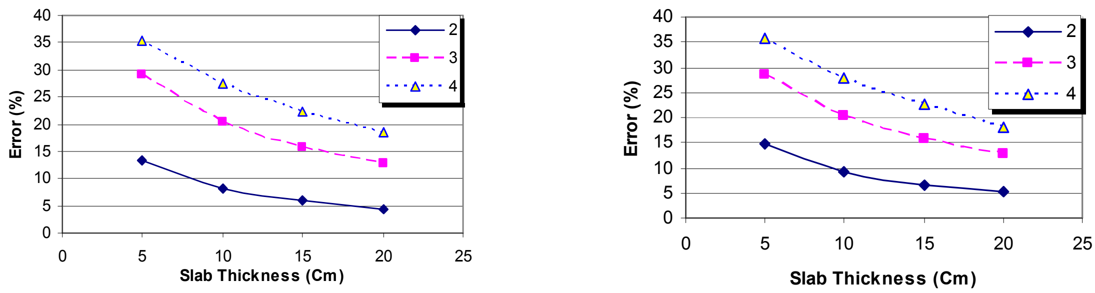

Figure 4 Estimation of error due to rigid floor assumption in interior braces

Figs. 3 and 4 show error of braces in second level of two story buildings. It is observed on both diagrams that with increasing in length-to-width ratio and decreasing slab thickness, error values rapidly increase. It was observed from Fig 3 that when plan dimension ratio is 4 and slab thickness is 5 Cm errors are 20 and 35 % in static and spectral analysis respectively. Negative values of error in exterior braces shows that rigid floor caused superior forces than flexible floor assumption. This made the design non-economical. On the contrary in interior braces, flexible floor causes higher forces than rigid floor assumption. This made the design non- conservative. Figs 3 and 4 also show when length to-width exceed 3, decreasing in slab thickness have strong effect on values. Differences in values of error due to rigid assumption in static and spectral analysis for external braces are significant but these values for interior braces are insignificant. This may due to excitation of diaphragm modes which appear as main modes.

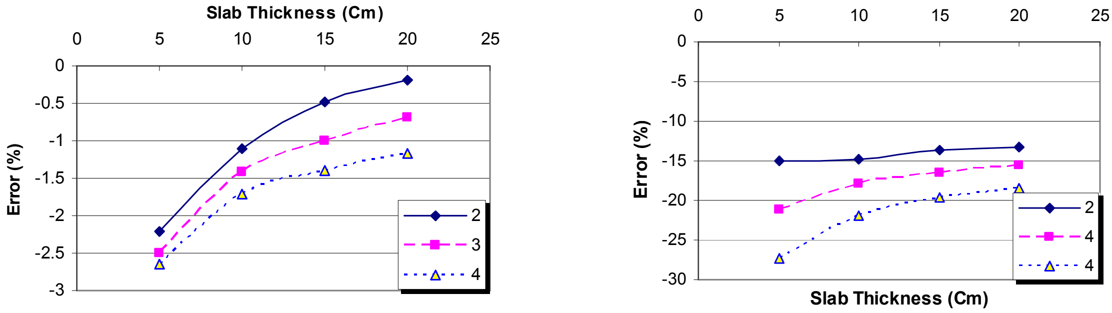

Figure 5 Estimation of error due to rigid floor assumption in exterior braces

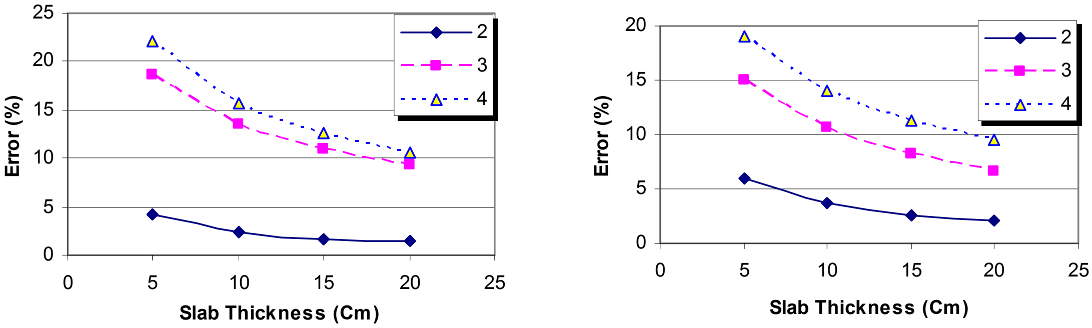

Figure 6 Estimation of error due to rigid floor assumption in interior braces

Figs. 5 and 6 show error of braces in second level of two story buildings. Second level is considered because maximum error values were observed in this level. In comparison with two stories, error values in five story buildings are lower than counterpart building. On the other hand, error values caused rigid floor in five story building are lower than 2 stories.

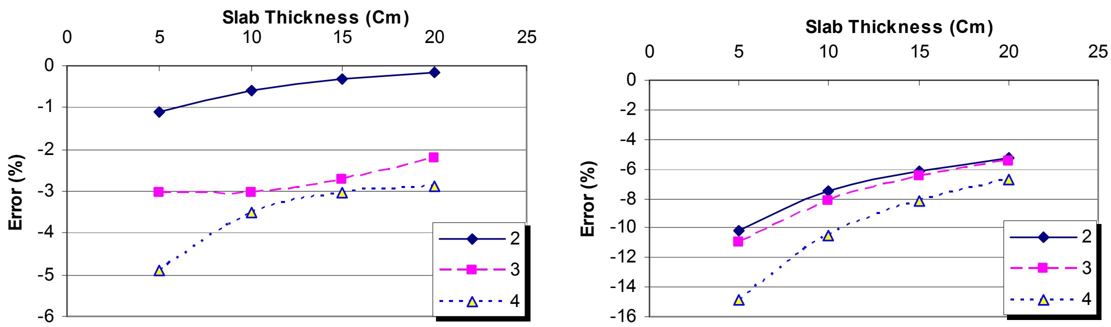

Figure 7 Estimation of error due to rigid floor assumption in exterior braces

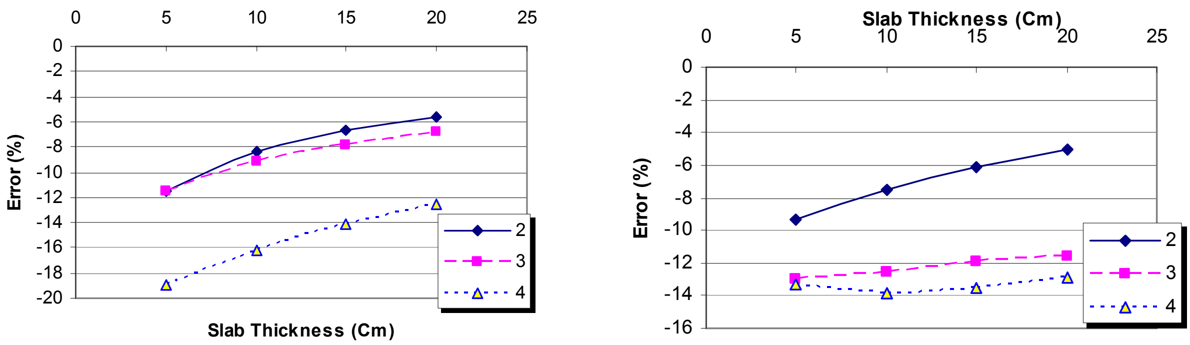

Figure 8 Estimation of error due to rigid floor assumption in interior braces

Figs. 7 and 8 show error of braces in second level of two story buildings. Similar to five story, maximum error values in ten story buildings were observed in second level. Based on result from 2, 5 and 10 story building, it can be concluded that second story level in these building are more sensitive to rigidity and flexibility of diaphragm. Also values of error decrees when number of stories increased.

4. BASE SHEAR IN SPECTRAL ANALYSIS

Result of spectral analysis and values of periods obtained from buildings show that diaphragm flexibility causes superior period than diaphragm rigidity. Based on Fig 9, considering flexibility in diaphragm, causes shifting response factor from zone A to zone B, and values of error related to diaphragm rigidity assumption can be significant.

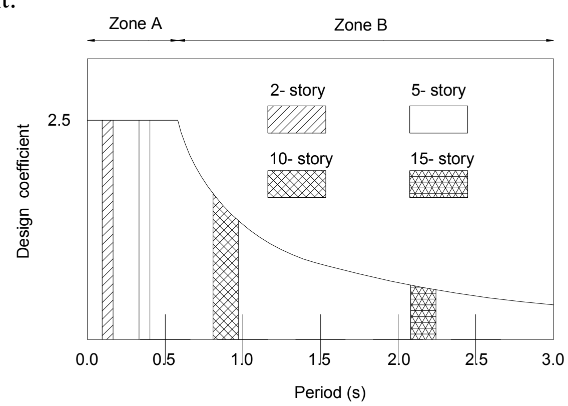

Figure 9 Building response factor (Iranian code of practice)

In the following figures, dynamic base shear ratio (V_f/V_r = ratio of base shear in real floor rigidity to rigid floor assumption) was computed for buildings with various slab thickness and length-to-width ratio.

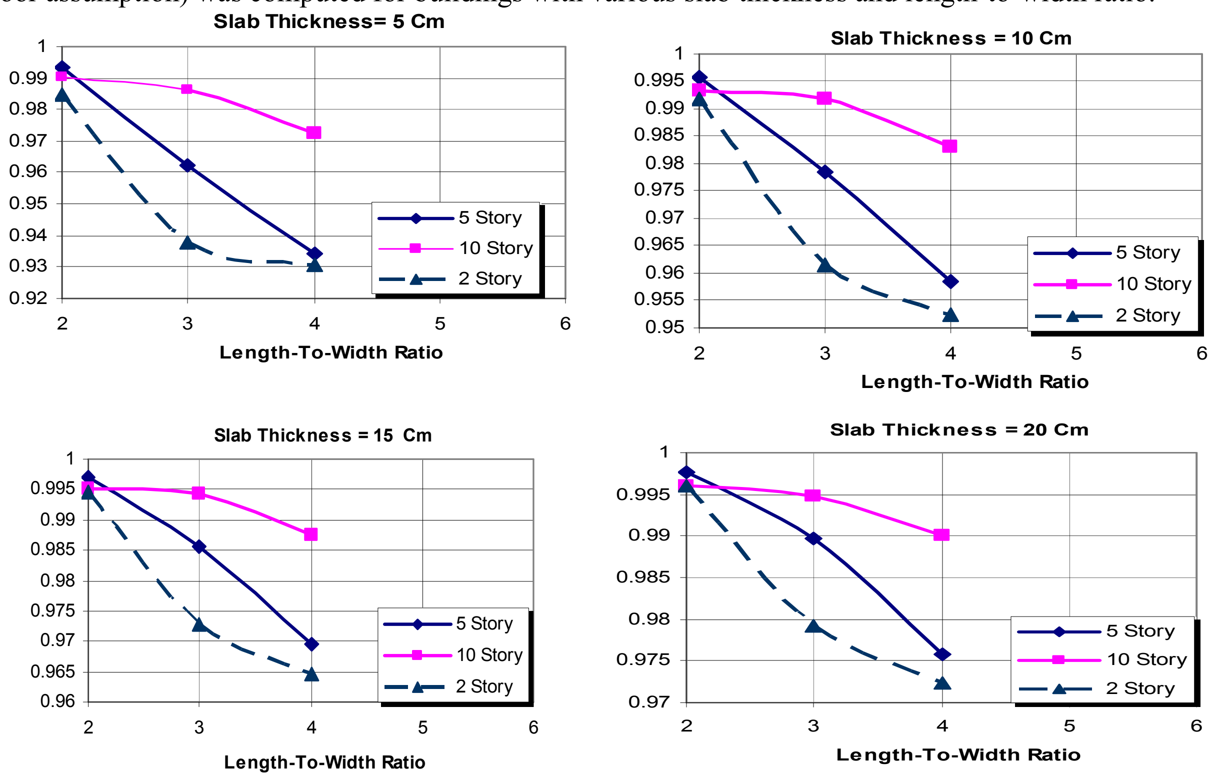

Figure 10 dynamic base shear ratio versus length-to-width ratio

Figure 10 shows the dynamic base shear ratio versus length-to- width ratio in case of real rigidity and rigid floor assumption. It is observed that values of V_f/V_r increased when the number of story decreased. In case of slab thickness = 5 Cm, two story buildings and length-to-width = 4, value of V_f/V_r reached 0.93 that display 7% descending in base shear.

5. CONCLUSION

This study shows that the lower three story of building are sensitive to the amount of floor rigidity. In addition the interior lateral resistant systems such as interior braces are more sensitive to rigidity and values of axial force in braces are non-conservative. Dynamic spectral analysis is also performed on models and results shows that diaphragm flexibility increases natural period of structures and decreases dynamic base shear. In low rise buildings, plan dimension ratio is important and if this ration exceed of 3, values of error will be large. In mid rise buildings (10 and 15 story buildings) plan dimension ratio is not as important as low rise buildings.

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