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Influence of Flexural Stiffness of Slab on the Dynamic Behavior in Shear Wall Structures

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ABSTRACT

Response spectrum analysis and nonlinear time history analysis for 20 story residential building are performed to confirm the influence of slab stiffness on the seismic behavior using Midas ADS and Perform 3D. Slab is modeled as rigid diaphram, semi-rigid diaphram and flexible diaphram changing the flexural stiffness of slab. As a results, natural periods of the building and inter story drift ratio decrease when out-of-plane flexural stiffness of slab is considered. Also member forces acting on the walls and reaction forces are redistributed due to slab. The more flexural stiffness is taken into consideration, the more slab effect is increased.

1. INTRODUCTION

Currently, Shear wall system is used for lateral-force-resisting system of residential buildings in Korea. In the modeling process of the buildings, slab is assumed to be a rigid diaphram with no out-of-plane flexural stiffness of slab in practice because of simplicity to analysis. In fact, slab thickness of residential buildings that were built in 1990s is about 135-150mm which is not thick enough to consider the stiffness. However, the minimum thickness of standard floor slab is set to be 210mm due to block the inter-floor noise in 2009 and there is a need to take into account a flexural stiffness of slab since it is not small now.

2. RESPONSE SPECTRUM ANALYSIS

2.1 Example Structures

Based on the actual floor plan of residential building in Korea, elastic analysis model, OD20 is modeled as shown in Fig. 1. The number of stories is 20, story height is 3m and design compressive strength of concrete is 24 MPa. Response modification factor(R) is 4 and important coefficient(I) is 1.2.

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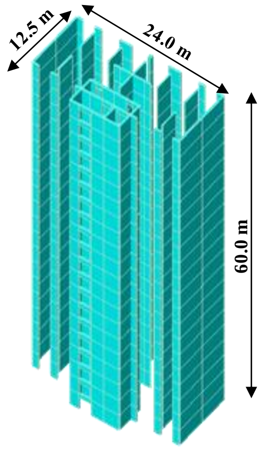


Fig. 1 Three-dimentional elastic analysis model

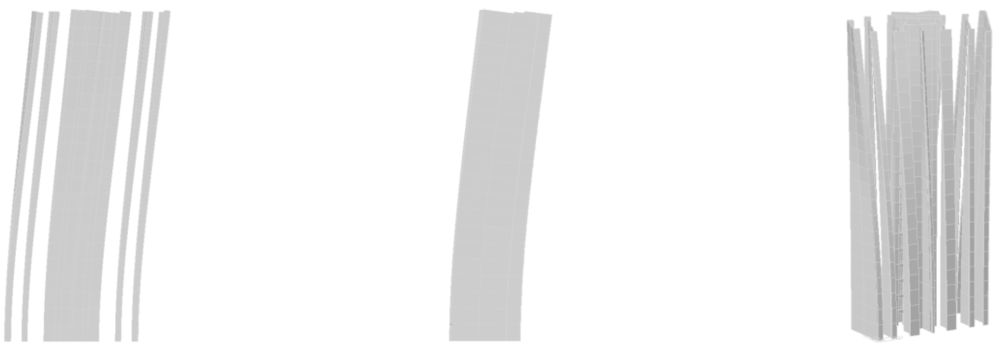
With modeling of slab as variable, the analysis models are divided into OD20, ODS20 and OS20 as shown in Table. 1. The slab of of OD20 is assumed as rigid diaphram and that of OS20 is plate. In the ODS20, rigid diaphram and plate bending is used simultaneously. For gravity loads, dead load is assumed to 6.56kN considering self weights and live load is 2kN per unit square meters uniformly.

Table. 1

Model	OD20	ODS20	OS20
In-plane stiffness	∞	∞	○
Out-of-plane stiffness	x	○	○

2.2 Eigenvalue analysis results

As shown in Fig.2, first mode of all models proceeds in the long side direction(x-dir) because of the small amount of walls. And second mode goes on in the short direction(y-dir) with strong outer walls.



(a) mode 1 (b) mode 2 (c) mode 3

Fig. 2 Mode shapes elastic model

Since the story mass is constant regardless of slab modeling method, natural period is different depending on the stiffness of slab. Natural periods becomes shorter when the flexural stiffness of slab is considered. In addition, as the more flexural stiffness is taken into account, the period becomes shorter as shown in Fig. 3. The natural periods of ODS20 and OS20 are almost same, which means that the effect of in-plane stiffness of slab is not a big deals.

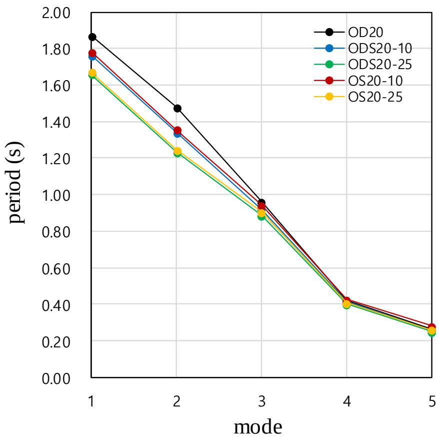
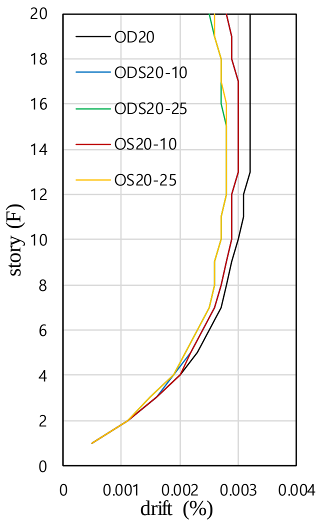


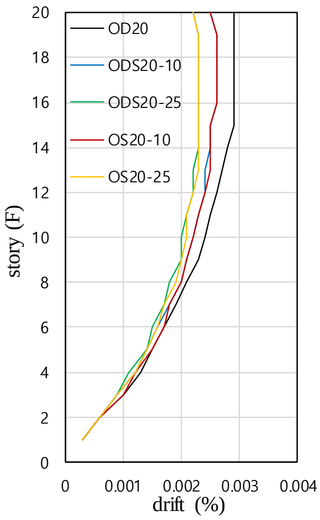
Fig. 3 Natural periods of models

2.3 Interstory drift raio

In all cases, maximum drift ratio goes down when the flexural stiffness of slab is taken into consideration. It decreases by 7% and 9% in the x-direction and y-direction respectively when the stiffness is considered by 10%. The maximum drift ratio of OS20 is little larger than that of ODS20, but the difference is ignorable.



(a) story drift ratio (x-dir)

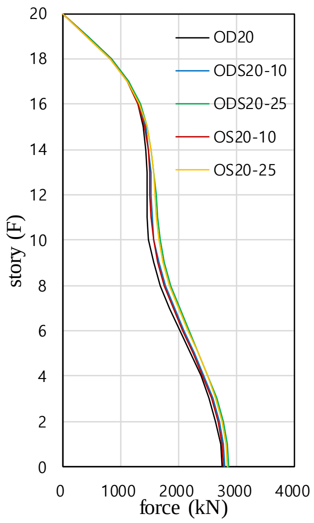


(b) story drift ratio (y-dir)

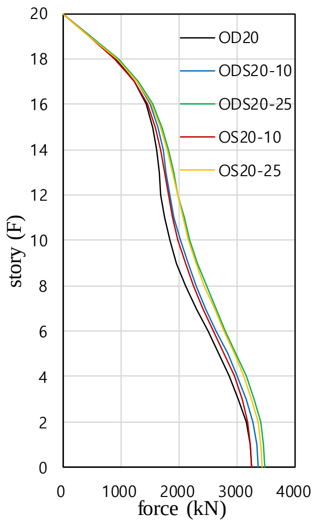
Fig. 4 Interstory drift ratios of models

2.4 Shear force distribution

Considering flexural stiffness of slab in the response spectrum analysis, the natural period of the building is shortened and this cause an increase in seismic load. As shown in Fig. 5, base shear force increases about 5% and 10% when the stiffness is considered as 10% and 25% respectively. It means that the more flexural stiffness is taking into account, the more seismic load is applied. So OD20 with rigid diaphram that has no out-of-plane stiffness can underestimate the risk of earthquakes.



(a) story shear distribution (x-dir)

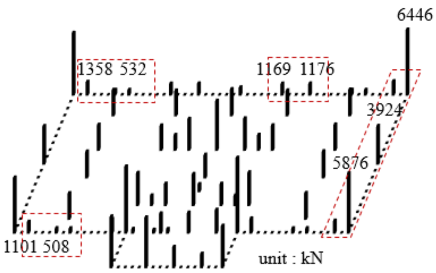


(b) story shear distribution (y-dir)

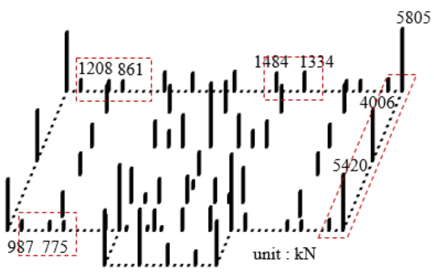
Fig. 5 Story shear force distributions of models

2.5 Force redistribution

Slab redistributes lateral load to the vertical members which resist the load. This reduces the difference between the loads acting on the large members and small members and the gap between the loads acting on upper and lower story decreases. Reaction force is also redistributed as like member force as shown in Fig. 6. It is concentrated on a specific point on OD20 that slab is modeled as rigid diaphram but the force is relatively uniform when flexural stiffness is considered.



(a) OD20



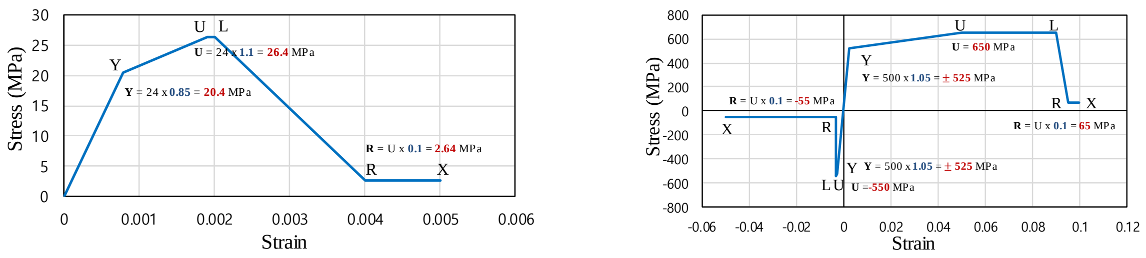
(b) ODS20-25%

Fig. 6 Reaction force distribution chart

3. NONLINEAR TIME HISTORY ANALYSIS

3.1 Nonlinear modeling

In the nonlinear analysis, expected material properties shall be utilized throughout as opposed to nominal or specified properties. According to the Guidelines for Performance-Based Seismic Design of Residential Buildings(2015) in Korea, expected strength factor is 1.1 for concrete and 1.05 for reinforcement. Also stress-strain curves of material are used as shown in Fig. 7, because stiffness of members is determined by the curves of fiber element.



(a) stress-strain curve of concrete (b) stress-strain curve of reinforcement

Fig. 7 Stress-strain curves of materials

Fiber model is used for nonlinear modeling of flexural behavior in walls. For slab modeling, since the influence of in-plane stiffness is not a big deal, rigid diaphram and 10% of plate bending effect is used at the same time. P-delta effect is also considered and 3% of Rayleigh damping is applied in the analysis.

3.2 Ground motion records

Responses of a nonlinear time history analysis are sensitive to a characteristic of ground motion records, so KBC 2016 requires using not less than three ground motion records for time history analysis. In this study, seven ground motion records are selected to use an average response of earthquake. The average spectra of ground motions shall not be less than 90% of 1.3 times the target spectra for the period range from 0.2T to 1.5T according to the code.

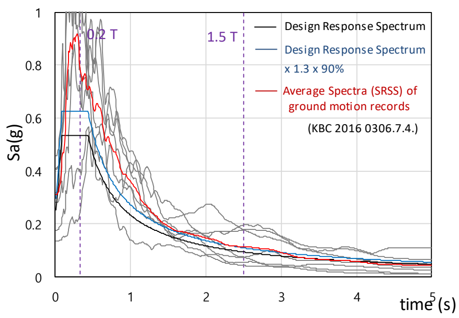
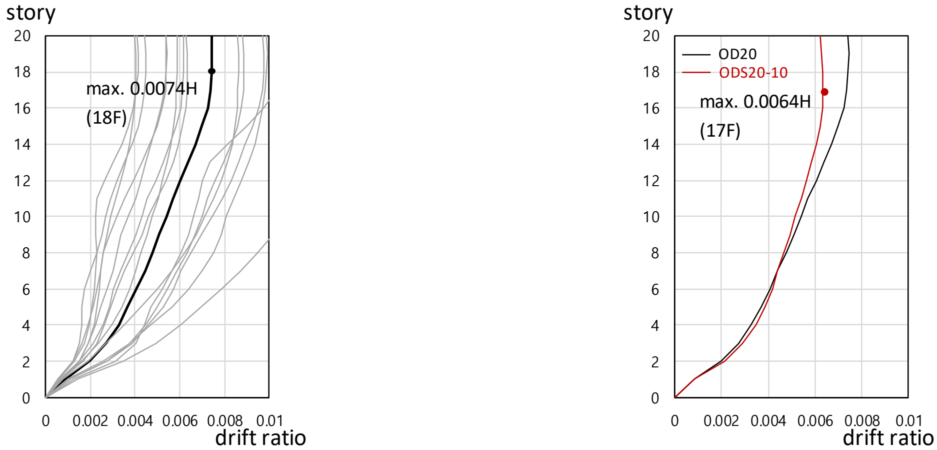


Fig. 8 Seven ground motion records

3.3 Interstory drift ratio

Fig. 9 shows the difference of interstory drift ratio between OD20 and ODS20-10. As like response spectrum analysis, maximum interstory drift is reduced by 13% when the flexural stiffness is considered. Also as increasing the drift ratio about 4% on lower floors, the gap of story drift between upper and lower floors decreases owing to slab effect.



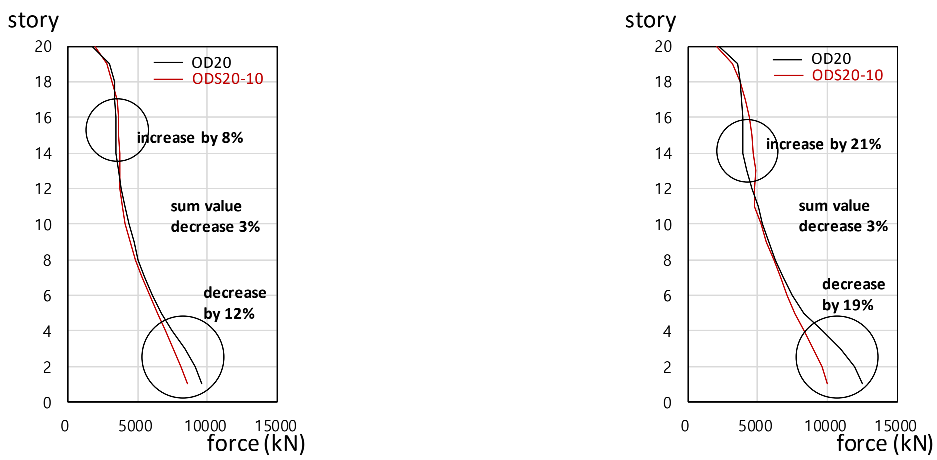
(a) story drift ratio of OD20

(b) story drift ratio of ODS20-10

Fig. 9 Story drift ratio of nonlinear models (SRSS)

3.4 Story shear force distribution

Unlike response spectrum analysis, the sum of story shear force acting on the building is decreased by 3%. However, as shear force of lower floors decreasing by 12%, the distribution is more uniform between stories due to redistributed lateral forces.



(a) story shear of ODS20-10 (x-dir)

(b) story shear of ODS20-10 (y-dir)

Fig. 10 Shear force distributions of nonlinear models (SRSS)

4. CONCLUSIONS

Natural periods of models become shorter when flexural stiffness of slab is considered. Also considering out-of-plane stiffness much, the periods is more decreased. As the period changes, the acceleration values obtained from response spectrum analysis are different. Therefore, earthquake loads may be underestimated when slab is modeled as rigid diaphram for simplicity of the analysis in practice.

There are no big difference between the dynamic behavior of ODS20 and OS20. This means that in-plane stiffness of slab is relatively bigger than flexural stiffness of vertical members even in a shear wall system, so if there is a need to consider slab stiffness in practice, applying rigid diaphram and considering only plate bending is more advantageous than slab is modeled as plate because of decreasing degree of freedom.

Also the member forces and reaction force distribution is more uniform in the case of ODS20 because slab redistributes the seismic load.

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Kim, H.S., Lee, D.G. and Kim, H. J. (2006), “The effect of slab stiffness on the behavior of shear wall building structures with pilotis,” *Architectural Institute of Korea., Vol.22, No 8.*