Proceedings of the Tenth Pacific Conference on Earthquake Engineering
Building an Earthquake-Resilient Pacific
6-8 November 2015, Sydney, Australia

Seismic performance for a low-rise irregular building with soft-weak story

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ABSTRACT: The buildings with bearing walls for the upper stories and frames for the lower stories are mainly applied to multi-housing and multi purposed facilities in Korea. This building types have serious vulnerability as they are characterized by vertical and horizontal irregularity. For acquiring the seismic safety of the buildings of this type from an earthquake attack, it is necessary to understand seismic response behavior and failure mode of them considering stiffness and strength irregularities. In this study, the seismic performance of the low-rise reinforced concrete buildings with soft-weak story considering the irregularities was evaluated using nonlinear parametric analysis. Particularly a regularity index was introduced to quantify the soft-weak story irregularity simultaneously and it was used to review the criteria for classifying the irregularity.

1 INTRODUCTION

In Korea many low-rise apartment houses have built with bearing wall system but the first story of most of the buildings has been designed as the frame system for open space. This unique system forms the soft-weak story on the first story and is considered as vertical irregular building. The system is very vulnerable to earthquake since seismic damage would be concentrated on the first soft-weak story. This topic have been studied in other country for many years (Al-Ali & Krawinkler, 1998, Lu et.al, 1999, Ruiz & Diederich, 1999) since many buildings with soft-weak story collapsed by the past earthquake, Mexico City Earthquake in 1985 and Northridge Earthquake in 1994 and so on. Valmundsson and Nau (1997) investigated irregularity criteria of the UBC by nonlinear seismic analysis for the multi-storey buildings varying distribution of the story stiffness and strength. Das and Nau (2003) designed the 78 irregular buildings and analysed seismic performance of the models. They reported that the design criteria were unnecessary conservative in some kind of irregular buildings. On the other hand, Chintanapakdee and Chopra (2004) tried to consider the more realistic irregular building with strong column and weak beam in the analysis model. The researchers were demonstrated that the seismic demand by seismic response analysis corresponded with the result estimated by the pushover analysis approximately. Based on these researches, the Design Standards of many countries have required to applying the special seismic design to the building for preventing the significant irregularities. The Korean Building Code (KBC, 2009), in common with that of many other countries, specifies the irregularity criteria, seismic category and design methods. Particularly, it is required to design using the special load combination when the building which have vertically discontinued members is designed.

These ways to improve the seismic capacity of the building with soft weak story remain controversial in Korea. Because most of the design criteria was derived from the UBC, however, the criteria to classify irregular building, special seismic load and other design parameters for the building have not verified considering the structural condition in Korea. Therefore, it is necessary to evaluate the seismic performance of the vertical irregular building varying stiffness and strength distribution.

For this, the nonlinear seismic response analysis for the 5-stories building was conducted considering varying stiffness ratio and strength ratio of the first story to the story above. The seismic performance and behaviour of the vertically irregular building was evaluated by a new index quantifying the softness and weakness of the story simultaneously. In addition, the criteria for determining irregularity of the building were reviewed by this index.

2 ANALYSIS MODEL AND METHOD

The 5-stories reinforced concrete building with three spans in two horizontal directions was designed by the KBC. Designed building was considered as the reference model having regular vertical distribution of the lateral stiffness and strength. While, the parametric models were assumed that the stiffness and/or strength of the first story were less than the story above. Those were achieved by multiplying the lateral strength and stiffness for the upper stories of the reference model by increasing factors listed in Table 1. The lateral stiffness and strength vertical distribution of the models are shown in Figure 1.

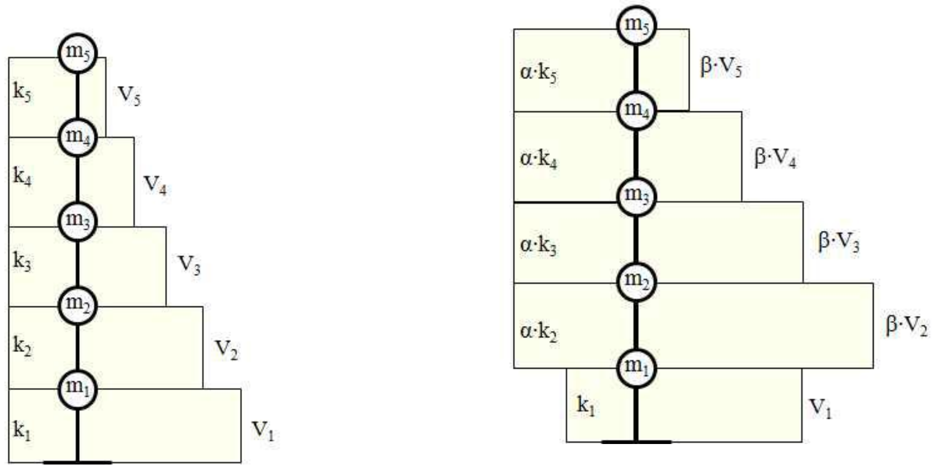
CANNY (2009) commercial program was used for the three dimensional nonlinear seismic response analysis. Each member of the building was idealized by a linear element having springs which behaved following the hysteresis loop. Figures 2-3 show the analysis model and the nonlinear spring model for the frame.

The beam was modeled by using only flexural rotational springs at the both ends. The column was modeled with two flexural springs, a shear spring and an axial spring. The tri-linear model which represented the stiffness degradation and pinching behavior was applied to the flexural spring. For the shear spring, the model, featuring in strength deterioration in addition to the flexural behavior, was used. And axial hysteresis model featured in stiffness degrading, yielding in tension and elastic in compression.

Accenleration record of the El-Centro earthquake (1950) NS component and artificial waves were used for seismic simulation. These acceleration level were modified considering the design spectrum of the KBC and these are described in Figure 4.

Table 1. Variables and factors

Stiffness and Strength Ratio	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
Factor α	-	1.11	1.25	1.43	1.67	2.00	2.50	3.33	5.00	10.0
Factor β	1.07	1.19	1.34	1.53	1.79	2.14	2.68	3.57	5.36	10.7



(a) Reference model (b) Parametric model

Figure 1 Lateral stroy strength and stiffness distribution of the analysis models

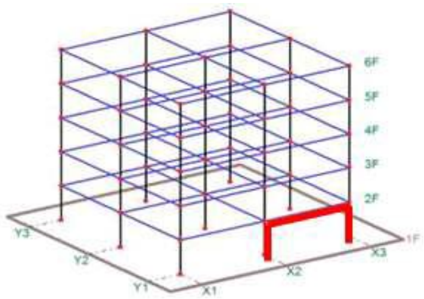


Figure 2 Anlysis model

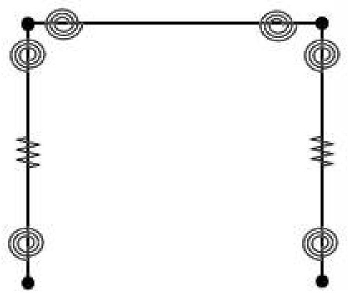


Figure 3 Nonlinear spring model of the frame

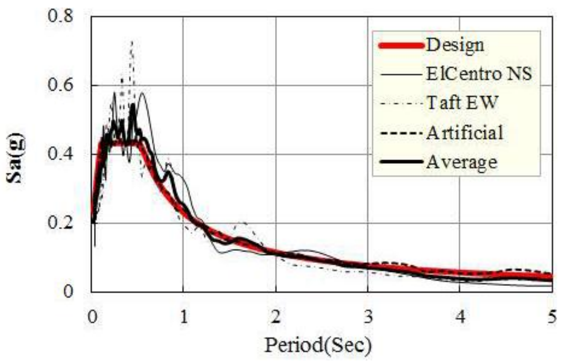
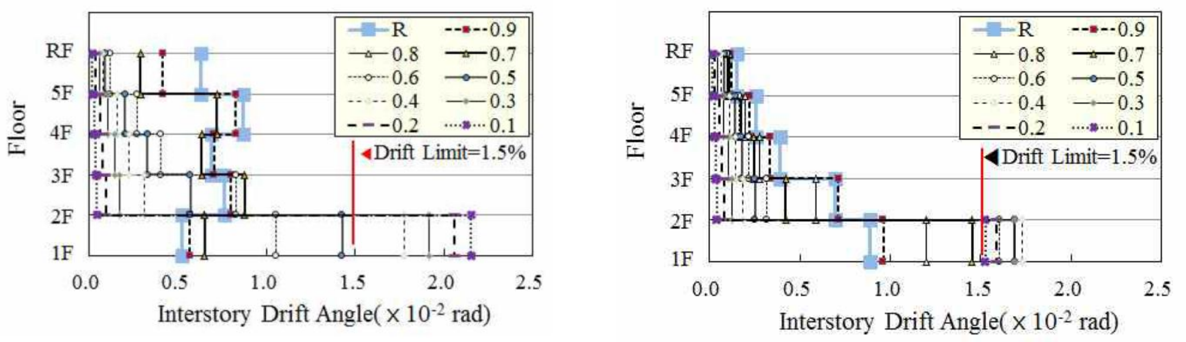


Figure 4 Seismic design spectrum and response spectrum of the input waves

3 ANALYSIS RESULTS

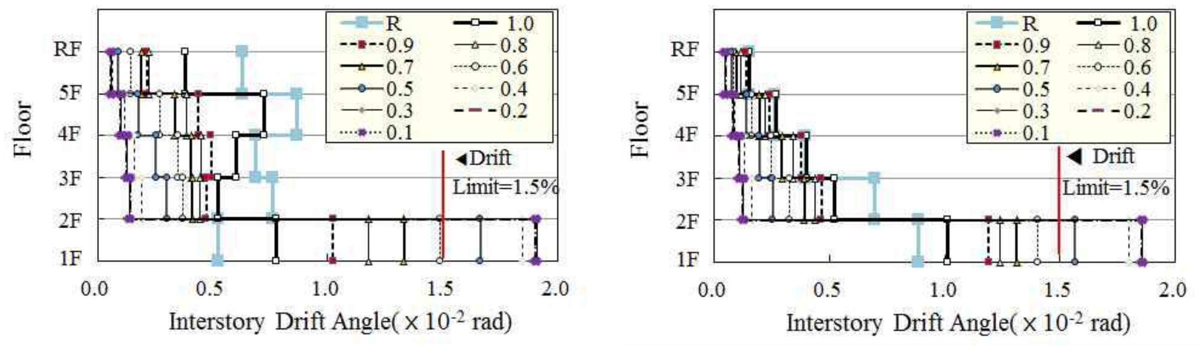
Inter-story drift angle of the stiffness or strength irregular model were shown in Figures 5-6 and legend in the figures means the stiffness ratio and strength ratio of the first story to the upper story, respectively.

As the lateral stiffness of the first story was decreased, the story drift increased. In the case of the stiffness ratio of the first story was less than 70%, story drift was exceeded the allowable story drift limit designated by the KBC. In the case of the strength irregular model remaining the regular stiffness distribution, similar results were drawn.



(a) El-Centro NS (b) Artificial wave

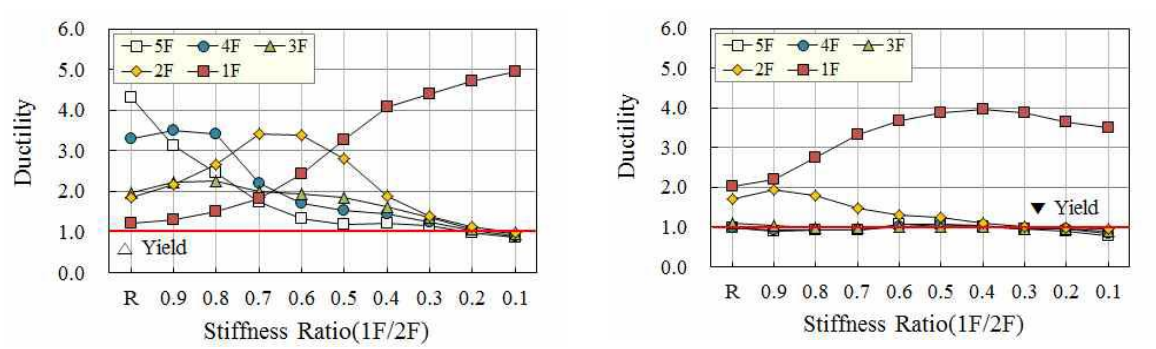
Figure 5 Vertical distribution of the inter-story drift angle of stiffness irregular models



(a) El-Centro NS (b) Artificial wave

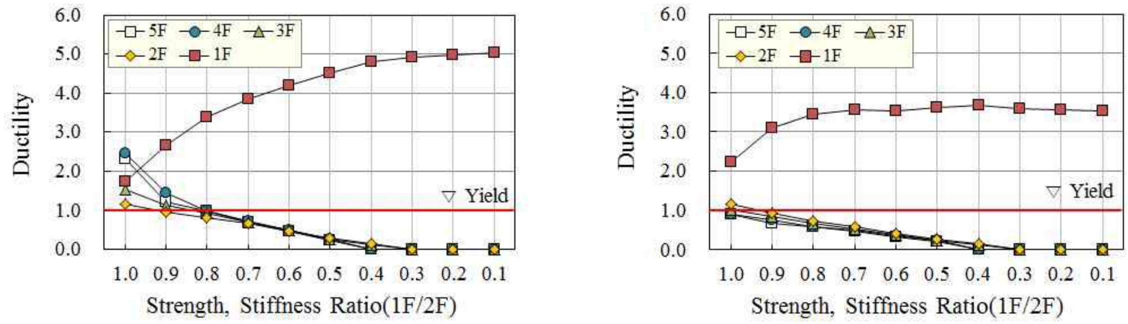
Figure 6 Vertical distribution of the inter-story drift angle of strength irregular models

On the other hand, ductility of the columns on each story represents differences. In case of stiffness irregular model, shown in Figure 7, the members of soft story experienced large plastic deformation and those of the upper stories yielded also. But in the case of the strength irregular model with the ratio of less than 90%, the member of the upper stories almost remained elastic. Whereas the ductility level of the members on the weak story was similar with the case of the soft story models.



(a) El-Centro NS (b) Artificial wave

Figure 7 Ductility of the columns in cases of stiffness irregular models



(a) El-Centro NS (b) Artificial wave

Figure 8 Ductility of the columns in cases of strength irregular models

To evaluate story drift ratio considering the stiffness and strength irregularity simultaenously, a Regularity Index (hereinafter referred as to RI) was assumed by multiplying the stiffness and strength ratios of the first story to those above. The value of the RI decreases as irregularity increases.

Figure 9 descibes the relation between the RI and the story drift (⊿) depending on variables of the parametry model. The numbers in the table meaned the RI as the variables and the color in the table means the story drift ratio (⊿) resulted from the parametric analysis. The darker color means the greater deformation.

The strory drift occurred in similar distribution with the values of RI. Particulary, when the value of the RI was less than 0.65, story drift was exceeded the allowable story drift, 1.5%.

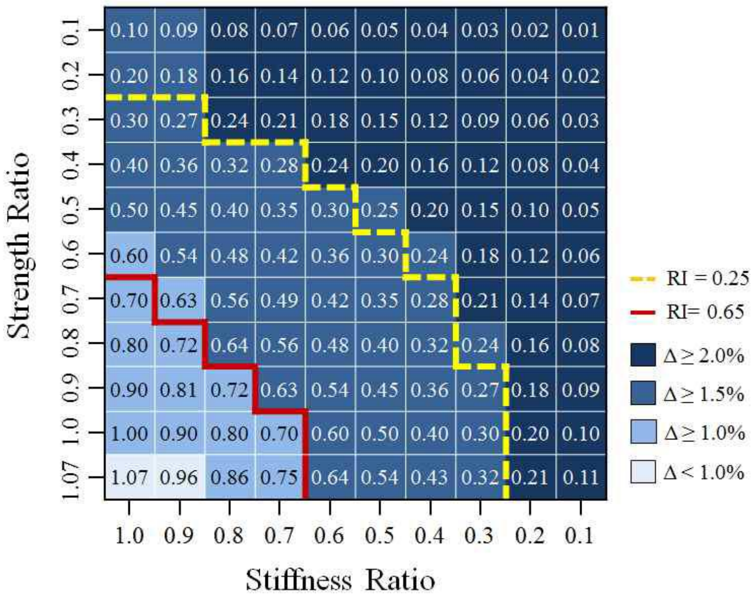


Figure 9 Relationship between Regularity Index (RI) and story drift (⊿) depending on variables

4 CONCLUSIONS

In this study, the nonlinear seismic time history analysis for the 5-story RC building designed according to the KBC was carried out to evaluate the story drift response depending on the vertical stiffness and strength irregularity. The parametric analysis was conducted considering varying stiffness and strength ratios of the first story to the second story from 0.1 to 1.0.

The results showed that the story drift tended to be increased and concentrated on the first story as the strength and stiffness ratios of the story decreased comparing with the regular model. Those tendency was inverse proportional to the Regularity Index, defined as the product of strength and stiffness ratios of the soft-weak story. Also, when the Regularity Index was less than 0.65, the drift of the soft-weak story was exceeded the 1.5% limit prescrived by KBC.

There results lead us to the conclusion that the suggested Regularity Index could be utilized for evaluating the seismic performance and behiviour of the irregular building with soft-weak story quantitatively. Futher studies for more variables and different cases are needed to apply it to seismic design and evaluation.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MEST) (No. NRF-2014R1A1A2055210).

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