Advanced Engineering Days

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Soft-story deficiency due to open ground story in properly designed reinforced concrete buildings

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Cite this study: Akın, A. (2021). Soft-story deficiency due to open ground story in properly designed reinforced concrete buildings. 1st Advanced Engineering Days, 99-101

Keywords
Soft story
Reinforced concrete
Open ground story
Infill wall
Seismic response

ABSTRACT

The possible deficiencies that may be caused by the infill walls have been revealed in the literature. The absence of infill walls at the ground story that is termed as the open ground story has generally been related to a soft story deficiency. However, the scale of an accumulation of seismic demands at the ground story due to the absence of infill walls at that particular level should depend on some other parameters regarding the characteristics of infill wall, structural system and even ground motion. The seismic code-compliant reinforced concrete buildings are considered in this study. The soft-story problem due to the open ground story in these types of buildings was considered with a special emphasis on the varying amounts of shear walls. Five-time history records were selected to be used in nonlinear time history analyses of three different building models. The results show that there may be a risk for the soft story formation even in the case of properly designed buildings which may be eliminated by a certain amount of shear walls.

Introduction

The effects of infill walls on the lateral response of reinforced concrete (RC) frame buildings in various stages of the seismic response are known to a certain level thanks to the former studies in this field [1-2]. These studies have concluded that non-uniform allocation of strength and stiffness may take place due to the irregular distribution of infills along the height or on the plan of the building. The open ground story (OGS), where there no infill walls to be able to be used for parking facility or commercial purposes, is generally related to a soft story deficiency. The soft story is defined considering the relative inter-story drift ratios (IDR) of the adjacent stories in Turkish seismic code [3]. However, the IDR values are estimated using lateral drifts that are obtained from linear static analysis according to the code.

The current study focuses on the severity of the soft story irregularity that may be induced by OGS in properly designed RC buildings with none or varying amounts of shear walls. The accumulation of inelastic seismic demands at the ground story as a result of time history analyses will be investigated for this purpose.

Material and Method

SeismoStruct software was used for the nonlinear modeling and dynamic time-history analyses. The models used in the analyses represent 4-story residential RC buildings which have three spans along both orthogonal axes. The RC buildings were designed in three groups to have no shear walls (NSW), two shear walls (SW-2) and four shear walls (SW-4) along the x-axis. The relative cross-sectional areas of shear walls with respect to the floor area are 0.36% and 0.72% for groups SW-2 and SW-4, respectively. The corresponding cross-sectional dimensions of one shear wall was selected as 250×1750 mm2. All three buildings were designed according to the previous seismic code of Turkey by considering capacity design principles and with a selection of high-ductility level. The slabs and beams were assumed to behave as a rigid diaphragm in the lateral direction. The dead and live loads of slabs were 4.38 and 2.0 kN/m2, respectively. The unit weights of the concrete and infill walls were assumed as 24 and 8 kN/m3, respectively. Only the weights of the infill walls were considered (i.e., as non-structural members) in the design of structural systems. The characteristic compressive strength and modulus of elasticity of concrete were chosen as 25 and 30000 MPa, respectively. The typical S420 steel with a characteristic yield strength of 420 MPa was assumed for the transverse and longitudinal reinforcements. The reinforcement details of the columns, all of which have identical cross-sectional dimensions of 250×600 mm2, are shown in Table 1. All shear walls are reinforced by 10ϕ14 longitudinal bars at the end columns and 18ϕ14 longitudinal bars at the main body. ϕ10 bars were used by a spacing of 160 mm. as the lateral reinforcements at the main body of shear walls. The cross-sectional dimensions of all beams were 250×500 mm2. The longitudinal reinforcements of beams which vary depending on the location and supporting members were chosen such that capacity design principles are ensured. The transverse reinforcement of all beams is ϕ8/140 mm. The layout plan for the structural system of the NSW model is shown in Fig. 1. The shear walls were replaced by the columns C02 and C14 in group SW-2 and columns C01, C04, C13 and C16 in group SW-4.

Table 1. Longitudinal reinforcements of columns

Group	Columns	Longitudinal Reinf.	Lateral Reinf.
NSW	C05, C08, C09, C12	14ϕ20	ϕ8/100 mm
	C01, C04, C13, C16	10ϕ20	
	All other columns	8ϕ20	
SW-2	C05, C08, C09, C12	12ϕ20	
	All other columns	8ϕ20	
SW-4	C05, C08, C09, C12	10ϕ20	
	All other columns	8ϕ20	

Three infill wall patterns that are bare frame (BF) without infills, fully infilled (FI) and open ground story (OGS) were considered in the study. Four interior spans (B1-B2, B3-B4, C1-C2 and C3-C4) and two exterior spans (A2-A3 and D2-D3) which are along the x-axis were assumed to be infilled where required. The thicknesses of interior and exterior infills are taken to be 100 and 200 mm, respectively. The details of the modeling were explained by Akın (2019). A nonlinear time history analyses of the models were employed by using five ground motion records: "Dinar-Turkey", "Düzce-Turkey", "Imperial Valley-California-06", "Kobe-Japan" and "Managua-Nicaragua-01".

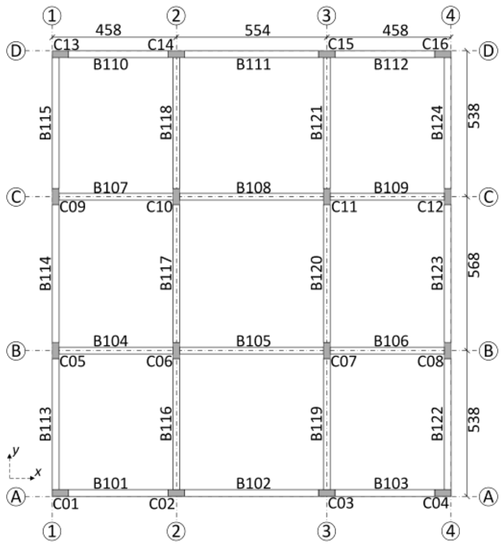

Figure 1. Plan view of the model in group NSW (dimensions in cm.)

Discussion of Results

The moment-rotation hysteretic curves of the frame members at the integration sections were checked to determine the progress of the sectional inelastic response and plastic hinge formation. In the discussions, the models are entitled to represent the presence and amount of shear walls (i.e. NSW, SW-2 and SW-4), infill wall pattern (i.e. BF, FI and OGS) and ground motion record (i.e. Dinar, Düzce, ImpVall, Kobe and Managua) in the given order. The story at the enterance level was named as "ground story" and the upper three stories are "first", "second" and "third" from the bottom to the top.

The consequent distribution of plastic hinges on the frames along A-A and B-B axes for the BF and OGS models which were subjected to Düzce record is illustrated in Fig. 2. It is apparent that there was a significant accumulation of inelastic seismic demands at the ground story of NSW models due to the infill wall pattern of OGS in comparison to BF. In group SW-2, there was also an increase in the inelastic demands at the ground story of the OGS model compared to BF. However, this was not as serious as it was in group NSW. On the contrary, the distribution of plastic hinges remained almost identical in case of OGS when compared with BF model in group SW-4.

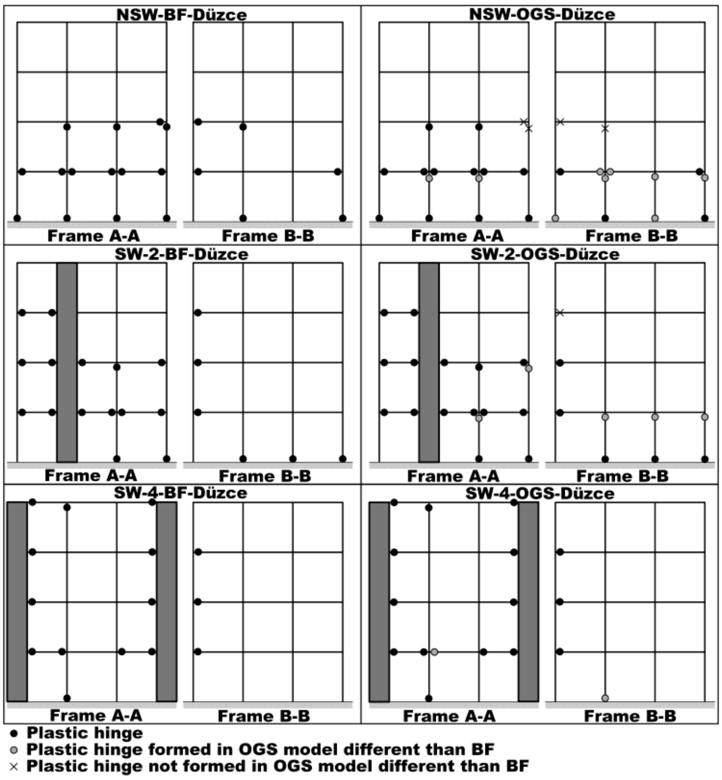

Figure 2. Lateral drift ratio profiles of the models

Conclusion

The results of this study have pointed out a considerable accumulation of inelastic seismic demands at the ground story of seismic code-compliant frame type (i.e., NSW) RC buildings due to OGS. The plastic hinge formations which were observed at both ends of the majority of ground story columns under all considered ground motion records show that a column sidesway mechanism may easily be produced for these types of buildings with OGS. Such an accumulation of seismic demands at the ground story was also the case for SW-2 models with a lower intensity. It may be stated that the risk for a possible sidesway mechanism stands also for the SW-2 models with OGS by observing the number and distribution of plastic hinges although this was reduced thanks to the shear walls with a ratio (i.e., shear wall area/floor area) of 0.36%. The results of SW-4 models have indicated that the effect of infill walls on the lateral response of the structure and consequently the risk for a soft-story deficiency due to OGS could be reduced significantly by the participation of shear walls with a ratio of 0.72%. These results further designate that a threshold value may exist for the amount of shear walls to eliminate the risk for a soft-story deficiency in new constructions, if an infill wall pattern with OGS is required in these buildings.

Funding:

This research received no external funding.

Conflicts of interest:

The authors declare no conflicts of interest.

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