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EFFECT OF INFILL WALL STIFFNESS VARIATIONS ON THE BEHAVIOR OF REINFORCED CONCRETE FRAMES UNDER EARTHQUAKE DEMANDS

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ABSTRACT

Interstory drift concentration under seismic demands is a common issue in reinforced concrete frames which may result in premature failures. In this study, an organized stiffness distribution along the building height was studied to mitigate the drift concentrations. The targeted stiffness distribution was obtained by placing infill walls whose stiffness and strength properties vary with the elevation of the frame. IDARC-2D was used for structural analysis. Experiments performed by others were used to verify the hysteretic parameters of the numerical model. Then, three five-bay, five-story, planar frames were designed. These were a bare frame and the frames with infill walls – one with uniform stiffness and the other with varying stiffness and strength properties through the elevation. Nonlinear dynamic and pushover analysis methods were used to observe the performance of the designed frames. The results showed that an organized stiffness distribution could mitigate the drift concentrations at the lower stories and result in a more balanced interstory drift distribution along the height of the frame.

INTRODUCTION

Reinforced concrete (RC) structures with infill walls are the most common building types in earthquake-prone regions of Turkey. The infill walls are generally neglected in structural design process due to the complications encountered in modeling them and their interaction with the surrounding frame. However, presence of the infill walls has been proved to affect stiffness, strength and seismic behavior of the structures significantly. Depending on the capacity demand ratios, infill walls may be either beneficial or detrimental under seismic demands. Infill walls typically increase the global stiffness and strength of the structures. This situation may be advantageous for non-ductile buildings up to a certain limit. On the other hand, brittle nature and a rich variety of failure modes of infill walls may cause unforeseen and irreversible damages. Particularly, soft-story mechanisms may occur due to drift concentrations at lower stories of multi-story structures. To mitigate the negative effects of the infill walls, an organized stiffness distribution along the height of the structure may be applied by using infill walls with different stiffness and strength properties.

The main purpose of the study is to investigate the effects of stiffness variations in infill walls to the seismic behavior of the frames. In order to achieve the purpose, an analysis software which supports infill walls, was selected. Firstly, the infill wall model parameters of the selected software were calibrated and verified by simulating a series of previously performed experiments. Afterwards, a planar, five-story, five-bay RC frame was designed according to the Turkish Earthquake and RC Codes. The stirrup spacing of the members at the confinement regions were designed with the typical deficiencies observed in residential buildings in Turkey. Then two types of infilled frames were

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obtained by introducing infill walls into the bare frame. The infill walls of the first infilled frame had a uniform stiffness and strength distribution along the height of the building. In the second infilled frame, the infill walls had a decreasing stiffness and strength distribution through the elevation of the frame. These three frames were analyzed using nonlinear dynamic and pushover methods. The results were compared in terms of interstory drift ratios.

MODELING THE NONLINEAR BEHAVIOR OF INFILLED RC FRAMES

A numerical study was performed to estimate the hysteretic control parameters and to verify the selected analysis software. In this study, a series of experiments conducted by Çankaya (2011) were simulated using IDARC-2D Version 7.0.

Four single-bay, 1/5-scale, four-story, planar RC frames were subjected to displacement-based pseudo-static cyclic loading in the experiments. The parameters of the experiments were the presence of the infill walls which were built with hollow clay tiles and the reinforcement detailings. Frames #1 and #2 were bare frames with brittle and ductile detailing, respectively; and Frames #3 and #4 were infilled frames with brittle and ductile detailing, respectively. The details of the test setup and construction for the frames are presented by Çankaya (2011).

The selected software presents several hysteretic models and provides adjustable parameter sets to capture the intended behavior. IDARC implements the Three-parameter Park Model (Park et al., 1987) to represent the nonlinear cyclic behavior of RC members. This hysteretic model has four parameters to control stiffness degradation, stiffness deterioration and pinching effects. On the other hand, Smooth Hysteretic Model (Reinhorn et al., 1995) is employed to simulate the cyclic behavior of infill walls. This model has a wider range of parameters to represent the complex cyclic behavior of the infill walls.

For modeling the hysteretic behavior of the RC members, a parametric study was performed on the bare frames. Firstly, the RC members were defined in IDARC in terms of moment-curvature relationships. Then, the parameters of the Three-parameter Park Model were calibrated for simulating the experimental results (Table 1).

Table 1. Adapted hysteresis control parameters

Parameter	**Frame #1**	**Frame #2**	**Frame #3**	**Frame #4**
α (Stiffness Degradation)	200.00	200.00	200.00	200.00
β_1 (Ductility-based Strength Degradation)	0.01	0.01	0.01	0.01
β_2 (Energy-based Strength Degradation)	0.01	0.01	0.01	0.01
γ (Slip or Crack-closing)	0.20	0.50	0.20	0.15

The infill model of IDARC utilizes equivalent strut approach to model the infill walls. This approach replaces an infill panel by two diagonal, compression-only struts. IDARC uses the prism strength of the infill panel for calculating the strength envelope of an equivalent strut. Since the results of the prism tests showed a wide distribution, a value in vicinity of the results that yielded the best fit is selected for data input. Since no other experimental data is available, other strength parameters of the infill walls were calculated using the formulae proposed by IDARC. The parameters of the Smooth Hysteretic Model were set to default values except the ductility capacity of the infill wall which is set to 15.0 and 13.0 to fit the experimental results for Frame #3 and Frame #4, respectively.

The analyses were performed using the displacement-controlled quasi-static loading histories which were measured at every story level during the tests. The maximum interstory drift ratios applied in the first story are summarized in Table 2.

Table 2. Applied maximum interstory drift ratios (%) at the first story (each cycle applied twice)

Frame No.	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
#1	0.7	1.1	1.5	1.9	-	-
#2	0.7	1.1	1.5	2.1	2.5	3.4
#3	0.1	0.3	0.7	1.0	1.4	1.8
#4	0.1	0.3	0.6	0.9	1.5	2.0

Computed shear force versus interstory drift ratio relations for the first stories of all frames are presented in a comparative fashion in Figure 1.

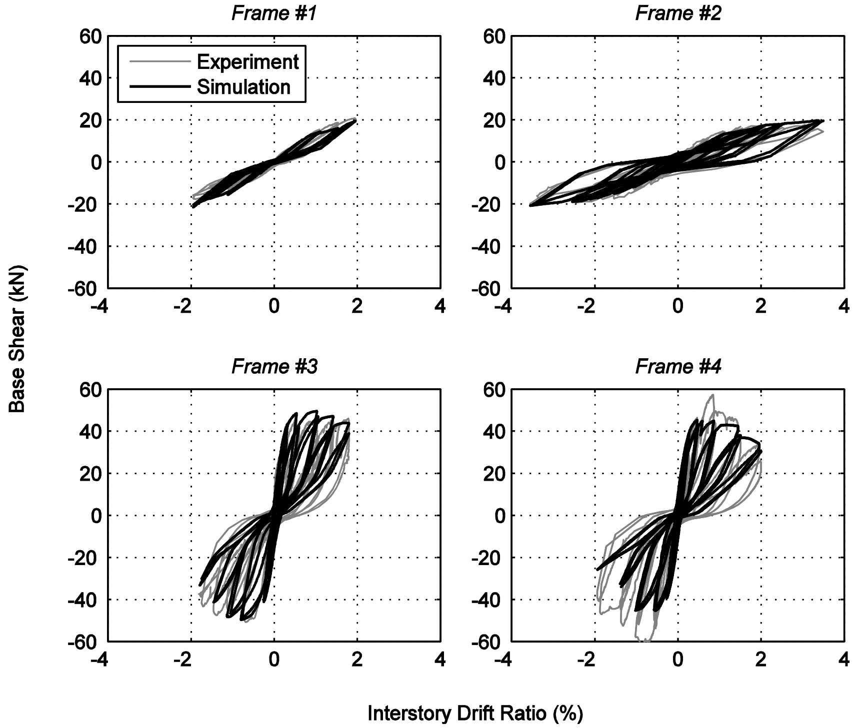

Figure 1. First story hysteresis curves of the experimental and analytical systems

For the bare frames (Frame #1 and Frame #2), the overall behavior matches closely with the experimental results. In addition it can be seen that the pinching behavior observed in the experiment may be modeled by selecting the proper parameter for the slip. For Frame #3, it can be observed from the figure that the selected control parameter for the slip behavior simulated the pinching accurately. Moreover, the infill model used by IDARC represents the contribution of the infill wall to the stiffness and strength of the system, and the strength degradation at increasing drift levels satisfactorily. However, in the experiment, Frame #4 reported to exhibit a different failure mechanism than Frame #3. Shear failure occurred at the upper ends of the first story columns and the upper stories started to move as a rigid body. The software failed to model this failure mechanism, since the shear modulus of the columns are accepted infinitely high by default.

EFFECT OF INFILL WALLS ON THE DRIFT DISTRIBUTION OF INFILLED RC FRAMES

Previous studies have shown that under seismic demands, drift concentration in lower stories of infilled frames may cause major damages. In this study, it is anticipated that a well-organized stiffness distribution along the height of the building may help mitigating the concentration phenomena. The stiffness variations in frames are aimed to be controlled by the infill walls, since they have a major effect on overall stiffness of structures. It is possible to alter the stiffness and strength properties of the infill walls by applying available retrofitting or weakening techniques, as well as by changing the thickness or the masonry material of the infill panels. Therefore, it is assumed that necessary techniques are used to obtain the targeted stiffness levels of the infill walls.

At the beginning, in order to observe the effects of stiffness variations on the drift distribution of multi-degree-of-freedom (MDOF) systems, four simple linear systems were constructed. The MDOF systems had various stiffness distributions to represent the effect of infill walls with various stiffness properties at the floor levels. Figure 2 presents the selected mass and stiffness properties, and first mode vibration periods of the selected MDOF systems.

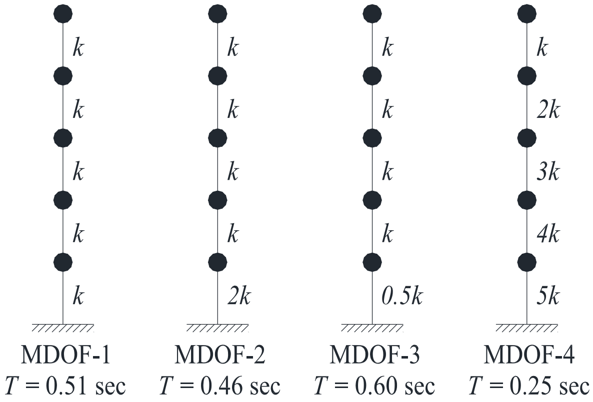

Figure 2. Selected simple multi-degree-of-freedom systems and the first mode periods

The stiffness of a story with typical infill panels is represented with a stiffness of *k*. The increasing stiffness values correspond to stories with either thicker or reinforced infill walls. The decreasing values correspond to stories with weaker infill walls whose stiffness values were accepted to be reduced. Modal analyses were performed to determine the natural periods and the modal shapes of the systems. Considering that the deflected shapes of the selected systems are dominated by the first modes, the interstory drift ratios were followed by the first modes of the systems.

The interstory drift distributions of the linear MDOF systems are presented in Figure 3. The ratios were normalized with respect to the maximum drift which was observed in the first story of MDOF-3. This value was normalized such that its value is unity. As it can be observed from the figure, MDOF-1 has an increasing drift concentration in the lower stories caused by the regular stiffness distribution in elevation. In MDOF-3, the soft first floor caused a significant concentration on the drift of the first story. On the contrary, a strong first floor in MDOF-2 limited the drift of the first story; however the drifts of the upper floors increased compared to those of MDOF-3. The stiffness distribution of MDOF-4 caused a more balanced drift profile and the drift is well distributed among the individual floors. Thus, in a system with higher stiffness value at the lower stories which is uniformly decreasing along the building height, drift concentrations in the lower floors could be mitigated.

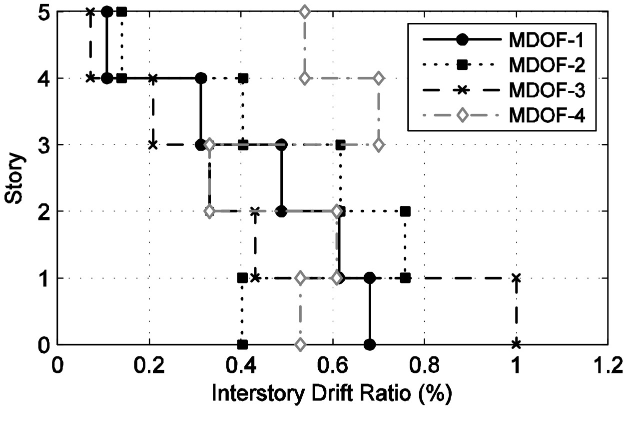

Figure 3. Interstory drift ratios of the MDOF systems

The target structures of this study are the typical residential buildings in Turkey. Considering that generally the first mode governs the dynamic response of such frames, modifying the first mode shape may help controlling the interstory drifts. For this purpose, infill walls were utilized to change the first mode shape by altering the stiffness distribution along the height of the structure.

Three frames were analyzed in this stage of the study. Initially, a planar, five-bay, five-story RC bare frame (BF) was designed and numerically modeled in IDARC. Then, two types of infilled frames, namely IF-1 and IF-2, were obtained by placing infill walls into two bays of BF. The infilled frames have similar infill wall amounts to the average infill ratios in the literature (Bal et al., 2008; İnel, 2009) with two of the five bays having infill panels. The modeled frames were assumed to be located in a building that is symmetrical in both directions. The plan of the building and the overall geometry and dimensions of the modeled frames are presented in Figure 4. Proportioning of the selected frames is based on the following material properties. The compressive strength of the concrete was assumed to be 20 MPa. The modulus of elasticity of the concrete was calculated as 28 500 MPa using the formula proposed by the Turkish RC Code (TS500, 2000). The yield stress and the modulus of elasticity of the steel were taken as 420 MPa and 200 000 MPa, respectively. A uniform dead load of 0.45 t/m^2 and live load of 0.20 t/m^2 were assumed on the slabs of the building. Gravity loads from the slabs were calculated by triangular distribution to the beams and axial loads to the columns.

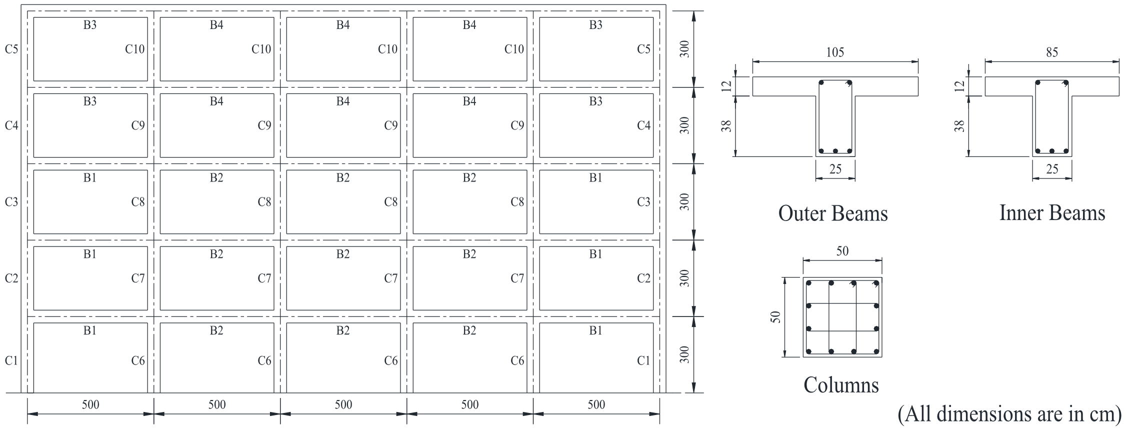

Figure 4. Designed frame, member types and dimension details of the RC members

The reinforcement details of the members were initially determined according to the Turkish Earthquake Code (TEC2007) and the Turkish RC Code (TS500, 2000). Afterwards, the calculated stirrup spacings for the confinement regions were doubled in all the members in order to represent the common deficiencies of the residential buildings in Turkey. Modified stirrup spacings were confirmed to be in accordance with the typical observed values in the residential buildings (İnel, 2009). The reinforcement details of the beams and the columns are presented in Table 3.

Table 3. Reinforcement details of the designed frames

Location of Reinforcement		**Beam Type**				**Type of Reinforcement**	**All Columns**
		B1	**B2**	**B3**	**B4**		
Left	**Bottom**	3Ø16	3Ø14	3Ø12	2Ø14	**Longitudinal**	12Ø18
	Top	4Ø16 + 2Ø12	5Ø14 + 2Ø12	2Ø16 + 2Ø12	3Ø12 + 2Ø12		
	Stirrup	Ø8 / 192 mm	Ø8 / 192 mm	Ø8 / 192 mm	Ø8 / 192 mm		
Midspan	**Bottom**	3Ø12	3Ø12	3Ø12	3Ø12		
	Top	2Ø12	2Ø12	2Ø12	2Ø12		
	Stirrup	Ø8 / 235 mm	Ø8 / 235 mm	Ø8 / 235 mm	Ø8 / 235 mm	**Stirrup**	Ø10 / 200 mm
Right	**Bottom**	3Ø16	3Ø14	2Ø14	2Ø14		
	Top	4Ø16 + 2Ø12	5Ø14 + 2Ø12	2Ø14 + 2Ø12	3Ø12 + 2Ø12		
	Stirrup	Ø8 / 192 mm	Ø8 / 192 mm	Ø8 / 192 mm	Ø8 / 192 mm		

The first infilled frame, IF-1, was aimed to represent the common infill wall practice observed in the residential buildings in Turkey. Hollow clay tiles with dimensions of 19×19×13.5 cm were assumed to be used in the infill panels. Total infill wall thickness was assumed 23 cm with 2 cm of plaster on each side. Weight of an infill panel was calculated to be 0.4 t/m^2 based on the information provided by manufacturers. The prism strength of an infill panel was assumed to be 3 MPa depending on Paulay and Priestley (1992). The initial stiffness of an individual infill panel was calculated by IDARC as 80 kN/mm and the lateral yield force as 420 kN.

In the second infilled frame, IF-2, it was aimed to have a pre-organized stiffness distribution throughout the height of the building by modifying the infill walls used in IF-1. Linear modal analyses of simple MDOF systems showed that a descending stiffness distribution proportional to the building height is advantageous in terms of linear interstory drift profile. Depending on this observation, the infill panels in IF-2 were aimed to have the stiffness properties in a descending form, where the stiffer infill walls are located in the lower stories and the flexible infill walls in the upper stories. The stiffness values of the infill panels in IF-2 were determined to be 2.0, 1.6, 1.2, 0.8 and 0.4 times of those of the infill walls used in IF-1. By this distribution, the lower three stories were accepted to be reinforced using different methods to obtain the mentioned stiffness values. On the contrary, the upper two stories were assumed to be weakened using various techniques mentioned in the literature (Mohammadi et al., 2011; Preti et al., 2012). Since the modification in stiffness affect the strength properties of the infill walls as well, the yield strength of the reinforced infill panels were assumed to be increased by 40%, 30% and 20% in the first, second and third floors, respectively. In the fourth and fifth stories, the yield strength values were assumed to be decreased by 20% and 40%, respectively. These factors were selected arbitrarily, since no specific modifying method was selected. It is also considered that IF-1 and IF-2 should have the similar initial period to have comparable seismic demands for the systems. To obtain the similar periods, the initial stiffness values of the infill walls in IF-1 were taken 10% higher than the original value. The initial stiffness and the yield strength values of the infill walls are presented in Table 4. The first natural mode periods of BF, IF-1 and IF-2 were calculated as 0.74, 0.50 and 0.51 seconds, respectively, by linear modal analyses.

Table 4. Initial stiffness and yield strength values of the infill walls

Story	**IF-1**		**IF-2**	
	Initial Stiffness (kN/mm)	**Yield Force (kN)**	**Initial Stiffness (kN/mm)**	**Yield Force (kN)**
5	88	420	32	252
4	88	420	65	336
3	88	420	97	504
2	88	420	129	546
1	88	420	161	588

Nonlinear dynamic analyses were performed to calculate the seismic response of each frame. Initially, ten strong ground motion acceleration records were adopted from the study of Lepage (1997). Table 6 presents the information about the selected ground motions. The records encompass a wide range of soil conditions and frequency contents. The selected ground motions were normalized with respect to El Centro 1940 NS scaled to 0.40 *g* peak ground acceleration using the method proposed by Lepage (1997) to yield the similar displacement demands. The peak ground accelerations used to normalize each record are presented in Table 5.

Table 5. Ground motion records used in dynamic analyses

Record	**Record Duration (sec)**	**Characteristic Period, T_g (sec)**	**Original Peak Ground Acceleration (g)**	**Normalized Peak Ground Acceleration (g)**
Hachinohe 1968 EW	40	1.14	0.19	0.19
Santa Barbara 1952 S48E	40	1.03	0.13	0.21
Sendai 1978 NS	40	0.95	0.26	0.23
Seattle 1949 S02W	50	0.89	0.07	0.25
Taft 1952 N21E	30	0.72	0.16	0.31
Kobe 1995 NS	30	0.70	0.83	0.31
El Centro 1940 NS	30	0.55	0.35	0.40
Llolleo 1985 N10E	50	0.50	0.71	0.44
Tarzana 1994 NS	30	0.44	0.99	0.50
Castaic 1971 N21E	30	0.35	0.32	0.63

The presented acceleration records were applied to BF and IF-1 to determine the most critical records in terms of interstory drift distributions. Examination of the results showed that the presence of the infill walls limited the roof displacement up to a certain point in most earthquakes. However, in Sendai, Seattle, Kobe and El Centro, the roof displacements of IF-1 were almost equal or higher than that of BF. In these earthquakes, the drift concentrations at the lower stories of IF-1 are also quite significant. Individual infill wall hystereses of the frames were then examined and it was seen that the infill walls at the lower stories had passed to the post-peak stage of their response in the mentioned ground motions. Beyond the post-peak stage, dramatic decrease in the stiffness and strength of the infill walls caused drift concentrations at the lower stories, thus formation of soft-story mechanisms. Based on these observations, dynamic analyses of IF-2 were carried out with these four ground motion records, namely Sendai, Seattle, Kobe and El Centro, which were determined to be the most critical motions.

The interstory drift ratios of BF, IF-1 and IF-2 at maximum roof displacements are compared for each of the selected critical ground motions in Figure 5. In Sendai and Seattle earthquakes, the interstory drift demands dropped and a well distributed demand obtained. In Kobe and El Centro, dramatic drops in the lower story interstory drift ratios took place. On the other hand, the infill walls in those stories still passed to the post-peak stage.

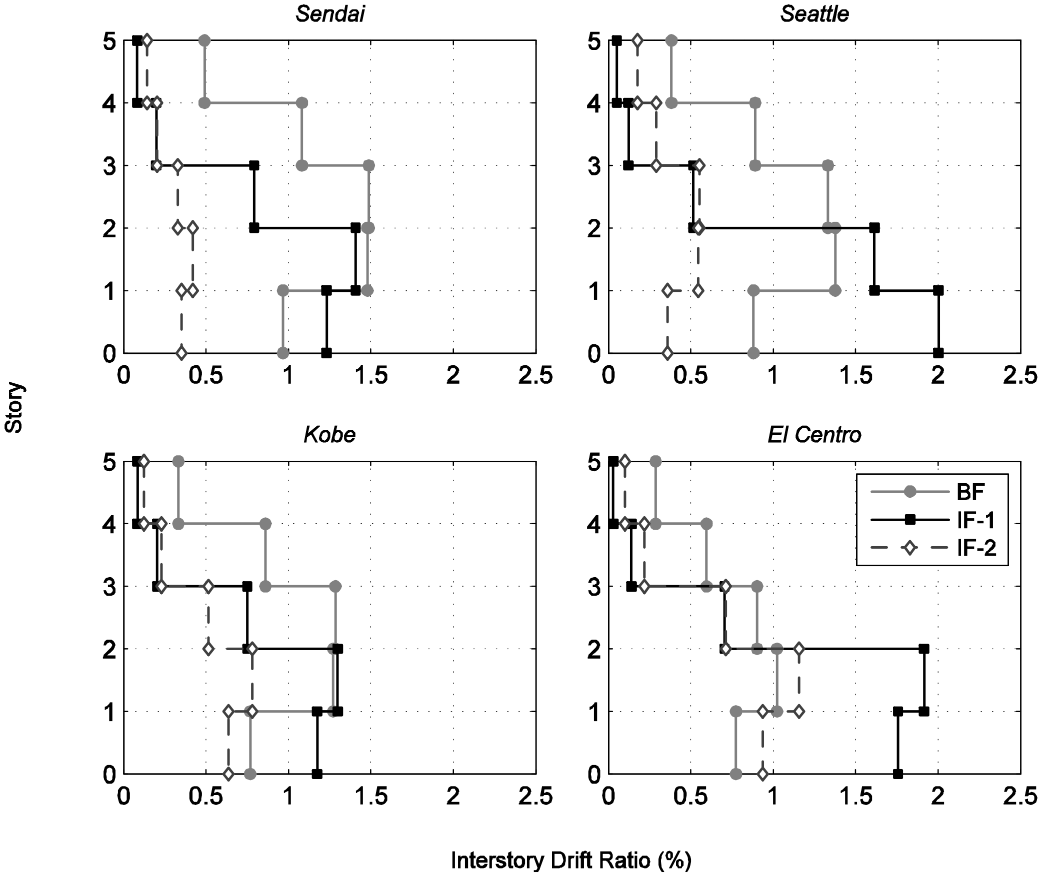

Figure 5. Interstory drift ratios of BF, IF-1 and IF-2 for the selected critical ground motions

The pushover analyses were performed to determine the performance of the three frames according to TEC2007 using SAP2000, since the infill model in IDARC does not support pushover analysis. The frames were assumed to be located in the first seismic zone (peak ground acceleration 0.4g) and on a type Z3 (medium dense soil) of local site. The lateral load pattern was calculated according to the equivalent earthquake load procedure and assigned to the frames at the floor levels. Using the procedures described in TEC2007, seismic displacement demand was determined for each frame, and the frames were pushed to the demanded displacements to determine the performance levels.

In SAP2000, linear behavior of the RC members is determined through the cross sectional and the material properties. The nonlinear behavior of the RC members was defined by assigning plastic hinges at both ends of the members. The hinge properties were determined by simplified moment-curvature with tri-linear relation as in IDARC. Using the strain limits defined by TEC2007 for concrete and reinforcement, curvature values were calculated for damaged-limit states for each member. The calculated values defined in SAP2000 for each hinge; therefore it was possible to determine the damage region of each RC member and the performance of the entire structure, consequently.

The infill walls were modeled as compression-only equivalent struts in SAP2000. To determine the nonlinear behavior of the infill walls, displacement-controlled incremental quasi-static analyses were performed in IDARC for each infill wall. Then, the results were simplified as tri-linear curves and defined as plastic springs at the mid-point of each equivalent strut.

The pushover curves of the three frames are presented in Figure 6. As expected, the presence of the infill walls substantially increased the strength and stiffness of the frame. The maximum base shear versus the frame weight ratio is 0.17 for BF. This ratio increased to 0.27 and to 0.29 for IF-1 and IF-2, respectively. The maximum shear force was reached in relatively low displacements for the infilled frames. The initial stiffness of IF-1 and IF-2 is 2.80 and 3.07 times that of the BF, respectively.

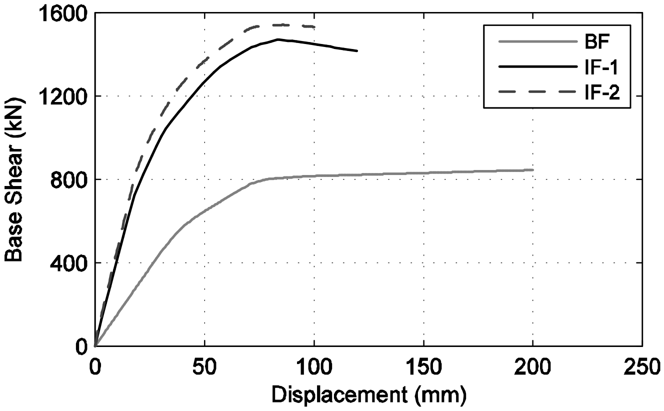

Figure 6. Pushover curves of BF, IF-1 and IF-2

The plastic states of the members were evaluated at the end of the analyses and the performance level of each frame was determined. The bare frame was determined to be in “Collapse Prevention” level and it did not satisfy the life safety requirements while IF-1 was in “Life Safety” zone and IF-2 was in “Immediate Occupation” zone.

Interstory drift ratios at the code displacement demands for each frame are presented in Figure 7. The maximum interstory drift ratio was observed in the second story of BF as 1.78%. The interstory drifts of IF-1 was lower that those of BF; however the drift concentration at the lower stories dominated the behavior. In IF-2, the interstory drifts at the lower floors decreased and those at the upper floors increased when compared to IF-1. This leads the frame to have a more balanced interstory drift distribution while preventing the drifts to concentrate in the lower stories.

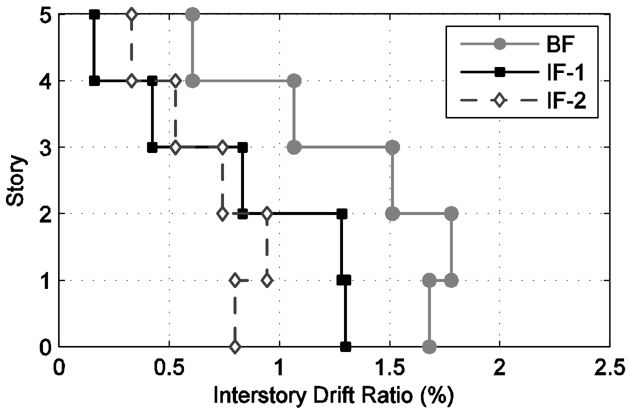

Figure 7. Interstory drift ratios of BF, IF-1 and IF-2 for pushover analysis

DISCUSSION OF THE RESULTS

As mentioned above, the study consists of two phases. In the first phase, it was intended to calibrate and verify the selected analysis algorithm, IDARC, by simulating previously performed experiments. The experiments included two planar bare and two infilled RC frames. In these simulations, IDARC satisfactorily represented the behavior of the tested frames and the contribution of the infill walls to their response. When the hystereses for individual loading groups were examined separately, it was seen that the simulation results showed a good approximation with the experimental results. In Frame #4, algorithm failed to model the behavior accurately. This is due to the shear failure of the first story columns during the experiments. IDARC assumes infinite shear modulus in its models. Since, shear failures were not considered in the planned study, the subsequent analyses were carried out using IDARC.

In the second phase of the study, it was aimed to investigate the effects of infill wall stiffness variations on the seismic behavior of the designed frame. To achieve this purpose, seismic responses of the three designed frames were compared in terms of interstory drift ratios. In the regularly infilled frame, IF-1, the infill walls limited the interstory drift ratios and consequently, the peak displacements up to a certain point. For the ground motions in which the infill walls at the lower stories had passed to the post-peak stage of their response, the stiffness and strength of the lower stories decreased rapidly and soft-story mechanisms were formed.

It is observed that, the presence of the infill walls can be advantageous, since they shorten the period of the structure; hence, the seismic displacement demand decreases. However, the uniform stiffness distribution along the height of the structure could cause drift concentrations in the lower stories which may force the infill walls to exceed their lateral strength capacity. To mitigate the drift concentrations at the lower stories, infill walls with varying stiffness and strength properties were used to obtain an organized stiffness distribution through the height. Observations in linear systems indicated that uniformly decreasing stiffness - with larger values in the lower stories - provides a better drift distribution along the height of the structures. Analyses of the nonlinear systems confirm this observation, the interstory drift distributions of IF-2 were more balanced than those of BF and IF-1. The organized stiffness distribution also limited the maximum interstory drift ratios when compared to BF and IF-1, except El Centro, in which the ratios are lower than that of IF-1 but higher than that of BF.

Pushover analysis was also performed, since it is a common application used to determine the seismic performance of the buildings in practice. The results indicated that the organized stiffness distribution improved the performance of the frame when compared to those of BF and IF-1 by decreasing the drift concentration at the lower stories. Particularly, this limits the damage in the lower story columns. The interstory drift distribution of IF-2 at the demanded displacement was observed to have a balanced profile when compared to the other frames.

CONCLUSIONS

The analysis results firstly indicated that within the scope of the presented study the selected software, IDARC-2D, and its infill wall model which is based on the equivalent strut approach can be used to simulate the behavior of the RC frames with infill walls under cyclic loading satisfactorily. Though, the program did not have the capability to simulate the shear failure in the columns that occurred due to forces developed by the infill walls. The calibration of the hysteretic control parameters using the experimental data was satisfactory.

The existence of the infill walls increased the stiffness and strength of the frame substantially. The base shear capacities of the infilled frames were increased by approximately 100%. Moreover, the initial stiffness values of the infilled frames were as high as three times of the bare frame. Since the maximum displacement induced by strong ground motion is sensitive to stiffness (Shimazaki and Sozen, 1988; Lepage, 1997); with decreasing periods, the displacement demand for the infilled frames decreased. However, the drift concentration in the lower stories of IF-1 caused a soft-story mechanism in some of the selected ground motions and the upper stories moved together almost as a rigid body.

In some of the selected ground motions, the interstory drift ratios of the lower stories of IF-1 exceeded those of BF. The organized stiffness distribution managed to limit these drifts in IF-2. The drifts observed in the lower stories of IF-2 were smaller than those of BF, except El Centro ground motion. The maximum interstory drift levels of IF-2 in El Centro are about the bare frame demands. Still, it can be concluded that the selected distribution was proved to be advantageous in controlling drift distribution of the frames.

In the pushover analyses, the existence of an organized stiffness distribution revealed a better interstory drift distribution along the elevation of the frame. The evaluation of the member damage states revealed that the selected stiffness distribution improved the seismic performance of the frame when it was compared to those of BF and IF-1.

The results of the study showed that neglecting the infill walls in structural design can be extremely misleading while analyzing the seismic response. Expected behavior in structural designs which ignore the infill walls may not be the actual behavior and unforeseen damages may occur in the buildings during earthquakes. The results also indicated that, existing infill wall retrofitting and weakening techniques can be used to improve the seismic performance of the frame structures if they are executed appropriately throughout the structure. Buildings with stiffer lower stories and a uniform stiffness change throughout the height were determined to exhibit better seismic performance. This targeted stiffness distribution along the elevation can be obtained by using infill walls which have varying stiffness properties.

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