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RESEARCH PAPER

The Influence of Deterioration Parameters on the Response of Low-Rise Symmetric and Asymmetric RC Buildings

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Abstract The variability in engineering design decisions results in the building models with considerably different deterioration properties. So, this paper investigates the effect of different deteriorating hysteretic model parameters on the response of asymmetric buildings. The example buildings are 5-story symmetric and asymmetric buildings. The maximum interstory drift ratio over the height of building is selected as the structural response in this study. A proper hysteretic model is used to simulate the deterioration properties of structural elements. The median response of building with different mass eccentricities is evaluated by 3D modeling. The results are provided for both torsionally stiff and torsionally flexible buildings. The results show that the effect of deterioration parameters is different for flexible side and stiff side elements. Those effects are mainly significant for higher intensity levels. That intensity threshold level is independent of all hysteretic parameters except for the plastic rotation capacity.

Keywords Deterioration parameters · Asymmetric buildings · Torsionally stiff · Torsionally flexible

1 Introduction

For a realistic seismic assessment of structural performance, it is needed to predict the dynamic response of buildings with deteriorating properties and the inclusion of P-Δ effects in evaluation. Previous studies have been done independently in quantifying P-Δ effects on the behavior of non-deteriorating buildings [1–4]. It was because of the lack of hysteretic models capable of simulating deteriorating behavior [5]. As a result, the redistribution of damage and the ability of building to sustain deformations before collapse may not be taken into account. These deformations might be significantly larger than those associated with loss in resistance of individual elements.

On the other hand, some researchers focused in developing deteriorating models that can reproduce experimental results [6–8]. Recently, several efforts have been carried out to combine P-Δ effects with the structural component deterioration in the performance assessment [4, 5, 9, 10]. The results have shown that the parameters of deteriorating hysteretic models may have great influences on the pre-collapse response of buildings.

Although most of response evaluations of deteriorating buildings were carried out by SDOF systems [10–13], there were several studies done by MDOF frame-type buildings [4–6, 9, 10]. However, these studies did not use realistic building models in response evaluations. Additionally, the asymmetry of buildings is not considered in the response assessment of those groups of studies.

Several studies have been conducted on asymmetric buildings [14–17]. Most of these studies were done using simple single-story models. However, the studies on more realistic multi-story buildings are growing now [15, 17]. In most of the published researches on asymmetric buildings, engineering demand parameters (e.g., ductility) in flexible and stiff edges have been studied. These studies have investigated the effect of asymmetric system parameters on inelastic EDPs and have tried to improve torsional provisions of seismic codes to reduce poor torsional behaviors [16, 18]. However, some others have tried to control

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torsional effects on nonlinear EDPs introducing a new seismic design methodology which is based on the interdependence between strength and stiffness of lateral load-resisting elements [19, 20]. The deteriorating buildings have not been investigated in asymmetric building researches in detail. Furthermore, the influences of deteriorating hysteretic properties on the deformation capacity of such systems have not been studied yet.

So, the main objective of this paper is to develop a methodology for evaluating the pre-collapse behavior of symmetric and asymmetric low-rise reinforced concrete (RC) buildings with deteriorating hysteretic properties. For this purpose, a set of strong ground motions is introduced that may cause the building to deteriorate in strength. A proper hysteretic model is used to simulate the deterioration properties of structural elements. The behavior of modern low-rise RC buildings is investigated using symmetric and asymmetric 5-story special moment frame buildings. Asymmetric buildings are grouped to torsionally flexible and torsionally stiff buildings. In each group, the buildings have 10 and 20 % mass eccentricity. In total, five buildings are used as basis models in the evaluation of structural response with deteriorating properties. The maximum interstory drift ratio over the height of building is selected as the EDP. The median of EDP is studied when the deterioration parameters have different values. The aim is to study the influences of hysteretic parameters on the deformation capacity of asymmetric RC buildings.

2 Numerical Model

2.1 Structural System

Reinforced concrete special moment frame (RC-SMF) buildings are selected as the structural system in this research. ACI code is typically utilized at RC building design in Iran. So, we design our building models based on its provisions. The 3D model of buildings is designed based on ACI 318-05 [26]. The fundamental period for design is 0.6 s, and the buildings have a design seismic coefficient (fraction of the building weight applied as an equivalent static lateral force) of 0.078.

Although the two-element building models are simple models, they are statically determinate and less efficient to simulate the response of most eccentric buildings [27]. Furthermore, Anagnostopoulos et al. [28] showed that the simplified 1-story shear models were inadequate to model the behavior of realistic multi-story buildings in inelastic range. Therefore, a building model with four lateral load-resisting frames is selected for this investigation, as shown in Fig. 1. Furthermore, a 3-bay configuration is selected for frames, because it is the simplest model to represent important design features that may impact the structural response, thus allowing us to conduct a broad study on RC-SMF buildings [23].

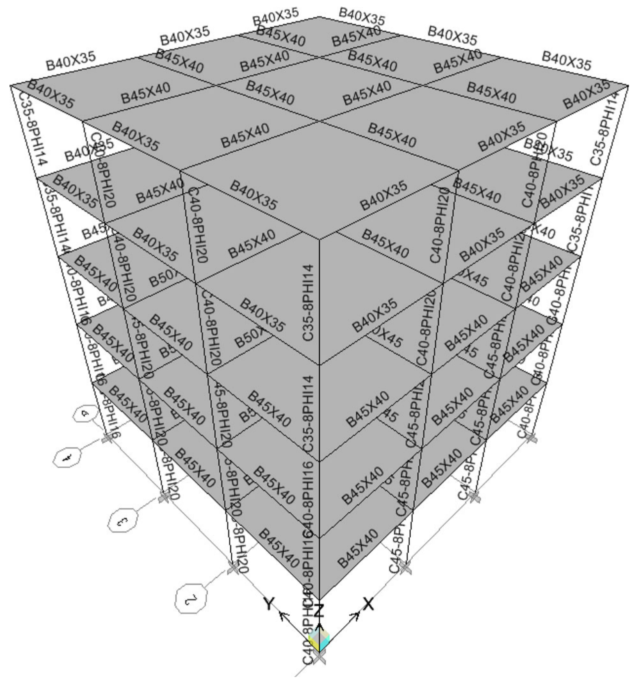

Fig. 1 The configuration of 5-story building in this study

OpenSees software [29] is used for modeling and analysis. To examine the deformation capacity of a frame-type building, it is necessary to simulate the elastic and inelastic behavior of its beam-column elements. Structural elements are simulated with the concentrated plasticity model, and nonlinear behavior is assigned to the structural components using the described hysteretic model. Floors are modeled as rigid slabs, and soil–structure interaction effects are considered to be insignificant. Zareian and Medina [30] introduced a modeling method to avoid the unrealistic damping forces in inelastic responses. Structural damping (with 5 % damping ratio) is modeled using a Rayleigh-type damping and proportional to mass and initial stiffness of structural elements based on their study. The specific provisions of special moment frame buildings are included in the design to enforce the joints to remain elastic. Accordingly, the joints are not modeled in the evaluation.

2.2 Deterioration Model

Response evaluation is based on a hysteretic model that accounts for history-dependent strength and stiffness deterioration. The monotonic backbone curve of this model consists of an elastic branch, a strain-hardening branch and a negative tangent stiffness branch as shown in Fig. 2. Moreover, this model captures four basic modes of cyclic deterioration. These modes are strength deterioration of the

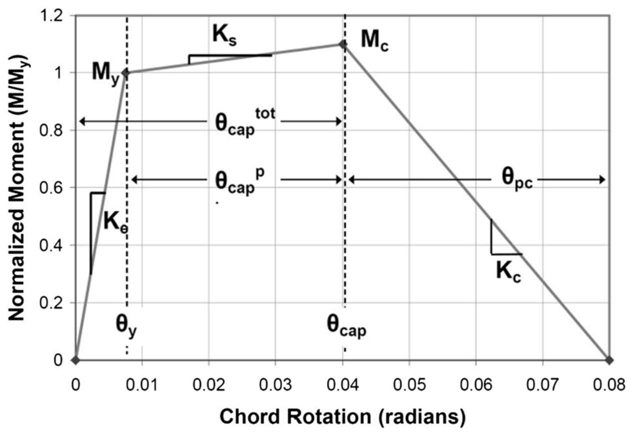

Fig. 2 Monotonic behavior of hysteretic model developed by Ibarra et al. [7]

inelastic strain-hardening branch, strength deterioration of the negative tangent stiffness branch, accelerated reloading stiffness deterioration, and unloading stiffness deterioration. Ibarra et al. [7] developed this model to evaluate the collapse capacity of SDOF system and MDOF frames. This model is very suitable for simulating strain softening and cyclic deterioration of reinforced concrete beam–columns [24]. The parameters of model are related to the physical properties of beam–columns using empirical predictive equations developed by Panagiotakos and Fardis [25] and Haselton [23]. It has been found that plastic rotation capacity ($\theta_{\text{cap}}^{\text{p}}$ or shortly θ_{p}), post-capping rotation capacity (θ_{pc}), and hysteretic energy dissipation capacity (expressed by the parameter γ) are the most significant parameters of the deteriorating model that can change the performance of RC frame buildings [8, 9, 23].

2.3 Ground Motion Selection

Table 1 shows the list of far-field records used in this study. This ground motion set has been frequently used in previous researches [21–24]. Figure 3 shows the acceleration response spectrum of the selected records. Spectral acceleration at the first translational mode period of vibration in direction of excitation is considered as the ground motion intensity measure.

2.4 Structural Irregularity

This research tries to study the maximum interstory drift ratio of 5-story symmetric/asymmetric RC buildings with deteriorating properties. Indeed, it is desired to show how the deformation capacity of asymmetric buildings change when the deteriorating parameters of structural element model vary and how these changes may be influenced by increasing plan irregularity.

There are several parameters that may have significant changes in the responses of asymmetric buildings. As the first step, the irregularity of building is considered in the simplest way by inducing 10 and 20 % mass eccentricities in the one-way of plan. Therefore, the plan of building is divided into the flexible side and stiff side as shown in Fig. 4. It is also decided to keep the effects of all other important parameters constant in each asymmetric building.

The asymmetric 5-story building models are divided into torsionally stiff and torsionally flexible building groups. This classification is based on a relative comparison between a building's torsional and lateral periods. A torsionally stiff building has a fundamental torsional period that is significantly shorter than its fundamental lateral period, whereas a torsionally flexible building has a longer torsional than lateral period [31]. As shown in Eq. 1, the ratio of the first torsional frequency to the first translational frequency is introduced as a measure of frequency ratio (Ω) in this study and used to distinguish torsionally flexible building from torsionally stiff ones. The frequency ratio alters by changing the mass moment of inertia of floors in different mass eccentricities. The values of $\Omega = 0.6$ and $\Omega = 1.8$ in the results stand for torsionally flexible and torsionally stiff buildings, respectively.

$$\Omega = \frac{\omega_\theta}{\omega_l} \quad (1)$$

3 The Results of the Analysis

The assessment is performed by incremental dynamic analysis [32] using far-field ground motions. Although bi-directional excitation gives more realistic results, in the present study, the 3D building models are subjected to one-directional ground motion records. Each of two horizontal components of a ground motion record is used in nonlinear dynamic analysis. Spectral acceleration at the fundamental translational mode period is considered as the ground motion intensity measure. The intensity measure increases in an IDA until the maximum interstory drift ratio in a story or a series of stories grows unlimitedly. Figure 5 shows the outcome of IDA for asymmetric 5-story torsionally stiff and torsionally flexible buildings. The results are shown for 20 % mass eccentric buildings.

3.1 Effect of Deterioration Parameters on EDP

The evaluation of inelastic EDP of deteriorating systems provides valuable information about the effect of deteriorating model on deformation capacity. The EDP used in this study is *maxIDR* which is the maximum interstory drift ratio over the height of building. The results are

Table 1 The ground motions data

	EQ ID	Event	Year	Mag.	Fault mechanism	Campbell distance (km)	Vs_30 (m/s)	Lowest useable freq. (Hz)
1	12011	Northridge	1994	6.7	Blind Thrust	17.2	356	0.25
2	12012	Northridge	1994	6.7	Blind Thrust	12.4	309	0.13
3	12041	Duzce, Turkey	1999	7.1	Strike-slip	12.4	326	0.06
4	12052	Hector-Mine	1999	7.1	Strike-slip	12.0	685	0.04
5	12061	Imperial Valley	1979	6.5	Strike-slip	22.5	275	0.06
6	12062	Imperial Valley	1979	6.5	Strike-slip	13.5	196	0.25
7	12071	Kobe, Japan	1995	6.9	Strike-slip	25.2	609	0.13
8	12072	Kobe, Japan	1995	6.9	Strike-slip	28.5	256	0.13
9	12081	Kocaeli, Turkey	1999	7.5	Strike-slip	15.4	276	0.24
10	12082	Kocaeli, Turkey	1999	7.5	Strike-slip	13.5	523	0.09
11	12091	Landers	1992	7.3	Strike-slip	23.8	354	0.07
12	12092	Landers	1992	7.3	Strike-slip	20.0	271	0.13

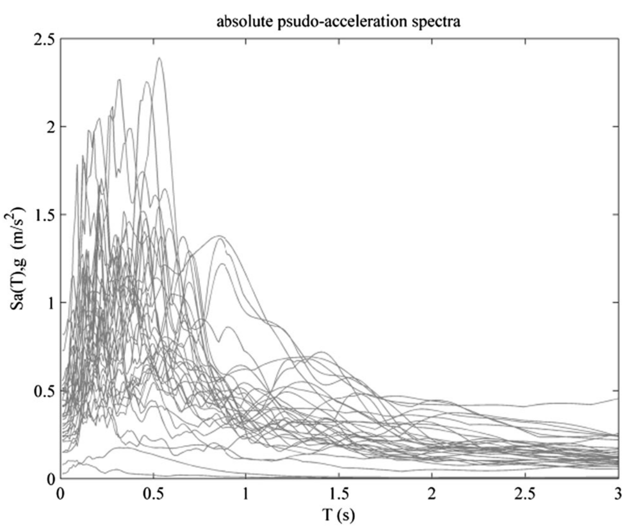

Fig. 3 Acceleration response spectrum of the ground motion records

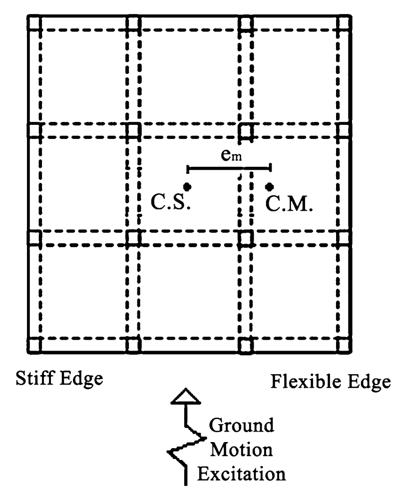

Fig. 4 The plan of 5-story buildings. (e_m eccentricity, *CM* center of mass, and *CS* center of stiffness)

represented as the median of EDP in symmetric and asymmetric buildings. For each irregular building, the median of the results is shown based on the EDP of the exterior frame in the flexible and stiff sides of building.

The sensitivity of response to the variation of deterioration parameters is also investigated. For a given parameter, μ is associated with a condition at which the value of parameter is calculated by empirical calibration equations. The increment with respect to the mean value of each deterioration parameter is introduced as $\pm n\sigma$, where n is the coefficient for σ that stands for standard deviation. Four additional values of each parameter are generated as $\mu \pm \sigma$ and $\mu \pm 1.7\sigma$. These values have been frequently repeated in the sensitivity studies of frame structures recently [22, 23, 33]. The most important objectives of this section are: (a) to determine the intensity levels at which the effect of deterioration parameters starts; (b) to evaluate the amount of changes in the deformation capacity when deterioration parameters are varied; and (c) to investigate how the level of irregularity in the buildings changes the effect of hysteresis parameters on the deformation capacity.

3.1.1 *Effect of Post-capping Rotation Capacity on EDP*

The median of *maxIDR* for the symmetric 5-story building is shown in Fig. 6 when the hysteretic models have different post-capping rotation capacity (θ_{pc}). In Fig. 6, the vertical axis is the intensity level of earthquake records represented by spectra values at the fundamental period of building, normalized by the gravity acceleration. The horizontal axis of Fig. 6 shows the median of maximum

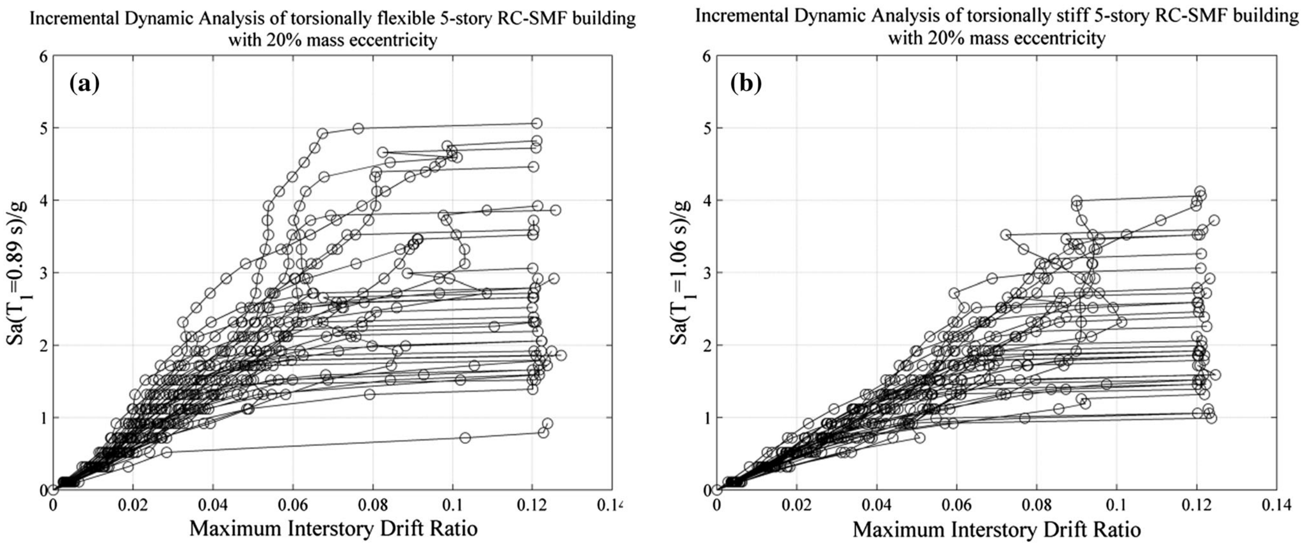

Fig. 5 The results of IDA for 20 % mass eccentric 5-story (**a**) torsionally flexible and (**b**) torsionally stiff buildings

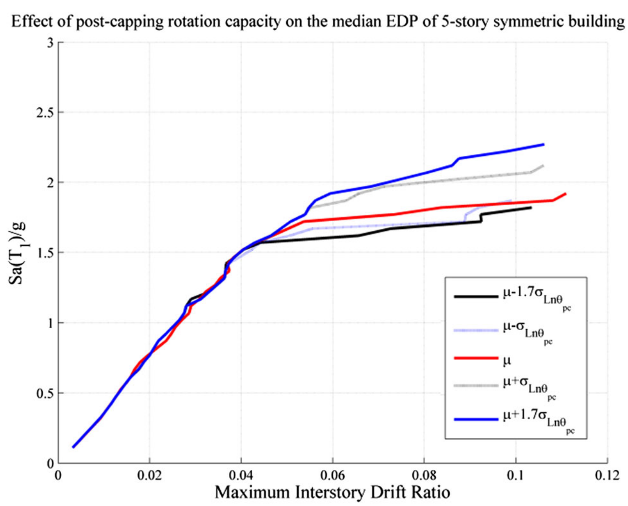

Fig. 6 The effect of post-capping rotation capacity on the median *maxIDR* of symmetric 5-story building

interstory drift ratios. Each of the five curves on the figure is representing the responses for a specific value of post-capping rotation capacity in hysteretic models of building elements. Generally, at the intensity levels lower than 1.5 g, the changes of post-capping rotation capacity of beam–column elements do not influence the results significantly.

In Fig. 7, the median of *maxIDR* is shown on the flexible sides and stiff sides of torsionally flexible ($\Omega = 0.6$) and torsionally stiff ($\Omega = 1.8$) buildings. For asymmetric 5-story buildings as shown in Figs. 7a–d and 8a–d, the same range of intensity level is found to exist in which the variations of θ_{pc} do not change the results. Additionally, it is interesting to note that the maximum interstory drift ratio of building at which the curves start to deviate from each other is within the range of 0.04–0.06 independent of the torsional behavior of building.

For the symmetric 5-story building with the same values of all deterioration parameters for structural elements except for the post-capping rotation capacity, the median EDP at which the curves start to differ from each other is not dependent on the value of θ_{pc}, as shown in Fig. 6. Therefore, the median responses of building are the same until the strain-softening branch in the rotational springs is reached. As the post-capping rotation capacity of springs increases, the deformation capacity of structural elements improves, and the building can sustain additional displacements. Consequently, the difference between the intensity level at which the building starts to deteriorate in strength and the intensity level at which the collapse occurs, gets larger as the post-capping rotation capacity increases. Comparing Fig. 6 to Fig. 9, this finding is similar with the results of Ibarra's study [5]. Figure 9 represents the effect of post-capping stiffness (α_c) on the EDP of a 9-story frame model based on Ibarra's study. The vertical axis of the figure is called *relative intensity* where $Sa(T_1)/g$ is the normalized measure of the ground motion, and η is a measure of the strength of the building and is equivalent to the base shear coefficient [5]. The horizontal axis of Fig. 9 shows maximum of story drift over story yield drift over the height as the EDP where θ_{iy} is the yield story drift [5]. He concluded that the decrease of post-capping stiffness (that is equivalent to the increase of θ_{pc}) could improve displacement capacity of SDOF systems and MDOF frames. There are similar findings for the asymmetric 5-story building, as shown in Figs. 7a–d and 8a–d.

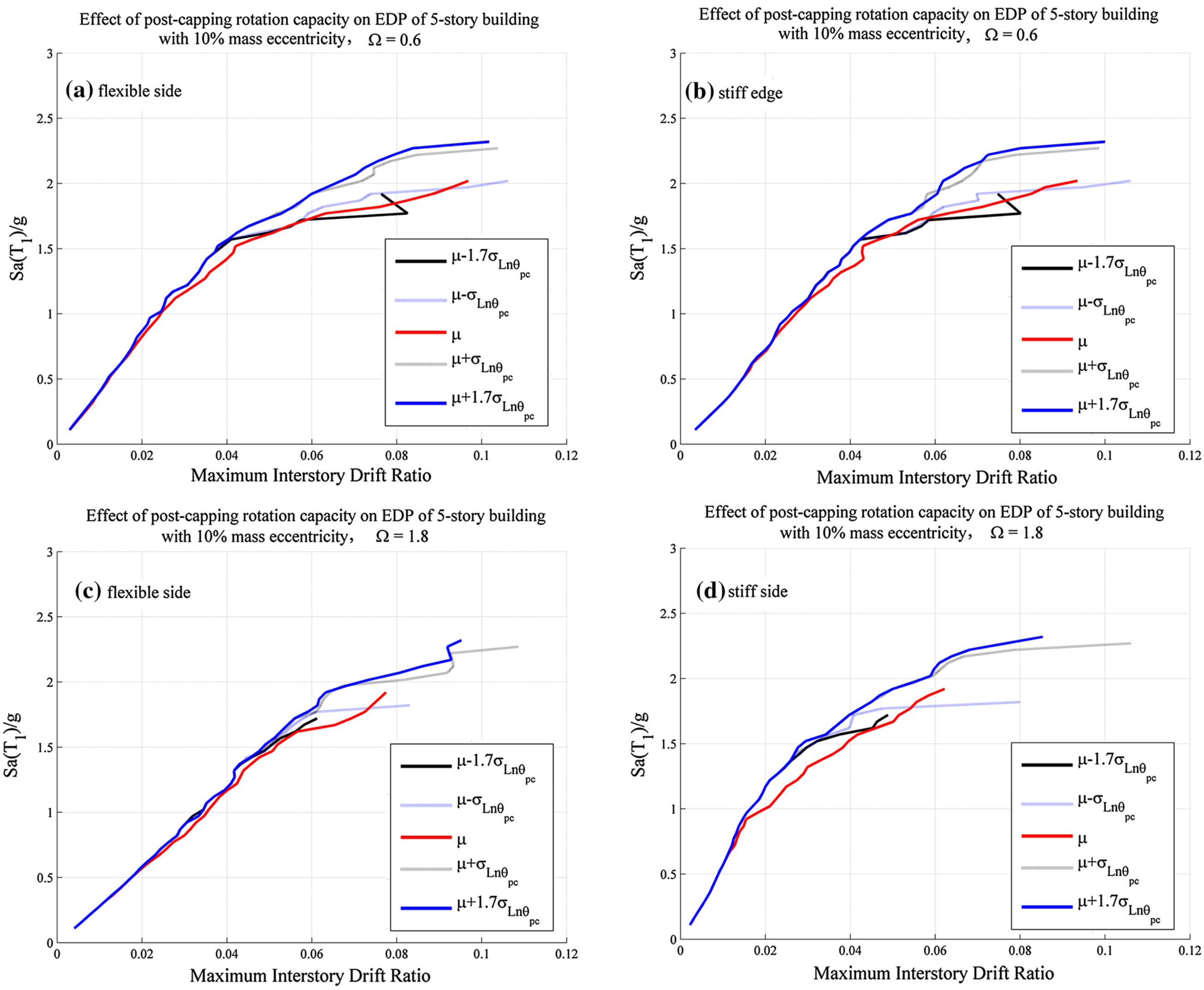

Fig. 7 The effect of post-capping rotation capacity on the median *maxIDR* of the 10 % mass eccentric 5-story torsionally flexible (**a**,**b**) and torsionally stiff (**c**,**d**) buildings

For the torsionally flexible buildings ($\Omega = 0.6$), the influence of post-capping rotation capacity on the variation of the median response is larger for the flexible side than the stiff side almost at any intensity level. Comparing the results in Figs. 7a–d and 8a–d, these effects are larger in the stiff side than the flexible side for the torsionally stiff building.

3.1.2 Effect of Plastic Rotation Capacity on EDP

Figure 10 shows the median of *maxIDR* for the symmetric 5-story building when the rotational springs of structural elements have different plastic rotation capacity (θ_p). Although some variations of θ_p produce differences in the median response at $Sa(T_1) > 0.7$ g, there are no significant differences in the median response up to the intensity level of 1.5 g. It means that at the lower intensities, the changes of plastic rotation capacity of beam–column elements do not influence the results. For the symmetric 5-story building, the deviation of a curve from the others happens within the median EDP range of 0.04–0.07 for different values of θ_p.

Figure 11a–d shows the results of 5-story, 10 % mass eccentric building. The median response in the flexible side and the stiff side of torsionally flexible building is represented in Fig. 11a, b. Figure 11c, d are the median response of torsionally stiff building. The median of response for 20 % mass eccentric 5-story buildings is also represented for torsionally flexible and torsionally stiff cases in Fig. 12a–d. Similar to the symmetric building, the variations of plastic rotation capacity of structural elements have important effects on the results of mass eccentric systems at the intensity levels, that is, higher than 1.5 g. The deviation of a curve from the others happens within the median of maximum interstory drift ratio which ranges from 0.04 to 0.07. These maximum responses often occur

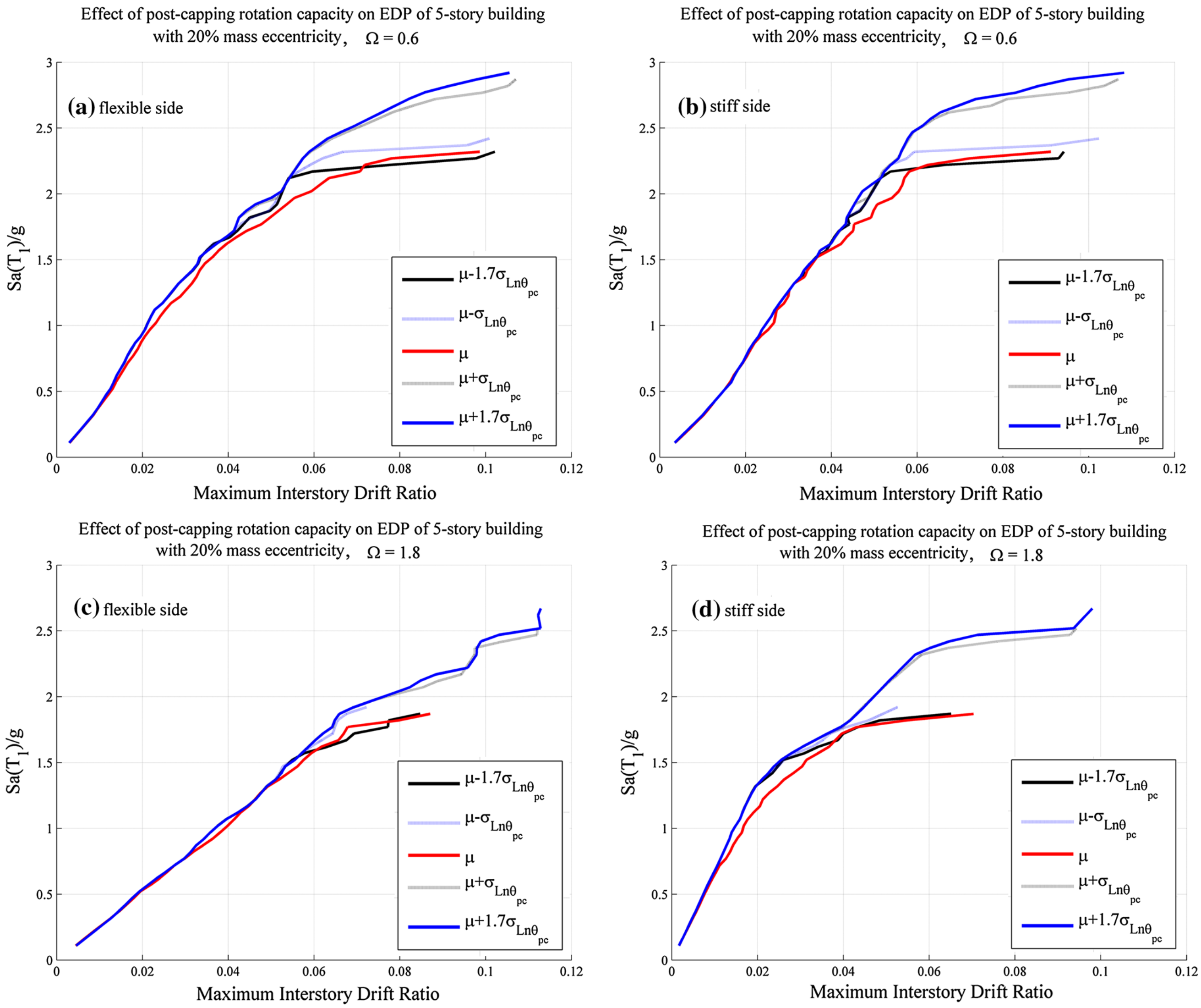

Fig. 8 The effect of post-capping rotation capacity on the median *maxIDR* of the 20 % mass eccentric 5-story torsionally flexible (**a**,**b**) and torsionally stiff (**c**,**d**) buildings

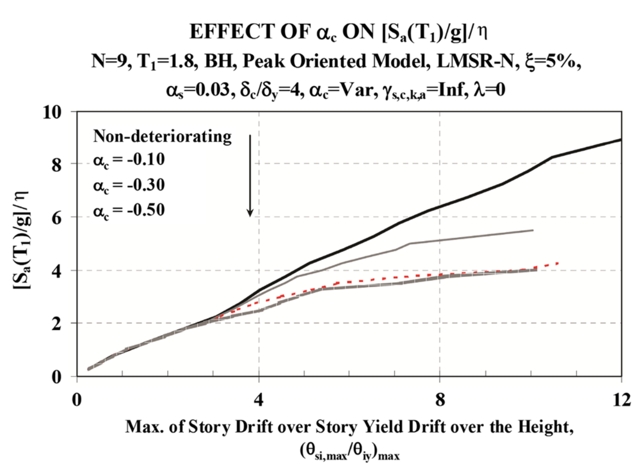

Fig. 9 Effect of post-capping stiffness on maximum of story drift over story yield drift over the height of a 9-story frame [5]

in the flexible side of building where the effect of inertial forces is large.

For both symmetric and asymmetric 5-story buildings that have identical deterioration properties except for the plastic rotation capacity, the median EDP at which a curve starts to differ from the others is dependent on the value of θ_p. When the structural elements have lower values of plastic rotation capacity, the deviation happens in lower values of maximum interstory drift ratio. The reason is that the strain-softening branch in rotational springs reaches earlier as the plastic rotation capacity decreases. As a result, the deterioration in strength happens early in the lower intensity levels.

Almost at any intensity level, the influence of plastic rotation capacity on the variation of the median response is larger for the flexible side than the stiff side, as shown in

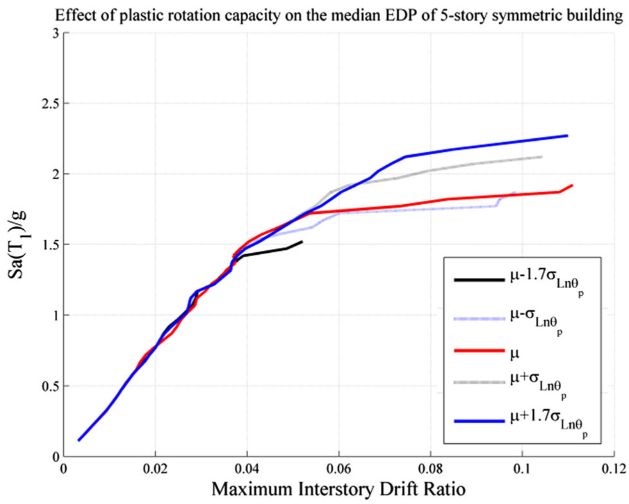

Fig. 10 The effect of plastic rotation capacity on the median *maxIDR* of symmetric 5-story building

Fig. 11a–d in the torsionally flexible building. These effects are larger in the stiff side than the flexible side of torsionally stiff building.

3.1.3 Effect of Cyclic Deterioration on EDP

Cyclic deterioration is assumed to be proportional to the hysteretic energy dissipation capacity of a building defined by the parameter γ [5]. Indeed, the value of γ is related to the rate by which the hysteretic energy is exhausted. While a small value of γ is associated with a fast rate in the hysteretic energy dissipation, that energy is exhausted slowly for larger values of γ. Figure 13a, b shows the effect of cyclic deterioration on the response of an SDOF system based on Ibarra's study [5].

Figure 14 shows the effect of cyclic deterioration on the median of *maxIDR* of symmetric 5-story building. The variations of hysteretic energy dissipation capacity (γ)

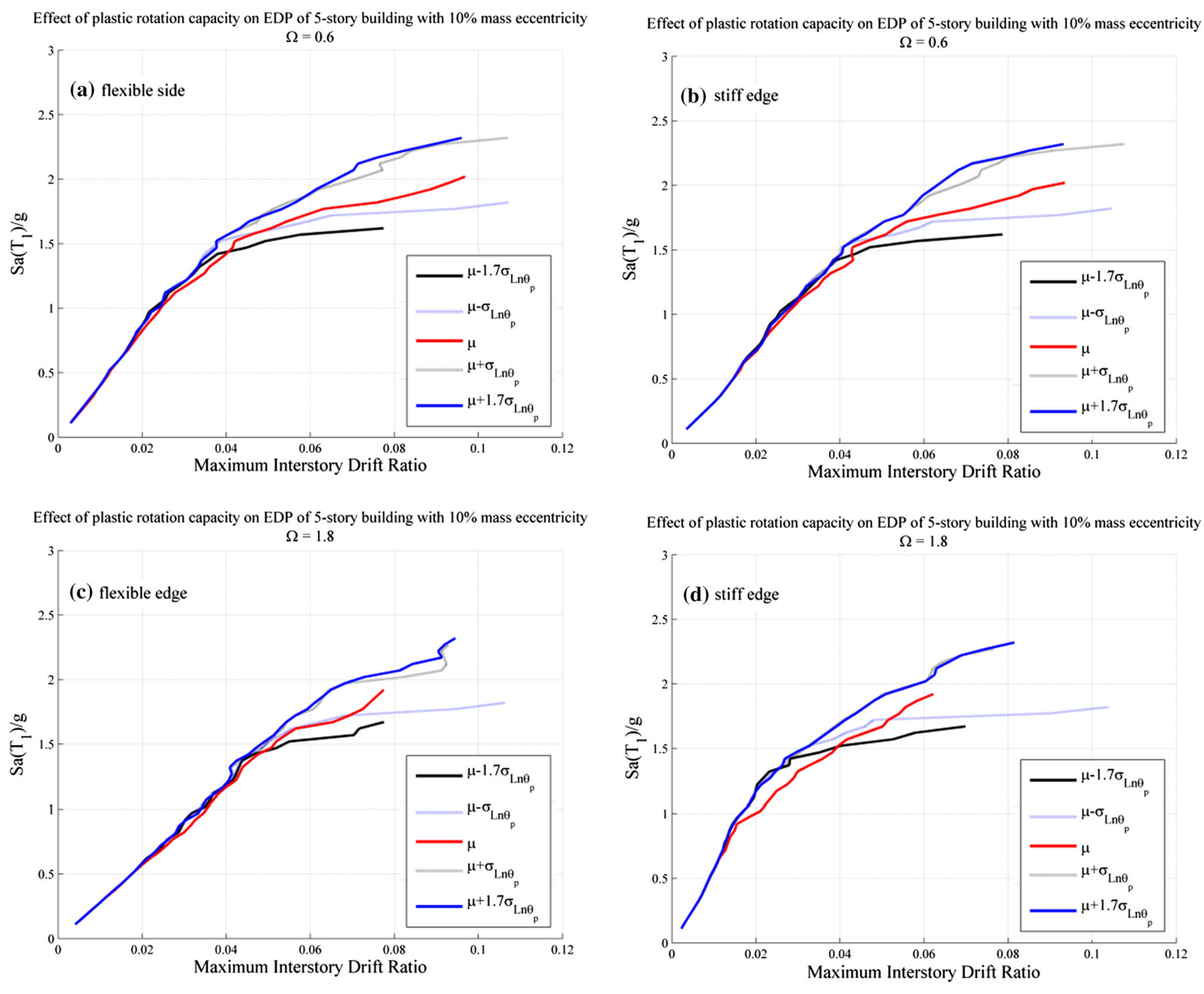

Fig. 11 The effect of plastic rotation capacity on the median *maxIDR* of the 10 % mass eccentric 5-story torsionally flexible (**a**,**b**) and torsionally stiff (**c**,**d**) buildings

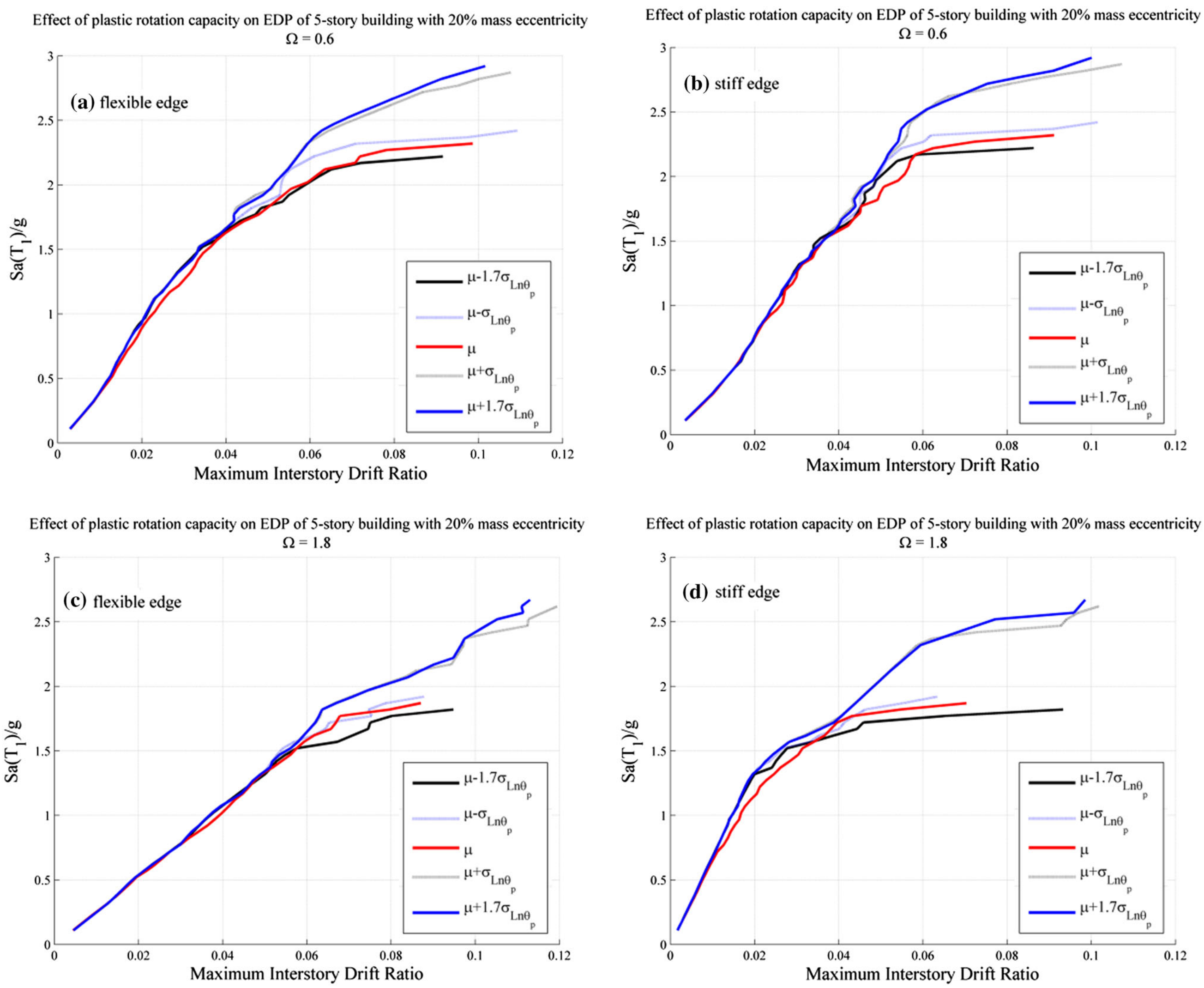

Fig. 12 The effect of plastic rotation capacity on the median *maxIDR* of the 20 % mass eccentric 5-story torsionally flexible (**a**,**b**) and torsionally stiff (**c**,**d**) buildings

produce differences in the median response at $Sa(T_1) > 0.7$ g, i.e., at the lower intensities, the cyclic deterioration does not have a significant effect on the response. The median EDP at which the curves start to deviate from each other is about 0.023 for symmetric building. This happens at the intensity level about 0.72 g for all values of γ. This intensity level is approximately less than half of the collapse capacity of symmetric buildings.

The median of response for 5-story buildings with 10 % mass eccentricity is shown in Fig. 15a–d. Figure 15a, b is associated with the median response of building in the flexible side and the stiff side of torsionally flexible building. Figure 15c, d is related to the median of structural response with torsionally stiff behavior. For both sets, the intensity level at which the curves start to deviate from each other is about 0.72 g that is similar to the intensity level in symmetric building. The median of maximum interstory drift ratio of the building at this level of intensity is about 0.02–0.03. Similarly, for 20 % mass eccentric 5-story buildings, the median of response is shown for torsionally flexible and torsionally stiff cases in Fig. 16a–d. For 20 % mass eccentric building, the intensity level at which the curves start to deviate from each other and its associated interstory drift ratio are similar to the results of 10 % mass eccentric building. The intensity level of 0.72 g is approximately 2.5 times smaller than the collapse capacity for 10 and 20 % mass eccentric buildings. Although the cyclic deterioration causes the curves to deviate at the intensity level about 0.72 g, it does not have significant effect unless it gets greater than 1.5 g.

The difference between the curves in the results of flexible side shows larger increments in the median EDP in comparison with the results of stiff side for the torsionally flexible building. This means that for torsionally flexible

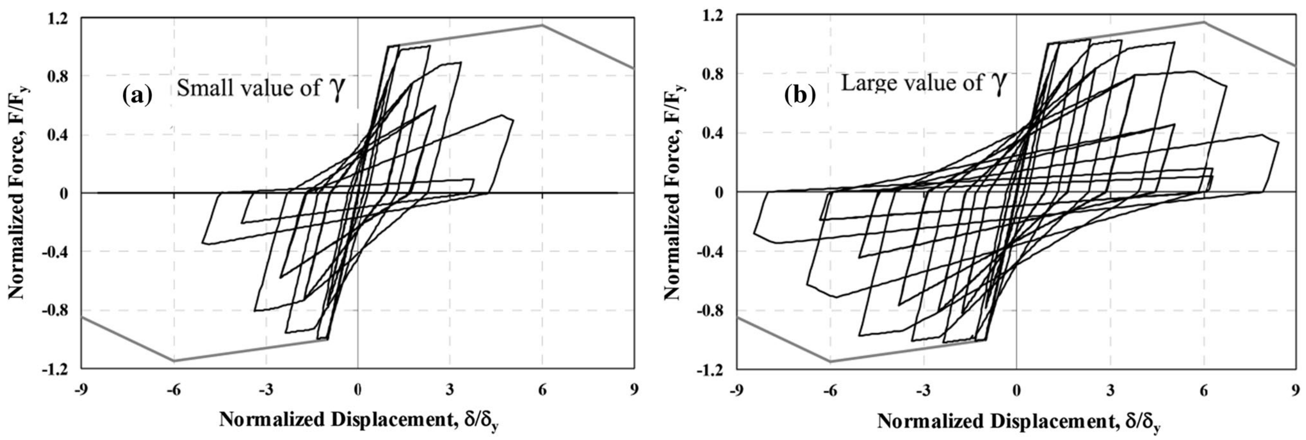

Fig. 13 The effect of cyclic deterioration on the response of an SDOF system [5]

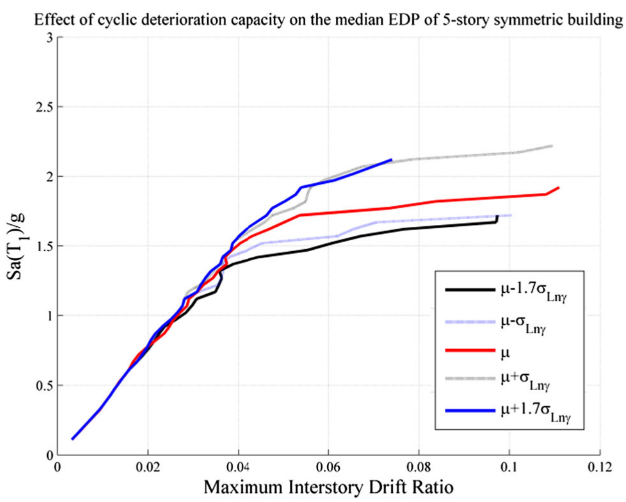

Fig. 14 The effect of cyclic deterioration on the median *maxIDR* of symmetric 5-story building

buildings, the influence of cyclic deterioration on the median response of flexible side is larger. However, these effects are larger in the stiff side than the flexible side for the torsionally stiff building.

For symmetric and asymmetric 5-story buildings, the post-capping and the plastic rotation capacities of structural elements are unchanged as the hysteretic energy dissipation capacity varies (e.g., as shown in Fig. 14). It is expected that the building experiences earlier deterioration if the hysteretic energy dissipation capacity of structural components reduces. It means that deterioration happens in the lower intensity level as the value of γ decreases. However, there are not significant differences between the intensity levels at which curves start to deviate from each other. The difference between the curves is considerable when the maximum interstory drift ratio of buildings is larger than 0.04. This happens at the higher intensity levels than 1.5 g for the buildings studied in this paper. It is a condition in which most of the structural elements reach their plastic rotation capacity. This is in good agreement with the results of Ibarra's study on 2D frame models [5], comparing Fig. 14 with Fig. 17. Figure 17 represents the effect of cyclic deterioration on the EDP of a 9-story frame model based on Ibarra's study. The vertical axis is the relative intensity, and the horizontal axis represents maximum of story drift ($\theta_{si,max}$) over story yield drift over the height. He found that the effect of cyclic deterioration on the response of SDOF and MDOF systems is small before the ductility capacity is reached. Generally, the intensity level at which a curve starts to deviate from the others is not significantly dependent on γ unless the plastic rotation capacity of the structural elements reaches.

As the value of γ increases, the rate of hysteretic energy dissipation in structural elements decreases, and the building deformation capacity improves. As a result, the difference between the intensity level at which the influence of cyclic deterioration starts and the intensity level at which the collapse occurs gets larger. This difference becomes more considerable for the torsionally flexible buildings, e.g., as shown in Fig. 15a–d. The improvement of deformation capacity causes an appropriate moment redistribution to happen in the building. Moment redistribution may be the most probable cause of an increase of at least 100 % from the intensity at which the springs start to deteriorate in strength to the intensity at which collapse happens.

4 Conclusions

The influences of deterioration parameters on the maximum interstory drift ratio of symmetric and asymmetric low-rise buildings are studied. The investigation is carried out on RC-SMF 5-story building models. The 10 and 20 %

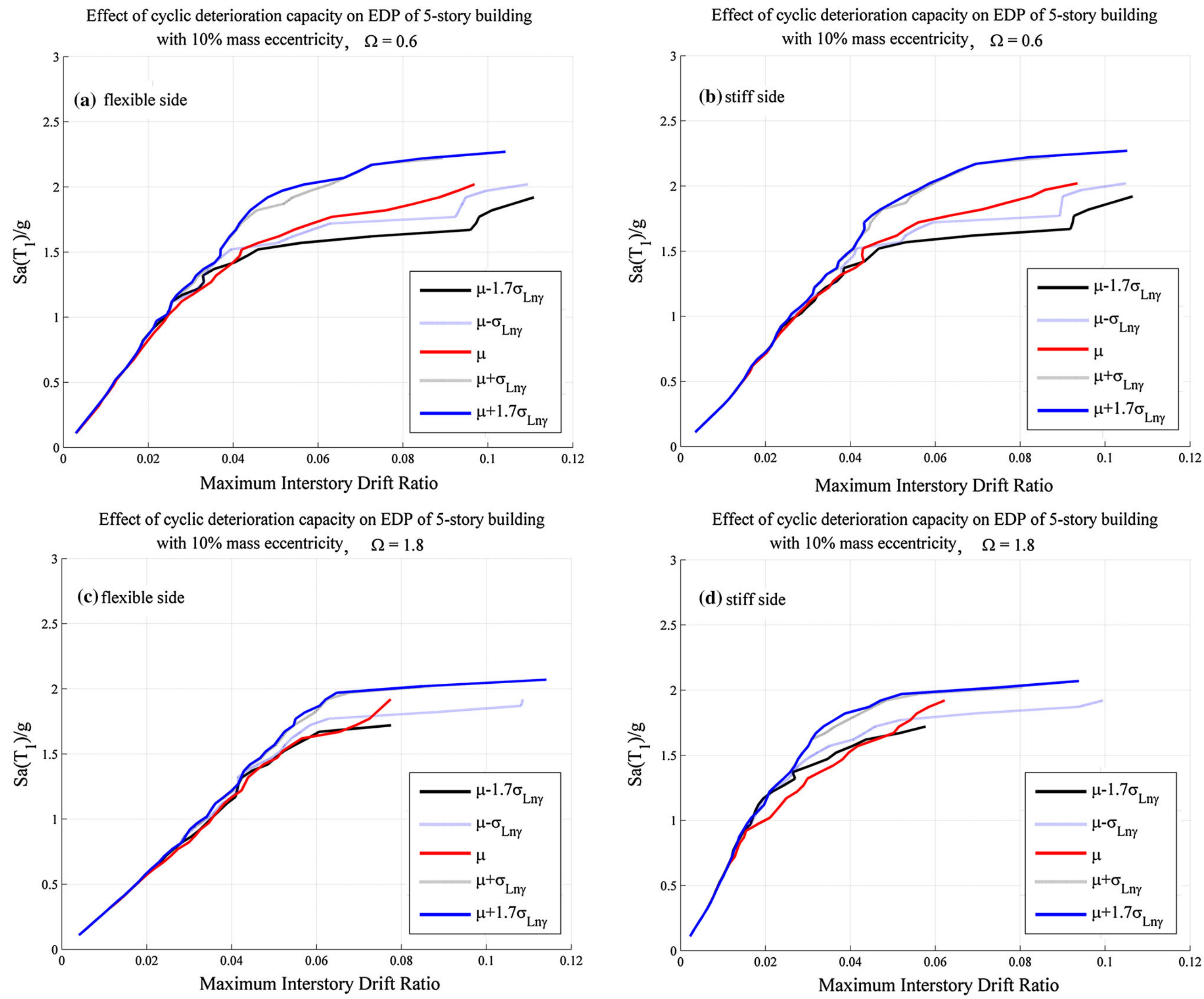

Fig. 15 The effect of cyclic deterioration on the median *maxIDR* of the 10 % mass eccentric 5-story torsionally flexible (**a**,**b**) and torsionally stiff (**c**,**d**) buildings

mass eccentric buildings are considered as the asymmetric systems. The results are represented in the form of the intensity—EDP curves that show the response variation when the hysteretic modeling parameters are changed. It is found that:

- The median maximum interstory drift ratio at which the symmetric or asymmetric building models start to deteriorate in strength is not dependent on the value of post-capping rotation capacity.
- The increase of post-capping rotation capacity in the rotational springs of structural elements improve the deformation capacity of buildings and cause the buildings to remain stable up to higher intensity levels.
- In 5-story building models with the same hysteretic properties of elements except for plastic rotation capacity, the intensity—EDP relationship starts to deviate from the others in a lower intensity level as the plastic rotation capacity gets a smaller value.
- The increase of hysteretic dissipation capacity causes the 5-story buildings to experience a smaller value of interstory drift at a specific intensity level, independent of structural irregularity in plan.
- The decrease of hysteretic dissipation capacity causes the 5-story buildings to deteriorate in strength soon. This phenomenon is more considerable in torsionally flexible buildings.
- The influence of cyclic deterioration becomes significant as the plastic rotation capacity of rotational springs is reached.
- Comparing the median response of flexible side with the results of stiff side, the influence of deterioration parameters on the median response of flexible side is larger in torsionally flexible building. For torsionally

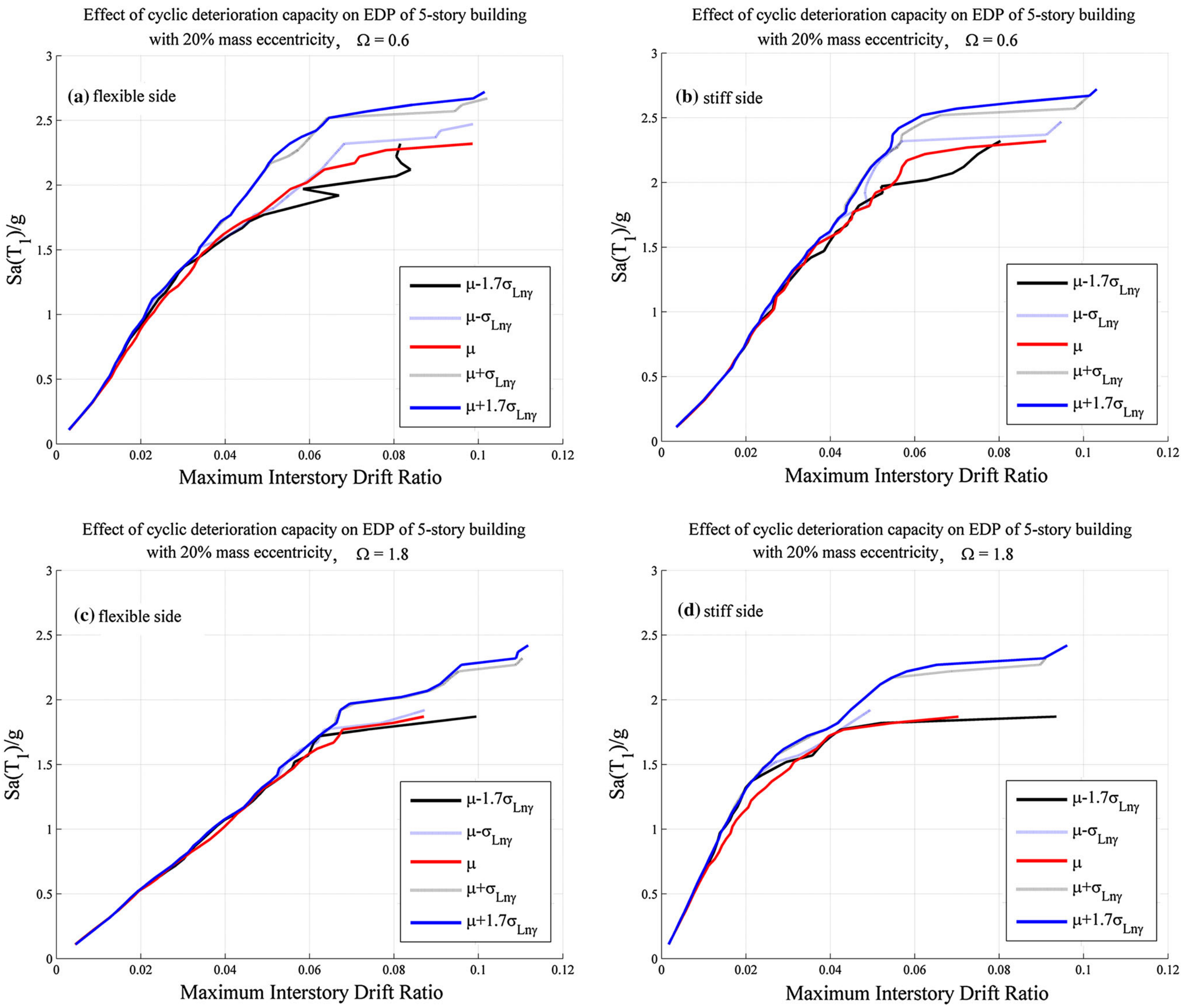

Fig. 16 The effect of cyclic deterioration on the median *maxIDR* of the 20 % mass eccentric 5-story torsionally flexible (**a**,**b**) and torsionally stiff (**c**,**d**) buildings

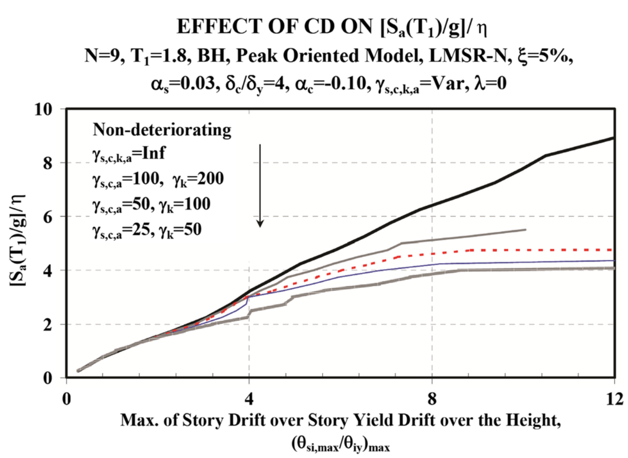

Fig. 17 Effect of cyclic deterioration on maximum of story drift over story yield drift over the height of a 9-story frame [5]

stiff buildings, the larger influences occur in the stiff side.

- The influence of deterioration parameters on the median EDP of the symmetric and asymmetric 5-story buildings starts at similar intensity levels. Regardless of the torsional behavior of building, these effects are small unless the intensity level is greater than 1.5 g.
- Moment redistribution may be the most probable cause of an increase of at least 100 % from the intensity at which a building starts to deteriorate in strength to the intensity at which collapse happens.
- This study helps to understand how deterioration in strength and stiffness is going to affect the behavior of lateral-resisting elements in asymmetric buildings. According to the results, those elements are influenced

differently in torsionally flexible and stiff buildings. It may have significant effect on the collapse performance of such buildings which is programmed as a future study. The primary results of ongoing study have shown that it is important for engineers to understand the effects of deterioration on the behavior of torsional buildings. That is because the design decisions can change the parameters of deteriorating building models, and the interpretation of ultimate limit state of behavior (i.e., the collapse state) is not easy without understanding the damage distributions, especially in torsionally flexible buildings.

- This investigation is based on realistic designed buildings with more complex modeling details than either the simple SDOF systems or 2D MDOF frames. However, there is a good agreement between the results of this study and the results of Ibarra's study on the influences of deterioration parameters on the response of SDOF systems or MDOF frames.

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