2011 International Conference on Computer and Software Modeling
IPCSIT vol.14 (2011) © (2011) IACSIT Press, Singapore

Nonlinear Behaviour of Reinforced Concrete Building under Repeated Earthquake Excitation

Mohd Irwan Adiyanto [1], Ade Faisal [1]and Taksiah A. Majid [2 +]

[1]School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, Penang, Malaysia.
[2] Disaster Research Nexus, School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, Penang, Malaysia.

Abstract. Current practices in earthquake engineering only apply single earthquake on building structure during modelling and analysis. However, in real earthquake event, the tremors always occurred repeatedly until two or three times after the first tremor. This phenomenon can affect the stiffness and strength of the structural system. Due to lack of time, any rehabilitation action is impractical. Thus, the building may experience greater damage due to several repeated tremors. This paper presents the nonlinear behaviour of generic reinforced concrete building under excitation of single and repeated earthquake. The pushover and non-linear time history analysis were performed with consideration of various level of force reduction factor, R. Nonlinear behaviour of structure, in term of interstorey drift ratio were presented using incremental dynamic analysis curve. The results from analyses demonstrate that the repeated earthquake phenomenon require greater interstorey drift demand compared to single earthquake.

Keywords: Repeated earthquake, force reduction factor, interstorey drift ratio, reinforced concrete.

1. Introduction

For years and for any purpose, either designing a new building or evaluation on the existing one, current practices in earthquake engineering such as FEMA 368 [1] and the Eurocode 8 [2] only consider single earthquake in analysis. However, in a real earthquake event, the first tremor is always followed by other tremors just a few hours after the first one. This is a nature of earthquake and in technical views it is called as repeated earthquake phenomenon [3]. Thus, in reality the earthquake load might hit the structure more than one time during a great earthquake event. The buildings may experience minor to moderate damage that lead to stiffness and strength degradation of the global structure due to action of the first tremor. At that moment, any rehabilitation action is impractical due to time constraint. Therefore, when the not yet repaired building subjected to the second and third tremors, the building is expected to experience worse damage even collapse.

It had been proved that the repeated earthquake strongly affecting the ductility demand which is generally higher than the single earthquake, and might lead to greater damage [4]. Based on a comprehensive study, Hatzigeorgiou and Liolios [5] had concluded that the interstorey drift cause by repeated earthquake phenomenon is larger than the single earthquake. Thus, traditional seismic design procedure (based on single earthquake) should be generally reconsidered [3,4]. Force reduction factor, R (denoted as R-factor afterward) or well known as behaviour factor, q_0 in Eurocode 8 [2] can be defined as ratio of the ground motion intensity, $Sa(T_1)/g$, to the design lateral force in the structure, V_d, normalized with the weight of the structure, W as in Eq. 1.

$$R = \left(Sa\left(T_1\right)/g\right)/\left(V_d/W\right) \tag{1}$$

[+] Corresponding author. Tel.: + (604 - 5996201); fax: +(604 - 5941009).
E-mail address: irwano_07@yahoo.com

The nonlinear behaviour of building and the distribution of maximum interstorey drift ratio (IDR) along the height are strongly affected by R-factor. As the level of relative intensity (R-factor) increases, maximum IDR migrates towards the bottom stories [6,7]. From pushover analysis, higher level of R-factor will give lower yield strength of structural system. The latter tends to cause a concentration of interstorey drift at lower storey [8].

In this paper, the effect of variation of R-factor alongside the occurrence of repeated earthquake phenomenon on nonlinear behaviour of reinforced concrete (RC) building is presented. Two types of generic RC moment-resisting frame consist of 3 and 18 storey had been used to represent the low and high rise building, respectively. The pushover analysis had been performed to both models separately with five level of R-factor (R = 1, 1.5, 2, 4, 6). Besides, by using the single and repeated earthquake time history from near-field earthquake (NFE), the nonlinear time history analysis (NTHA) had been performed on both model by keep the constant value of ground motion intensity at fundamental period of generic models, $Sa(T_1,5\%)$ with damping ratio of 5%. Seismic response in term of maximum IDR is presented using incremental dynamic analysis (IDA) curve.

2. Materials and Methods

The concept of developing the simple model that can represent the real building as presented in previous research [6] had been adopted in this in study, with some modification into 3D model. In modelling process, both 3 and 18 storey models were assigned to have typical storey height of 3.6 m and one bay of slab panel with 7.2 m run of length in X and Y axis as shown in Fig. 1. By referring to Eurocode 8 [2], the fundamental period at first mode, T_1 for both 3 and 18 storey models were determined as 0.45 and 1.71 seconds respectively. Hence, moment of inertia, stiffness, as well as the size of structural members is tuned and adjusted so that the building can achieve the fundamental period at first mode, T_1 as determined before. To match real construction practice, the global lateral stiffness is distributed in parabolic shape for 18 storey model where the size of structural member is changed for every 3 storey [9]. For 3 storey model, uniform distribution is applied. To induce inelastic action in beam rather than in column, the *Strong Column ~ Weak Beam* philosophy was implemented. The detail regarding both models was presented in [10].

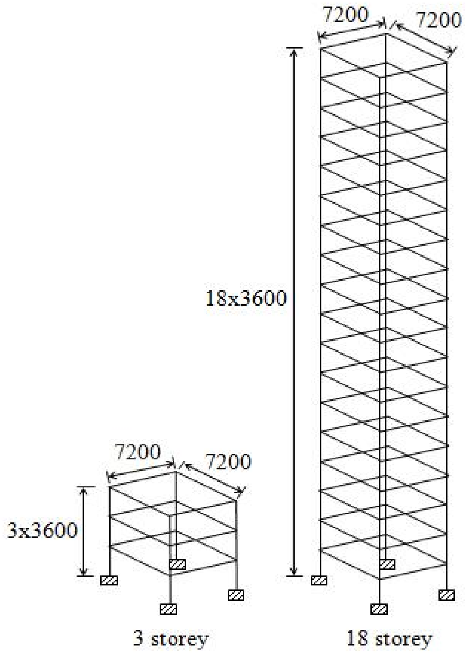


Fig. 1: 3D view of 3 and 18 storey models

In this study, a total of 20 ground motions with magnitude in range of 6.2 to 7.6 Mw classified as NFE with forward directivity effect were used based on published record by Baker [11] and the list of details can be found in [10]. For scaling purpose the Type 1 response spectrum of Eurocode 8 [2], for condition of Soil

B and Seismic Zone III at Greece had been used. Two sets of repeated earthquake consist of 20 motions each, were generated with appropriate scale factor as proposed [3,4]. Thus, the Case 1, Case 2, and Case 3 represent the single, repeated with after-shock only, and repeated with fore and after-shock earthquake, respectively as shown in Fig. 2.

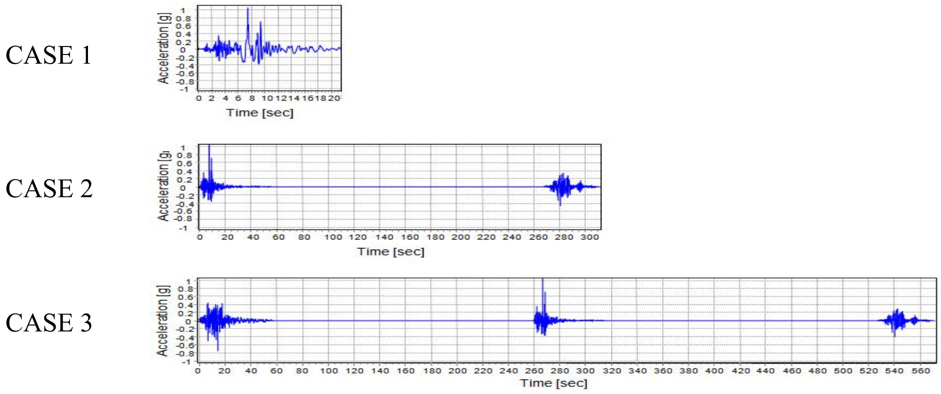
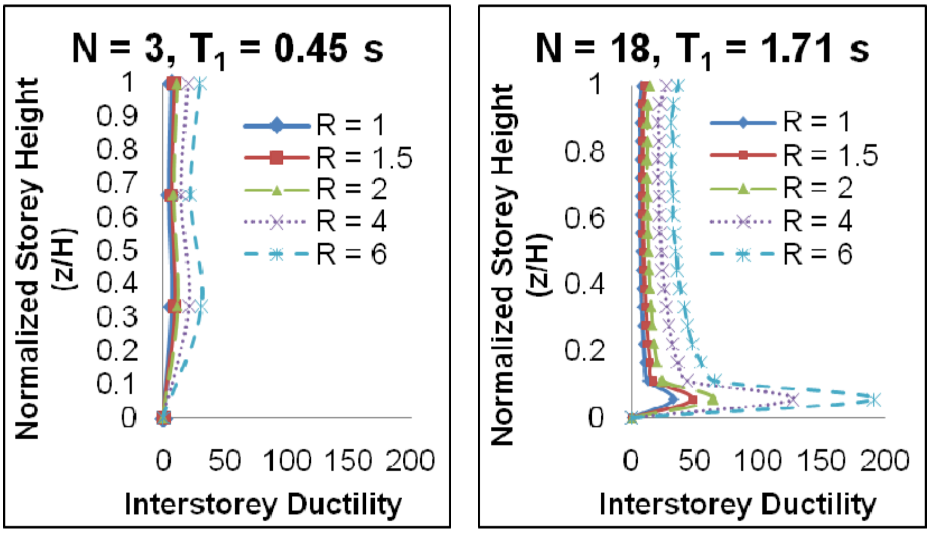


Fig. 2: Typical profile of generated ground motion

3. Results and Discussion

In order to predicting the building's capacity against lateral load, it is practical to perform the pushover analysis that provides the information regarding the strength and lateral displacement of structural system [12].



(a) (b)

Fig. 3: Interstorey ductility demand (a) 3 storey model and (b) 18 storey model

The interstorey ductility demand for both 3 and 18 storey models is shown in Fig. 3. It is clearly observed that the interstorey ductility demand is relatively larger for weaker structure (high R-factor) compared to stronger structure. This observation is true for both low and high rise models. From this result, it can be predicted that the weaker structures will experience higher response such as higher lateral displacement when subjected to earthquake loads compared to stronger structures counterpart. The distribution of interstorey ductility demand of 3 storey model is rather uniform for structures with low R-factor ($R \leq 2$) and tends to concentrates at lower storey as the level of R-factor increases. For 18 storey model, the distribution of interstorey ductility demand is observed to be higher in lower storey before become uniform at the middle and upper part of the building regardless the level of R-factor assigned.

Finally, it can be clearly observed that the 18 storey model provides more ductility compared to the 3 storey model counterpart. Hence, it is predicted that at same level of R-factor, the 3 storey model will experience larger response when subjected to earthquake loads compared to 18 storey model.

Fig. 4 presents the IDA curve for both 3 and 18 storey models considering various cases of earthquake excitation. The ratio of 5% damped Spectral Acceleration at the fundamental period of structure ($Sa(T_1,5\%)$) to the design strength of the structure (normalized to its total weight) had been selected as the intensity measure (IM). On the other hand, maximum IDR (maximum over all storeys) had been selected as the damage measure (DM).

From Fig. 4, it can be clearly observed that both models response elastically indicated by a straight line at relatively low level of R-factor. The 3 storey model exhibit the 'softening' behaviour as the curve clearly 'soften' just after the initial buckling at R ≥ 1 with slope that lower than the elastic region. The curve 'flatten' where the maximum IDR increase rapidly at small increment of ground motion intensity (smaller increment of R-factor). At this level the building had reached global dynamic instability where the structure responds with practically infinite values of DM and numerical non-convergence had been encountered during the analyses [13]. For this model, the Case 2 and Case 3 of repeated earthquakes presented the same pattern as Case 1 (single earthquake) but require greater demand at same level of ground motion intensity.

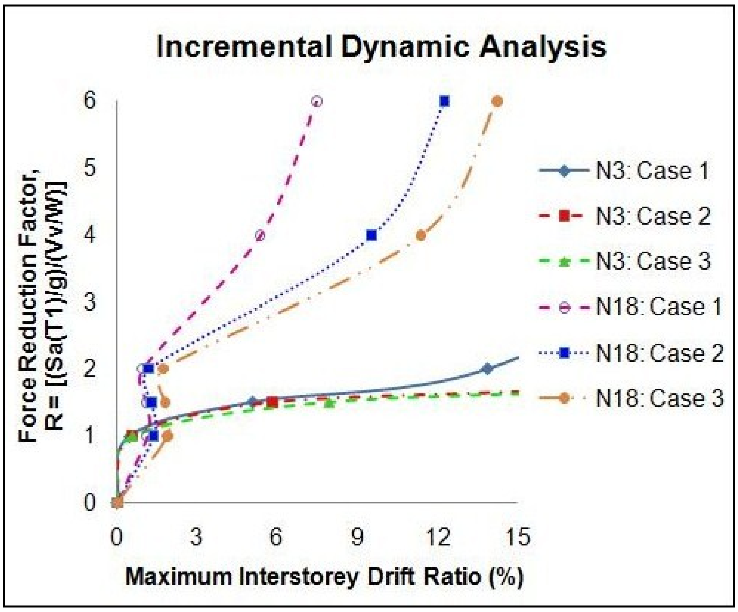


Fig. 4: Incremental dynamic analysis curve for 3 and 18 storey models

Different nonlinear behaviour was observed for 18 storey model. At relatively low level of R-factor (R ≤ 2), the maximum IDR was observed to be constant where slightly difference was observed between all 3 cases of earthquake. The constant response of maximum IDR (close-to-vertical range) at these levels of R-factor corresponds to the migration of maximum IDR from top toward the bottom part of the structure [7]. Further reduction in strength or increasing of ground motion intensity (high R-factor) leads to rapidly increases of maximum IDR as it reached the bottom storey. In present study, the 18 storey model exhibit a bit of 'hardening' behaviour at R ≥ 4. At these levels, the structure experienced the deceleration of the rate of DM accumulation as the R-factor increases [14]. Again, the repeated earthquake produced higher magnitude of maximum IDR compared to the single earthquake counterpart. As predicted from pushover analysis, the 3 storey model experienced larger response due to lower ductility compared to 18 storey model.

4. Conclusions

This paper presents the nonlinear behaviour of 3 and 18 storey RC building subjected to single and repeated NFE. The effect of various level of R-factor was considered in modelling and analyses. It is concluded that the level of R-factor is strongly affecting the interstorey ductility demand and magnitude of maximum IDR for both 3 and 18 storey models. As the level of R-factor increases, the maximum IDR also increases and require higher ductility demand. From the IDA curve, it was observed that the nonlinear behaviour of structural system did not affected by the type of earthquake, neither single nor repeated. However, it is proved that the repeated earthquake phenomena require greater interstorey drift demand compared to single earthquake. Thus, it is important to consider the repeated earthquake in structural analysis instead of current practice which use single earthquake to avoid underestimate that might lead to unsafe structures. Besides, the use of pushover analysis gives an advantage on predicting the structural response when subjected to earthquake loads.

5. Acknowledgements

The authors gratefully acknowledge the support given by Universiti Sains Malaysia through USM fellowship scheme to accomplish this study.

6. References

[1] FEMA. *NEHRP recommended provisions for seismic regulations for new buildings and other structures, 2000 Edition, Part 1: Provisions, FEMA 368, Building Seismic Safety Council for the Federal Emergency Management Agency*, Washington D.C., 2000.

[2] CEN Eurocode 8. *Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings*, Final Draft prEN 1998, European Committee for Standardization, Brussels, 2003.

[3] G. D. Hatzigeorgiou. Behavior factors for nonlinear structures subjected to multiple near-fault earthquakes. *Computers and Structures*. 2010, 88: 309-321.

[4] G. D. Hatzigeorgiou. Ductility demand spectra for multiple near- and far-fault earthquakes. *Soil Dynamics Earthquake Engineering*. 2010, 30: 170-183.

[5] G. D. Hatzigeorgiou and A. A. Liolios. Nonlinear behaviour of RC frames under repeated strong ground motions. *Soil Dynamics Earthquake Engineering*. 2010, 30: 1010-1025.

[6] R. A. Medina and H. Krawinkler. Seismic demands for non-deteriorating frame structures and their dependence on ground motions. *Report No. TR 144*, John A. Blume Earthquake Engineering Center, Department of Civil and Environmental Engineering, Stanford University, Stanford, 2003.

[7] B. Alavi and H. Krawinkler. Behavior of moment-resisting frame structures subjected to near-fault ground motions. *Earthquake Engineering and Structural Dynamics.* 2004, 33: 687-706.

[8] F. Zareian and H. Krawinkler. Simplified performance-based earthquake engineering. *Report No. 169*, John A. Blume Earthquake Engineering Center, Department of Civil and Environmental Engineering, Stanford University, Stanford, 2009.

[9] E. Miranda and C. J. Reyes. Approximate lateral drift demands in multistory buildings with nonuniform stiffness. *Structural Engineering*. 2002, 128(7): 840-849.

[10] M. I. Adiyanto and T. A. Majid. Seismic response of low and high rise RC building subjected to repeated earthquake. *Proc. 2nd Civil Engineering Colloquium*. Penang, 2011: 108-119.

[11] J. W. Baker. Quantitative classification of near-fault ground motions using wavelet analysis. *Bulletin of Seismological Society of America*. 2002, 97(5): 1486-1501.

[12] H. Krawinkler and G. D. P. K. Seneviratna. Pros and cons of a pushover analysis of seismic performance evaluation. *Engineering Structures*, 1998, 20: 452-464.

[13] D. Vamvatsikos and C. A. Cornell. Applied incremental dynamic analysis. *Earthquake Spectra*. 2004, 31(2): 523-553.

[14] D. Vamvatsikos and C. A. Cornell. Incremental dynamic analysis. *Earthquake Engineering and Structural Dynamics*. 2002, 31: 491-514.