Ductility Reduction Factor for MDOF System with Vertical Irregularities Subjected to Strong Earthquake Action

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Summary Ductility reduction factors of irregular multi-degree-of-freedom (MDOF) systems are obtained by modifying those of regular MDOF systems through a modification factor. The vertical irregularities are introduced by changing the combined-strength-and-stiffness at the first storey of a regular system. Irregularity ratio, ductility ratio, fundamental period, storey number and velocity pulse of a ground motion, have been investigated to gain insight into the modification factors.

INTRODUCTION

One of the most controversial issues in seismic design provisions for buildings is the development of force reduction factor, which is expressed implicitly as a response modification factor (R) in the International Building Code (IBC, 2006), and a behavior factor (q) in the Eurocode 8 (EC8, 2004). It is confirmed that all these reduction factors consider two influence factors as the ductility reduction factor R_{μ} and the structural overstrength factor R_{s}. In respect to R_{μ}, the main influence factors are considered to be the ductility levels, materials and systems of structures. However, only the EC8 accounts for the structural vertical irregularity effects on R_{μ} by reducing the q-values by 20%. In addition, all these codes have not yet specially accounts for the velocity pulse-like effect of ground motion on R_{μ}, which may be different from non-pulse-like cases.

The presence of irregularities in the vertical distribution of some parameters (i.e. mass, stiffness, strength) have been recognized as one of the main causes of severe damage or poor performance of structures during earthquakes. The effects of vertical irregularities on the seismic responses of structures have been extensively investigated in the last few decades (e.g., Valmundsson 1997; Chintanapakdee 2004; Fragiadakis 2006). Previous studies (Bertero et al. 1978,) also show that structures subjected to pulse-like ground motions have larger drift and strength demands compared with structures subjected to common earthquakes.

ANALYSIS METHOD

Both regular and irregular models are subjected to seismic excitations to conduct the nonlinear dynamic time-history analysis. Velocity pulse-like ground motion records and the nonlinear structural analysis computer program Canny are used. A total of 2,880 time history analysis are performed for the following permutations: six pulse-like ground motion records; irregular and regular systems with 4, 8, and 16 stories; fundamental periods ranging from 0.05n to 0.1n; irregularity ratios ρ of 0.9, 0.8, 0.7, and 0.6; and target ductility ratio μ of 1, 2, 4, 6, and 8.

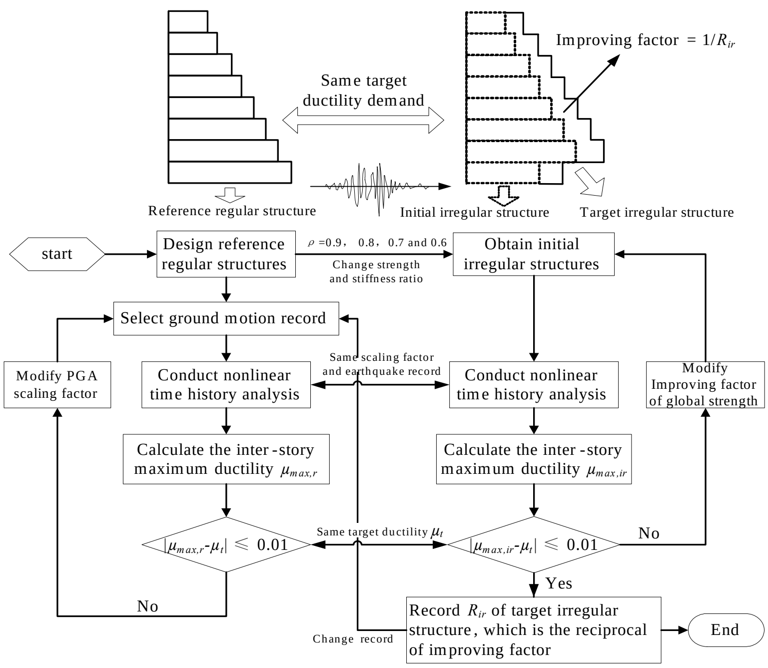

Fig. 1 Calculation method for modification factor

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NUMERICAL ANALYSIS RESULTS

Lateral strengths required to control the maximum storey ductility of irregular MDOF systems are commonly greater than those for regular MDOF systems. The ductility reduction factor of regular MDOF systems must be modified for application to the design of irregular MDOF systems accordingly. The modification factor (R_{ir}) is mainly affected by irregularity ratios, ductility ratios and earthquake pulse-like effects. The R_{ir} decreases with decreasing ρ (Fig.2). The storey number and fundamental period have little influence on R_{ir} (Fig.3). The effects of pulse-like cases are very different from that of no-pulse-like cases (Fig.4).

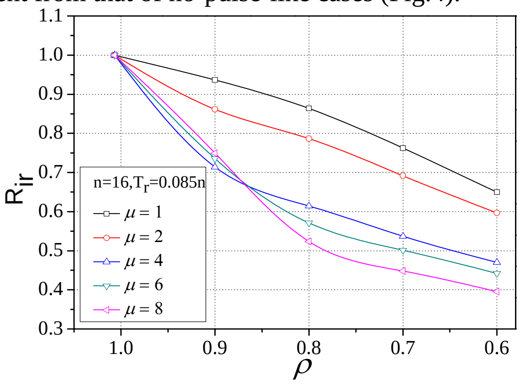

Fig. 2 Effects of ρ and μ on R_{ir} for 16 storey structure

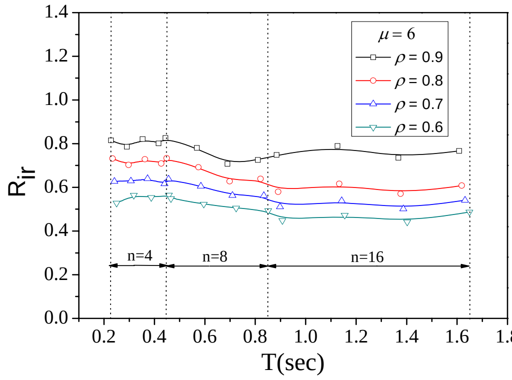

Fig. 3 Effects of fundamental period and storey number

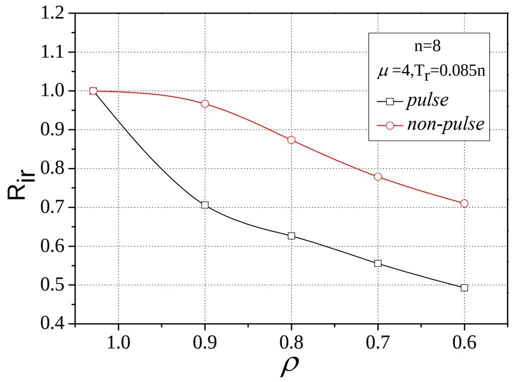

Fig. 4 Comparison results of R_{ir} under pulse-like and non-pulse-like cases

CONCLUSIONS

Reference values of R_{ir} have been suggested based on statistical mean values of considerable outcomes. It can be employed to obtain the ductility reduction factor, $R_{\mu m,ir}$, for irregular MDOF systems from the $R_{\mu m,r}$ values for regular MDOF systems.

Table 1 Suggested values of R_{ir} for pulse-like and non-pulse-like cases

Irregularity Modification factor	Case	ρ = 0.9	ρ = 0.8	ρ = 0.7	ρ = 0.6
R_{ir} (calculated in the present study)	Pulse-like	0.76	0.68	0.60	0.52
	Non-pulse-like	0.98	0.91	0.81	0.73
R_{ir} (suggested for practical design)	Pulse-like	0.80	0.70	0.60	0.50
	Non-pulse-like	1.00	0.90	0.80	0.70
k_r (considered in q factor in EC8)			0.80		

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