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PROBABILISTIC ASSESSMENT OF VERTICAL IRREGULARITY EFFECTS ON THE SEISMIC PERFORMANCE OF STEEL MOMENT RESISTING BUILDINGS

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In the past decade of earthquake engineering science, the probabilistic seismic performance assessment of structures has grown as a measurement for predicting the reliability of structural systems under seismic excitations. This approach assesses the structural performance of buildings by probabilistic estimation of the responses under ground motion records. In particular, the estimation of the mean annual frequencies (MAFs) of exceeding the structural performance levels and the confidence level for satisfying the performance objectives has been applied as a decision making framework for design and assessment of common regular structures (Cornell et al., 2002). On the other hand, the prediction of the seismic performance of structures with special features such as vertical irregular buildings is important for earthquake engineers from viewpoint of designing new structures or rehabilitating existing vulnerable buildings (Shakib and Pirizadeh, 2014).

In this paper, the effects of different types of structural vertical irregularities on the seismic performance of steel moment resisting frame structures are evaluated based on the probabilistic approach. For this purpose, the seismic performance of structures with geometric and non-geometric vertical irregularities is assessed by studying (i) the limit-state capacities, (ii) the mean annual frequency of exceeding different limit-states and (iii) the confidence levels in meeting performance objectives.

In this study, the stiffness, strength and combined stiffness & strength vertical irregularities (i.e. non-geometric vertical irregularities) with level of 60% in three different locations including bottom half stories of structure, first bottom story and middle story of structure have been investigated. Also the various setback configurations (i.e. geometric vertical irregularities) which occurred in three different height levels of structure are studied. Three cases of structures have symmetric setbacks about the vertical axis of the structure (two-side setback) and the other nine cases have asymmetric setbacks (one-side setback).

For investigating the effects of non-geometric vertical irregularities on the seismic response and capacity of the structure, the median IDA curve of each case of irregular structures is compared to that of the corresponding regular structure. As a result, the influence of stiffness vertical irregularities on the median IM capacity of the structure was negligible (less than 2%) but the strength and combined stiffness & strength irregularities decreased the median IM capacity of the structure up to 10% in the inelastic limit-states based on the position of these irregularities. In the stiffness, strength and combined strength & stiffness vertical irregularities, when the position of irregularities is in the bottom stories of the structure, the CP and especially GI limit-states are exceeded at the lower drift ratio capacities, compared to the regular structure. Therefore, the prohibition of designing the structures with extreme stiffness and strength vertical irregularities at very high seismic zones is necessary for preventing from the earlier collapse and global instability of structures in these zones. In the next step, the confidence levels of satisfying the LS and CP performance objectives for different cases of irregular structures are compared to those of the regular structure. It is shown that the non-geometric vertical irregularities lead to decreasing the confidence levels of satisfying these performance objectives. This status is more predominant for the CP performance objective (Pirizadeh and Shakib, 2013).

Similarly, the seismic performance of code-designed setback structures with different setback ratios is compared to the code-designed regular structure. The probabilistic performance curves of structures with different setback ratios are compared to that of the regular structure in Figure 1. According to this figure, the mean annual frequency of exceeding limit-states for all setback structures is increased to that of the regular structure. The rate of this increase is between 1.1 to 2.5 times that of regular structure for IO and LS performance level based on the ratio of setbacks. For CP and GI performance levels, the ratios of the MAFs of setback structures to the MAF of the regular structure are in the range of 1.5 to 2.9, depending on the ratio of the setbacks.

In addition, the confidence levels of satisfying the LS performance objective for the code-designed setback structures are decreased by about 10% to 45%, with respect to that of the regular structure. This pattern is more serious at the asymmetric setbacks with more than 50% reductions in the tower floor areas. Therefore, it is seen that the presence of setbacks decreases the capacity of structure and the torsional effects of one-side setbacks intensify this problem. The findings indicate that the expected seismic performance requirements are not provided in the setback structures as satisfactory as in the regular structure, although these buildings were acceptable structures from viewpoint of the Iranian seismic code (2010). Therefore, it seems to be essential to stipulate more restrictive limits or apply more accurate analytical procedures in the design of setback buildings under the simultaneous orthogonal seismic excitations, especially for structures with critical setback ratios (Pirizadeh and Shakib, 2014).

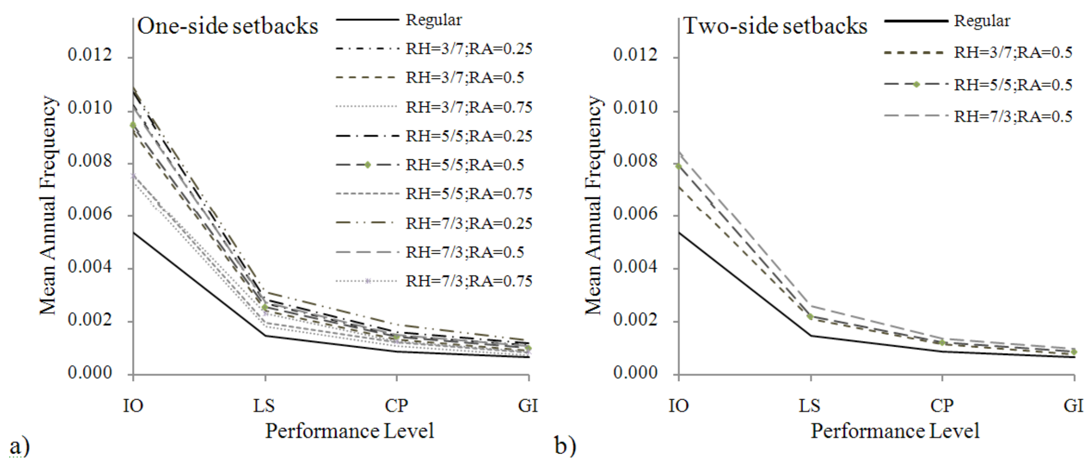

Figure 1. The probabilistic performance curve of various setback structures in comparison with the regular structure
a) one-side, b) two-side setbacks

Overall, the probabilistic seismic performance assessment of vertically irregular buildings indicated that the limitations for this type of buildings should be defined in accordance with: (i) the expected performance objective for structure, (ii) the level of seismic intensity, (iii) the diverse positions of irregularities over the height, (iv) the numbers of vertically irregular stories and (v) the combined action of non-geometric and geometric vertical irregularities with the torsional irregularities.

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