EVALUATING THE EFFECT OF SYMMETRY ON SEISMIC BEHAVIOR OF IRREGULAR BUILDINGS IN PLAN

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ABSTRACT

Different seismic regulations provide different definitions related to irregular criteria in buildings. In addition, these regulations categorize the buildings into two kinds: regular and irregular buildings. Seismic regulations neglect the effect of symmetry on the seismic behavior of irregular buildings as a factor against irregular buildings in plan; therefore, in this paper the effect of symmetry on the behavior of unparallel systems is studied. For this purpose, 6, 10 and 15 storey concrete buildings designed based on Design Regulation of Iran are used. In addition, the conventional software ETABS 9.5.0 and capacity spectral method are used to determine operation point of models. The paper concluded that in ten storey buildings, the wedge-shaped models show critical behavior rather than trapezoidal -shaped, asymmetric models.

INTRODUCTION

Although structural properties have important effects on the strength of structures against the earthquake, architectural design also has a key role on the performance of earthquake resistant structures. Among important decisions related to architectural design, configuration of the structures is mentioned. The configuration of the structure involves size, shape and dimensional ratios of the structure. In addition, the configuration of the structure includes location, shape and approximate size of basic structural components. In other words, the configuration of the structure refers to geometrical properties of the building (Naeim, 2001). Generally, seismic codes classify buildings into two categories based on the configuration point of view (geometrical properties of the building): regular and irregular buildings. These regulations recommend that for the buildings with irregularity of mass and stiffness, dynamic analysis method should be applied. Of different kinds of irregular configuration, triangular-shaped or wedge-shaped buildings are considered here. In seismic codes such as UBS-97 (1997), there are not any clear criteria for such buildings. A few studies exist which have studied seismic response of vertically irregular building structures (Stefano and Pintucchi, 2008, Trung et al., 2012, Michalis et al., 2006, Chopra and Goel, 2002).

In seismic codes, there is not any clear and accurate criteria for such buildings. For example, without considering the irregularity index of the buildings, the UBC-97 classifies such buildings as irregular in plan. Stefano and Pintucchi presented an overview of the progress in research regarding seismic response of plan and vertically irregular building structures. Three areas of research have been surveyed. The first was a study related to plan-irregularity by means of single-storey and multi-storey building models. The second area encompassed passive control as a strategy to mitigate torsional effects by means of base isolation and other types of devices. Finally, the third area evaluated vertically irregular structures and setback buildings (Stefano and Pintucchi, 2008).

Trung et al. focused on investigating the seismic behaviors of vertically irregular steel special moment frame (SMF) buildings compared with the regular structures. All buildings in this study were located in Los Angeles subjected to 20 earthquake ground motions with a seismic hazard level of 2% probability of exceedance in 50 years. The beam–column connections of the buildings were modelled to consider the panel zone deformation. In addition, a ductile connection model accompanied by strength degradation was incorporated in the analysis program in order to obtain more accurate response results. Three types of irregularities (mass, stiffness and strength irregularity)specified as vertical irregularities in the IBC 2000 provisions were imposed to the original building. Nonlinear static and dynamic analyses were performed. The effects of different irregularity types and levels on the seismic behavior of the buildings were investigated and discussed in terms of the height-wise distribution of storey drifts, maximum storey drift demands, global collapse storey drift capacities, and confidence levels (Trung et al., 2012).

Michalis et al. presented a methodology based on incremental dynamic analysis (IDA) to evaluate structures with vertical irregularities. Four types of storey-irregularities were considered: stiffness, strength, combined stiffness and strength, and mass irregularities. Using the well-known nine-storey LA9 steel frame as a base, the objective was to quantify the effect of irregularities, both for individual and combinations of stories, on its response. In this paper a rational methodology to compare the seismic performance of different structural configurations was proposed by means of IDA. This entailed performing non-linear time history analysis for suitable ground motion records scaled to several intensity levels and suitably interpolated the results to calculate capacities for a number of limited cases, from elasticity to final global instability (Michalis et al., 2006).

Chopra and Goel developed an improved pushover analysis procedure based on structural dynamics theory, which retained the conceptual simplicity and computational attractiveness of current procedures with invariant force distribution. In this modal pushover analysis (MPA), the seismic demand due to individual terms in the modal expansion of the effective earthquake forces is determined by a pushover analysis using the inertial force distribution for each mode (Chopra and Goel, 2002).

In this paper, the effect of symmetry on the nonlinearity behavior of three dimensional buildings are studied. A number of six, ten and fifteen storey concrete buildings are designed based on ACI 318-08 by conventional software program (ETABS 9.5.0) and the capacity spectral method is used to determine operation point of the models. Formation of plastic hinges in different regions are also studied.

To account for the structural behavior, the angle α is considered as shown in Fig. 1.

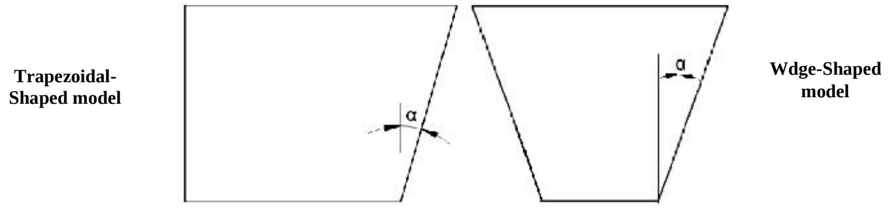

Figure 1. Suggested parameter to investigate the behavior of irregular configuration

The asymmetric and symmetric models for trapezoidal-shaped and wedge-shaped which have been used in this paper are displayed in Fig. 2 as follows:

According to Fig. 1, for six, ten and fifteen storey buildings with symmetric (wedge-shaped) and asymmetric (Trapezoidal-shaped) plan, the effect of symmetry on the behavior of the unparallel systems is studied. All models are considered in a zone with very high seismic risk, type II soil, residential application and the nonlinear static analysis is done to determine the performance point of the structures. The mass center displacement for the highest level of the structures is determined as a performance point of the structure. To investigate the nonlinear behavior of models and providing an opportunity to compare the behavior of different structures, the authors suggest the N_{bf} index (Nonlinearity behavior factor) as follows:

$$N_{bf} = (n_{(A-B)} \times 1 + n_{(B-IO)} \times 1 + n_{(IO-LS)} \times 3 + n_{(LS-CP)} \times 6 + n_{(CP-C)} \times 9) / n_{Total} \quad (1)$$

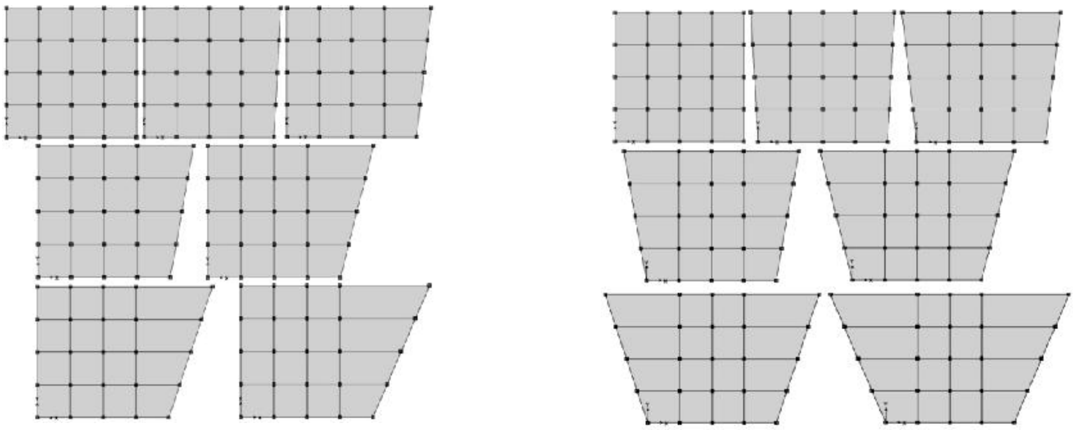

Figure 2. Asymmetric and symmetric models

Where $n_{(A-B)}$, $n_{(B-10)}$, $n_{(IO-LS)}$, $n_{(LS-CP)}$, $n_{(CP-C)}$ and n_{Total} are total number of formed hinges indifferent regions. Fig. 3 shows the percentage of formed plastic hinged in *LS-CP* and *IO-LS* regions for ten storey buildings. As shown in this figure, in buildings with trapezoidal shaped model in plan, increasing α degree leads to reduce the percentage of the formed plastic hinges in *IO-LS* regions and therefore will increase the percentage of formed plastic hinges in *LS-CP* region. Also, the same changes in the buildings with wedge shaped model are seen.

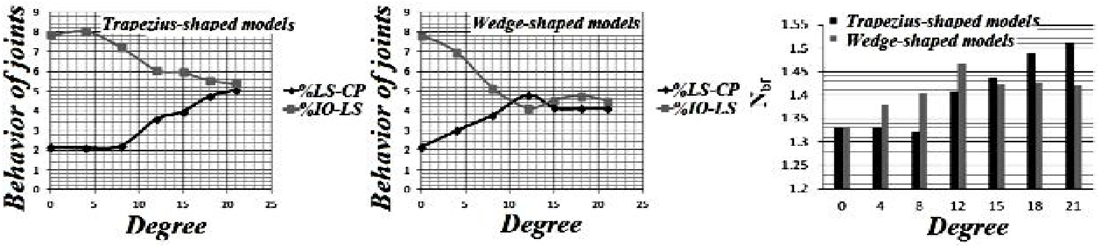

Figure 3. a) The percentage of formed plastic hinges in different zones of the structural performance with respect to ~ degree for ten storey models, b) variation of N_{bf} index with respect to ~ degree for symmetric and asymmetric ten storey models

For both shapes, the changes of N_{bf} have also been drawn in Fig. 3. As shown in this Figure, in buildings with trapezoidal shaped model, increasing in α degree will lead to an increase in the amount of ductility demand of the structure as well as the percentage of the formed plastic hinges. However, in buildings with wedge shaped model, there are no regular noticeable changes. As shown in Fig. 3, in ten storey building, the effect of symmetry is evident on the nonlinearity behavior of wedge-shaped models. In the symmetric wedge-shaped models with~ degree greater than 12°, the nonlinearity behavior of the structure will improve with an increase in~ degree. However, the wedge-shaped models show critical behavior rather than asymmetric trapezoidal-shaped models.

Fig. 4 shows the percentage of formed plastic hinged in *LS-CP* and *IO-LS* regions for six storey buildings. As shown in this figure, in buildings with trapezoidal shaped model in plan, increasing α degree leads to reduce the percentage of the formed plastic hinges in *IO-LS* regions and therefore will increase the percentage of formed plastic hinges in *LS-CP* region.

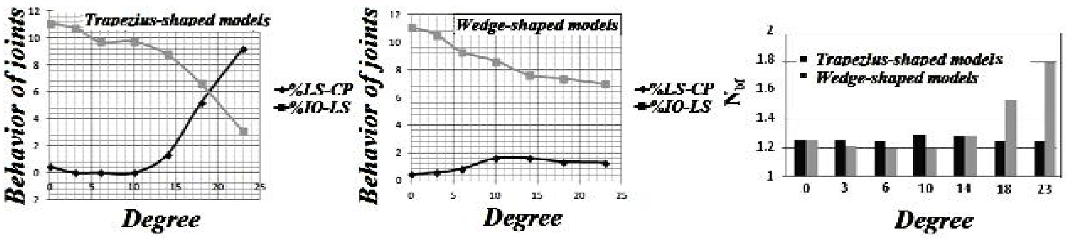

Figure 4. a) The percentage of formed plastic hinges in different zones of the structural performance with respect to ~ degree for six storey models, b) variation of N_{bf} index with respect to ~ degree for symmetric and asymmetric six storey models

Fig. 5 shows the percentage of formed plastic hinged in *LS-CP* and *IO-LS* regions for fifteen storey buildings. As shown in this figure, in buildings with trapezoidal shaped model in plan, increasing α degree leads to reduce the percentage of the formed plastic hinges in *IO-LS* regions and therefore will increase the percentage of formed plastic hinges in *LS-CP* region. Moreover, as shown in Fig. 4, in fifteen storey models, both of wedge-shaped and trapezoidal-shaped models have displayed the same behavior. From the Figs. (1-3), it can be found that the behavior of the trapezoidal-shaped models are more critical than the behavior of the wedge-shaped models.

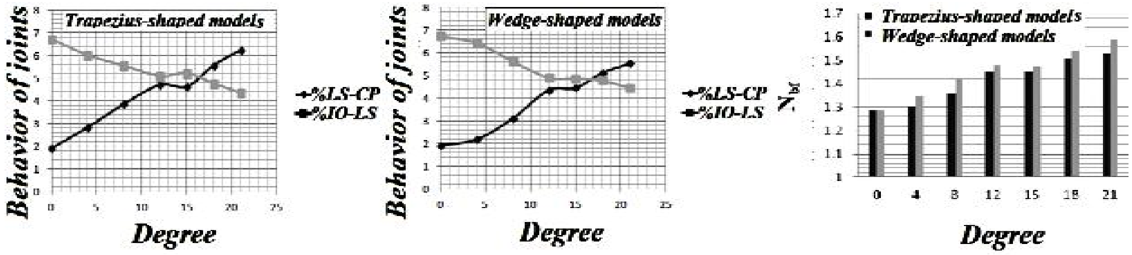

Figure 5. a) The percentage of formed plastic hinges in different zones of the structural performance with respect to ~ degree for fifteen storey models, b) variation of N_{bf} index with respect to ~ degree for symmetric and asymmetric fifteen storey models

CONCLUSIONS

In this paper, effect of symmetry on the seismic behavior of irregular buildings in plan as an effective factor on the seismic behavior of irregular buildings is studied. This is done by comparing the behavior of symmetric and asymmetric models with different values of geometric irregularity. Generally, the most important conclusions are as follows:

1- As shown in Fig. 4 by increasing the value of ~ degree in six storey models, the effect of symmetry and elimination of torsion are evident in the models. In symmetric models with the ~ degree greater than 10°, nonlinear behavior of the structure improved partially by increasing in ~ degree. However, the results show that the nonlinear behavior of the structure decreased considerably in the asymmetric models with ~ degree greater than 10°.

2- As shown in Fig. 3, in ten storey buildings, the effect of symmetry is evident on the nonlinear behavior of the wedge-shaped models. In the wedge-shaped, symmetric models with ~ degree greater than 12°, nonlinear behavior of the structure improved by increasing in ~ degree. However, the wedge-shaped models show critical behavior rather than the trapezpidal-shaped, asymmetric models.

3- As shown in Fig. 5, in fifteen storey buildings, the effect of symmetry is not evident on the improvement of the nonlinearity behavior of the structure. However, the structure is entered into nonlinearity region more than previous ones by increasing the ~ degree and subsequently increasing the percentage of formation of plastic hinges. Therefore, generally, it can be concluded that by increasing the height of the structure, the effect of torsion on the irregularity behavior of structures would be reduced.

4- As shown in Fig. 5, in fifteen storey models, both of wedge-shaped and trapezoidal-shaped models have displayed the same behavior. It should be mentioned that the results demonstrate that the behavior of the trapezoidal-shaped models are more critical than wedge-shaped models. This increase happen in the low angles so that the behavior of the wedge-shaped structures with ~ degree is almost similar to the behavior of the trapezoidal-shaped structures with 2~ degree.

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