PUSHOVER ANALYSIS FOR ASYMMETRIC AND SET-BACK MULTI-STORY BUILDINGS

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SUMMARY

To extend the pushover analysis to eccentric multi-story buildings a procedure has recently been developed. It takes into account the higher modal and three-dimensional effects induced by torsion. The procedure uses an elastic spectrum analysis of the building to obtain the target displacements and load distributions for pushover analyses. Then two-dimensional inelastic static analyses are conducted on the lateral load resisting elements of interest. To investigate the efficiency of this method for different types of eccentric buildings, three systems are studied. The first model is a ductile moment resisting frame building. The second model is a set-back building and the last one is a wall-frame structure. Each building is subjected to ten spectrum compatible time history records as ground motion excitations at the base. The means of the maximum responses of these buildings are computed using three-dimensional inelastic dynamic analyses and using the proposed procedure. A comparison of the two sets of results demonstrates both the capabilities and limitations of the proposed procedure.

INTRODUCTION

Pushover analysis, as a practical way of estimating the deformation and damage pattern of a structure, is getting increasingly more attention. The procedure consists of two parts. First, a target displacement for the building is established. The target displacement is an estimation of the top displacement of the building when exposed to the design earthquake excitation. Then a pushover analysis is carried out on the building until the top displacement of the building equals to the target displacement [Tso & Moghadam 1998]. The extent of damage in the building at this target displacement level is considered representative of the damage the building will experience when subjected to the design level ground shaking. Development of this procedure for planar structures has begun two decades ago [Saiidi & Sozen 1981]. The original pushover procedure does not account for the three-dimensional effects. The first study to use pushover analysis for asymmetrical buildings involves the use of a 3-D inelastic program [Moghadam & Tso 1996]. In another study a simple push-over analysis method for asymmetric buildings is developed [Kilar & Fajfar 1997]. An alternative approach to pushover analysis of asymmetric buildings uses the results of elastic dynamic analyses of the building to obtain the target displacements and load distributions for pushover analysis [Tso & Moghadam 1997]. An extension to this method is the direct use of elastic response spectrum analysis instead of elastic time-history dynamic analysis to obtain target displacements [Moghadam & Tso 1998]. A study on two 7-story wall-frame buildings showed that pushover analysis provides reasonable estimation of their displacements profiles [De Stefano & Rutenberg 1998]. Finally, a comparison of different pushover procedures for eccentric buildings is reported recently [Moghadam & Tso 1999].

The present paper investigates the efficiency of the response-spectrum-based pushover method for three different types of eccentric buildings. They are ductile moment resisting frame buildings, set-back buildings and wall-frame structures.

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PROCEDURE

The procedure consists of two parts. First, the target displacements are determined by performing an elastic spectrum analysis on the building. The top seismic displacements of the resisting elements in an asymmetrical building are different due to torsional response. Therefore, many target displacements need to be determined, one for each resisting element. The accuracy of a pushover analysis is also depends on using an appropriate distribution of the lateral loads. Usually, an inverted triangular load distribution is assumed. However, due to the three-dimensional nature of the problem, the height-wise distributions of the lateral loading on the resisting elements near the perimeter can be substantially different from that on the building as a whole. To account for this effect, one can use the force distribution on each element based on the elastic spectrum analysis of the building.

Once the target displacements and the corresponding lateral load distributions are found, a series of 2-D pushover analyses can be carried out for specific elements. Only inelastic modelling of these elements will be needed. Each element is loaded with a set of static loads with the same distribution as the elastic force distribution on the element obtained from the spectrum analysis of the building. The element is pushed until its top displacement attains its target displacement.

EXAMPLE BUILDINGS

To illustrate the application and accuracy of the proposed procedure, the seismic responses of three seven-story buildings subjected to an ensemble of ten artificial ground motion records as input are computed. The plans of the buildings are similar (Figure 1). The first building is a reinforced concrete ductile moment resisting frame building. The building has a rectangular plan measuring 24m by 17m and story height of 3m. The ground motions are assumed to come from the Y-direction and the lateral load resisting elements in that direction consist of three identical ductile moment resisting frames (Figure 2). Frame 2 is an interior frame and frames 1 and 3 are located at the edges of the buildings as shown. The mass distribution of each floor causes the CM of the floor to shift a distance of 2.4m from frame 2 towards frame 3. More information about this building can be found elsewhere [Moghadam and Tso 1998].

The second building is similar in all aspects to the first building; the only difference is that the three regular frames (Figure 2) are replaced by three set-back frames (Figure 3). The third building is also similar to the first building; the only difference is that the frame 2 is replaced by a wall. All three buildings have a mass eccentricity equal to 10% of the width of the building.

For each building, the accuracy of the pushover results is established by comparing the results obtained using an inelastic dynamic analysis on the building, treating it as a multi-degree of freedom (MDOF) system.

APPLICATION OF THE PROCEDURE TO THE EXAMPLE BUILDINGS

The structural models were subjected to an ensemble of 10 horizontal artificial ground motion records. The shapes of response spectrum of these records are similar to the Newmark-Hall design spectrum in order to minimize the mismatch in frequency contents between the input ground motion and the design spectrum. The acceleration response spectra for the artificial records are shown in Figure 4. The inelastic dynamic and static analyses are conducted using the computer program CANNY [Li 1993].

The mean seismic displacements and interstory drift responses of the three buildings over the ensemble of records are shown in Figures 5 and 6. The pushover results are based on a triangular load distribution. A comparison of the curves in each plot shows that the pushover procedure gives good estimation of the trend of the responses. However, it generally overestimates the actual value of the responses, specially in the set-back building.

Then, the effect of using load distribution resulted from response spectrum analysis is evaluated. The lateral load distribution on the frames and walls resulted from response spectrum analysis are compared with the triangular distribution in Figure 7. These distributions are normalized to generate one unit of base shear. Of particular interest in the case of frame building, is the relatively large increase of the loads at the roof and the drastic reduction of loads near the base of frame 3 due to the higher modal effect. In the wall-frame structure, the load distribution on the wall and frames is almost triangular with larger loads at the lower floors. Shown on the Figure 8 are the comparison of the responses when load distribution resulted from response spectrum is used in pushover analyses. For the frame building the pushover results have been improved. The improvement is specially pronounced in local response parameters that are not shown here. But the pushover estimations are deteriorated for the set-back and wall-frame building. More research is needed to identify the exact cause of this deterioration. However, as the stiffness and strength distributions in set-back and wall-frame are not uniform, it is reasonable to expect the load distribution in the inelastic range to differ substantially with the elastic load distribution. As a result, using response spectrum load distribution for such systems can not improve the results.

CONCLUSIONS

A response-spectrum based pushover procedure is used to obtain seismic response estimates of three types of asymmetrical building systems. This procedure includes some of the three dimensional effects caused by the torsional responses. The main features of the procedure are the use of elastic response spectrum analysis of the building to obtain the target displacements and the load distributions used in the pushover analyses. In this procedure, there is no need to model the inelastic behaviour of all the elements in the building. It is sufficient to find the target displacements of the planes of interest and only model the inelastic behaviour of those elements for 2-D pushover analyses. The case studies show that the procedure leads to good estimates of the trends of the responses for asymmetrical multi-story buildings. The use of load distribution resulted from response spectrum analysis in pushover analysis, improves the result for the frame building and deteriorates the results for the set-back and wall-frame systems.

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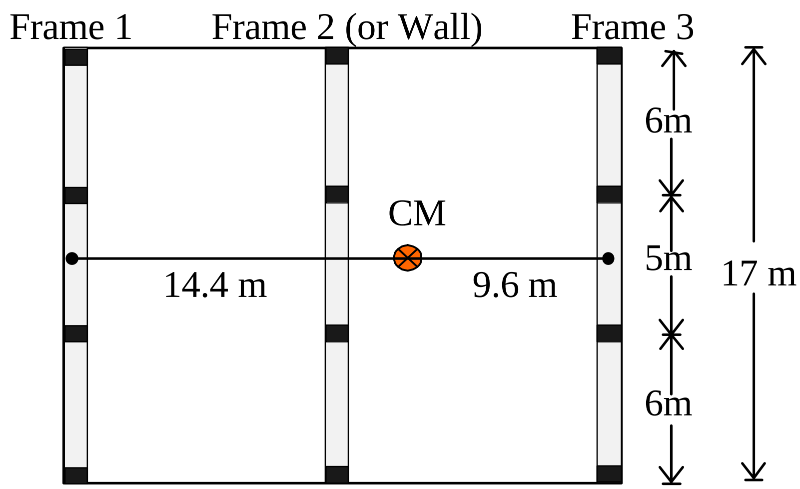


Figure 1: Plan of the seven-story buildings

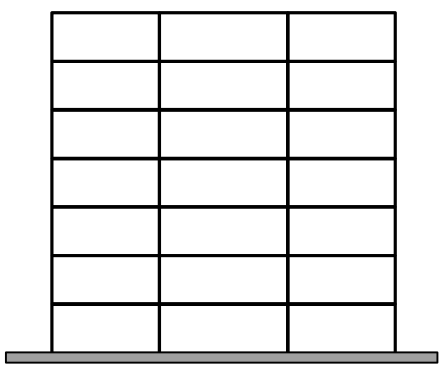


Figure 2: Original frame

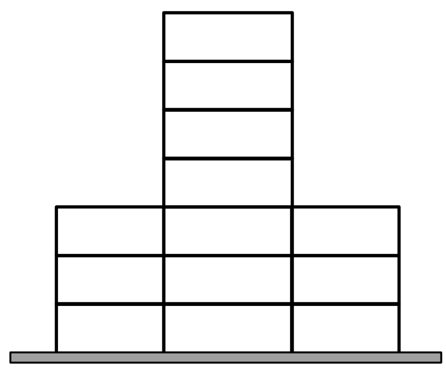


Figure 3: Set-back frame

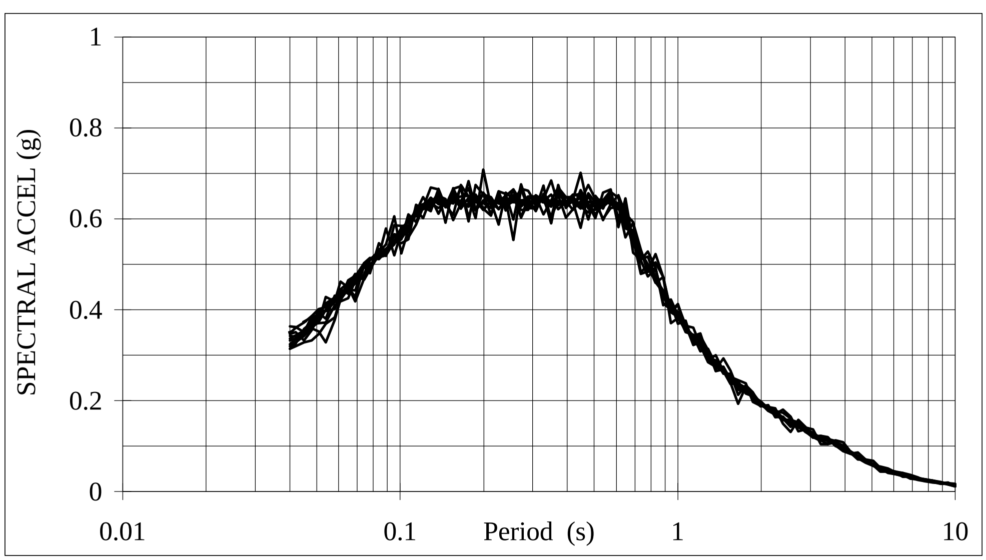


Figure 4: Response spectra of the artificial records

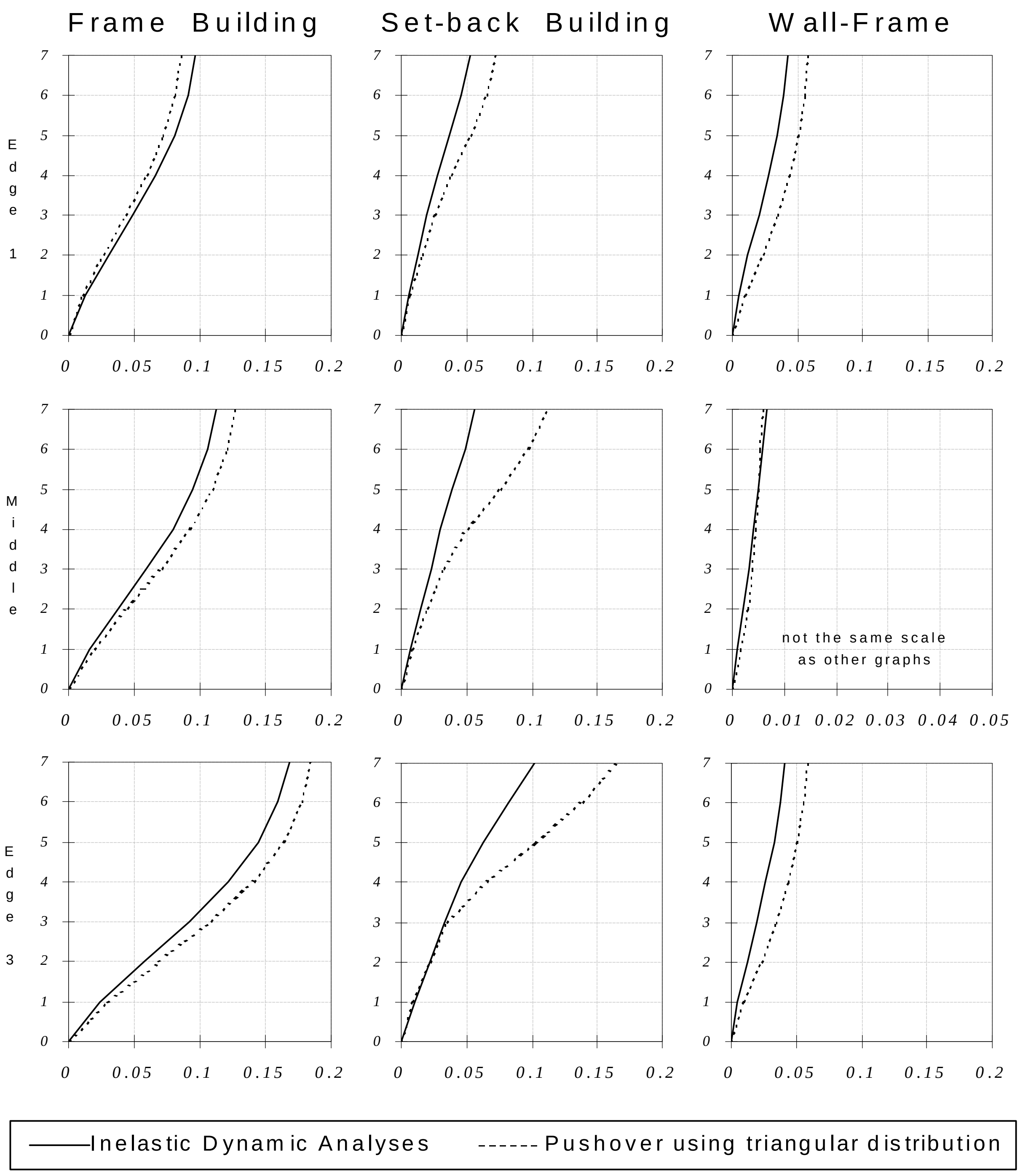


Figure 5: Mean of maximum displacements (m)

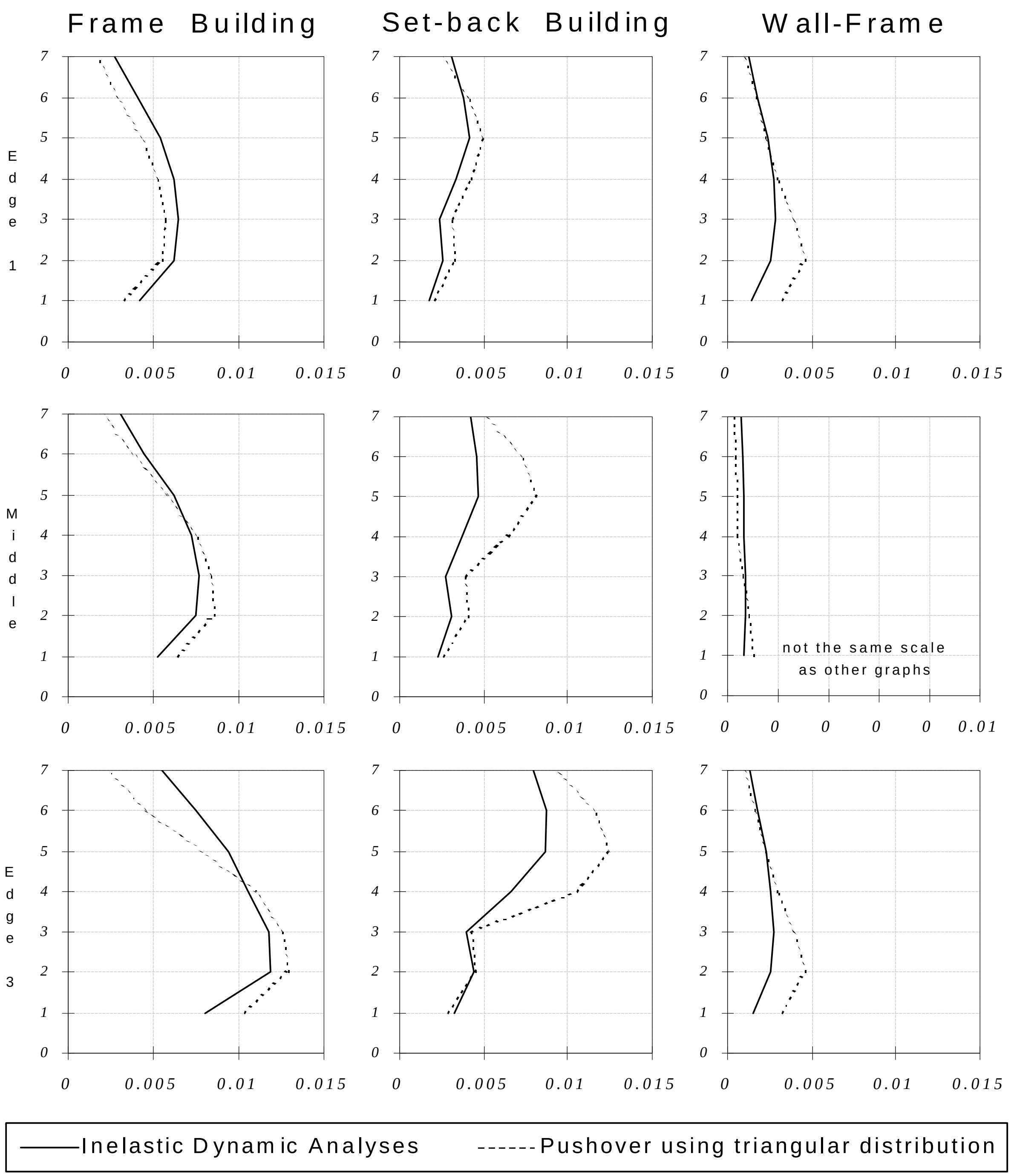


Figure 6: Mean of maximum story drift ratio

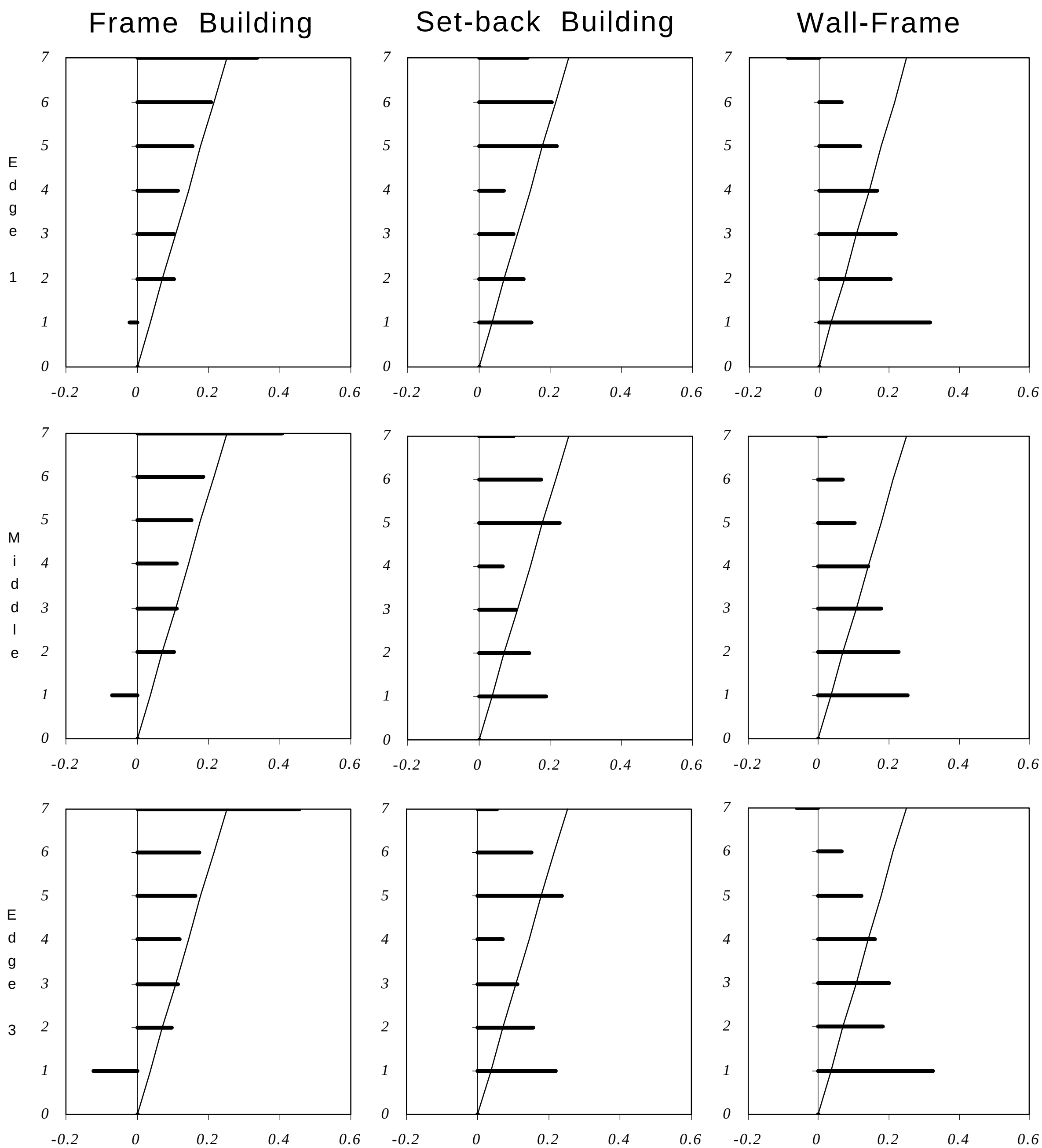
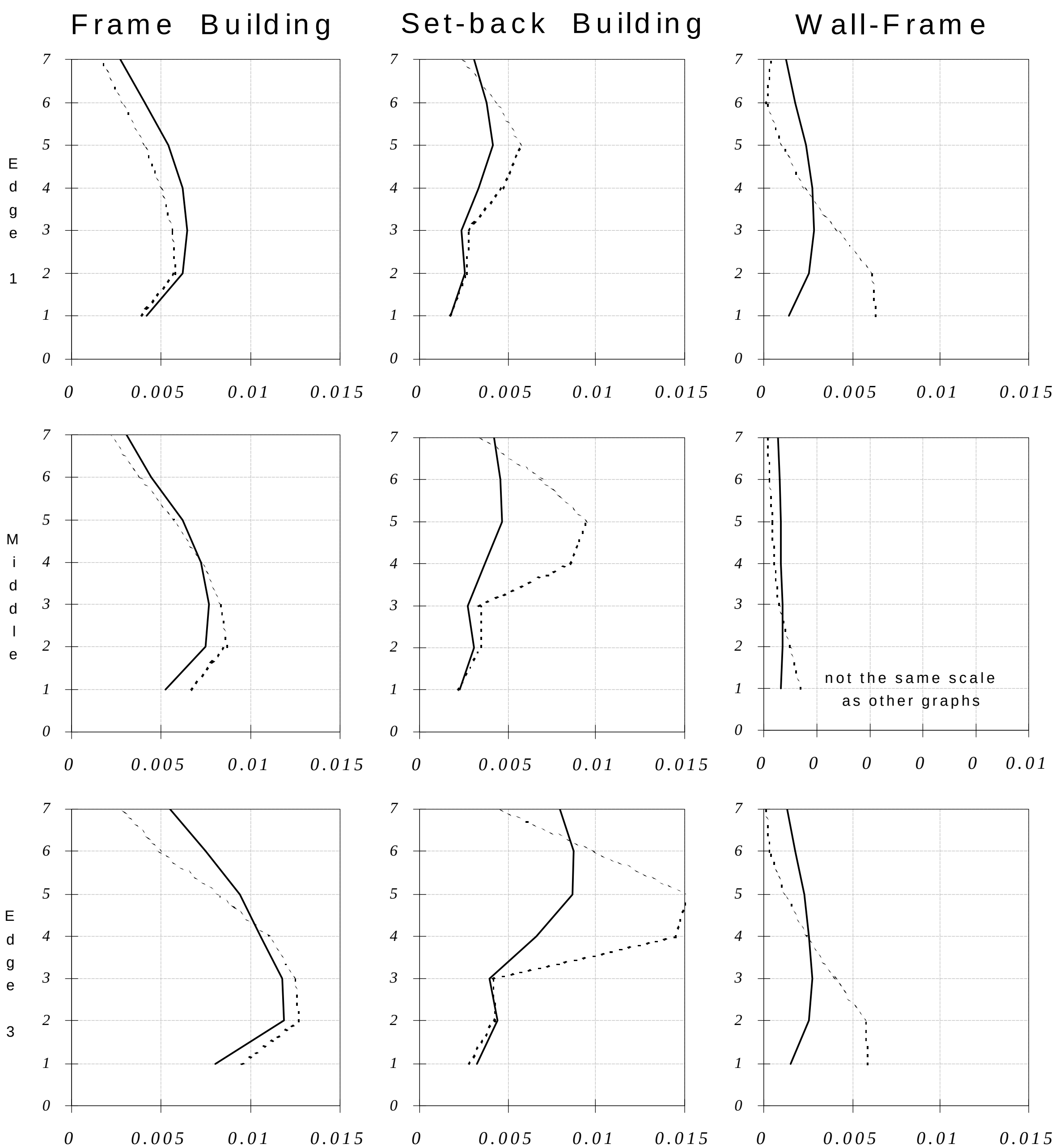


Figure 7: Load distributions resulted from response spectrum analyses



— Inelastic Dynamic Analyses ---- Pushover using response spectrum distribution

Figure 8: Mean of maximum story drift ratio