Pushover Analysis of Asymmetrical Infilled Concrete Frames

T. Mahdi
Building and Housing Research Centre, Tehran, Iran

V. BAHREINI
Islamic Azad University, Arak Branch, Arak, Iran

SUMMARY: (10 pt)
In this paper, the nonlinear seismic behavior of three concrete frames with unsymmetrical plan in three, four and five stories are evaluated. The plan configurations of these space frames contain reentrant corners, where both projections of the structure beyond a reentrant corner are greater than 33 percent of the plan dimension of the structure in the given direction. For each of these structures, bare and infilled frames are considered. In the present analysis, three types of infill arrangements and material types (strong and weak) have been considered. The results show that infill walls have generally beneficial effects. In using the weak infill walls, the improvement in the capacity curve is less than 15%. On the other hand, for the strong infill walls considerable increases in the capacity have been observed.

Keywords: Pushover, performance level, irregular building, infill wall, concrete frame

1. INTRODUCTION

Structural irregularities are commonly found in structures. The existence of an asymmetry in the plan is usually leading to an increase in stresses of certain elements that consequently results in a significant destruction. Furthermore, unreinforced masonry infill panels (MI panels) are widely used throughout the world, including seismically active regions. They are usually used as interior partitions and external walls in concrete frames, but they are treated as nonstructural elements and not included in the analysis and design procedure. Such a simplified design approach does not consider the initial beneficial effects on the strength capacity of the concrete frames, does not predict the level at which the damage in the infill panel occurs, and it does not take in consideration the effect of the infill arrangement on irregularities of the building (Fardis, 2000; Bachmann, 2002; Hashemi & Mosalam, 2006).

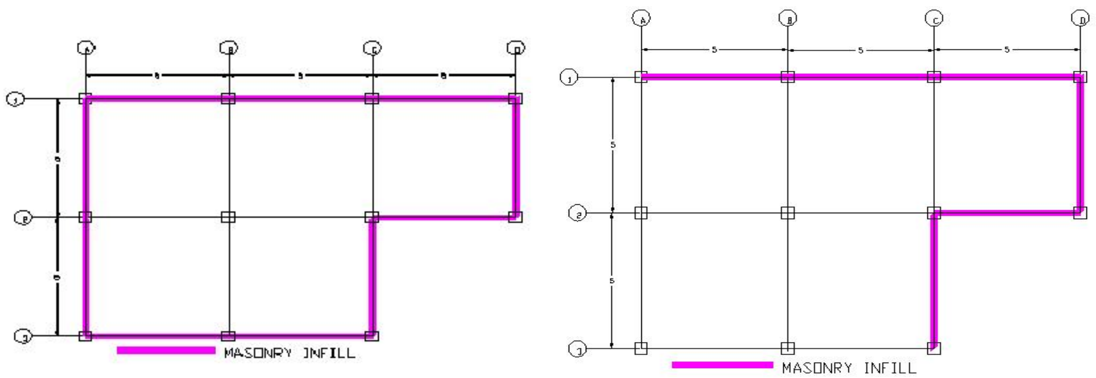
The first set of nonlinear static procedure comprises the Capacity Spectrum Method (CSM), introduced by Freeman (Freeman et. al., 1975). In 1981, nonlinear dynamic analyses on an equivalent SDOF system had been proposed (.Saiidi & Sozen, 1981). Based on this idea, the N2 method has been suggested (Fajfar & Fischinger, 1988). These first proposals are characterized by their simplicity and usually consider the first mode in computation of the pushover/capacity curve, and consequently have been limited to planar structural models.

The first study to use pushover analysis for irregular buildings was carried out in 1996 (Moghadam & Tso, 1996). Moghadam's study was then extended to cover plan-eccentric buildings and taken the three-dimensional torsional effect into account. In this later work, an elastic spectrum analysis of the building was used (Moghadam & Tso, 2000). Later on, many theoretical contributions had been made to improve the performance of the analysis and had been reviewed by Themelis (Themelis, 2008). Furthermore, many authors had dealt with the practical aspects of plan irregularities (.Faella et. al., 2004; Yu et. al., 2004; Ambrisi et. al., 2008; Pinho et. al. 2008; Herrera & Soberón, 2008).

2. DESCRIPTION OF THE ANALYZED BUILDING

In this paper, three, four and five stories are considered. In each of these three cases, plan configurations of the structure contain reentrant corners, where both projections of the structure beyond a reentrant corner are greater than 33 percent of the plan dimension of the structure in the given direction, as shown in Fig. 2.1. For each of these buildings, bare and infilled frames are considered. For the bare frame, the differences between center of mass and rigidity are less than 2.4% of the corresponding dimension of the building, in both directions.

The structural system used for these buildings is taken as concrete intermediate moment-resisting space frames (IMRSF). Soil type is considered as type B in the USGS classification and a soil profile A spectrum according to Eurocode Classification. Furthermore, the peak ground acceleration is assumed equal to 0.3g that corresponds to that used for high seismic zone in the IS 2800 (BHRC, 1999). All the floors are considered to be subjected to dead loads equal to 570 Kg/m^2 and to live loads equal to 200 Kg/m^2. At the roof, dead loads of 580 Kg/m^2 and live loads of 150 Kg/m^2 are considered. The 28-day strength of concrete, yield strength of steel, are 250, 4000 Kg/cm^2 respectively. For MI walls, two material types (strong and weak) have been considered. The Strong panel consists of perforated clay units and has a compressive strength f_m equals to 50 Kg/cm^2, while the weak panel consists of porous clay units and has a compressive strength f_m equals to 8.7 Kg/cm^2.



(a) (b)

Figure 2.1. Typical plans of the analyzed buildings with different infill arrangements

The infill's arrangements used in this paper are as follows:

a. In all external walls (Fig. 2.1a)
b. In two of the external walls (Fig. 2.1b)
c. The same as (a), but with no infill walls in the ground floor (soft story)

The combinations of dead loads are as follows (ATC, 1996):

$$PG1 = 1.1(Q_D + Q_L) \tag{2.1}$$

$$PG2 = 0.9D_D \tag{2.2}$$

In the above equations, Q_D is the total dead loads and Q_L is the total live loads.

For lateral seismic loads, the analysis has performed by assuming two types of lateral loads distributions. First by assuming a triangular distributions similar to that obtained by the equivalent static analysis method, and second by assuming rectangular distributions proportional to the weight of the floor. Combining these loads with the vertical loads defined in Equations 1 and 2, buildings have been tested under the effect of sixteen different combinations.

The dimensions of different members have been carried out using the Iranian code for concrete structures (MPO, 2004). Then, all the frames have been subjected to vertical and lateral loads based on the non-linear static procedure given by the ATC40 (ATC, 1996).

3. MODELLING OF MASONRY INFILL WALLS

MI walls are laterally much stiffer than the RC frames, and therefore, the initial stiffness of the MI-RC frames largely depends upon the stiffness of MI walls. Accordingly, it is quite important to have a reliable method to estimate the stiffness of the MI walls. For global building analysis purposes, the compression struts representing infill stiffness of solid infill panels may be placed concentrically across the diagonals of the frame, effectively forming a concentrically braced frame system (see Fig. 2.1.).

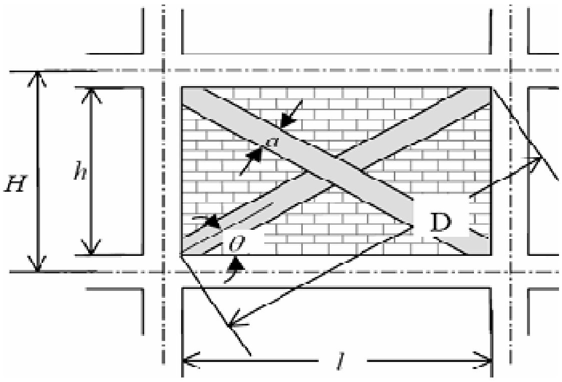


Figure 3.1. Modelling the MI wall with compression struts

4. RESULTS

4.1. Capacity Curves

To obtain the capacity curve, seismic loads are calculated and distributed over the height of the frame using both rectangular and triangular forms. Examples of the resulting capacity curves for the three-story frame without infill are shown in Fig. 4.1. All other curves show similar features. They are linear initially but start to deviate from linearity when inelastic actions start to take place. With the increase of displacements, the capacity curves become linear, but with much smaller slopes that sometimes approaching flat shapes. Furthermore, it can be concluded that the curves obtained for the two gravity load combinations are approximately similar to each other while they are more sensitive to the type of lateral loads, as shown in Fig 4.2. In this figure, it can be seen that the triangular distribution of lateral forces (PX2) yields lower results than the rectangular one (FX2). For the rest of frames, with or without infills, similar results are obtained.

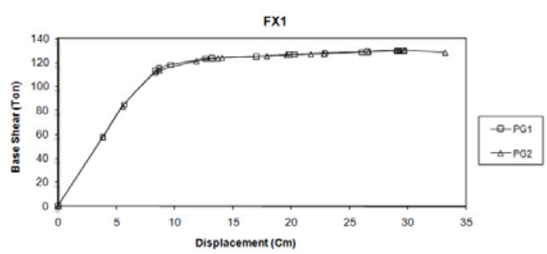


Figure 4.1. Capacity curves for the three-story RC frames without infill subjected to two different vertical load combinations

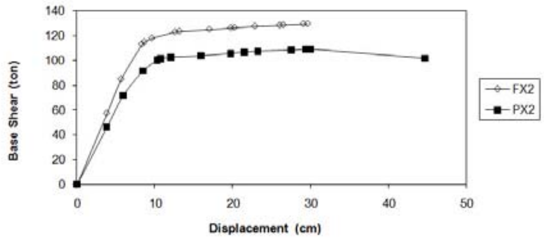


Figure 4.2. Capacity curves for the three-story frames without infill subjected to two different lateral load combinations

To understand the effect of infill's type on the strength capacity of the concrete frames, two types of infill panels are assumed. As shown in Fig. 4.3, the weak infill panel shows a little improvement over the bare frame while the strong panel has shown a considerable increase in strength in the initial stages. However, the decline of strength in the aftermath of the elastic stage is also noticeable.

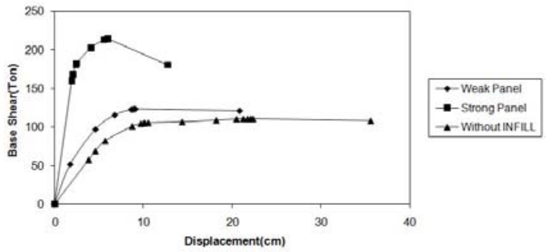


Figure 4.**3**. Capacity curves for the three-story frames with and without infill subjected to rectangular distribution of lateral forces

4.2. Performance Points

In order to specify the performance point, the method suggested by ATC40 has been adopted (ATC, 1996). The design spectrum given by the IS 2800 (BHRC, 1999) has been fed into the software as the demand spectrum. Based on this, and as shown in Fig. 4.4, the performance point has been found at a base shear of 94 kg and a displacement of 20 cm.

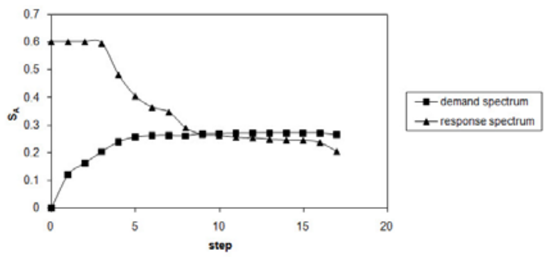


Figure 4.**4**. Capacity and demand curves for the three- story frame without infill

The results obtained for the three-story frame with and without infill are presented in Table 4.1. By comparing the results given in this table, it can be seen that the presence of infill increases the base shear forces and decreases the displacements at the performance point. This confirms the results found earlier by other researchers on the beneficial effects of infill on increasing strength and reducing displacements (Fardis, 2000; Hashemi & Mosalam, 2006).

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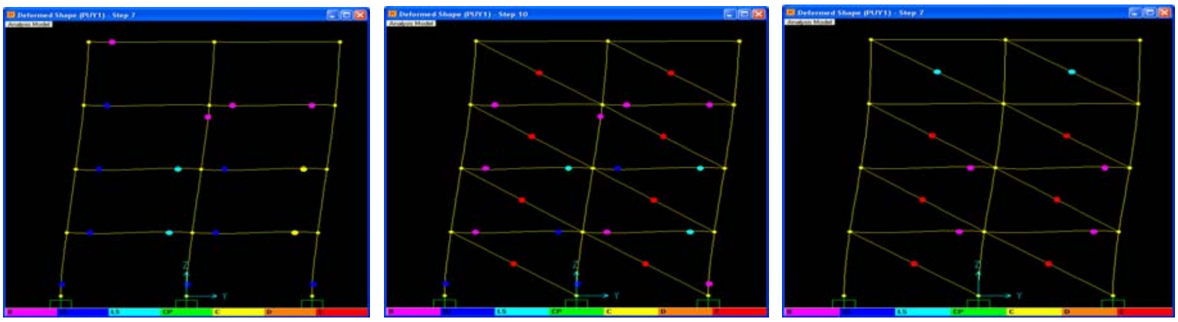
Table 4.1. Performance points for the three-story frame with and without infill walls under different lateral loads

Performance point	Without infill		With infill (Fig. 2.1.a)	
	Displacement (cm)	Base Force (ton)	Displacement (cm)	Base Force (ton)
FX1	14.96	124.30	11.68	137.20
FX2	14.50	124.20	11.76	135.57
FY1	15.57	125.84	12.67	134.00
FY2	15.46	125.00	12.70	132.50

In all cases studied, failures of infills have occurred in the early stages before any failure in the frame. However, and as shown in Fig. 4.5., comparing the two frames with and without infill, it can be seen that the presence of infills and especially strong infills has improve the performance of different frame members. Generally, and by comparing the numbers and locations of plastic hinges in these three cases, it is clear that frames without infills are more prone to destruction than frames with infills.



(a) (b) (c)

Figure 4.5. Plastic hinges for the four-story frames at the performance point a) without infill b) with weak infill panels c) with strong infill panels

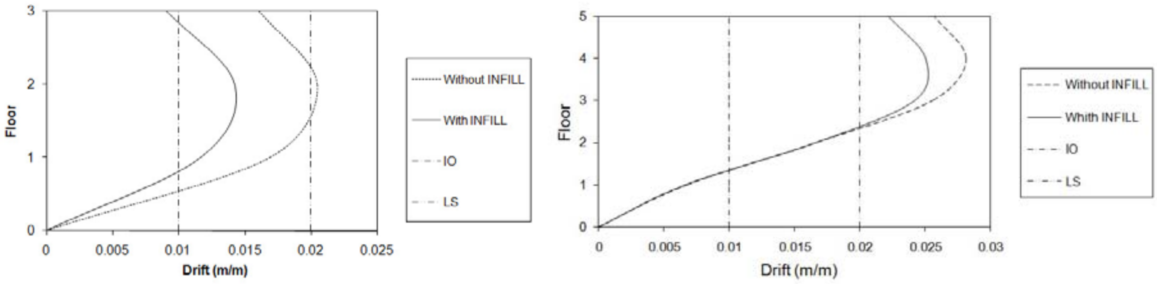
The results mentioned above are in line with the observations made on the performance of regular and irregular infilled frames in previous earthquakes. As example, in the 1990 Manjil Earthquake and in the cities of Loushan and Rasht few kilometers from the epicenter of the earthquake, most the infill walls were largely damaged. However, and according to the observations made by Moghaddam (Moghaddam, 2002), the original frames had escaped the quake with minor damages. It can be concluded that most of the energy resulted from the quake had been dissipated by the damaged infill walls in such a way that made the frame safer.

4.3. Drifts

From the results obtained for the three-story frame, it is clear that using frames without infills cause higher drifts than expected. On the other hand, and as shown in Fig. 4.6a for the partially infilled frames shown in Figure (2.1. a), the drift decreased considerably and fall within the life safety limits. However, the differences in results between infilled and bare frames are less noticeable for the five story frame, as shown in Fig. 4.6b.

4.4. Soft Stories

Soft stories are stories that are more vulnerable to seismic damage than others due to the fact that they are less stiff, less resistant, or both. This is shown numerically in Fig. 4.7 where the infill walls of the ground floor have been removed making the ground floor columns more vulnerable.



(a) (b)

Figure 4.6. (a). Drifts for the three-story frames (b). Drifts for the five -story frames

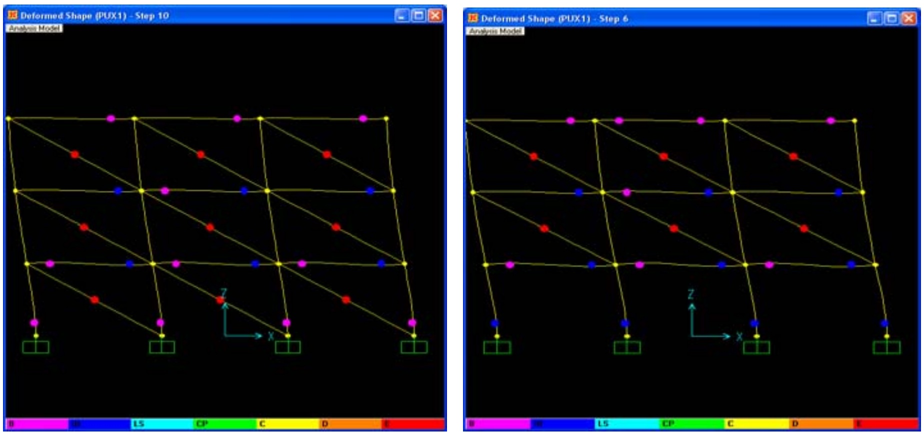


Figure 4.7. Effect of soft-story on the plastic hinges in the three-story frames.

5. **CONCLUSIONS**

In all the cases studied, the following points have been observed:

1. Bare frames are more vulnerable than infilled frames.
2. Omitting infills in the ground floor makes the columns of this floor more vulnerable.
3. For three-story frames, bare frames yield higher drifts than the allowable life safety ones, while the infilled frames yield drifts less than the life safety performance level. However, for the five-story frames both bare and infilled frames yield drifts higher than the allowable life safety as shown in Fig. 4.6.
4. Although failure of infills occur in the early stages of an earthquake, their presence is beneficial since the energy resulted from the quake is dissipated by the damaged infill walls

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