INFLUENCE OF INFILLED WALLS WITH OPENINGS TO THE SEISMIC RESPONSE OF PLANE FRAMES

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ABSTRACT

In this paper, the seismic behaviour of multistory, reinforced concrete, partially infilled frames is investigated. Using the Method of Contact Points for the analysis of masonry infilled frames, the influence of the masonry infill panel opening in the variation (reduction) of the infilled frames stiffness has been investigated. A parametric study is carried out using as parameters, the area and the position of the masonry infill panel opening. The investigation has been extended to the case of soft stories, where infill does not exist.

Key words: Infilled frames, masonry wall, seismic response, soft story.

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INTRODUCTION

As it is known, in many countries situated in seismic regions, reinforce concrete (RC) frames are infilled by brick or concrete-block masonry walls. For decades now, these infill walls were not taken into account when designing the bearing structures. However, an extensive experimental (Smith, 1966), (Smith et al., 1969), (Page et al., 1985), and analytical (Syrmakezis and Vratsanou, 1986), (Syrmakezis and Asteris, 1996) investigation has been made. An extensive and in-depth State-of-the Art Report can be found in the research work of Tassios (Tassios, 1984). Recently, it has been shown that there is a strong interaction between the infill masonry wall and the surrounding frame, leading to:

- Considerable increase of the overall stiffness (and, in many cases, higher base shear force).
- Increase of dissipated energy.
- Redistribution of action-effects and, some times, unpredictable damages along the frame.
- Considerable reduction of the probability of collapse, even in cases of defective infilled frames, when they are properly designed.

Approximately 80% of the cost of damages of structures from earthquakes is due to damage of the infill walls and to consequent damages of doors, windows, electrical and hydraulic installations (Tiedeman, 1980). In spite of its broad application and its economical significance, this structural system has resisted analytical modeling; the following reasons may explain this situation:

- ♦ Computational complexity: The particulated infill material and the ever changing contact conditions along its interface to concrete, constitute additional sources of analytical burden.
- ♦ Structural uncertainties: The mechanical properties of masonry, as well as its wedging conditions against the internal surface of the frame, depend very much on local construction conditions.
- ♦ The non-linear behaviour of infilled frames depended on the separation of masonry infill panel from the surrounding frame.

The main goal of this paper is to establish the relationships between the parameters of a wall opening (such as position and opening percentage), as well as the investigation of the redistribution of action-effects (diagram of shear force) of plane infilled frames under earthquake loads. A major assumption used in modeling infill walls is that the material of its elements, under the plane stress condition of the infill wall, is homogenous and anisotropic (orthotropic). For the analysis, a Finite Element (FE) method with rectangular 8 degree of freedom (DOF) element has been used. The analysis has been performed using the recently proposed by the authors Method of Contact Points for the analysis of masonry infilled frames (Syrmakezis and Asteris, 1996 and 1999). According to this method the infill FE model is initially considered to be linked to the frame FE model at two corner points, at the ends of the compressed diagonal of the infill. The structure is then analyzed. By applying appropriate nodal forces, the infill model points overlapping the RC model, are linked to the neighbouring points of the RC model and the process is repeated, until a final equilibrium condition is reached. In order to clarify the method, a special computer program has been used.

Using this computer program, several cases of wall infilled frames have been investigated. The influence of the following parameters of infilled walls to the seismic response of RC frames has been studied: a) position of opening, b) opening percentage, c) anisotropy of masonry infill wall. In addition the shear force distribution of a three storey one bay frame for different arrangements of infill wall has been investigated.

INVESTIGATION OF OPENINGS INFLUENCE TO THE INFILLED FRAMES STIFFNESS

Although infill walls usually have oversized openings, the more recent research has focused on the simple case of infill wall without openings. Research of infill wall with openings is mostly analytical and limited, and bears no comparison due to the different materials used and the different types of openings. It is worth to note that the infill wall contribution is much reduced when the structure is subjected under reversed cyclic loading, in real structures under earthquake conditions. The relevant experiments findings (Vintzeleou and Tassios, 1989) showed a vast reduction in the response of infilled frames under reversed cyclic loading. This paper presents investigation results of the influence of the opening size and its position to the infill wall in seismic response of masonry infilled frames, based on the method of contact points described above. The problem is examined in the elastic region for monotonic loading. Also, the ratio λ (stiffness with wall opening to stiffness without a wall opening) is used for comparison with bibliography data.

The method of contact points was for the first time used in the one-storey frame, showed in Fig. 1, for a 30kN horizontal loading with a similar uniform load distribution in the surrounding frame and infill wall surface. On this frame, various opening cases are examined.

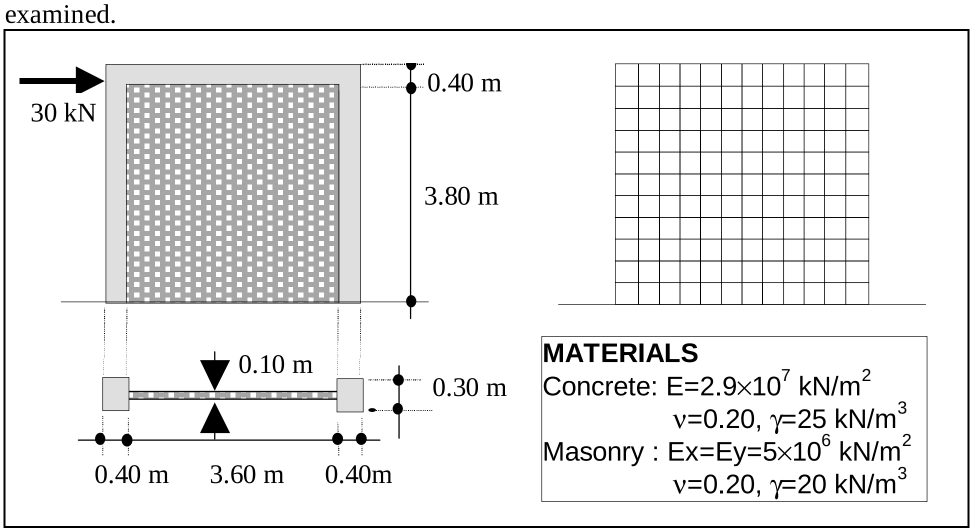


Figure 1. Geometry, mesh and materials characteristics of an one storey one bay frame

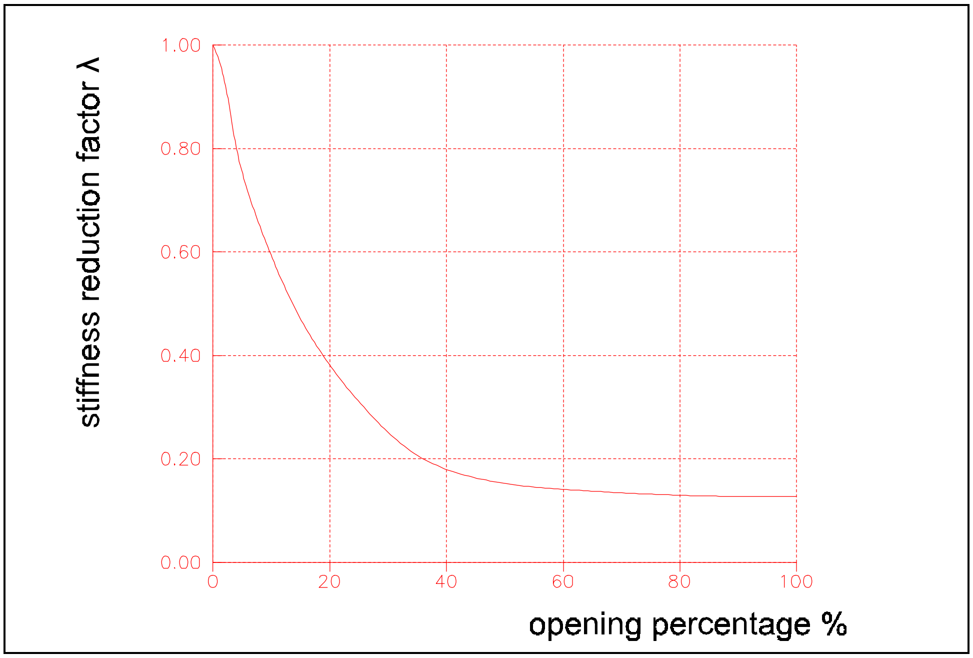


Figure 2. Stiffness reduction factor λ of the infilled frame in relation to the opening percentage

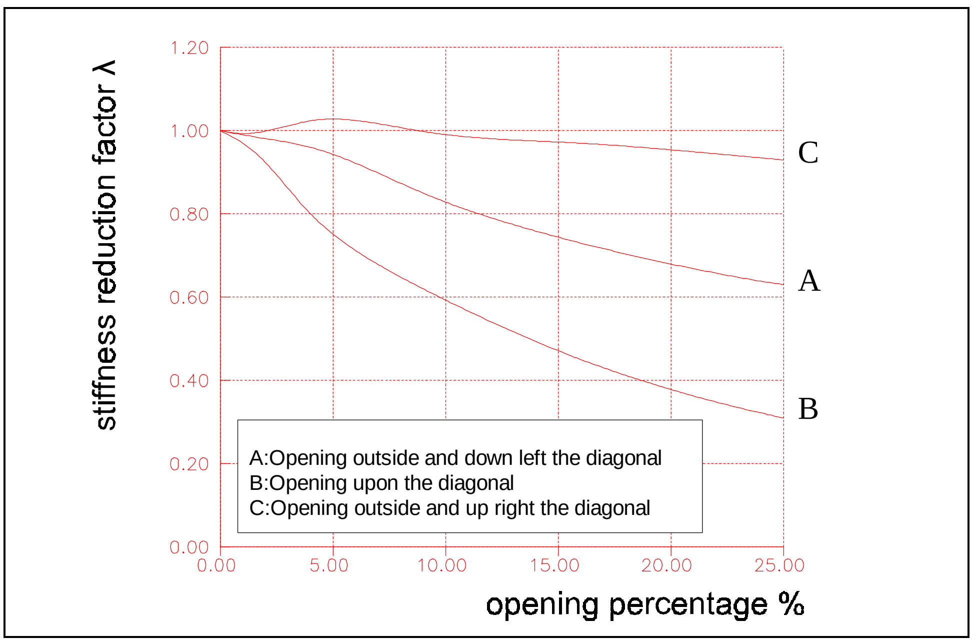


Figure 3. Stiffness reduction factor λ of the infilled frame in relation to the opening percentage

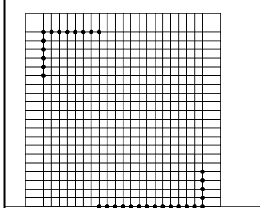
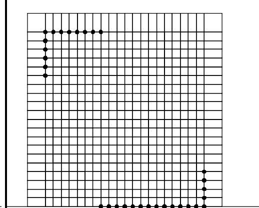
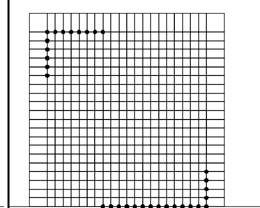
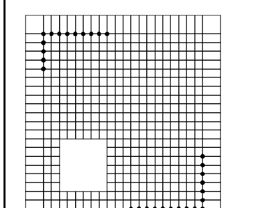
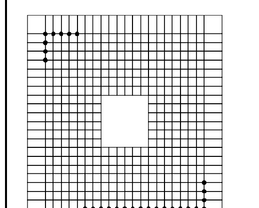
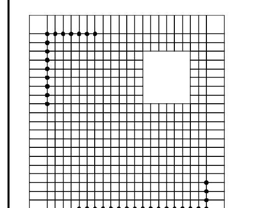
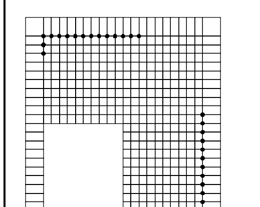
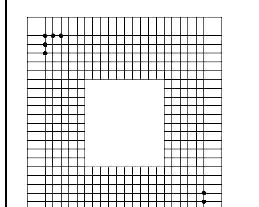
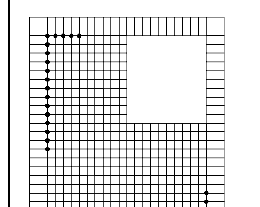
opening percentage %	opening position		
	A outside and down left of the diagonal	B upon the diagonal	C outside and up right of the diagonal
0.00			
9.00			
25.00			

Figure 4. Contact/interaction areas between the infill masonry wall and the surrounding frame for different opening percentages.

Figure 2 shows the case of an opening in the center of the infill wall (with dimensions ratio equal to the infill wall dimensions ratio) and the variation of λ factor (stiffness with wall opening to stiffness without a wall opening) as a function of the the opening percentage (opening area/infill wall area). As it is expected, the increase in the opening percentage leads to a decrease in the frame's stiffness. This decrease is 87% for a bare frame (100% opening). For openings exceeding 50%, the stiffness factor λ remains practically constant.

Figure 3 shows the opening influence for three different positions (upon the diagonal-case B, outside and down left of the diagonal-case A, and outside and up right of the diagonal-case C). Namely, the variation of the stiffness reduction factor λ of the infilled frame as a function of the opening percentage is depicted. The higher value of stiffness reduction of the frame arises when the opening is upon the diagonal. This is explained, as the action of the compressed diagonal of the infill wall is abolished in this case. In Figure 4 dots are depicting the contact/interaction areas between the infill masonry wall and the surrounding frame for different opening percentages, for the same three opening positions A, B, C. The changes to the contact lengths between infill wall and surrounding frame is remarkable from case to case.

INFLUENCE OF THE INFILL WALL ORTHOTROPY

The available research findings of the infill wall opening influence to the infilled frame stiffness reduction is based on the assumption for an isotropic behaviour of infill wall material (Utku, 1980), (Wong and Saiidi, 1982), (Gianakas, patronis and Fardis, 1987). In this section the results of the comparison between the isotropic and orthotropic behaviour of infill wall are presented. In particular, the results of an isotropic analysis with $E_y/E_x = 1$, and of an orthotropic analysis with a limit ratio value of $E_y/E_x = 2{,}00$ are shown ($E_y = 5 \times 10^6$ kN/m^2 for both cases).

Figure 5 shows the variation of the stiffness reduction factor λ of the infilled frame as a function of the opening size, for the case where the opening is at the center of the infill. It is observed that the orthotropic influence is small, for the usual values of the moduli of elasticity ratio (E_y/E_x) of the infill masonry wall between 1.00 and 2.00.

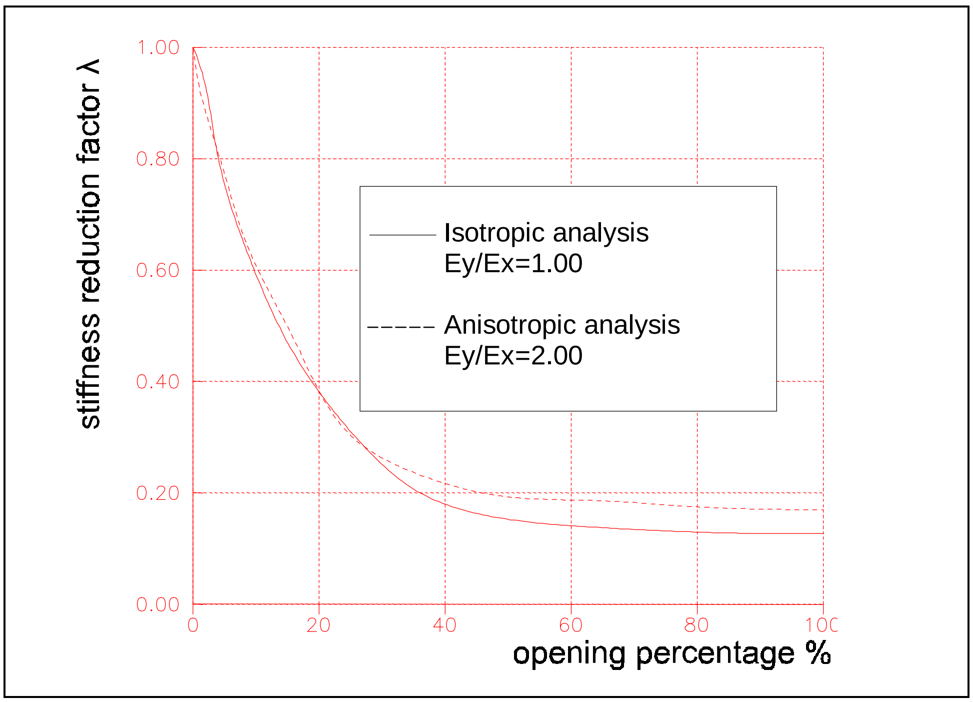


Figure 5. Stiffness reduction factor λ of the infilled frame in relation to the opening percentage for isotropic and anisotropic analysis

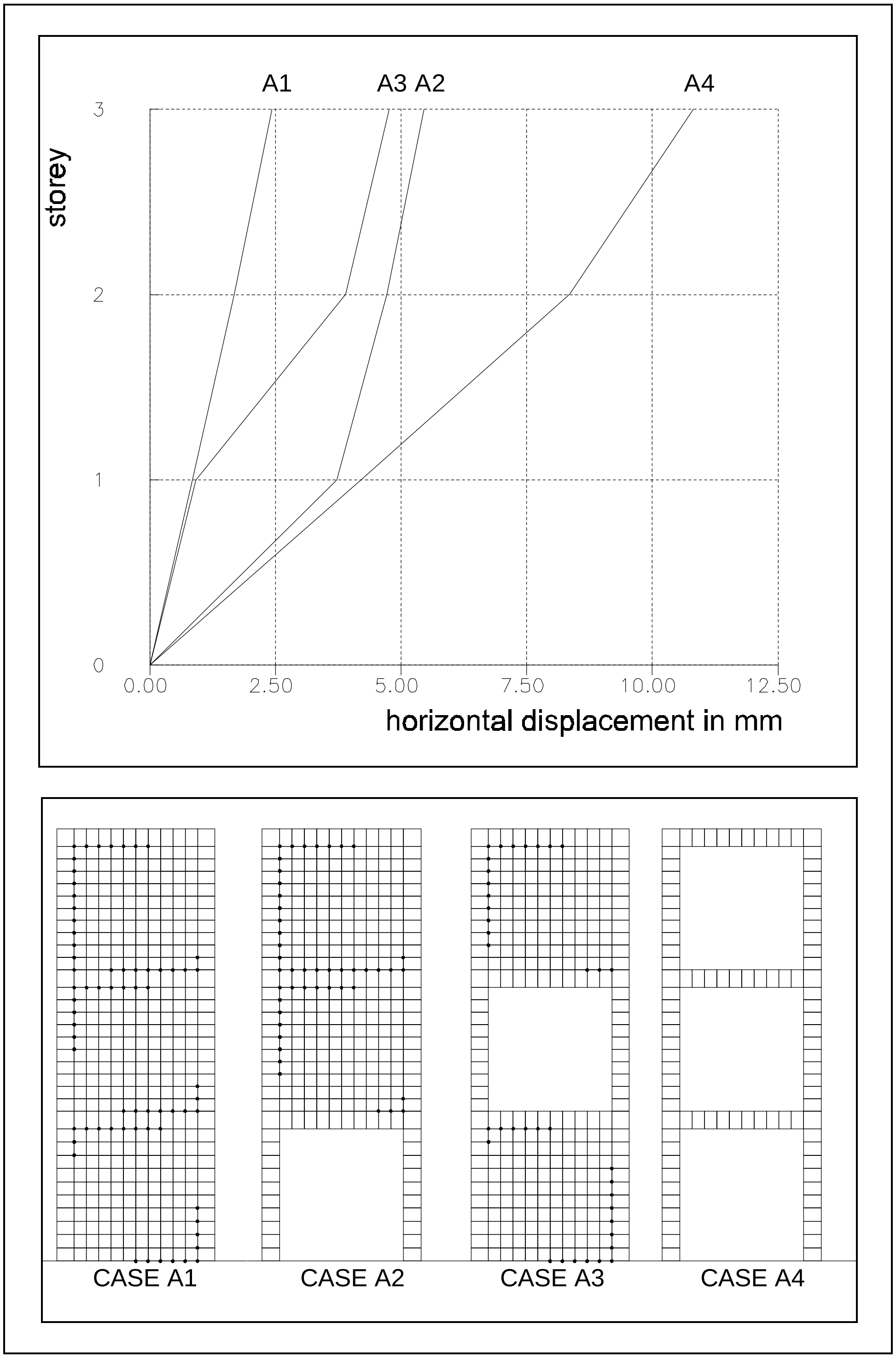


Figure 6. Storey displacements for different arrangements of the infill wall

SOFT STOREY

Several times, soft stories appear, due to a stiffness decrease in a floor, compared to the adjacent ones. This fact results a concentration of high stresses to the carrying elements of the soft storey, leading in most cases to extensive damages. The most usual case of a soft storey in a building is the ground soft story (pilotis), where, oppositely to the higher floors, infill walls do not exist. In such case the rigidity of the ground floor appears drastically decreased due to the decrease of infill walls. In these buildings severe damage during an earthquake appears in the vertical carrying elements of the ground floor, whereas most of the other building elements remain usually undamaged. For example, after the 1978 Thessaloniki Greece earthquake, only 16,4% of the buildings with infill walls in the ground floor showed damages (in the frame or the shear walls), while the same happened to a 29,8% of the buildings with a non rigid ground floor (Penelis et al., 1988).

In this section, the seismic behavior of multi storey infilled frames, compared to partially infilled frames (free ground floor, free interim floor etc.) is investigated. The method of contact points was applied for the case of a three storey one bay frame, loaded with the vertical and horizontal seismic loads simultaneously, with a value for the seismic coefficient ε=0.30. The frame is constructed with reinforced concrete 30/50 cm sections for both columns and beams, whereas the infill wall is rectangular with a 4 meters side in all three storey. The mechanical characteristics for both the reinforced concrete and the infill masonry walls are the ones shown on Figure 1.

Figure 6 shows the storey displacements of a three storey one bay frame for four different cases of the infill wall arrangement. It is observed that the infill wall (cases A1, A2, A3) has a considerable contribution to the stiffness and lateral resistance of frame. Particularly the case of infilled frame with infill walls in all three stories (case A1), contributes up to 77% decrease of the lateral displacements. In the same figure, contact areas between surrounding frame and infill walls for four different cases of the infill wall arrangement are depicted with dot lines.

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