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Paper No. 953. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

A METHOD FOR THE MODELLING OF INFILLED FRAMES (METHOD OF CONTACT POINTS)

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ABSTRACT

The paper presents a method (Method of Contact Points) for the analysis of masonry infilled frames subjected to earthquake static loads (in-plane lateral loads). The main goal of the method is the modelling of infilled frames and the investigation of their behaviour. Especially, the influence of masonry infill wall to the aseismic behaviour of plane frames has been studied.

KEYWORDS

Anisotropy, equivalent diagonal strut, infilled frame, masonry, method of contact points, Finite Element, surrounding frame.

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 and analytical investigation have been recently made. Typical of these analyses were those of Smith (Smith, 1966, Smith *et al.*, 1969), Page (Page *et al.*, 1985), Syrmakezis (Syrmakezis *et al.*, 1986), as well as an extensive and in-depth State-of-the Art Report can be found in the research work of Tassios (Tassios, 1984). From the last work have been shown that there is a strong interaction between the R. C. frame and the infill masonry wall:

- 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.
- When they are properly designed, infilled frames may considerably reduce the probability of collapse, even in cases of defective frames.

Inspite of its broad application and its economical significance (given that 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)), this structural system has resisted analytical modelling; 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.

In the last two decades many experimental and theoretical investigations have been performed on the behaviour of frames with brick masonry infill. In almost all these studies, the infill was assumed to be elastic and isotropic. The influence of the directional properties of masonry as well as its non-linear deformation characteristics have therefore not been considered.

This paper describes a new method for the modelling of infilled frames taking into account the anisotropy of masonry as well as the non-linear deformation characteristics depended on the separation of frame and panel.

METHOD

In order to formulate the Method of Contact Points three requirements have to be met:

- A Finite Element (FE) Model
- A failure surface for masonry and
- A criterion for the separation of masonry panel from the surrounding frame

The FE Model

For this analysis a rectangular FE model with 8 degrees of freedom (DOF) has been used. The major assumption for the modelling of masonry behaviour under plane stress is that the material is homogeneous and anisotropic (orthotropic). Especially the material shows a different modulus of elasticity in the x direction (Ex) and a different in the y direction (Ey).

Failure surface

The mode of failure of solid brick masonry under biaxial stress depends on both the state of stress and the orientation of the stress to the jointing planes. If one or both of the principal stresses at a particular location is tensile, failure occurs in a plane (or planes) normal to the surface of the wall with the joints playing a significant role. If both principal stresses are compressive, the influence of joints is less significant and failure usually occurs by spalling or splitting of the panel in a plane parallel to the surface of the wall (Dhanasekar *et al.*, 1985). In general, therefore, failure must be expressed in terms of the principal stresses at a point and their orientation to the bed joints. An alternative formulation is to define the failure surface in terms of stresses normal and parallel to the bed jointing planes.

A failure surface in this form has been derived from the biaxial tests of Dhanasekar (Dhanasekar *et al.*, 1985). According to these tests results an analytical failure surface under plane stress is proposed. The equation of this failure surface were derived and plotted in Fig. 1. The equation of the failure criterion is:

$$2.27\sigma_x + 9.87\sigma_y + 0.573\sigma_x^2 + 1.32\sigma_y^2 + 6.25\tau^2 - 0.4444\sigma_x\sigma_y + 0.00116\sigma_x^2\sigma_y + 0.4902(\sigma_x\tau^2 - \sigma_y\tau^2) = 1 \qquad (1)$$

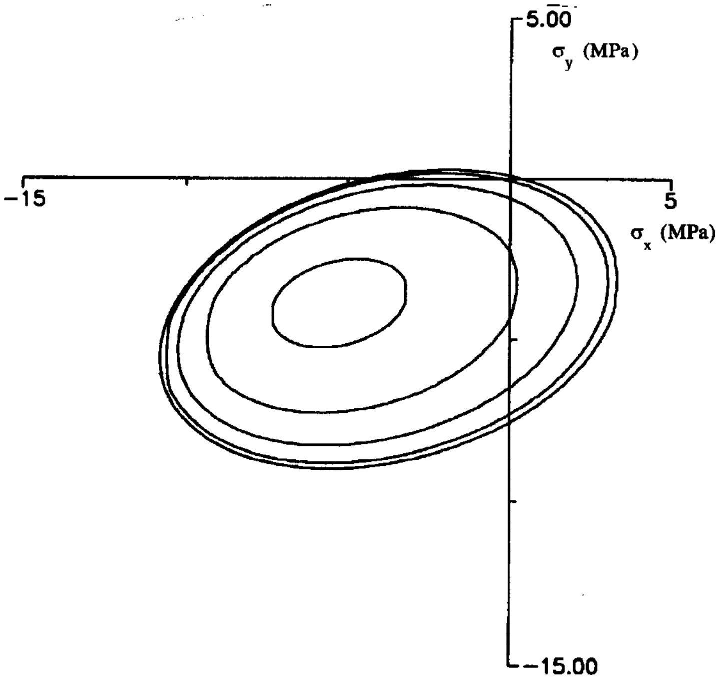


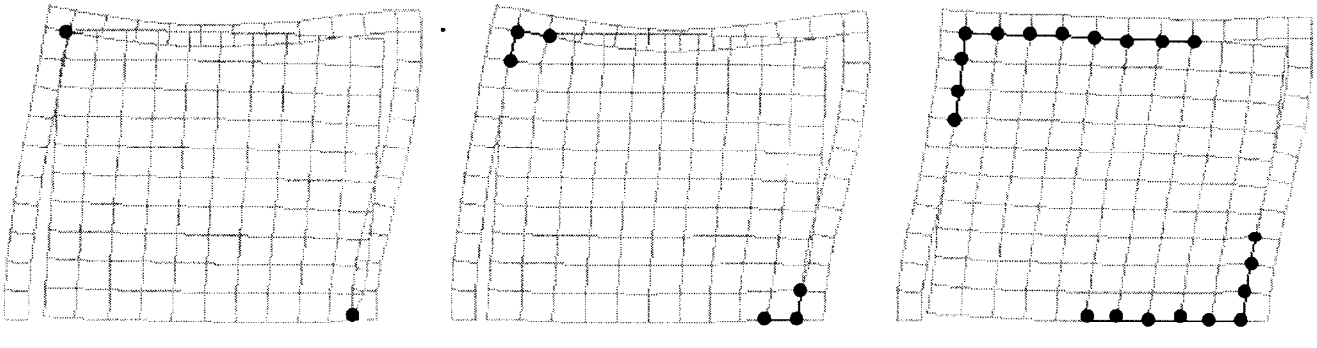
Fig. 1. Failure surface for masonry in σ_x, σ_y, τ space

For an isotropic material a failure criterion proposed by Syrmakezis (Syrmakezis *et al.*, 1995), has been used. For the plane (σ_x, σ_y, τ=0), the proposed failure criterion is based on the combination of a specific masonry plane failure line for the cases biaxial tension, biaxial tension-compression, biaxial compression-tension and Von Mises failure ellipse for the case of biaxial compression.

Criterion for the separation

The analysis has been performed on a step-by-step basis. Initially the infill FE model is considered to be linked to the surrounding frame FE model at two corner points (only), at the ends of the compressed diagonal of the infill. (When the load is applied, the infill and the frame separate over a large part of the length of each side and contact remains only adjacent to the corners at the ends of the compression diagonal).

The structure is then analyzed and the deformed mesh is presented on the Fig. 2a. From this figure we can see that the infill model points, overlapping the surrounding frame FE model, are linked to the neighbouring points of the surrounding frame FE model (Fig. 2b) and the process is repeated, until a final equilibrium condition is reached (Fig. 2c).



(a) (step 1)

(b) (step 2)

(c) (final step 8)

Fig.2. Iteration steps of Method of Contact Points for an one-storey two-columns masonry infilled frame

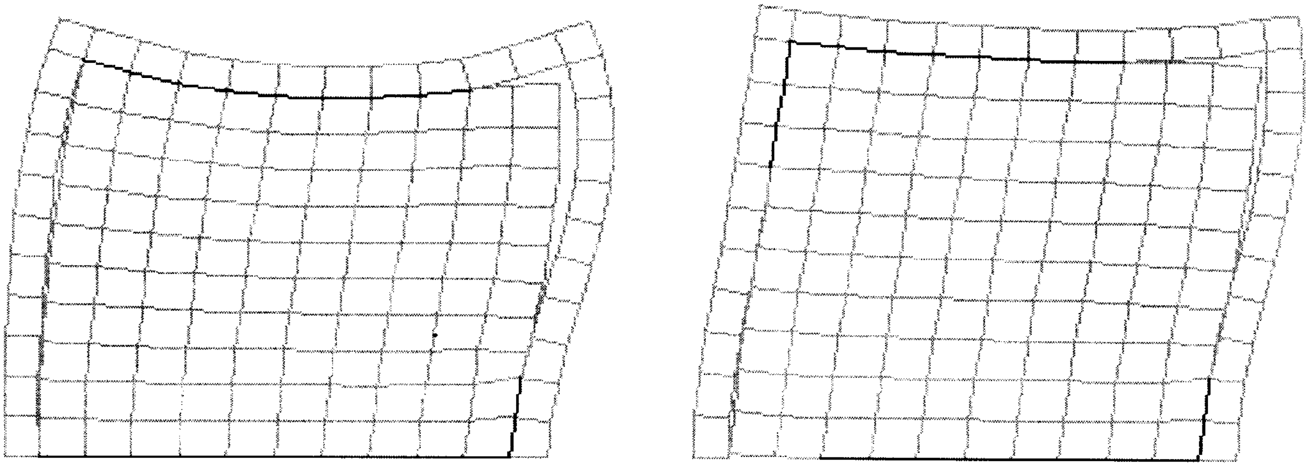
RESULTS

In order to clarify the method, a FORTRAN program has been utilized. Using this program several cases of wall infilled frames have been solved. The influence of the following parameters has been studied:

- The influence of loading
- The Influence of masonry elastic properties
- The Influence of geometry of infill panel
- The Influence of the site of infill panel to the multi story-multi columns infilled frame

The influence of loading

In order to study the influence of loading an one floor two columns infilled frame with surrounding frame from concrete C20, section 0.30 m x 0.30 m and a square masonry infill panel dimensions of 4.00 m long x 4.00 m high x 0.10 thickness and modluli of elasticity Ex = 4362.5 Mpa, Ey = 7555 Mpa has been studied for different values of seismic coefficient ε. The deformed mesh for values of seismic coefficient, 0.10 and 0.40 are shown in Fig.3.



ε=0.10 ε=0.40

Fig.3. Deformed mesh of an one-storey two-columns masonry infilled frame for values of seismic coefficient 0.10 and 0.40

It has been shown by experiment that the diagonal stiffness and strength of an infilling panel depend not only on its dimensions and physical properties but also on its length of contact with surrounding frame (Smith, et al., 1969), (Page et al., 1985). As the lateral loads are increased (ε is increased) the length of contact between surrounding frame (left column) and infill panel is increased but the contact between of infill panel and the basis is reduced. This is expected as the torning moment of infill panel increased. We should mention that in small values of ε ($\varepsilon \sim 0.00-0.15$) there is no contact between the infill and the left column of the frame (see Fig. 3).

Equivalent diagonal strut

When a lateral load (with or without vertical loading) is applied to an infilled frame, the frame usually separates from the infill at low load level at the unloaded corners, and the load is transferred by diagonal strut action within the masonry (see Fig. 4) with contact finally being restricted to regions adjacent to the loaded corners.

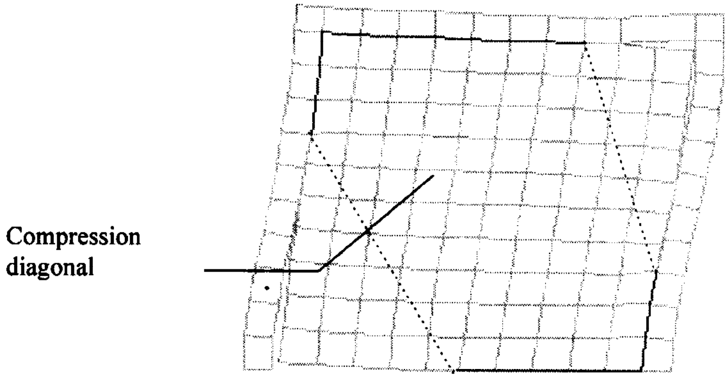


Fig.4. Load-deflection curves of an one-storey two-columns infilled frames

To study the influence of the compressed diagonal is proposed to define its width w as:

$$w = \frac{E}{d} \tag{2}$$

where: E is the area between dotted lines (see Fig.4) and d is the length of diagonal of infill panel

Trying to study the influence of the compressed diagonal in multi storey infilled frames a non-dimensional parameter α is introduced:

α=(width of compressed diagonal panel of multi storey infilled frame)/(width of compressed diagonal of an one storey two columns infilled frame).

Using the proposed method the following multi storey infilled frames have been studied:

- one-storey infilled frames with two to five columns
- two-columns infilled frames with one to four storey and a two-storey three-columns infilled frames

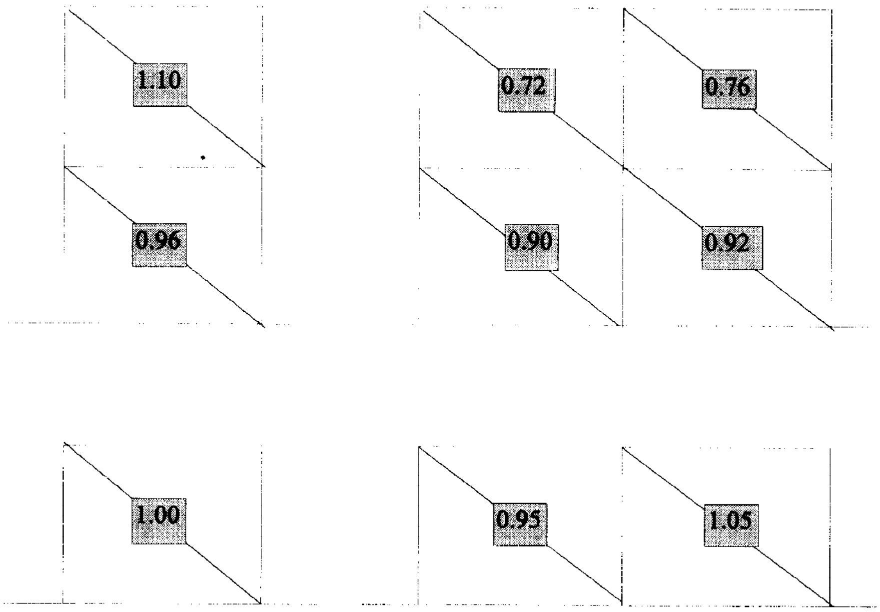


Fig.5. non-dimensional parameter α of compressed diagonal for different infilled frames

The results presented in Fig. 5 indicate that the compressive diagonal area (strut) of infill panel depended on the site of panel to the infilled frames. Especially for a two storey three columns frame the infill in the second floor contribute less than the infill in the first floor to the lateral stiffness of the frame.

Influence of masonry elastic properties

Based on the agreement between the predicted and the observed performance, the proposed method was used to carry out a more extensive study on the relative importance of the parameters used. This study also helps to establish the masonry properties which have a significant influence on the behaviour of practical infilled frames. The deformation characteristics consist of both elastic properties and infill panel geometry. The influence of the different geometry of panels on the behaviour of the infilled frames has been investigated for the following three different infill panels:

- Frame #1: infill panel of dimensions 4.00 m long x 5.00 m high x 0.10 m thickness
- Frame #2: infill panel of dimensions 4.00 m long x 4.00 m high x 0.10 m thickness
- Frame #3: infill panel of dimensions 5.00 m long x 4.00 m high x 0.10 m thickness

The elastic properties of the masonry would be expected to have a significant influence on the behaviour of infilled frames, as they directly affect the relative stiffness of the infill and its surrounding frame. In addition to the load-deflection characteristics, the ultimate load and failure mode of the infill could also be affected. A summary of the results of the analysis is contained in Table 1.

Table 1 Influence of the elastic properties of brick masonry on the strength of the infill

Elastic Properties		Frame					
Ex (MPa)	Ey (Mpa)	Frame #1		Frame #2		Frame #3	
		Ultimate load, kN	Ratio*	Ultimate load, kN	Ratio*	Ultimate load, kN	Ratio*
4362.5**	7555.0**	140	1	150	1	230	1
7555.0	7555.0	85	0.61	85	0.57	100	0.43

* Ratio = ultimate load/ultimate load for original material model

** Original material model

In all cases, failure occurred by corner crushing. Especially, failure starts on the bottom right corner of the infill panel which is under heterosemous principal stresses (in a stress state of biaxial tension-compression).

The load-deflection curves obtained from the analysis of an one-storey, two-columns infilled frame with varying moduli of elasticity as well as for different geometry of infill panel are given in Fig. 6 and 7. The curves are given only up to the ultimate load of the masonry infill.

In Fig. 6 three curves are shown, a curve for the bare frame, a curve for the frame using the Method of Contact Points and a curve assuming not separation of frame and infill panel. According to these curves, the mode of modelling of infilled frame was found to be significant. Analysis not taking into account the separation of frame and panel over-estimates the influence of masonry stiffness. On the other hand, analysis not taking into account the masonry infill (bare frame) under-estimates the influence of masonry stiffness. It can be also seen in Fig. 6 the non-linear behaviour of infilled frame depending on the separation of surrounding frame an infill panel.

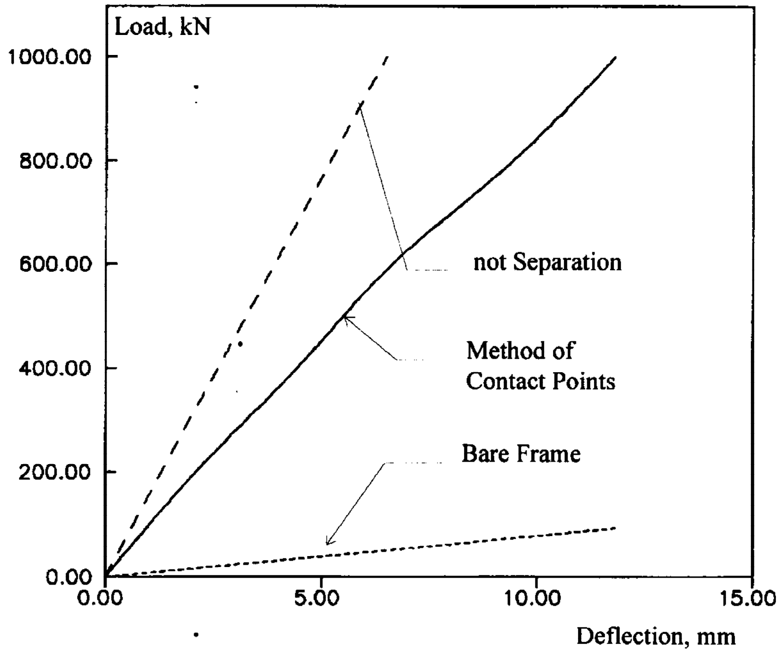


Fig.6. Load-deflection curves for an one-story two columns infilled frame (Deflections at the Load point)

In Fig. 7a three curves are shown, a curve for Frame #1, a curve for Frame #2 and a curve for Frame #3. It can be seen that the Frame #3 (infill panel dimensions 5.00 m long x 4.00 m high) has the best effect influence than the others on the ultimate strength of the infill.

Another problem of the analysis of infilled frame is not taking into account the anisotropy of masonry (masonry is a multi-phase and insubordinate material according to Prof. Tassios). The load-deflection curves obtained from the analysis of an one-storey, two-columns infilled frame for two different case of elastic properties are given in Fig. 7b. The curves are drawn only up to the ultimate load of masonry infill.

As can be seen, the influence of infill stiffness on lateral strength of infilled frame is significant. For example, for square infill panel (Frame #2) isotropic masonry reduces the ultimate load by 43%.

CONCLUSIONS

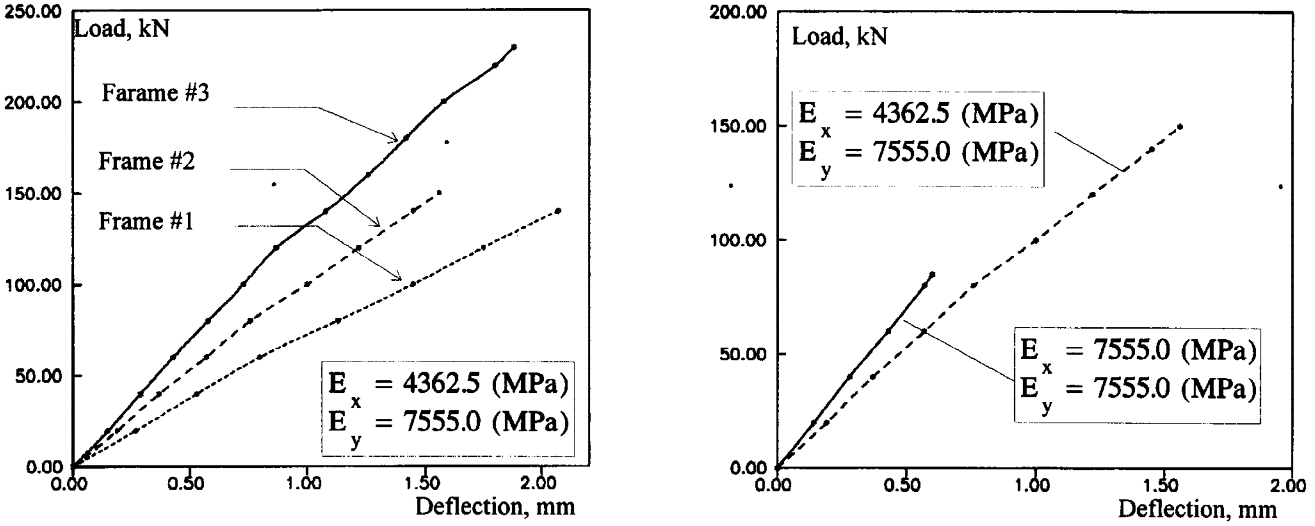
A detailed parametric study of the influence of brick masonry properties, as well as the geometry of infill panel on the behaviour of infilled frames subjected to earthquake static loads (in-plane lateral loads) using the proposed Method of Contact Points has revealed the following:

(a) The Method of Contact Points is able to reproduce the non-linear behaviour of infilled frames caused by the separation of frame and panel and seems to be in a good agreement with previous experimental works.

(b) The moduli of elasticity of the masonry infill significantly influences the load-deflection characteristics of the infilled frames and to lesser extent, can influence its ultimate strength.

(c) The geometry of infill panel affects the load-deflection characteristics of the infiled frames.

(d) The compressive diagonal area (strut) of infill panel depended on the site of panel to the infilled frames.



(a)

(b) (Frame #2)

Fig.7. Load-deflection curves for an one-story two columns infilled frame (Deflections at the Load point)

ACKNOWLEDGEMENTS

Computations were carried out on the Silicon Graphics computer of computational center of National Technical University of Athens.

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