Numerical Model to Account for the Influence of Infill Masonry on the RC Structures Behaviour

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Abstract. It is a common misconception considers that masonry infill walls in structural RC buildings can only increase the overall lateral load capacity, and, therefore, must always be considered beneficial to seismic performance. Recent earthquakes have showed numerous examples of severe damages or collapses of buildings caused by structural response modification induced by the non-structural masonry partitions.

From a state-of-the-art review of the available numerical models for the representation of the infill masonry behaviour in structural response, it was proposed an upgraded model. The proposed model is inspired on the equivalent bi-diagonal compression strut model, and considers the non-linear behaviour of the infill masonry subjected to cyclic loads. The model was implemented and calibrated in a non-linear dynamic computer code, *VISUALANL*.

In this paper, it is presented the proposed model and the results of the calibration analyses are briefly introduced and discussed.

Introduction

The principal objective of this work is define a numeric model, built-in a computer program, *VISUALANL* [1, 2], which accounts for the influence of infill masonry walls in the RC building's response to cyclic loading, as the produced by earthquakes.

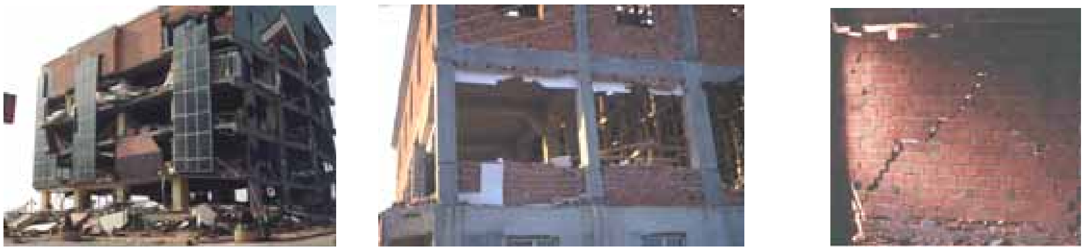
The presence infill masonry walls in RC buildings is very common. For this reason, a lot of studies have been developed in this field in the last years. However, even nowadays, in design and/or assessment of existing buildings, infills are usually considered as non-structural elements, and their influence is neglected.

The global structural response of buildings to vertical loads does not change significantly with the consideration of infill panels. But, this is not totally true for horizontal loading, as the produced by earthquakes. For horizontal loading, infill panels can drastically modify the response, attracting forces to parts of the structure that have not been designed to resist them [3].

Influence of infill masonry on the structural seismic behaviour

Ii is incorrect assume that masonry infill panels are always beneficial to the structural response. The contributions of the infills for the building seismic response can be positive or negative, depending on a series of parameters, as relative stiffness and strength between the frames and the masonry [4].

Numerous examples of building's damages and collapses can be attributed to structural modifications of the basic structural system induced by the non-structural masonry partitions. Even if they are relatively weak, masonry infill can drastically modify the structural response (Fig. 1).



a) b)

Figure 1 – Damage on masonry infill walls (Varum, 2003): a) RC frame building with almost fully damaged masonry infills; b) diagonal tension failure of a masonry wall

Masonry infill panels can increase substantially the global stiffness of the structure. Consequently, the natural period of the structure will decrease. Depending on the situations in which masonry walls extend, for example only to part of the storey-height (short-columns) leaving a relatively short portion of the columns exposed, may also induce vulnerable behaviour. Frequently, a column is shortened by elements which have not been taken into account in the global design (stairs, etc.) [5].

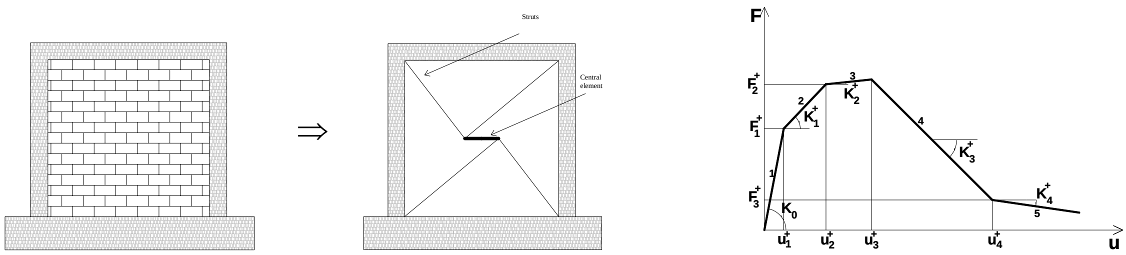
Modelling infilled frames

The infill masonry models can be classified as micro and macro models. In the micro-models, infill panels are modelled with detailing at components level: mortar, brick, and interface mortar/brick elements. With the micro-models, a more accurate representation of the infill panels' behaviour can be obtained. However, an enormous calculation effort and a large amount of parameters have to be calibrated. They can be useful for local analysis, but impractical for the analysis of a full building.

The macro-models are more simplified and allow the representation of the infill panel' global behaviour, and its influence in the building structural response. From the macro-models, the most commonly used is the bi-diagonal equivalent-strut model. Many examples of other macro-models can be found: i) homogenized frames sections, [6]; ii) theory of plasticity [7]; iii) behaviour coefficients [8], among many others.

The proposed macro-model is an improvement of the commonly used equivalent bidiagonal-strut model. The proposed improved model considers the interaction between the behaviour of masonry panels in the two directions. To represent a masonry panel are considered: four support strut-elements with rigid-linear behaviour; and, a central element where the non-linear hysteretic behaviour is concentrated (Fig. 2-a).

The non-linear behaviour is characterized by a multi-linear envelop curve, defined by nine parameters (representing: cracking, peak strength, stiffness decreasing after peak strength and residual strength) in each direction, what makes possible the non-symmetrical behaviour representation. The hysteretic rules calibrated for masonry models are represented by three additional parameters, namely: α - stiffness degradation; β - "pinching" effect; and, γ - strength degradation.



a) b)

Figure 2 – a) Implemented strut model b) Force-displacement envelope curve of the implemented model

Hysteretic behaviour of infill masonry

The non-linear behaviour of the central element is characterized by universal rules based on the Takeda's model [9, 10], reflecting the response to the load history and depending on the material behaviour (defined by the envelope curve and hysteretic parameters). The hysteretic rules are shortly exemplified in Fig. 3.

Loading rules. The loading stiffness depends on the maximum force and displacement value reached in the previous cycle (F_{max} and D_{max}). The loading begin at the point corresponding to null force (D_r) and its stiffness is defined by the Eq. 1:

$$K_r = \frac{F_{\max}}{D_{\max} - D_r} \tag{1}$$

Unloading rules. The unloading happens when a load inversion occurs. The unloading stiffness depends on the maximum displacement reached.

Before the yielding-point has been reached, the unloading stiffness (K_d) will be equal to the initial stiffness (K_0). If the maximum displacement reached is larger than the yielding displacement, but smaller than D_{cr} (cracking displacement), then the unloading stiffness (K_d) will depend on the parameter α, and the maximum displacement reached in that cycle, defined by:

$$K_d = \frac{F_{cr} - \alpha \cdot F_y}{K_0 \cdot D_{cr} + \alpha \cdot F_y} \cdot K_0 \tag{2}$$

If the maximum displacement reached is larger than D_{cr}, the unloading stiffness (K_d) will be always constant, depending only on the parameter α. The unloading stiffness is given by Eq. 3:

$$K_d = \frac{F_{cr} - \alpha \cdot F_y}{D_{cr} \cdot K_0 - \dfrac{\alpha \cdot F_y}{K_o}} \cdot K_0 \tag{3}$$

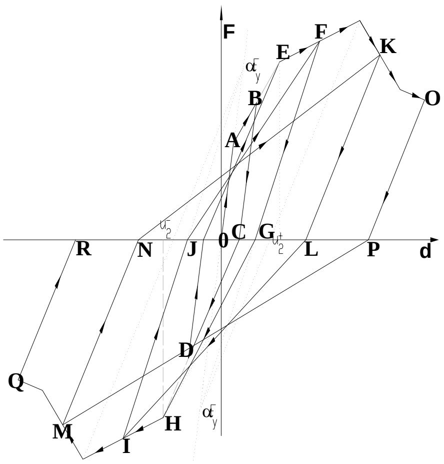


Figure 3 – Hysteretic rules for the implemented model

"Pinching" effect. Simulates the masonry cracks closing in the unloading-reloading branch. This effect is contemplated reducing the stiffness where the shear force is predominant relatively to bending-moment. The pinching effect is represented dividing the reloading branch in two sub-branches with different stiffness (Fig. 4). The pinching effect is controlled through the parameter β, that change the reloading stiffness, depending on the maximum displacement reached previously (see Eq. 4).

$$K = \frac{F_{\max}}{D_{\max} - D_r} \cdot \left(\frac{D_y}{D_{\max}} \right)^{\beta} \tag{4}$$

where: D_r is the displacement corresponding to null force of the previous cycle; D_y the yielding displacement.

Stiffness degradation. The stiffness degradation is controlled by the parameter α (Eq. 2).

Strength degradation. This effect represents the strength degradation for repeated displacement amplitude cycles. An improvement of the available strength degradation formulation has been made, to consider the influence of the degradation level in one direction in the other direction. The strength degradation is given by the following equations (see also Fig. 5):

$$\gamma = c \cdot \sum_{i=1}^{N} \frac{D_i}{D_f} \tag{5}$$

$$D_f = D_y \cdot \mu \tag{6}$$

$$PD_1 = \frac{e^{n\gamma} - 1}{e^n - 1} \cdot \left(1 - \frac{PD_2}{\zeta}\right) \tag{7}$$

where: PD_i is the degradation factor in direction i; D_i the displacement in the cycle i; D_y the yielding displacement; μ, c, n and ξ are constants that have to be calibrated with experimental results.

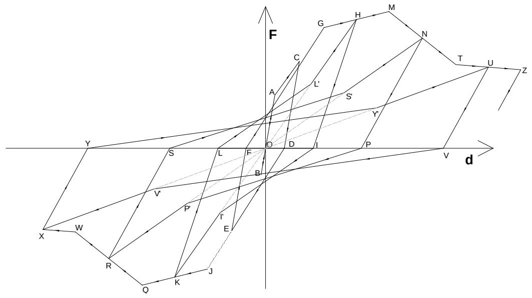


Figure 4 – "Pinching" effect

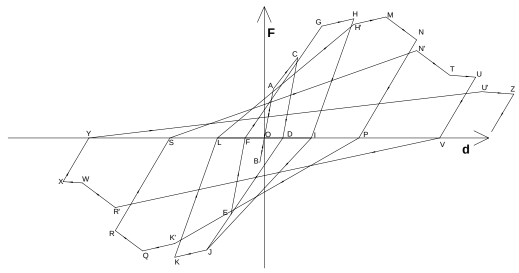


Figure 5 – Strength degradation

Internal cycles. When a load inversion happens before the maximum force or displacement reached, the model is able to reproduce the so-called internal cycles, with all the effects described before.

Efficiency of implemented model

The proposed macro-model for infill masonry was calibrated with the results of a cyclic test performed by Pires [11]. The infilled reinforced concrete model is a single-storey single-bay, scaled 2:3. Vertical forces were applied on the top of the columns, to simulate the dead load, and imposed cyclic horizontal displacements were applied (see Fig. 6).

The model properties (RC frames and masonry infill) were calibrated with test results on materials specimens. The concrete elements (beam and columns) are simulated with a global model, defined from a fibre model at section level, developed by Varum [3].

The results obtained with the numerical model are in good agreement with the experimental response (Fig. 7).

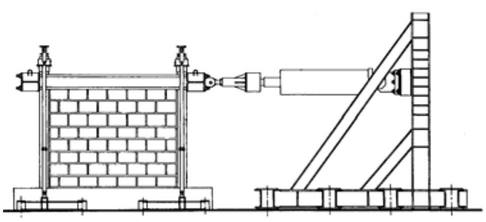


Figure 6 – Testing layout of a single-storey single-bay infilled masonry RC frame [11]

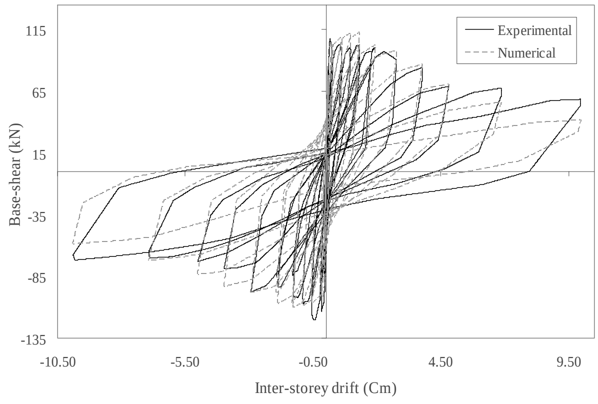


Figure 7 – Base-shear versus inter-storey drift (experimental and numerical results)

Conclusions

Masonry is a composite material. Its response to horizontal loads is highly complex and depends on many factors: material's properties and workmanship quality. The development of simplified non-linear numerical models and the increasing of computing capabilities permit considering the influence of infill masonry in structural assessment and design.

The influence of masonry infill panels in the structures behaviour subjected to horizontal loading, as earthquakes, can be predicted and simulated with simple macro models, as the one presented.

A more exhaustive testing campaign would help to fully understand the behaviour of infilled RC buildings, and to calibrate the proposed model.

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