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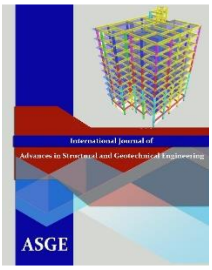



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# *SIMPLIFIED MODELLING OF MASONRY-INFILLED STEEL FRAMES UNDER CYCLIC LOADING*


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# SIMPLIFIED MODELLING OF MASONRY-INFILLED STEEL FRAMES UNDER CYCLIC LOADING

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## ABSTRACT

There are few finite element studies in the literature on the behaviour of masonry-infilled steel frames under cyclic loading, and most of them established complicated three-dimensional models. In this paper, a simplified finite element two-dimensional shell model of masonry-infilled steel frames under cyclic loading was developed. Element types and material constitutive model of cyclic plasticity were described. To simulate the actual behaviour of these frames, the interactions between the frame and the infill panel were accurately modelled. The proposed model was compared with previously proposed by another researcher three-dimensional solid model, then the two models were verified by typical quasi-static test results for infilled steel frames. The suggested model proved its capability for predicting the actual behaviour and failure modes of steel frames with masonry infills. In terms of CPU time, the two-dimensional shell model is greatly more effective than the three-dimensional solid one.

**Keywords:** Steel frames, Infilled frames, Masonry, Finite element analysis, Cyclic loading, Simplified model.

## INTRODUCTION

The beneficial aspects of masonry in contributing to a load sharing structural system in concrete and steel frame structures have become increasingly apparent since 1950s. Generally, much research has been done in the area of clay and concrete masonry units with regard to their structural and mechanical properties, as well as their overall behaviour in engineered masonry structures [1]. Presently, numerous experimental works [2-7] were performed on the cyclic behaviour of infilled steel frames under cyclic loading.

All of the mentioned experimental studies have conducted considerable works on the infilled steel frames' performance, however, because of difficulties and high cost of carrying out tests (especially in cases of wide parametric studies), the finite element (FE) modelling is openly used at present. Consequently, there is a pressing need for more accurate numerical modelling to undertake parametric analysis.

There were some reports for the numerical and analytical simulation of infilled steel frames. For example, Dawe et al. [8] developed a computer model for the structural analysis of masonry infilled steel frames. Moghadam et al. [9] presented a new analytical approach for the evaluation of shear strength and cracking patterns of infill panels. Doudoumis [10] analytically studied the behaviour of single-storey one-bay infilled frames under monotonic lateral loading. Puglisi et al. [11-12] proposes a model of the behavior of the masonry in infilled frames. Radnic et al. [13] presented a numerical model for both static and dynamic analysis of planar masonry-infilled steel frames, which are loaded only in their plane. Radić et al. [14] developed an analytical modelling of infilled steel frame structures. Chen and Liu [15] perfromed a finite element study to investigate the effect of vertical loading on the in-plane lateral behavior and strength of concrete masonry infills bounded by steel frames. Yekrangnia and Mohammadi [16] proposed a strut model for masonry infill walls in moment-resisting steel frames.

Most of these aforesaid numerical investigations developed three-dimensional models. In terms of time and calculation cost, performing a wide parametric study of infilled frames under cyclic loadings, using 3D model, is not economic. Therefore, proposing a simplified FE model taking into account proper contact relations and nonlinear behaviours, to accurately simulate the steel frames with masonry walls and predict their hysteretic behaviour, is needful.

The study in this paper aims to establish a 2D shell simplified models capable to simulate the actual cyclic behaviour of infilled steel frame. The details of the suggested models (Element types, material cyclic constitutive models and interactions between infills and frames) were described. The results of the suggested numerical models were compared with experimental data in order to validate their accuracy.

## NUMERICAL ANALYSIS

The FE simulation software ABAQUS [17] was used to develop a 2D shell model, able to represent the cyclic behaviour of infilled steel frames. The model was developed depending on the finite element modelling, performed as a part of the MSc thesis of the last author [18] under the supervision of the three first authors. All parts of the model are described as follows.

### Element Types, Meshes and Contact Modelling:

A four-node element (CPS4) was adopted for the infill panel and steel members. A homogenised macro-model (in which the blocks, mortar and the block-mortar interface were modelled as one element) was used to simulate the behaviour of the infill wall. In the 2D shell model, the defined thickness of a section is the out-of-plane dimension, whether this dimension is thickness or width.

The surface-to-surface contact (comprising two parts: normal interaction and tangent interaction) was used to simulate the contact between the infill panel and the steel frame. “Hard contact” was used for the normal interaction, whilst “frictionless formulation” was utilised for the tangent interaction. This frictionless formulation is suitable for the infilled frames simulated in the current study which have no special connection between the frame and masonry infill. A 2D shell FE model of a steel frame with an infill panel is shown in Fig. 1.

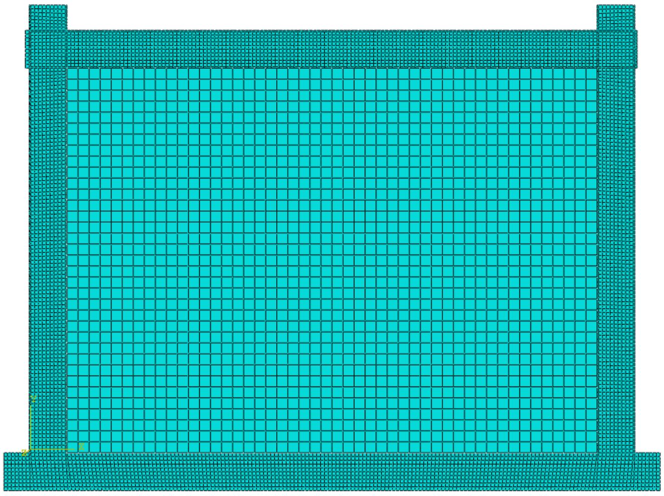

**Fig. 1: A 2D shell FE model of a steel frame with an infill panel**

**Material modelling:**

When steel elements are subjected to cyclic loadings, a steel cyclic constitutive model is needed, which is different from the monotonic model. Presently, steel stress–strain relationship is ordinarily defined as multi-linear forms. Those models, however, cannot give satisfying results under cyclic loading [19]. Based on plastoelasticity, Chaboche [20-21] proposed a cyclic combined model. In ABAQUS, this model can be implemented as a plastic constitutive model, containing a nonlinear isotropic hardening component and a kinematic hardening component [17].

As mentioned before, a macro-model was utilised to model the infill panel. In this model, adequate physical–mechanical parameters of an idealised material should be defined. Hence, the constitutive model presented by Radnić et al. [22] was used to simulate the masonry material. Fig. 2 shows the adopted model for masonry infill panel and its parameters. The Concrete Damaged Plasticity model in ABAQUS was used to model this material.

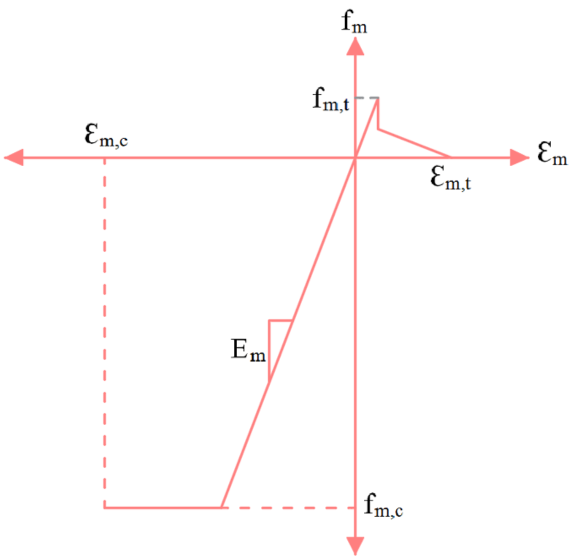


**Fig. 2: Adopted Constitutive Model for Masonry**

## VERIFICATION OF NUMERICAL ANALYSIS

In order to verify the capability of the suggested 2D finite element model to accurately model infilled steel frames with infill walls, the typical quasi-static cyclic tests, which were performed by Markulak et al. [23], was selected. They conducted an experimental study on nine one-bay, one-storey masonry-infilled steel frames with three different masonry infill types, including perforated clay blocks (specimen C-1), which is modelled in the current study.

### Comparison of Hysteretic Curves and Ultimate Capacity:

From Fig. 3, the finite element model accurately simulated the hysteretic behaviour and the carrying capacity of the masonry infilled steel frame. It was observed that severe pinching phenomenon of the hysteretic curve has occurred after the unloading process. From comparative curves, the three numerical methods simulated this phenomenon well.

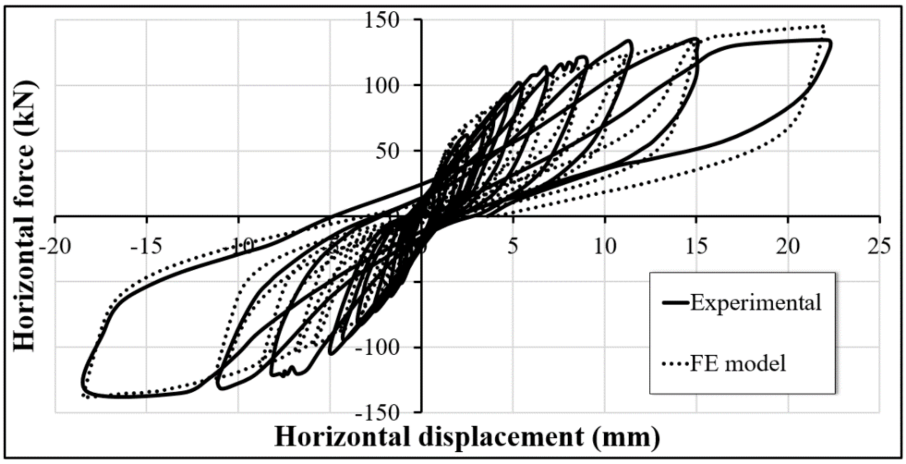


**Fig. 3: Comparison of Experimental and FE Hysteretic Curves**

### Comparison of Failure Modes:

Fig. 4 shows a comparison of the experimental and FE failure modes. It has been shown that the model was able to capture the actual failure mode of the infilled steel frames under cyclic loading. The gap between infill and frame, the damage of the corners of masonry wall, and the diagonal cracking in the wall were accurately simulated.

### Comparison of CPU Time:

Table 1 illustrates a comparison of the CPU time of the 3D solid and 2D shell models for an infilled steel frame, showing a great difference in the CPU time between them. To model a masonry infilled steel frame under cyclic loading, the 2D shell model consumed about 21% of the 3D shell model CPU time, which indicated that the 2D shell model is greatly more effective than the complicated 3D model.

**Table 1: CPU time comparison of the 3D and 2D FE models**

| | 3D solid | 2D shell |
|---|---|---|
| CPU Time (minutes) | 516 | 2460 |

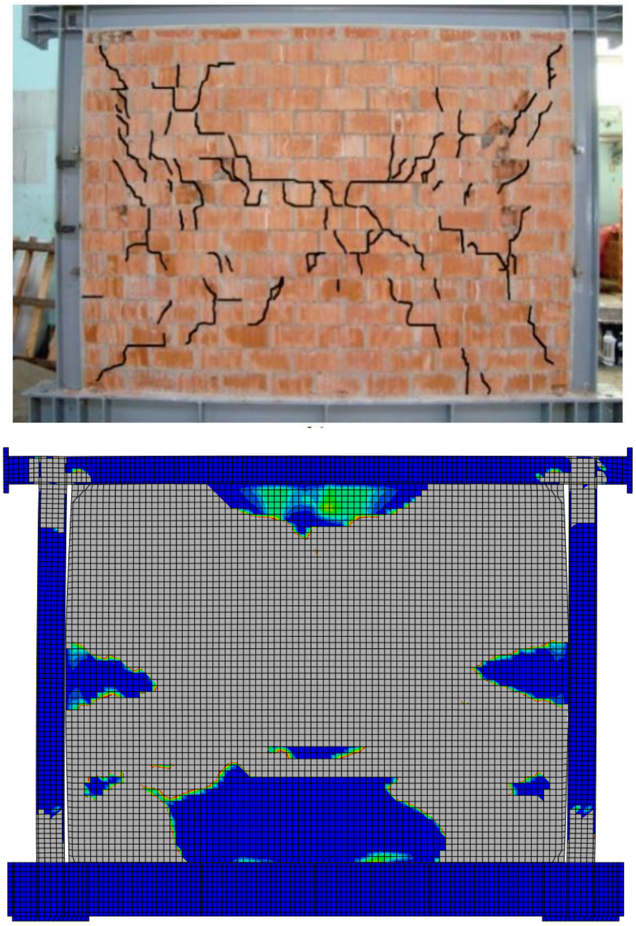

**Fig. 4: Comparison of Experimental and FE Failure Modes**

## CONCLUSIONS

A 2D shell FE models was established to simulate the cyclic behaviour of infilled steel frame. The proposed model was then verified by the results of masonry-infilled steel frames under reversed cyclic loading, evidencing its capability to predict accurately the cyclic behaviour of infilled steel frames and their failure modes. The 2D shell model was more effective than the 3D model. It consumed about 21% of the 3D solid model CPU time. This simplified model provides a strong tool for studying the infilled steel frames' behaviours.

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