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Cyclic testing of single bay steel frames with various types of masonry infill

Damir Markulak*, Ivan Radić, Vladimir Sigmund

University of Osijek, Faculty of Civil Engineering, 31000 Osijek, Croatia

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A B S T R A C T

This paper presents results of a part of the Croatian project "Seismic design of infilled frames" and deals with masonry infilled steel frames. The behaviour of steel frames infilled with masonry, commonly used in Croatia, was experimentally investigated under quasi-static cyclic loading. Besides, a new structural solution is proposed. Nine one-bay, one-storey masonry-infilled steel frames with three different masonry infill types: perforated clay blocks (C), lightweight AAC blocks (A) and newly proposed combination of these materials (CA), were built and tested. Proposed combined masonry infill (CA) allowed partial separation of the masonry from the frame at certain drift levels and prevented the infill's detrimental effects.

1. Introduction

The behaviour of masonry-infilled frames, as relatively frequent type of structures in southern Europe, has been investigated for more than 50 years. Despite numerous previous investigations of their structural behaviour, there is no codified approach to design these structures, as it is the case with other common structural types. That fact is especially emphasized for structures exposed to larger horizontal loads, as in the case of an earthquake. It has been generally recognized that behaviour of infilled frames under seismic loads could be poor. A typical example of the masonry infill's influence on the behaviour of one-bay steel frame is presented in Fig. 1a). The masonry infill panel, in the paper [1], was modelled by linear- and nonlinear equivalent compression strut models and nonlinearity was included by appropriate spring models. Results of the push-over analysis indicated the infill's favourable influence at small drifts increasing the structural stiffness and strength. However, after the peak value was reached damage in the masonry increased and panel-frame interfaces detoriated. The consequences were significant degradation of stiffness and strength and only low- to medium displacement ductilities could be achieved. The bare steel frame, on the other hand, had high possible ductility, Fig. 1b).

The behaviour modes, of infilled and bare steel frames, are different under horizontal loading. This could cause other possible detrimental effects, as has been shown in the previous experimental and analytical studies. They revealed that infill's presence changed the "original" steel-frame flexural behaviour into the new one similar to that of a truss girder [2]. Big diagonal compression forces in the infill exposed steel joints to considerable axial tension that might lead to prying action and could cause serious damage. Partial damage of the infill's panel over its height often caused a so called short column effect. This moved the position of diagonal compression strut along the height of the steel column. Large shear forces caused web buckling or/and large localized shear deformations of the steel column.

The behaviour of this complex interactive system is not properly understood which also contributed to its bad performance. Common design is often based on capacity of a bare steel frame and masonry infill is considered as non-structural element but not executed as such. Therefore, a large deal of damage costs caused by earthquakes could be attributed to infill walls, doors, windows, electrical and hydraulic installations (approximately 80% according to [3]). Design provisions for new masonry-infilled frames in modern codes, as in [4], are mostly given as general guidelines and detailed design procedures for this structural type are still lacking.

Three different structural types of these structures could be distinguished [4]:

(a) The moment resisting frames in which reinforced concrete infills are positively connected to the steel elements thus forming a monolithic structure.

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* Corresponding author. Tel.: +385 31 540 070; fax: +385 31 540 071.
E-mail addresses: markulak@gfos.hr (D. Markulak), radic@gfos.hr (I. Radić), sigmund@gfos.hr (V. Sigmund).

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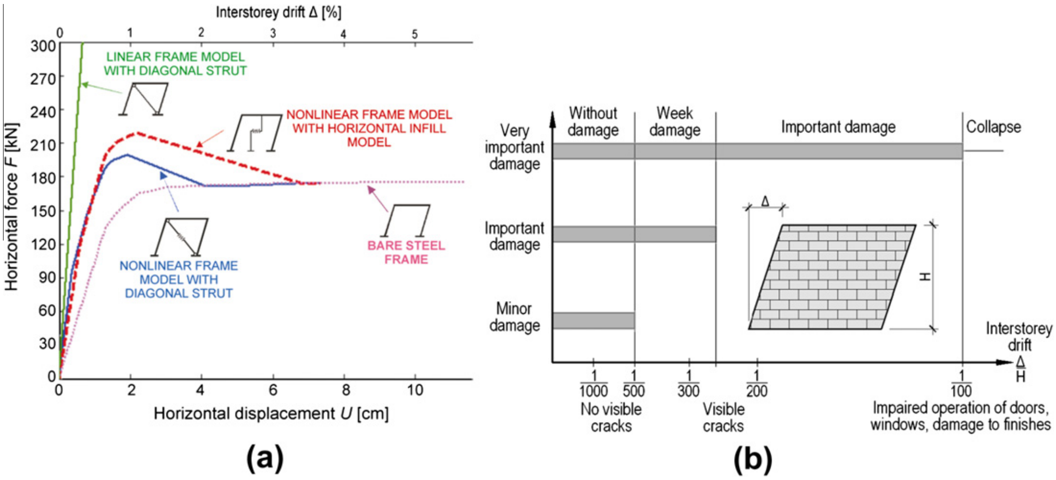

(a) (b)

Fig. 1. (a) Influence of masonry infill on the behaviour of steel frame (results of numerical analyses from [1]), (b) relative drifts of masonry infill for different damage states.

(b) The moment resisting frames in which the infills are structurally disconnected from the steel elements on the lateral and top sides.
(c) The moment resisting frames in which the infills are in contact with the steel frame, but are not positively connected to it.

Structures of the first type should be designed as composite steel–concrete structures and that of the second type as bare-frame steel structures. In the structures of the third type frame–infill interaction should be accounted for, as well as, uniform infill distribution in plan and elevation. For their analysis the use of diagonal strut model is allowed, but there are neither further design instructions nor the set range of applicability of that model. Since simplicity of the construction (and design) plays a significant role in the praxis, the second structural type has lower usage. Having this in mind, we directed our research towards combination of the second and the third structural type using simple construction method thus enabling the exploiting the advantages of each structural type to a certain extent. We attempted to establish the possibility of simple and efficient control of the frame–infill interaction in order to exploit favourable infill's influence and to avoid the detrimental ones.

2. State of the art

Numerous previous investigations pointed out important parameters that influence the behaviour of masonry-infilled frames exposed to horizontal loads. Behaviour of steel and reinforced-concrete (R/C) masonry infilled frames are also very different [2] and the conclusions for one are not directly applicable to the other.

The main parameters and the main sources of uncertainties that affect the behaviour of infilled frames are given below (excluding the ones associated with load characteristics due to their inherence in other structural types).

(a) *Material properties* – masonry is a composite material, heterogeneous by its nature. Its behaviour depends upon the arrangement and properties of its constituents. The properties should be determined according to various codes and procedures (for example [5–9]). There usually exists a great variation of obtained results as well as differences between the laboratory and in situ executed samples.
(b) *Construction procedure* – numerous experimental tests underlined the importance of the applied construction procedure [10,11] and care methods taken afterwards. They had influenced bonding, initial gaps, shrinkage rate, etc. They significantly affected frame–infill interaction.
(c) *Geometrical properties of the masonry panel* – the importance of masonry panel as active structural part highly depends on the height to length aspect ratios [11], infill thickness [12] and presence of openings [13].
(d) *Structural configuration* – horizontal and vertical arrangement of the main structural parts, uniform distribution of masonry panels in plane and in height, ratio of frame to infill stiffness, ratio of frame to infill strength, behaviour of the structural frame joints, etc. [3,14].
(e) *Representativeness of laboratory tests* – most of the laboratory tests were carried out on separate plane structures made in reduced scales [12,15–17]. They were often particularly designed to achieve some beneficial effects of the infill (i.e. taking favourable ratio of panel's height to length thus affecting above mentioned criterion (c), or assuring the ideal load transfer from frame elements to infill thus affecting criterion (d), etc.). It is necessary to check the adequacy of obtained results taking into account the actual structural proportions and real load transfer and deformation conditions that exist in buildings. This is even more important if we take into account small range of deformations that infill panels (Fig. 1b) could take. Recently, researchers [18,19] have pointed out a need for tests on full (or close to) size models (that however, cannot avoid certain limitations due to criteria (a) to (c)).
(f) *The adequacy of design methods* – accuracy of the behaviour prediction strongly depends on the applied design method/model [1,3,12,13,16,20]. These were developed alongside with the clarification of particular behavioural aspects of infilled frames (stress function method, equivalent diagonal-strut model, equivalent frame method, etc.). Recently, a widely accepted FEM method introduced powerful possibilities of simulating various complex effects such as frame to infill interface conditions and creation of micro- and macro linear/nonlinear structural models.

It is obvious that there are many influencing parameters with a wide range of possible values, particularly the uncertainty associated with material properties and construction procedures, for proper modelling of the infilled frames. Because of that many experimentally obtained results were relevant only in laboratory conditions and just a few were used as construction guidelines (for example in [20] where recommendations for achieving better