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Original Research Article

Modeling of dry-stacked masonry panel confined by reinforced concrete frame

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ABSTRACT

In order to increase the energy dissipation of wall/frame elements subjected to in plane shear loading a conceptually new system for masonry infilled RC frame has been proposed and proved as effective. The interaction between frame and infilled panel is considered as the major cause of the nonlinear behavior of structure. In this paper, the experimental results are briefly summarized and a micro finite element model is developed to simulate the monotonic response of the masonry infilled structure. A novel type of element called "initial gap element" is presented to simulate the gap between the frame and panel to allow the continual simulation of the response for the full load cycle. All the material parameters are experimentally evaluated. The initial testing included free vibration and cyclic tests on a bare RC frame followed by cyclic test on the RC frame infilled with a dry-stacked concrete brick panel. These results are used to verify the accuracy of the model. It is shown that the model is able to simulate the failure mechanisms exhibited by experiment including the crushing and cracking of the concrete frame and the diagonal compressive stress contribution of the masonry panel. The load–displacement response predicted by the model was also in good agreement with that obtained from the tests. Furthermore, the model was used for ultimate analysis, which discovered four typical stages of structural response of the dry-stack infilled RC frame and found the friction between bricks in the dry-stacked panel contributes significantly (about 50%) to the assembly.

1. Introduction

Reinforced concrete (RC) frame structures with masonry panels are very common all around the world. Although the infilled masonry panels are often considered non-structural elements, the behavior of infilled frame is strongly influenced by the interaction of the infill with the frame. On one hand, because the panels are significantly more rigid than the RC frame and hence may attract high seismic forces that could be damaging for both panels and frames [1,2], which is one of the typical causes of structural damage in columns commonly

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observed after earthquakes [3]; on the other hand, as the interaction between infilled panel and RC frame is almost unavoidable, the energy dissipation inside infilled panels can improve the seismic behavior of whole structure during the earthquake [4]. However, most of the energy dissipation in traditional structures was accompanied by the damage to both RC frame and masonry panel such as crushing of bricks or cracking of concrete elements and masonry with the corresponding reduction in the stiffness and structural integrity. To improve the seismic behavior, people usually add some damper to improve the energy dissipation. That has been proven as an effective method; however, it has not been widely used due to its high cost and complicated processes, especially for the low-cost buildings in developing countries.

The technique of dry stacking masonry units in construction has existed for thousands years. Pyramids in Egypt, which were built around 5000 years ago, and the Zimbabwe ruins that have existed since 400 AD, serve as very good examples of dry stacking [5]. Those structures have been through multiple seismic events, and still maintain structural integrity and stability, which implied the dry stacking method has considerable seismic behavior. Some research has been done previously on modern dry-stacked masonry [6–10]. According to previous research, a considerable nonlinear deformations have been attained (story drift of 2.5%) and the failure criterion for dry-stacked stone can be considered as a Mohr–Coulomb failure. However, during the cyclic test, the upper part of masonry wall tended to rotate around the bottom corner (i.e. the rocking mechanism), most energy dissipation was contributed by crush of corner, thus the dry-stacked walls were unable to dissipate much energy.

In order to increase the energy dissipation without damage related to the frame/panel interaction, a conceptually new system for framed masonry panel was proposed by Totoev et al. [11]. According to this concept, masonry infills should no longer be considered as non-structural elements. Instead, they should be accepted as "non-gravity-load-bearing" structural elements fully participating in resisting horizontal loads. To achieve this positive contribution from masonry panels to horizontal load resistance, panels should: (1) append less rigid influence to the frame and (2) contribute mostly to the energy dissipation of whole structure. It was proposed to build panels with dry-stacked masonry units capable of relative sliding in the plane of the wall and interlocked to prevent relative sliding out of the plane of the wall. A research program on this kind of structure was carried out by Lin et al. [12], the obtained data was used as a basis for the present numerical simulation.

This new system requires a comprehensive study which would be too costly to conduct experimentally. Hence, the planned finite element study was performed numerically using an experimentally verified FE model. The development of this model is the focus of this paper.

In numerical modeling of a RC frame infilled with dry-stacked masonry panel, there are three major challenges: (1) modeling of the nonlinear behavior of an RC frame, (2) modeling of the nonlinear behavior of a dry-stacked masonry panel, and (3) modeling the interaction between them.

The RC frame is designed to bear either vertical load only or a combined shear and vertical loading. It was previously demonstrated that 2D numerical simulations could produce results similar to those achieved in 3D numerical simulations and also with good correlation to experimental results [13].

Masonry is highly anisotropic composite material because both brick and mortar are nonlinear materials with each of them exhibiting significant discrete characteristics [14]. Moreover, the tension and shear strengths of traditional mortar joints are much lower than that for bricks. The joints therefore form a weak link in the composite. This composite nature of masonry presents a considerable modeling challenge. Two main approaches have been suggested [15] to model the behavior of masonry structures: macro modeling and micro-modeling, as shown in Fig. 1. In this paper, the micro-modeling approach has been adopted for the simulation of dry-stacked masonry panels.

Dry-stacked masonry is built by stacking brick/block without mortar, so the contact behavior between masonry units is quite different from the traditional masonry with mortar. Two different models were used by Lourenço et al. [16,17] for the nonlinear behavior of dry-stacked joints: the "coulomb friction model" and the "composite interface model". Compared with the experimental results, both of

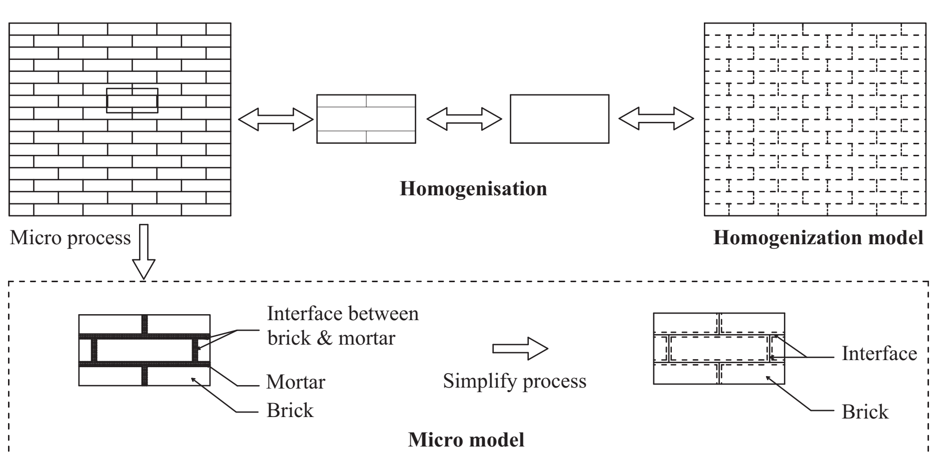

Fig. 1 – Two modeling approaches.