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# Testing and modelling the in-plane seismic response of clay brick masonry walls with boundary columns made of precast concrete interlocking blocks

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ABSTRACT

Post-earthquake evidence indicates that traditional rural masonry structures in China do not perform well when subjected to large intensity ground shaking. Because common cast-in-place (CIP) reinforced concrete (RC) construction is relatively expensive for many rural people the construction technique is currently unpopular in rural areas of China. In comparison, the assembly of precast concrete interlocking blocks to form fabricated columns is cost effective and easy to construct using available resources, and implementation of the technique in rural masonry structures will result in superior seismic behavior. To address these issues a study was undertaken to experimentally establish the performance of masonry walls with traditional concrete columns and with fabricated boundary columns constructed of precast concrete interlocking blocks, and finite element models were generated to extend the range of parameters considered in the study. It was established that the implementation of fabricated concrete boundary columns made of precast concrete interlocking blocks improved seismic response with respect to traditional construction practice and 37 trial buildings were constructed to demonstrate implementation of the technique. It was also established that computational models could be generated to adequately replicate laboratory observations, endorsing use of this method to extend the project scope.


## 1. Introduction

On 12 May 2008 the Wenchuan earthquake shook west China, causing the collapse of an estimated 6,945,000 buildings of which 94% were assessed to be rural buildings [1,2]. These rural Chinese buildings can be classified into three types, being brick masonry structures (with most bricks being clay bricks), brick-wood structures, and earth-wood structures [3,4], with 74% of all buildings that collapsed or were seriously damaged in the Wenchuan earthquake being assessed to be of brick masonry construction.

Jia [2] and Cao et al. [4] have reported that prior to the Wenchuan earthquake rural Chinese people gave little consideration to the design of buildings to withstand earthquakes. Meanwhile Chinese villagers have traditionally constructed their own homes in order to save the cost of employing construction professionals. Cast-In-Place (CIP) concrete technology is too complex for unskilled labor to properly perform, involving the preparation of formwork, the tying of reinforcement cages, and the manufacture of concrete. Thus, because rural Chinese people tended to avoid using skilled labor they also tended to construct their buildings without using reinforced concrete. In Hubei Province over 70% of rural masonry buildings have no reinforced concrete columns and ring beams [3] and the corresponding number in northeast Anhui Province is about 60% [4]. Li et al. [5] have reported that the majority of rural Chinese buildings are self-built with no professional design, and that no reinforced concrete columns and ring beams are used in these buildings. Examples of rural masonry buildings after the Wenchuan earthquake are shown in Fig. 1, illustrating the observed difference in earthquake performance that in part was dependent on whether reinforced concrete columns and beams were absent or present.

For the case where rural Chinese people have constructed their buildings using reinforced concrete columns and ring beams, these unskilled rural homeowners tended to use a reduced quantity of reinforcement, produce non-compliant concrete mixes, and/or produce poor formwork for the casting of concrete members. According to statistics published after the Wenchuan earthquake [6], it was found that brick masonry structures were far more extensively

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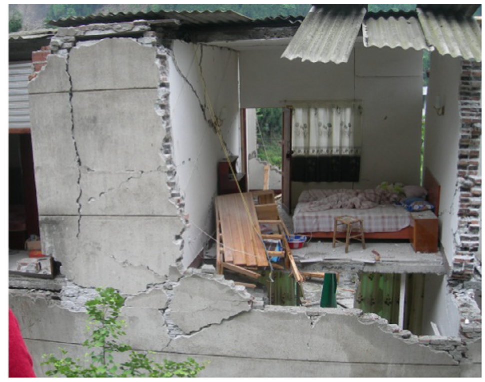
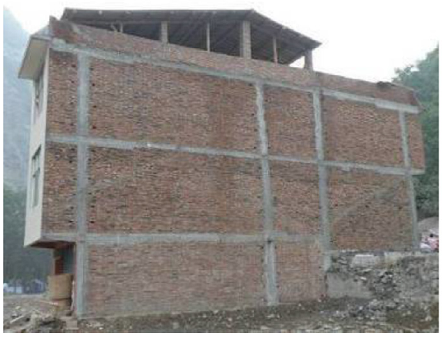
(a) Collapsed masonry building near Beichuan County, having no reinforced concrete columns and beams



(b) Severely damaged masonry building with collapsed precast slab, having no reinforced concrete columns and beams



(c) Masonry building near Pingtong Town in good condition, having reinforced concrete columns and beams

(d) Masonry building at Pengzhou, Bailu Town in good condition, having reinforced concrete columns and beams

**Fig. 1.** The condition of different masonry structures after the Wenchuan earthquake.

damaged than any other building type. This observation is explained by recognizing that many rural houses were built without reinforced concrete, or were built with reinforced concrete columns and ring beams constructed by the homeowners rather than by construction professionals, leading to poor construction quality.

In response to the problems identified above, efforts were directed to producing fabricated columns which can be assembled using small concrete blocks. The blocks are made of concrete rather than clay because the strength of concrete is superior to that of clay. This superior performance is recognized in the national Concrete Structures Code of China where the lowest grade of concrete has a compressive strength of 7.2 MPa and axial tensile strength of 0.91 MPa [7], compared to the values given in the national Masonry Structures Code of China where the highest compressive strength for clay brick is 3.94 MPa and the highest axial tensile strength is 0.19 MPa [8].

The fabricated concrete column elements that are composed of unreinforced precast concrete blocks are referred to as either precast columns or as core columns, with the latter having a cast-in-place reinforced concrete core (see Figs. 2–4). The concrete blocks used to fabricate the concrete columns are factory produced by experienced workers so that the quality of these components can be ensured. Because all components are manufactured as small blocks there is no formwork or reinforcement cages required on site, and unskilled rural people can readily assemble these blocks easily, quickly and properly by themselves so that the cost of hiring experienced construction workers can be saved. In general, it is expected that the fabricated columns (core columns and precast columns) will be cheaper than CIP reinforced concrete columns, whilst the structural performance of fabricated columns will be similar to that of CIP reinforced concrete columns.

Both types of fabricated columns are assembled using several standardized block shapes (see Fig. 2), with core columns using all block geometries (except Block 4) and having a CIP reinforced concrete core, and precast columns using all block shapes except Block 3. The assembled configurations of fabricated columns are shown in Fig. 3, and photographs from construction sites where fabricated columns have been used are shown in Fig. 4. The height of all blocks (except Block 4) is 180 mm, and the height of Block 4 is 340 mm, which is composed of dual 80 mm stubs located above and below the central 180 mm block. Using this mode of assembly it has been established that the use of precast concrete blocks is significantly cheaper than cast in-situ concrete construction, whilst the quality of the fabricated columns can be ensured.

Eleven physical experiments were undertaken to confirm the suitability of using these precast concrete blocks to form fabricated boundary columns, including tests on clay brick walls with and without CIP reinforced concrete columns and on clay brick walls with fabricated concrete columns. Recognizing the significant cost of physical experiments, the range of test parameters was subsequently extended using non-linear finite element analysis.

## 2. Experimental program

### 2.1. Reduced-scale specimens

Fig. 5 shows the adopted pseudo-static test set-up and loading history, with all wall specimens being positioned on a reinforced