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Shear spring model proposed for seismic evaluation of a timber framed masonry infilled wall

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A B S T R A C T

Masonry infilled timber frames (TFM) are widely used for residential houses in many countries in the world. Last two decades' seismic events showed that this typology is resilient for earthquakes, and even though it exhibits damages, it rarely collapses. For developing countries, TFM is a valid solution for life protection of the inhabitants.

Interaction between timber and masonry is difficult to assess and although numerical models simulate roughly the seismic behavior of TFM, they need expensive resources (time and software) to reach acceptable accuracy level. For this reason, this study proposes a simplified seismic evaluation method for timber framed masonry walls, based on a shear spring model calibrated with experimental result. The resulting envelope curve simulates satisfactorily the initial stiffness and maximum strength.

1. Introduction

Masonry infilled timber frames are being widely used for small-scale residential houses in earthquake prone regions such as in Romania, Haiti, Turkey, Greece, Italy, Portugal, Pakistan, Myanmar (Fig. 1) and China [4,17,10,20,27,21,5,6,1,23,25]. With a few exceptions (e.g., those in Portugal and Italy), most of the structures are un-engineered and were built following local historical practice of construction. In some countries, it only exists in old buildings (e.g., Portugal, Turkey, Haiti), while it is still a current construction practice in other countries like Romania, Myanmar, Pakistan and China.

The seismic performance of masonry infilled timber frames has been reported after several major earthquakes. In the 1999 M7.4 Kocaeli earthquake in Turkey, the houses with this type of structure sustained less damage in comparison with poorly constructed reinforced concrete ones with masonry infills [10,19]. Vintzileou et al. [30] reported the survival of timber framed houses in Greece during the 2003 M6.2 Lefkada earthquake, even when not properly maintained. In the 2010 M7.0 Haiti earthquake, the local traditional timber frames with masonry infills, referred to as Gingerbread houses, sustained significant damage yet very few collapsed [18]. In Qu et al. [25], based on the comparison between the statistics of their damage levels after 2013 Lushan earthquake masonry infilled timber houses sustained much less damage during the earthquake than the URM ones, while the confined masonry ones exhibited better seismic performance in general.

A comprehensive overview on the numerical work done on this subject was published in Poletti et al. [24], where the authors compare and describe briefly the differences between the existing models [14,15,26,3,22,11,29]. All the models are done with FEM software and are 2D or 3D, being either macro or micro-models. However, such modelling is difficult to conduct for engineers, due to the high level of complexity of both the structural system and of the FEM software.

So this paper proposes for the first time a simplified evaluation method based on a shear spring model which simulates monotonic lateral loading of a timber frame wall with masonry infills. The model fits in the macro-models category for TFM walls, and can be used for a house level analysis with further research. Each component spring is defined empirically, and their arrangement in series or in parallel was decided based on the experimental test of a wall specimen described in detail in Dutu et al. [8], but also considering engineering judgement. In this first phase of the model, empirical definition of the springs aims to use experimental tests as simple as possible (only monotonic loading), in order allow easy reproducing by engineers. The configuration of the shear spring model can be changed (since it involves many materials properties, based on the construction details of the target wall) in order to adapt it for other timber frames with infills. This is an important feature, due to the variation of the type of connections and infill arrangements that can occur even in the same country.

Innovation of the method is that the model includes all the phenomena characteristic of the TFM type of structure. And although they

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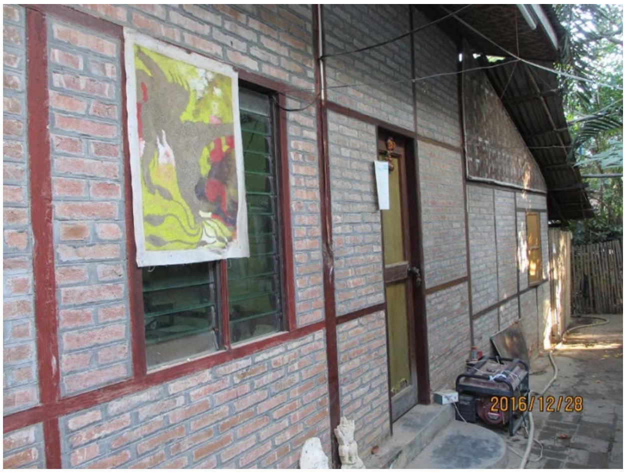

Fig. 1. TFM houses in Myanmar, undamaged after the August 24, 2016 earthquake (courtesy of Dr. Matsutaro Seki).

are represented separately, by means of the shear spring model they work together. The shear spring model is easier to be applied than the FEM, which is usually very complex for TFM, due to the large number of properties that should be included. It represents macro-modeling and a wall is evaluated, and then it can later be included in a simple model for a house. Although the shear spring model cannot catch the cyclic behavior, it can serve as a simple tool enabling engineers to make the initial evaluation of the house.

2. The reference static cyclic wall test

2.1. One masonry panel

Static cyclic tests were conducted on one masonry panel wall specimen whose dimensions are shown in Fig. 2, right [9]. The specimen considered for this study (TFM-CH) had the cross-halving connections. The timber was redwood pinus silvestris, glulam type, imported from Finland. The choice was made based on the fact that glulam properties do not vary as in the case of milled timber. In order to take into account the properties of this wood type, flexure and compression perpendicular to grain tests were conducted, and parameters obtained were included in the numerical model. The bricks were made in Japan with the dimensions 210 × 100 × 60 mm (~8.3:4:2.4 in.) and the mortar recipe is according to Portuguese TFM (Pombalino), 1:2:6 (cement:lime:sand). The water/(cement + lime) ratio is 1.75/2 [8]. Old buildings' mortar in Europe is mainly lime based, but since it takes several months to cure, for the laboratory tests a small quantity of cement was added, for faster curing [31]. These material choices were made considering the

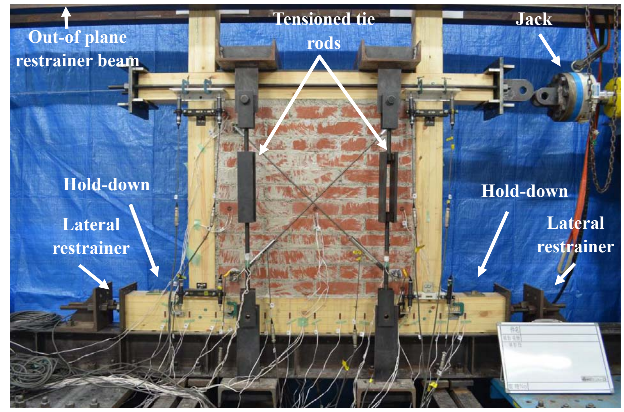

Fig. 3. Test setup for wall specimen [9].

continuation and in the same time extension study of the timber framed masonry structures, which started with the Portuguese example for the authors [8]. This test aimed to determine the contribution of one panel in the behavior of the overall wall and to indicate the transfer of the vertical force between the timber frame and the masonry panel.

The specimen was subjected to in-plane static cyclic loading (Fig. 3, left). The CUREE – Caltech standard protocol for wood frames was used [13]. The reference displacement, Δ, was chosen based on previous experimental test observations, as 0.033 rad displacement at the top of the wall [6]. As the input deformation, the shear angle, δ, was used to cancel the rocking and thus to observe the pure shear behavior of the wall, being calculated with the following equation:

$$\delta = \frac{D_1 - D_2}{\text{Height}} - \frac{D_3 - D_4}{\text{Width}} \tag{1}$$

where D1, D2, D3, D4 are the measured displacements and the positions of the wire displacement transducers is shown in Fig. 2 (left).

The specimen is supported on the steel beam of the reaction frame, by hold-downs on the vertical direction and lateral restrainers on the horizontal direction (Fig. 3). The vertical load was applied by tensioning tie rods, as shown in Fig. 3 and uniformly distributed on the top of the specimen using steel plates connected to the upper beam with screw nails. On the tie rods, 4 strain gauge/tie rod were used to measure the force applied. The initial force applied was 30 kN.

Test result in terms of lateral load [kN] and displacement [mm] are shown in Fig. 4. For this paper, only the envelope curve of the positive cycles was used. Due to some setup problems, after the 15th cycle only positive loading cycles were conducted. Behavior shows continue hardening until the test was stopped, at 100 mm displacement, when no fracture was observed, although local damages of compression perpendicular to grain and masonry panel cracks could be seen.

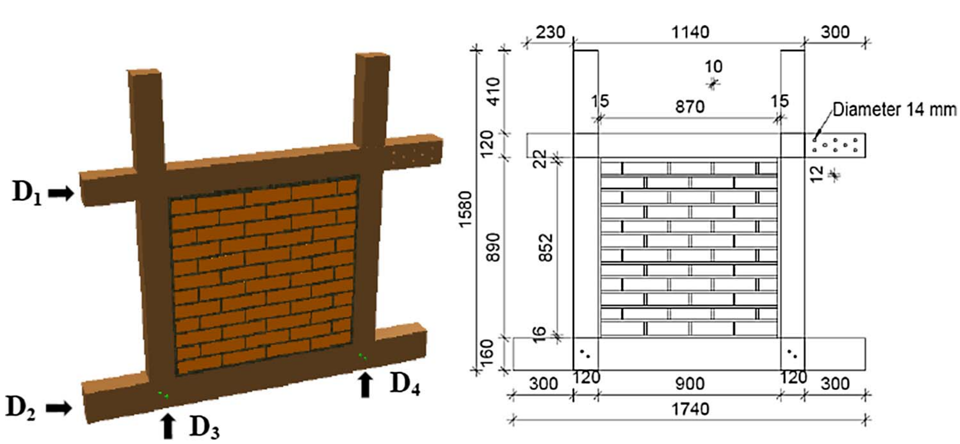

Fig. 2. TFM-CH specimen layout (left) and dimensions (right) [9].