

# Discussion on “Seismic capacity of masonry infilled RC frame strengthening with expanded metal ferrocement” by A. Leeanansaksiri, P. Panyakapo, A. Ruangrassamee [Eng. Struct. 159 (2018) 110–127]

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## ABSTRACT

A discussion on the paper by Leeanansaksiri et al. (2018) is presented. In the paper, strengthening of the masonry infill walls using ferrocement reinforced with standard expanded steel plates (EMS) was investigated experimentally. A bare frame without infill wall, a frame with a plain (unstrengthened) infill wall and a frame with a strengthened infill wall were tested under reversed cyclic lateral loading. The type of EMS to be used for strengthening was decided based on compressive strength tests on plain (unstrengthened) and strengthened masonry prisms and monotonic diagonal loading tests on wall panels. The results of the prism and panel tests were also used to determine the parameters of the analytical hysteric models, which closely estimated the experimental results of the frame tests. While the paper reached important conclusions related to the proposed strengthening technique, the authors of this discussion felt obliged to present their significant findings on the issues, raised in the paper for further research to increase the efficiency of the proposed technique. Furthermore, this discussion summarizes the findings of the authors on the strategies to investigate the efficiency of an infill wall strengthening technique.

## 1. Discussion

Leeanansaksiri et al. [1] (hereinafter “the authors”) investigated the contribution of ferrocement reinforced with standard expanded steel (EMS) plates on behavior of infilled reinforced concrete (RC) frames subjected to seismic loading, i.e. reversed cyclic lateral loading. A prototype frame, taken from a real 3-story RC school building in Thailand, was adopted and three RC frame specimens, including a bare frame with no infill wall (BF), a frame with a plain masonry wall (W) and one with a strengthened infill wall (W-SR), were tested. The strengthening application increased the lateral strength of the frame by 25%, the initial lateral rigidity by 26% and the energy dissipation capacity by 27% compared to the reference frame with plain masonry wall (W). The authors [1] found out that the contribution of the plain infill wall to the overall lateral strength of the frame was 84.5%, while the ferrocement application on the infill wall increased this contribution up to 89%. The strengthening layer also changed the failure mode of the specimen. The specimen with plain masonry wall (W) underwent diagonal cracking along the wall followed by bed-joint sliding shear failure along the lintel beam at mid-height of the wall. The diagonal cracks propagated along the mortar beds, which are much weaker than

the bricks. The lintel beam ruptured at the end of the test and no visible damage took place in the beam and columns of the frame. In the specimen with strengthened masonry wall (W-SR), on the other hand, different failure modes were observed in the forward and reverse directions of loading. But, in none of the loading directions, sliding shear failure took place in the mortar beds, implying that the ferrocement layer effectively prevented sliding shear failure in the wall. In the forward direction of loading, the ultimate failure was caused by corner crushing in the wall and shear failure of the columns in the plastic hinging regions. Yet, in the reverse direction of loading, diagonal compression failure of the infill wall resulted in the loss of lateral strength of the frame. The authors [1] concluded that the diagonal compressive strength and the shear strength of an infill wall can be increased by strengthening the wall with a ferrocement layer. Consequently, the sliding shear and diagonal compression failure modes of the infilled frame can be prevented with the proposed strengthening method. But, the ferrocement layer, reinforced with the expanded steel plate, does not improve the corner compression strength and prevent the corner compression failure, since this failure mode depends solely on the compressive strength of the masonry and mortar.

The discussers agree with the authors [1] that the seismic behavior

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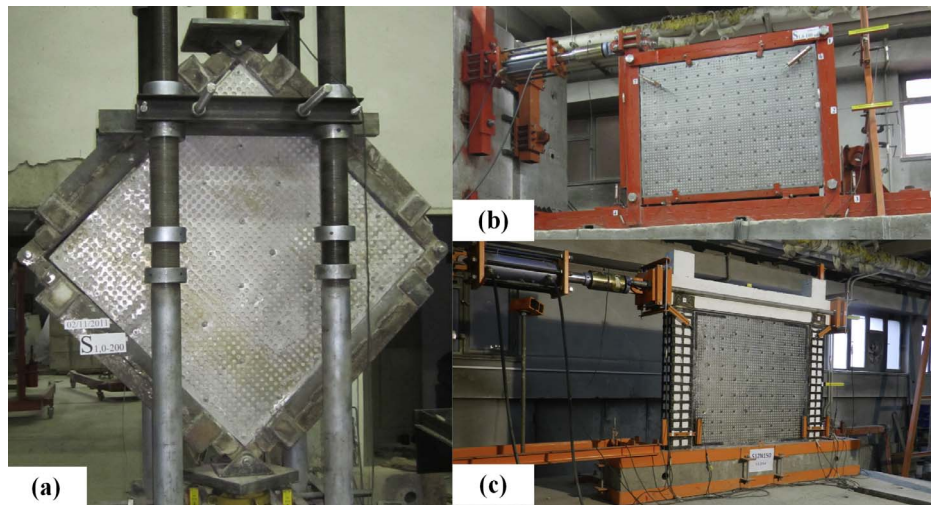


Fig. 1. (a) The first; (b) second; (c) third stages of the experimental program on strengthening the infill walls with perforated steel plates.

of an infilled RC frame can be significantly improved by strengthening the infill wall(s) of the frame with external steel plates. Previous studies of the discussers [2–5] indicated that the optimal efficiency of the proposed strengthening method can be achieved by a stage-wise research program. The discussers investigated the influence of strengthening the brick infill walls with perforated steel plates on the individual behavior of the wall and the overall behavior of the frame in a detailed experimental program, composed of three stages (Fig. 1). In the first stage [2],  $1000 \times 1000$  mm wall panels were tested under monotonic diagonal compression loading. The plate thickness and bolt spacing were adopted as the test parameters of this stage. When a real structural frame undergoes lateral loading, the infill walls of the frame are subjected to diagonal compression, i.e. they act as diagonal compression struts. However, the monotonic diagonal loading does not entirely simulate the loading conditions of an infill wall in an earthquake. Under monotonic loading, crushing and cracks in the wall do not cause disintegration of particles from the wall. The particles in the crushed and cracked portions of the wall continue transferring forces and contributing to the load capacity of the wall. In an earthquake, however, several particles disintegrate from the wall due to the reversal and fluctuations in the load and these particles cease to contribute to the load-carrying capacity. To validate the findings of the first stage of the program in the case of reversed cyclic loading,  $1500 \times 1180$  mm individual wall panels were tested under lateral loads in the second stage [3]. The individual wall panels were tested in an unstable steel frame in the first and second stages. This mechanism had no strength and stiffness in the diagonal direction, since all of the members of the frame were connected to each other with hinges. In this way, the steel frame only conveyed the load to the wall panels and did not affect the load capacity and deformation of the wall. Furthermore, the contact surface between the wall and frame could change along the course of loading with the help of this mechanism, as the wall underwent greater deflections. In addition to bolt spacing and plate thickness, the effects of additional corner strengthening techniques (reduced bolt spacing, L-shaped flat steel; concrete block as in Fig. 2) and the presence of lap splice in the external plate were also investigated in the second stage. The first two stages indicated that the load capacity of the wall can be increased in the range of 1.3–2.6 times the strength of the reference plain wall under monotonic diagonal compression and 1.3–2.3 times the strength of the reference wall under reversed cyclic lateral loading. Furthermore, the energy dissipation capacity increased 4–14 times and 5–10 times the respective values of the reference wall under monotonic diagonal and cyclic lateral loading, respectively. The use of perforated steel plates proved to be a very effective method for improving the load-deflection behavior of brick infill walls under seismic loading. The

discussers suggested keeping the bolt spacing at 100 mm at the corners and at 200 mm in the remaining portions of the wall for optimal effects of the method.

Following the promising results obtained in the tests on individual wall panels [2,3], the effects of strengthening the infill wall with perforated steel plates on the overall behavior of the infilled RC frame was investigated in the final stage with the help of reversed cyclic lateral loading tests on 14 half-scale single bay single story frame specimens [4,5]. The plate thickness and bolt spacing values used in the strengthening procedure were based on the test results of the previous two stages [2,3]. In addition to bolt spacing and plate thickness, the connection of the perforated steel plates to the columns was considered as another test parameter of the final stage. The strengthening procedure resulted in a 1.5–2 times increase in the lateral strength, 4.7–6.7 times increase in the energy absorption capacity and up to 2.4 times increase in the initial rigidity of the infilled RC frame with respect to the frame with plain wall (reference frame).

Connecting the perforated plates to the columns yielded to an average increase of 10% in the lateral load capacity of the frame. The discussers are also conducting experiments on strengthened infilled RC frames with column axial loading, at present.

The discussers would like to share some important findings of their research program, which will shed light on the future studies on strengthening the infill walls with external steel plates or ferrocement layers. First, the authors [1] implied that the strengthening applications on infill walls can only yield to drastic improvement in the seismic behavior of the infilled frame if the corner damage of the infill wall and the shear failure of the surrounding columns can be prevented. The statement “... in this loading direction that the effect of the strengthened infill wall contributed relatively low strength due to the corner compression failure of the wall and the shear failure of the column.” points out the need for the wall corner and column strengthening applications to achieve the real improvement potential of the infill wall rehabilitation. The authors [1] also informed about the direction of their future research by stating that “To prevent this failure mode, a special strengthening technique is required at the corner of the infill panel. Further research on this issue will be conducted to improve the strengthening infilled frame.” The tests of the discussers also underscored the need for corner strengthening of the infill and column rehabilitation to enhance the effects of the infill wall strengthening applications on the frame behavior. The corner strengthening techniques applied in the second stage [3] effectively decreased the degree of damage at the corners of the wall and prevented corner compression failure. The contribution of the external steel plates to the wall became more pronounced in the presence of additional corner strengthening measures. The minimum corner

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