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Experimental study on the influence of non-fired brick walls on the behavior of multi-span reinforced concrete frames

Bui Van Bang[1], Lam Thanh Quang Khai[2,*]

[1]Hau Giang Community College

[2]Faculty of Civil Engineering, Mien Tay Construction University

KEYWORDS

Reinforced concrete
Frame
Non-fired brick walls
Multi-span
Wall

ABSTRACT

In construction projects, the infill wall within the frame primarily serves the purpose of providing coverage. Nonetheless, this infill wall also plays a role in enhancing the stiffness of the frame, thereby minimizing the horizontal displacement of the structure. Infill walls are commonly constructed using fired clay bricks. However, in recent years, the extraction of clay for brick production has led to the depletion of clay resources and has had a significant negative impact on the environment. This study involved the use of non-fired brick to create infill walls within two-span reinforced concrete frames. The research findings indicate that the bearing capacity of the frame improved by 220% when utilizing non-fired brick measuring 40×80×180mm and 80×80×180mm. Utilizing 40×80×180mm non-fired brick results in an 8.4 times reduction in the horizontal displacement of the frame. In contrast, employing 80×80×180mm non-fired brick leads to an 8.9 times reduction in horizontal displacement, both measured against the case without brick filling at a load level of 50kN, which represents the destructive load level of the frame absent infill walls.

1. Introduction

Reinforced concrete (RC) frame structures with masonry infill walls have been widely studied and applied in both steel and RC frame systems. Recent research on the behavior of RC frames considering masonry infill includes, for example, study [1], which developed a nonlinear behavior model for infill walls in frames and used this model to determine the seismic response of infilled frame systems. The study showed that infill walls significantly influence the failure mechanism of RC frames and proposed a method for directly determining the frame–infill interaction forces as well as a design method for RC frame columns. On that basis, the authors established a design procedure for RC frames with masonry infill under earthquake loading.

Karim Benyahi proposed a numerical model for RC frames with and without masonry infill. The results led to a simplified micro-model for brick masonry walls and a modeling approach for RC frames with and without infill. The study demonstrated, based on both experiments and simulations, that bare RC frames are more adversely affected than infilled frames under lateral loading [2].

Mochamad Teguh [3] conducted an experimental evaluation of brick masonry walls in RC frame buildings subjected to lateral loads. The research presented tests on masonry infill in RC frames under combined lateral and vertical loading. The results showed good agreement between the experimental and numerical responses of the frames, confirming that the numerical model can adequately reproduce the damage patterns observed in RC members during testing. The bare RC frames experienced more severe damage than the masonry-infilled frames.

Studies [4-5] have shown that the composite action between single-bay RC frames and masonry infill walls is highly effective under seismic (lateral) loading. This interaction increases the flexural stiffness of the frame beams and alters the conventional "weak-beam–strong-column" design philosophy, thereby contributing to safer and more economical structural design of frame systems. In particular, study [6] numerically modeled RC frames with concrete grade 200 and hollow brick infill walls. The results indicated that non-structural infill and partition walls can significantly restrain the lateral displacement of RC frames under earthquake loading, in some cases by up to 270 % compared with bare frames without infill.

In a study by Koushal on the behavior of RC frames without infill, with partially infilled walls, and with fully infilled single-bay frames under lateral loading [7], the applied lateral load was used to simulate seismic effects on RC frames. The experiments showed that the maximum lateral deflection was obtained for bare frames and frames with openings, and the minimum for fully infilled frames. The results indicated that the ultimate lateral load capacity of fully infilled RC frames is always higher than that of bare frames. The fully infilled frame sustained a lateral load three times that of the bare frame and 1.25 times that of the partially infilled frame.

In this study, non-fired masonry bricks with dimensions 40×80×180 mm and 80×80×180 mm are used to fully infill RC frames (frames K2 and K3), and their behavior is compared with that of a two-span RC frame without infill (frame K1).

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2. Materials and Methods

2.1. Materials used for the test specimens

The materials used to fabricate the specimens were selected in accordance with [8]:

For concrete: sand with a fineness modulus from 0.7 to 1.0 was used to produce low-grade concrete with strength class lower than B15; sand with a fineness modulus from 1.0 to 2.0 was used to produce concrete with strength classes from B15 to B25.

For mortar: sand with a fineness modulus from 0.7 to 1.5 can be used to produce mortar with strength grade less than or equal to B5; sand with a fineness modulus from 1.5 to 2.0 is used to produce mortar with strength grade B7.5. These are illustrated in Figure 1.

Crushed stone 1×2: the coarse aggregate has D_{max} = 40 mm, D_{min} = 10 mm, 1.25D_{max} = 50 mm, and 0.5(D_{max} + D_{min}) = 25 mm, as shown in Figure 2.

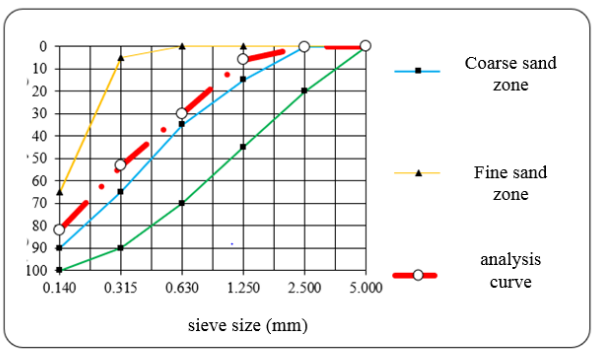


Figure 1. Particle size curve of sand.

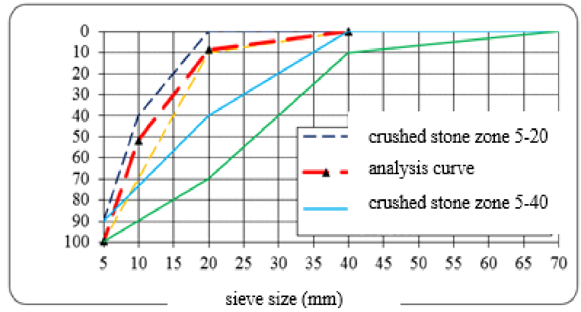


Figure 2. Particle size curve of crushed stone.

Reinforcing steel: the reinforcement used in the specimens was designed in accordance with TCVN 1651-1:2018; the concrete reinforcing bars were plain round bars [9].

Concrete mix design: The concrete mix proportions were designed in accordance with TCVN 9340:2012 for normal-weight concrete [10], with reference to the technical guidelines issued under Decision No. 778/1998/QĐ-BXD, the material proportions for 1 m^3 of B20 concrete were determined as shown in Table 1.

Infill masonry materials: non-fired concrete bricks in accordance with TCVN 6477:2016, Concrete masonry units, were used for the test specimens [11]. Two brick sizes were adopted: solid bricks of 40×80×180 mm and hollow bricks of 80×80×180 mm.

Water: the mixing water complied with TCVN 4506:2012, water for concrete and mortar – Technical requirements [12]. Based on comparison of the specified criteria, domestic tap water supplied by the Vinh Long Water Supply Company was selected for casting the test specimens.

Table 1. Mix proportions for B20 concrete.

Material	Mass (kg)	Bulk density (T/m^3)	Equivalent volume (liters)	Equivalent volume (m^3)
Sand	648	1.4	907.2	0.46
Cement	365	1.2	438	
Crushed stone	1219	1.41	1718.8	0.86
Water	198	1	198	

2.2. Design of test specimens

Specimen 1 (frame K1): the RC frame was designed with columns having dimensions 120×120×820 mm, using B20 concrete. Each column was reinforced with four longitudinal bars of ϕ8 and stirrups of ϕ6 at 100 mm spacing. The beams had a cross-section of 120×150 mm and a span of 2000 mm, reinforced with four longitudinal ϕ8 bars and ϕ6 stirrups with spacing a = 50–100 mm. The concrete cover for both beams and columns was 20 mm, as shown in Figure 3.

Specimen 2 (frame K2): the RC frame was designed with the same configuration as frame K1. The infill material consisted of non-fired solid bricks of size 40×80×180 mm (grade B5) laid with cement–sand mortar of grade B5, as shown in Figure 4.

Specimen 3 (frame K3): the RC frame was designed with the same structural configuration as frame K1. The infill material consisted of non-fired hollow bricks of size 80×80×180 mm (grade B5) laid with cement–sand mortar of grade B5, as shown in Figure 5.

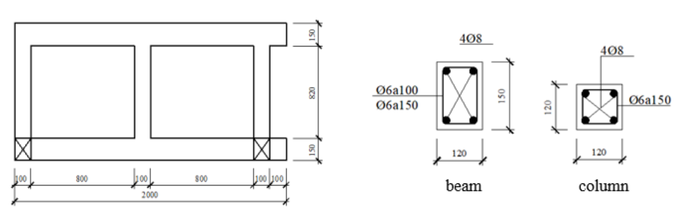


Figure 3. Frame K1 (RC frame without infill wall).

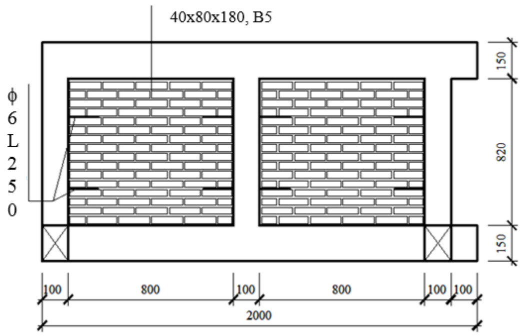


Figure 4. Frame K2 – RC frame with infill wall of non-fired solid bricks 40 × 80 × 180 mm.

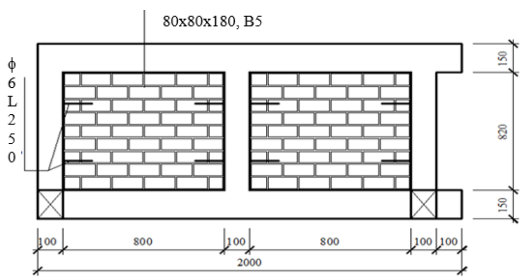


Figure 5. Frame K3–RC frame with infill wall of non-fired hollow bricks 80 × 80 × 180 mm.

2.3. *Fabrication of specimens*

Figure 6. Installation of formwork and reinforcement for the base beam and columns.

Figure 7. Installation of formwork and reinforcement and casting of concrete columns.

Figure 8. Installation of formwork and reinforcement and casting of the beam at the top of the columns.

For frame K1, the formwork and reinforcement were assembled (Figure 6), and then concrete was cast for the lower transverse beam at the column bases and for the columns (Figure 7). After 7 days from casting, the formwork for the beam at the top of the columns was installed (Figure 8), and the concrete was cured in accordance with the relevant standards.

Figure 9. Frame K2 after construction of the infill wall with non-fired solid bricks 40 × 80 × 180 mm.

Figure 10. Frame K3 after construction of the infill wall with non-fired hollow bricks 80 × 80 × 180 mm.

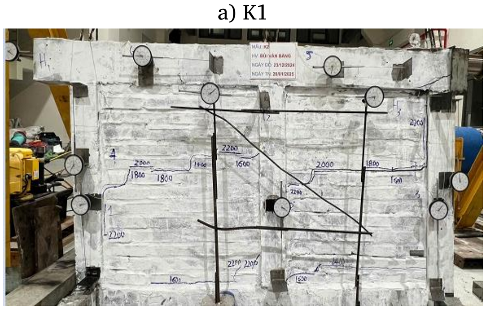
Figure 11. Frame after casting the upper beam.

For frames K2 and K3, the RC frames were constructed as follows: the formwork and reinforcement were assembled (Figure 6), and concrete was cast for the lower transverse beam at the column bases and for the columns (Figure 7). After 7 days of curing, the formwork was removed and the infill masonry walls were constructed according to the design (Figures 9 and 10). Subsequently, the formwork for the beam at the top of the columns was installed (Figure 11), and the concrete was cured in accordance with the relevant standards.

2.4. Installation of testing instruments in the two-span frame

Three lateral displacement gauges were installed at the tops of the three columns, three deformation gauges at the column bases, two deformation gauges at the column tops, and two deformation gauges at the midspan of the two beam segments (Figure 12).

a) K1



b) K2 and K3

Figure 12. Installation of instruments on beams and columns.

3. Results and discussions

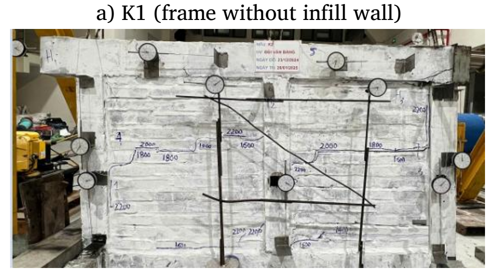
3.1. Crack initiation and propagation in the frames

The formation and propagation of cracks in the frames are illustrated in Figure 13.

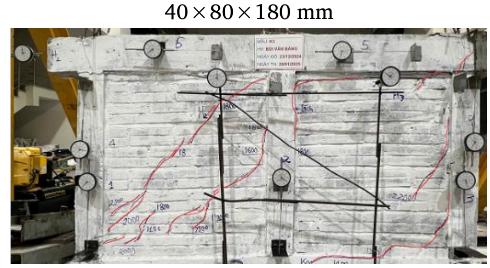
Frame K1 developed the first crack at a load level of 40 kN and failed at 50 kN. Frame K2 started to crack at 50 kN and failed at 110 kN, while frame K3 exhibited its first crack at 60 kN and also failed at 110 kN. These results show that the bare frame without infill developed cracks and damage much earlier than the frames with non-fired brick infill. The load-carrying capacity of the frame increased by about 2.2 times when non-fired infill bricks were used.

The number of cracks observed in K3 was greater than in K2. In K2, cracks were mostly confined to and propagated along the mortar joints, predominantly in the horizontal direction. In contrast, in K3 the cracks propagated along inclined paths at an angle of about 45° and cut through the hollow bricks.

a) K1 (frame without infill wall)



b) K2 (RC frame with infill wall of non-fired solid bricks $40 \times 80 \times 180$ mm

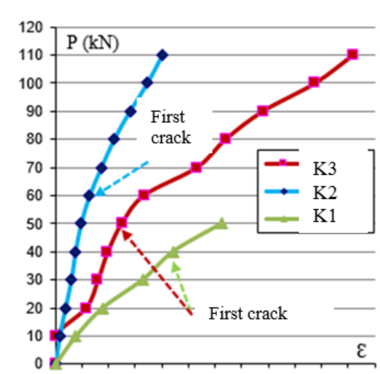


c) K3 (RC frame with infill wall of non-fired hollow bricks $80 \times 80 \times 180$ mm)

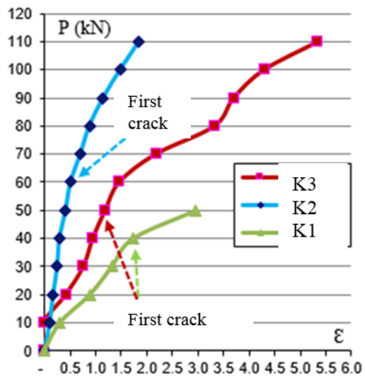
Figure 13. Crack initiation and propagation in the frames.

3.2. Load–strain relationship

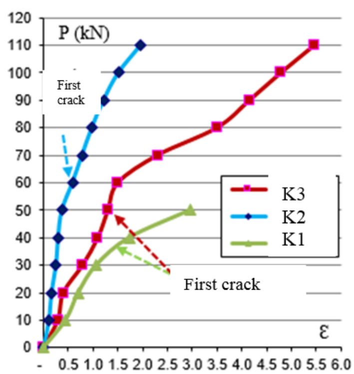
3.2.1. At the base of the left column (Figure 14a), the middle column (Figure 14b), and the right column (Figure 14c)



a) base of the left column



b) base of the middle column

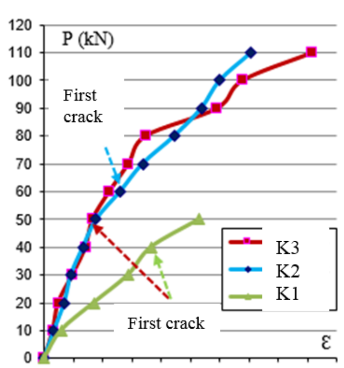


c) base of the right column

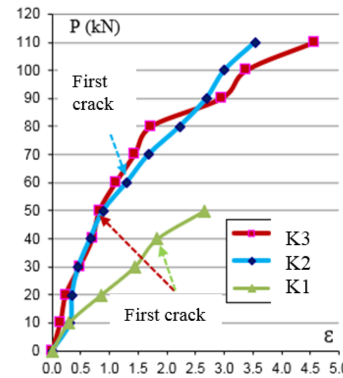
Figure 14. Load–strain relationship at the bases.

When the applied load was below 60 kN, the strain at the column bases differed by about a factor of 2 between the frames. At the failure load level of 110 kN, the strain in the frame with hollow brick infill was three times larger than that in the frame with solid brick infill for the two-span RC frame. These results indicate that the strain at the column bases is strongly influenced by the type of infill wall in the two-span frame.

3.2.2. At the top of the left column (Figure 15a) and the right column (Figure 15b)



a) top of the left column

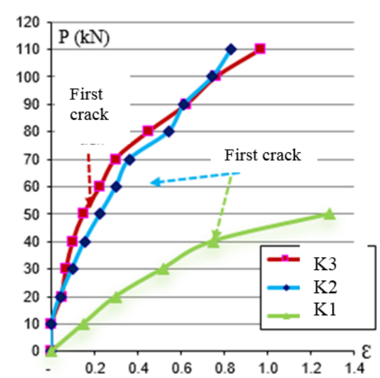


b) top of the right column

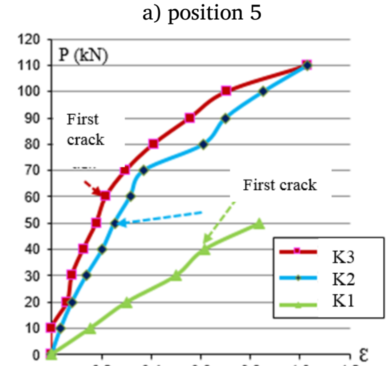
Figure 15. Load–strain relationship at the tops of the columns.

The strains at the tops of the columns were almost identical for both types of infill, i.e., hollow bricks and solid bricks. At the load level of 50 kN, the strain in frame K1 without infill was three times higher than that in the frames with infill walls. These results demonstrate that the strain at the column tops is primarily influenced by the presence or absence of infill walls and is only slightly affected by the type of infill material.

3.2.3. At the mid-span of the beams (Figure 16)



a) position 5

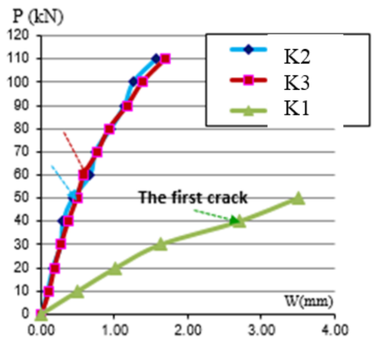


b) position 6

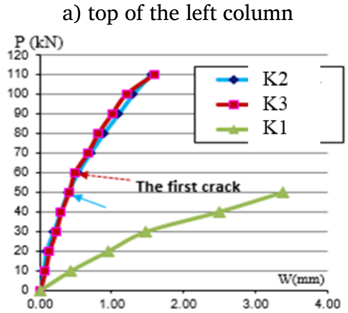
Figure 16. Load–strain relationship at the mid-span of the upper beams.

Similar to the strain at the tops of the columns, the strain at the mid-span of the two beam segments is only slightly affected by the type of infill material. The results mainly indicate that frame K1 without infill walls exhibits significantly larger strain.

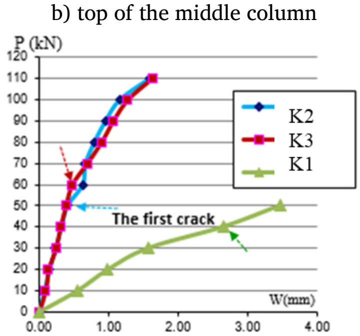
3.3. Load–displacement relationship at the tops of the columns (Figure 17)



a) top of the left column



b) top of the middle column



c) top of the right column

Figure 17. Load–displacement relationship at the tops of the columns.

When solid non-fired bricks were used as infill, the lateral displacement of the frame decreased by a factor of 8.4, and when hollow non-fired bricks were used, the lateral displacement decreased by a factor of 8.9 compared with the bare frame without infill at the load level of 50 kN.

4. Conclusions

The experimental results show that masonry infill walls in two-span RC frames using non-fired solid and hollow bricks approximately double the load-carrying capacity of the frame compared with the frame without infill. The strains in the frame were about 2–3 times higher than those in the infilled frames, and the infill wall with solid bricks produced fewer cracks than the wall with hollow bricks.

When non-fired bricks of size $40 \times 80 \times 180$ mm were used, the lateral displacement of the frame was reduced by a factor of 8.4, and when non-fired bricks of size $80 \times 80 \times 180$ mm were used, the lateral displacement was reduced by a factor of 8.9 compared with the bare frame at the load level of 50 kN, which corresponds to the failure load of the frame without infill walls.

The type of infill brick has a significant influence on the behavior at the column bases, while its effect is relatively small at the tops of the columns and at the beam sections above the walls.

The study indicates that non-fired brick infill walls, in addition to providing enclosure, also enhance the load-carrying capacity, increase the stiffness of RC frames, and contribute positively to environmental sustainability.

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