Behaviour of ACB Masonry In-Filled RC Frame under Cyclic In-Plane Lateral Load

T. M. Prakash, B. G. Naresh kumar, and Karisiddappa

***Abstract*—An attempt has been made to evaluate the performance of ACB masonry in-filled RC frame under cyclic in-plane lateral load. The frame itself was detailed with reinforcement conforming to ductile detailing as per the Indian standards. The specimen tested was a geometrically half-scale model and constructed as per conventional construction practice adopted in India. This means that the RC frame was cast initially, and later the masonry in-fill was provided without making any efforts to induce any structural connection between MI and RC frame interfaces. Obviously, the top of the masonry in-fill and the soffit of the beam remains the first plane of weakness. This also means that the popular diagonal strut action may not be mobilized fully. This should set the guiding principle for any attempt to develop an analytical model for the estimation of failure load. The details of the experimental set-up, the cracking and failure mode of the system and the significance of the experimental response are presented in detail.**

***Index Terms*—ACB masonry, in-filled RC frame, lateral load, diagonal strut, stiffness.**

I. Introduction

Masonry in-filled RC framed structures have become one of the most popular structural systems for multi-storeyed buildings, especially in the urban context. It offers a wide range of relative advantages. Here three relative advantages are highlighted:

1) Bare RC frame can be constructed at a faster rate and later the in-fill can be introduced.
2) Provision for flexibility in plan forms.
3) Provision of open ground storey which is generally used as parking spaces in the urban context.

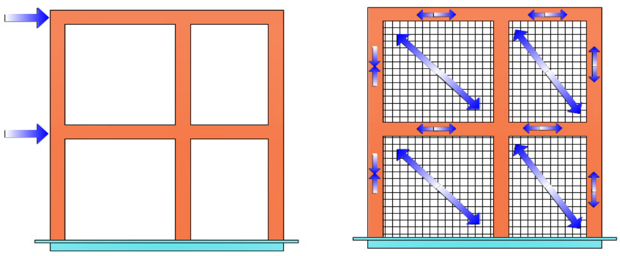
Very often the strength, stiffness and load carrying capacity of the in-fill material is seldom considered in the design of such MI–RC framed systems. If the in-fill material is heavy, it only adds to the self-weight and reduces the structural efficiency. On the other hand, if the in-fill material is light in weight and relatively stiff, then the structure becomes more efficient in resisting the lateral loads. One such in-fill material which possesses both the above-mentioned properties is ACB masonry. There is scanty information regarding the behaviour of ACB masonry in-filled RC frames under lateral in-plane loads, although there is significant information on the performance of brick masonry in-filled RC frames.

II. Earlier Studies

The first study on the behaviour of masonry in-fill (MI) was by Bryan Stafford Smith [1]-[4] wherein he idealized the effect of MI as a diagonal strut and after a series of experiments, and analysis had proposed a method to evaluate the width of the diagonal strut to be used in the analysis of RC frames. Abolghasem Saneinejad and Brian Hobbs [5] developed a design methodology to calculate the strut stiffness.

A. Influence of Masonry In-Fill Walls

Significant experimental and analytical research effort has been made in understanding the behaviour of masonry in-filled frames. In-fills interfere with the lateral deformations of the RC frame; separation of frame and in-fill takes place along one diagonal and a compression strut forms along the other. Thus, in-fills add the lateral stiffness to the building. The structural load transfer mechanism is changed from frame action to predominant truss action (Fig. 1), the frame columns now experience increased axial forces but with largely reduced bending moments and shear forces.



(a) (b)

Fig. 1. Change in the lateral load transfer mechanism owing to inclusion of masonry in-fill walls: (a) frame action in bare frame and (b) predominant truss action in in-filled frame.

B. Construction of Half-Scale Model

In the present investigation, a geometrically half-scaled single-bay single-storeyed RC frame has been constructed and tested. The RC frame of dimension 2.1m×1.6m outer to outer dimension and inner clear dimension of 1.9m×1.4m is constructed to fit within in the loading frame for testing. The model is constructed within a loading frame of 2000kN capacity for testing. The details are given in the following section. The ACBs of dimension 200mm (breadth), 200mm (depth) and 600mm (length) were used. Later, these ACBs were sawn using wooden saw manually to required length and breadth. For mortar, zone-II river sand and OPC 53-grade cement are used. The masonry in-fill constructed

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with conventional stretcher bond.

C. Experimental Programme

The test set-up model is as shown in Fig. 2. The test set-up is made using jacks, dial gauge and proving ring. The small rigid steel plate is pasted at the top of column at the one end; the digital dial gauge is fixed at that end, and all the readings were noted down from the same end for both the loading directions. The jack and the proving ring of 50kN capacity were used to load the model. The jack and the proving ring are shifted to opposite side to apply the cyclic load.

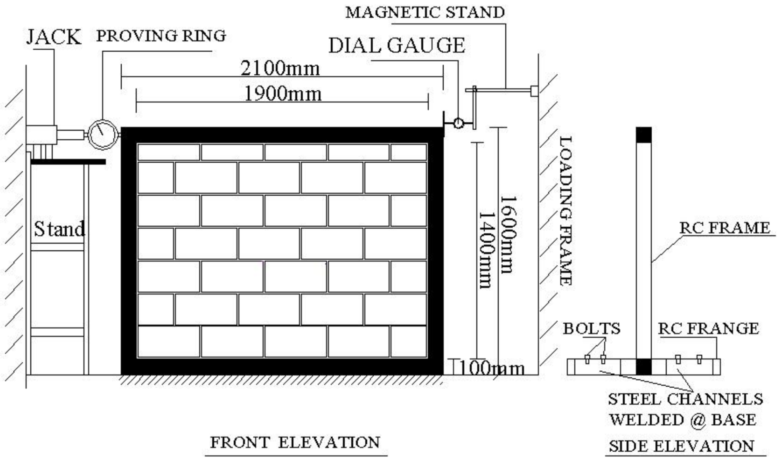

Fig. 2. Test set-up for ACB in-fill masonry RC frame for cyclic lateral in-plane loading.

D. Loading History for ACB In-Filled Masonry RC Frame

The model is tested under the 2000kN loading frame for reversed lateral in-plane cyclic loads. The model is subjected to lateral loads using jack which is mounted at top beam centre level, and the loads were recorded using a proving ring of 50kN capacity. The storey drift recorded using a digital dial gauge. The known increasing magnitudes of reversed cyclic in-plane lateral loads were applied up to the failure of the frame. The crack pattern and its progress were recorded and photographed. Fig. 3 shows the predetermined load history for the system.

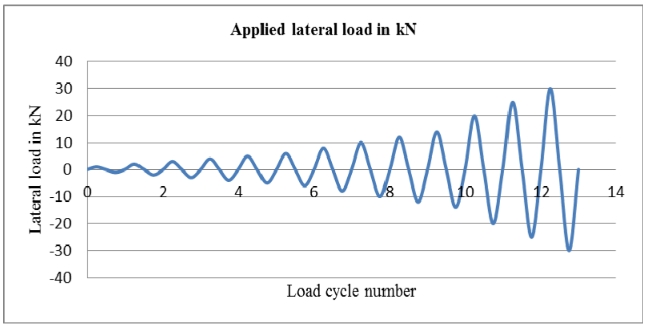

Fig. 3. Loading history for RC frames with ACB in-fill masonry.

E. Observations

During the first cycle, 1kN of load was applied at an interval of 0.2kN. The peak deflection was found to be 0.07mm. The effective stiffness was found to be 14.7kN/mm. During the 2nd cycle of load, the system went into slightly non-linearity after a deflection of about 0.07mm. During this cycle of load, there was a separation of masonry at the horizontal interface between the bottom of the beam and top of masonry. This crack also propagated vertically at the vertical interface between inner face of column and ACB masonry to a depth of about 2 courses. It was later observed that this crack sustained till the 11th (20kN) cycle. During the 11thcycle of load, there was a huge dissipation of hysteretic energy. The specimen went into a permanent offset. The summary of the load cycle is shown in Table I.

TABLE I: PEAK DEFLECTION AND EFFECTIVE STIFFNESS FOR EACH CYCLE OF LOAD

Load cycle	Load (kN)	Peak deflection (mm)		Effective stiffness (kN/mm)
		Positive	Negative	
1	1	0.06	–0.07	14.7
2	2	0.12	–0.15	12.658
3	3	0.09	–0.19	21.739
4	4	0.16	–0.24	18.867
5	5	0.23	–0.31	16.666
6	6	0.3	–0.37	16.666
7	8	0.4	–0.54	15.87
8	10	0.53	–0.73	14.93
9	12	0.75	–0.86	14.285
10	14	1.15	–1.18	11.36
11	20	2.96	–2.99	6.71
12	25	6.4	–5.67	4.03
13	30	24.53	–14.9	1.56

A combined plot of load–deflection of all the cycles of load is shown in Fig. 4.

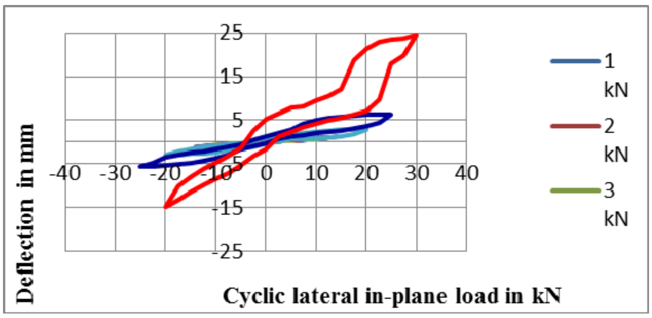

Fig. 4. Load vs. deflection curve for all the cycles.

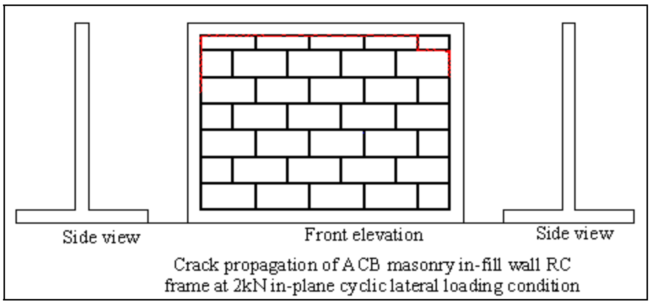

Fig. 5. Crack propagation at the2nd cycle.

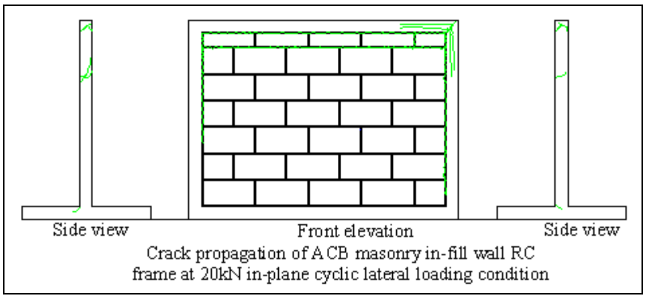

Fig. 6. Crack propagation at the 11th cycle

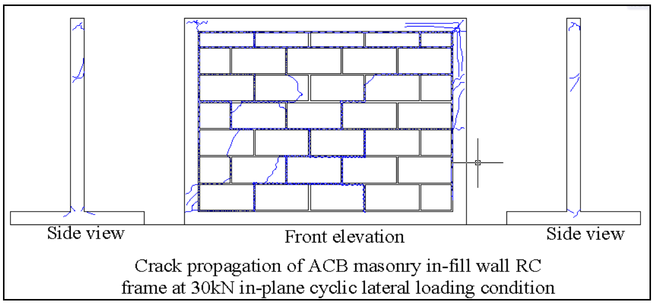

Fig. 7. Crack propagation at the 13th cycle.

F. Failure Pattern

During the 11th cycle, the beam–column junction at the one end started developing plastic hinges, and the cracks were noticed up to the point where the beam reinforcement was L-bent into the column. A minor crack appeared at the toe-end of the specimen. During the 12th cycle, the typical diagonal crack in the ACB masonry was noticed. During the 13th cycle, there was a diagonal crack in the other direction also. A few of the ACB units also developed cracks. During this cycle, crushing of concrete at both the toes was noticed. The specimen had almost developed the mechanism. It ceased to take any further load. It can be deemed that this corresponds to the failure load. Fig. 5, Fig. 6 and Fig. 7 show the sequence of failure patterns.

III. Conclusion

Based on the experiment on the half-scale model, the following broad sets of conclusions are highlighted:

1) The specimen withstood 13 cycles of reversed cyclic load with an increasing magnitude of peak load after each cycle. The specimen failed during the 13th cycle, primarily due to the development of a number of horizontal cracks and raking type of failure in in-fill masonry. A few of the light-weight masonry units also developed cracks, indicating the typical tensile splitting mode of failure. This is typical of string frame and relatively low-strength, high stiffness masonry.
2) The load–deflection response clearly indicates the significant dissipation of energy after each cycle of load, albeit the fact that the eventual failure was rather brittle in nature, perhaps again due to the high-stiffness and low-strength combination of ACB masonry.
3) Expectedly, the diagonal strut mode of failure was not mobilized, essentially because there was an inherent plane of weakness due to the construction practice. This leads to the formation of horizontal shear cracks in the RC columns along with plastic hinge formation at the junction of beam and column. A combination of these two leads to the raking failure of in-fill masonry.
4) During the second cycle of loading itself, a horizontal crack appeared at the soffit of the beam and hence the effective stiffness reduced during this cycle. Surprisingly, from the 3rd cycle onwards the participation of in-fill was very evident, which can be noticed from the significant increase in effective stiffness during the 3rd cycle. Later on there was a gradual reduction of stiffness in every cycle of loading. This non-linearity is extremely complicated to be handled in any of the conventional methods. Perhaps there is a need for modelling the in-fill masonry with a structural gap at the top of in-fill and soffit of the beam.

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