Influence of Methods of Construction on the Behaviour of Infilled Frames

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Summary - Lateral stiffness and strength of infilled frames having good bond at the interface of frame and infill are very much higher than those in which separation is allowed. To evolve a method of construction by which good bond can be achieved, four different types of construction are considered and eleven half-scale models of reinforced concrete frames with brick masonry infill with and without opening have been tested upto failure. It is recommended that the infill and frame be constructed in that order in stages to achieve perfect bond at the interface of frame and infill.

1. INTRODUCTION

From earlier investigations it is well known that lateral stiffness and strength of infilled frames having good bond at the interface of frame and infill are very much higher than those in which separation is allowed [1-5]. It has also been recommended to provide shear connectors at the interface of steel frames infilled with mortar panels. But it is observed by the earlier investigators and also some practising engineers have expressed that by the normal method of construction it is difficult to achieve a tight fit and required bond at the interface of reinforced concrete frame & brick masonry infill. Hence, some other construction procedures consistent with the current practice have to be developed. In this direction, in the present investigation an experimental study has been undertaken on eleven half-scale reinforced concrete frames with brick masonry infill with and without opening [6]. Four different types of construction are considered. One model in each type of infilled frame (solid, with window or door opening) under each type of construction has been tested upto failure and the results are reported.

2. MATERIALS USED

For the construction of infill panel, special quality 'wire cut bricks' (metric size) were used. Cement mortar of 1:3 proportion was adopted for the construction of masonry. Cement concrete of proportion $1:1\frac{1}{2}:3$ by weight was utilised for the construction of frames and lintels. 8 mm diameter ribbed steel as main steel and 3 mm diameter mild steel wire as stirrups were used for the reinforcement of frames. Physical and mechanical properties of materials used are summarised in Table 1.

3. METHODS OF CONSTRUCTION

Following four different types of construction were considered in the experimental investigation:

- Type I: Constructing the frame first and then the infill (i.e. the traditional method of construction)
- Type II: Constructing the infill first and then the frame.
- Type III: Similar to type II but with provision for joints similar to dove-tail shear connectors at the interface of frame and infill.
- Type IV: Similar to Type I, but the inner surfaces of the frame were oiled to avoid any bond between the frame and the infill.

4. TYPES OF INFILLED FRAMES

Three types of infilled frames were considered:

i) Solid infilled frames (4 numbers; one in each type of construction)

ii) Infilled frames with central window opening (4 numbers; one in each type of construction)

iii) Infilled frames with central door opening (3 numbers; one in each type of construction, except Type III).

5. CASTING OF SPECIMENS

Model infilled frames were constructed on 'back-to-back' principle. The infill in each half of the frame measured 135 cm x 135 cm x 10 cm surrounded by reinforced concrete frame members of 10 cm x 10 cm cross-section reinforced with 4 numbers of 8 mm diameter ribbed steel rods and 3 mm diameter stirrups spaced at 10 cm c/c. A central window opening (45 x 45 cm) or a central door opening (45 x 90 cm) was provided in the infill panel. Concrete lintel of 10 cm x 5 cm reinforced with 4 rods of 6 mm diameter and 3 mm dia stirrups at 10 cm c/c, was provided over the opening. Different stages of construction under different types of construction are shown in Fig.1.

6. INSTRUMENTATION AND TESTING

The specimens were instrumented to measure strains on the surface of the infill and the frame. Deflection was measured at the centre of the model which was tested on 'back-to-back' principle [1,5]. The model was loaded by a hydraulic jack and pump attached to a loading frame fixed to the main testing floor of the laboratory.

The test consisted of applying loads at 0.5 tonne intervals and then measuring strains, deflection and marking cracks, if any. Separation occurring at the interface of frame and infill was carefully observed at every increment of load and its development was traced in addition to other cracks developed in the infilled frame. The observed mode of failure and the corresponding crack patterns were also recorded.

7. DISCUSSION OF RESULTS

Load-deformation curves of model infilled frames of different types of construction are given in Fig.2 and 3 and typical modes of failure of Type I and II methods of construction are given in Fig.4.

From load deformation curves it is seen that in the elastic range not much of difference in the lateral deflection is found between Types II and III solid infilled frames but possess less deflection compared to Type I and IV. This trend is same in the case of infilled frames with window or door opening (Fig.3). Separation in Type I occurred at load higher than in Type IV but both failed almost at the same load. The corresponding failure modes are given in Table 2. Very few cracks were observed in the frame members and they did not extend into the infill due to separation at the interface of frame and infill.

In Type II and III, separation at the interface did not occur at all even at ultimate load in all the cases of infilled frames; namely, solid, window opening and door opening. This shows that in such types of construction, there exists good bond at the interface of frame and infill. Cracks which developed in the frame extended into the infill on the windward side of the frame showing the monolithic action of frame and infill in Type II and III methods of construction (Fig.4). Even the ultimate loads were much higher than those of Type I and IV. It is observed that of all the types of construction in all cases of infilled frames, Type II always resists the maximum ultimate load and possesses greater lateral stiffness.

8. CONCLUSIONS

Within the scope of the study made, the following conclusions can be drawn:

1. The natural bond existing at the interface of reinforced concrete frame and brick masonry infill in Type I method of construction is not sufficient to prevent separation at higher loads. In Type II and III methods of construction, separation was not observed even at ultimate loads. But separation occurred at early stages of loading itself in the case of type IV method of construction.
2. Infilled frames of Type II and III methods of construction behave similarly. As Type III demands extra care and poses more practical difficulties in providing shear keys around the interface, Type II method of construction is to be preferred.
3. As an alternative, to achieve perfect bond at the interface, it is suggested that the brick masonry may be built first and the reinforced concrete frame cast next using the masonry as part of formwork for concrete. To facilitate construction at the site, these two may be built in stages keeping the sequence of construction as suggested earlier.

REFERENCES

[1] H.K.BARUA, M.B.RAO and S.K.MALLICK: Behaviour of One-storey Reinforced Concrete Frame with Brick Masonry Infill under Lateral Loads - Journal of Structural Engineering, Roorkee, India, Vol.3, No.2, July 1975, pp 81-88.

[2] J.R.BENJAMIN and H.A.WILLIAMS: The Behaviour of One-storey Brick Shear Walls - Journal of Structural Division, A.S.C.E., Vol.84, ST4, July 1958.

[3] A.COULL: The Influence of Concrete Infilling on the Strength and Stiffness of Steel Frames - Cement and Concrete, Oct-Dec.1966, pp 162-169.

[4] T.C.LIAUW and S.W. LEE: On the Behaviour and Analysis of Multi-storey Infilled Frames subject to Lateral Loading - Proc. of The Institution of Civil Engineers, Part 2, Vol.63, Sept.1977, pp 641-656.

[5] D.V.MALLICK and R.P.GARG: Effect of Openings on the Lateral Stiffness of Infilled Frames - Proc. of The Institution of Civil Engineers, Vol.49, 1971, pp 193-209.

[6] R.JAGADISH: Studies on the Behaviour of Infilled Frames with Openings - Ph.D. Thesis, Indian Institute of Technology, Madras, India, Dec. 1981.

TABLE 1a

S.No.	Type of Infill	Type of Construction	Crushing Strength N/mm^2		Modulus of Elasticity N/mm^2		Relative Stiffness
			Concrete σ_{cu}	Brick masonry σ_{bw}	Concrete E_c	Brick masonry E_{bw}	λh
1	Solid	I	40.07	7.87	35633.2	5509.6	5.8124
2	Infilled	II	30.95	6.40	31309.2	4481.3	5.7011
3	Frame	III	33.70	7.08	32713.6	4952.6	5.7817
4		IV	37.30	6.89	34388.6	4823.6	5.6724
5	Infilled	I	35.34	7.87	33471.2	5509.6	5.9039
6	Frame with	II	32.95	6.40	32347.1	4481.3	5.6553
7	Window	III	37.07	7.08	34302.3	4952.6	5.7135
8	Opening	IV	29.45	6.89	30540.8	4823.6	5.8432
9	Infilled	I	36.75	7.38	34184.7	5166.9	5.7793
10	Frame with Door	II	31.40	7.08	31573.8	4952.6	5.8332
11	Opening	IV	41.18	8.07	36160.5	5649.6	5.8274

TABLE 1b

S.No.	Type of rod	Yield stress or Proof stress N/mm^2	Ultimate Strength N/mm^2	Modulus of Elasticity N/mm^2
1.	8 mm dia. ribbed Torsteel	450.8	597.8	0.255×10^6
2.	6 mm dia. round rods	343.1	492.0	0.191×10^6
3.	3 mm dia. mild steel wires	362.7	499.8	0.197×10^6

TABLE 2

S.No.	Type of Infilled Frame	Type of Construction	Load at separation (KN)	Load at first cracking (KN)	Ultimate load (KN)	Failure Mode
1	Solid Infilled	I	58.84	127.49	127.49	diagonal tension
2	Frame	II	..	122.58	166.71	,,
3		III	..	112.78	142.20	,,
4		IV	29.42	93.16	132.39	Crushing of frame at support. Premature failure
5	Infilled frame	I	39.23	44.13	73.55	diagonal tension
6	with	II	..	58.84	88.26	,,
7	window	III	..	49.03	83.36	,,
8	opening	IV	19.61	39.23	73.55	,,
9	Infilled frame with	I	19.61	24.52	53.93	Splitting tensile failure
10	door	II	..	29.42	73.55	,,
11	opening	IV	9.81	14.71	49.03	Splitting tensile failure followed by crushing

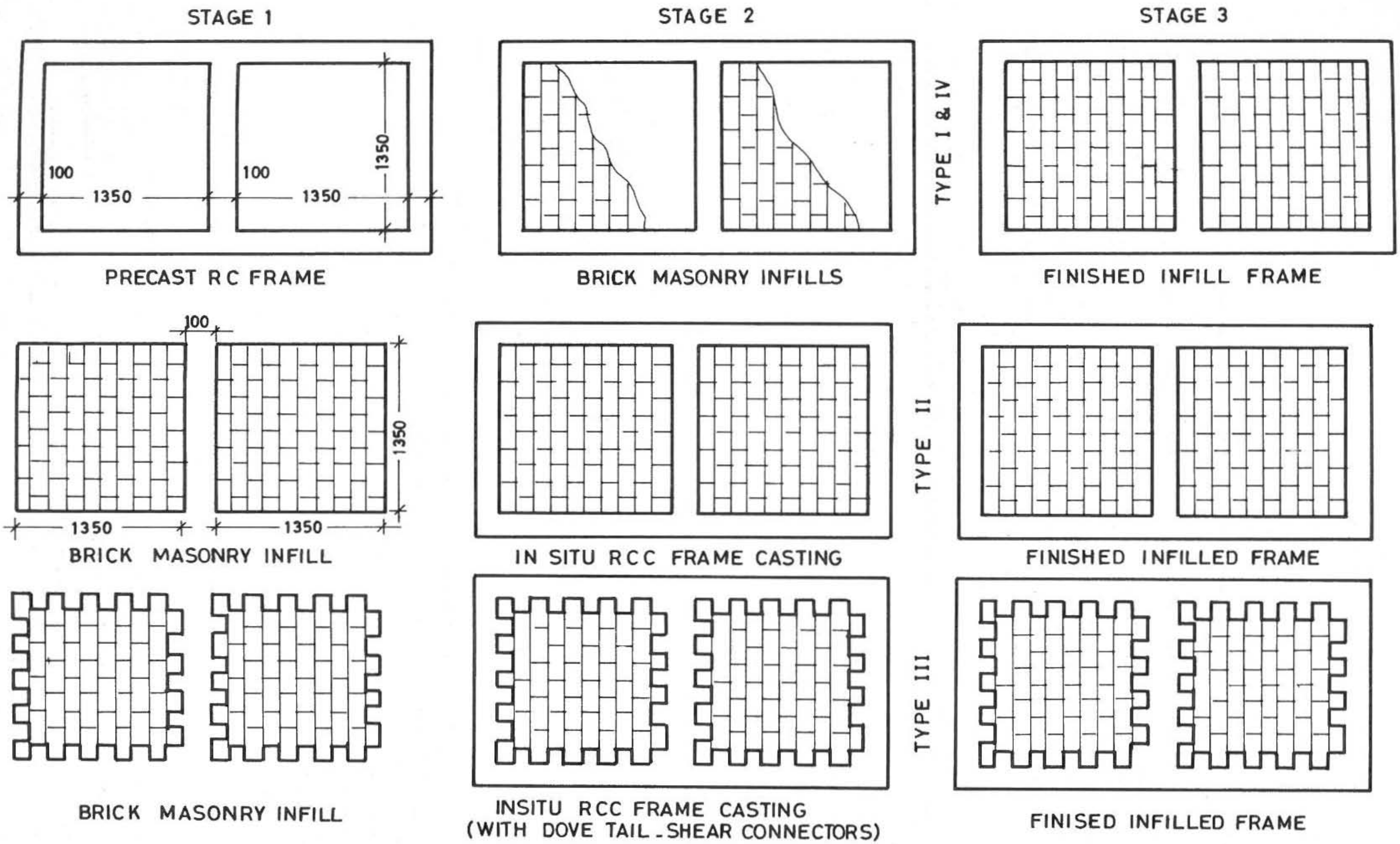


FIG. 1. DIFFERENT TYPES AND STAGES OF CONSTRUCTION.

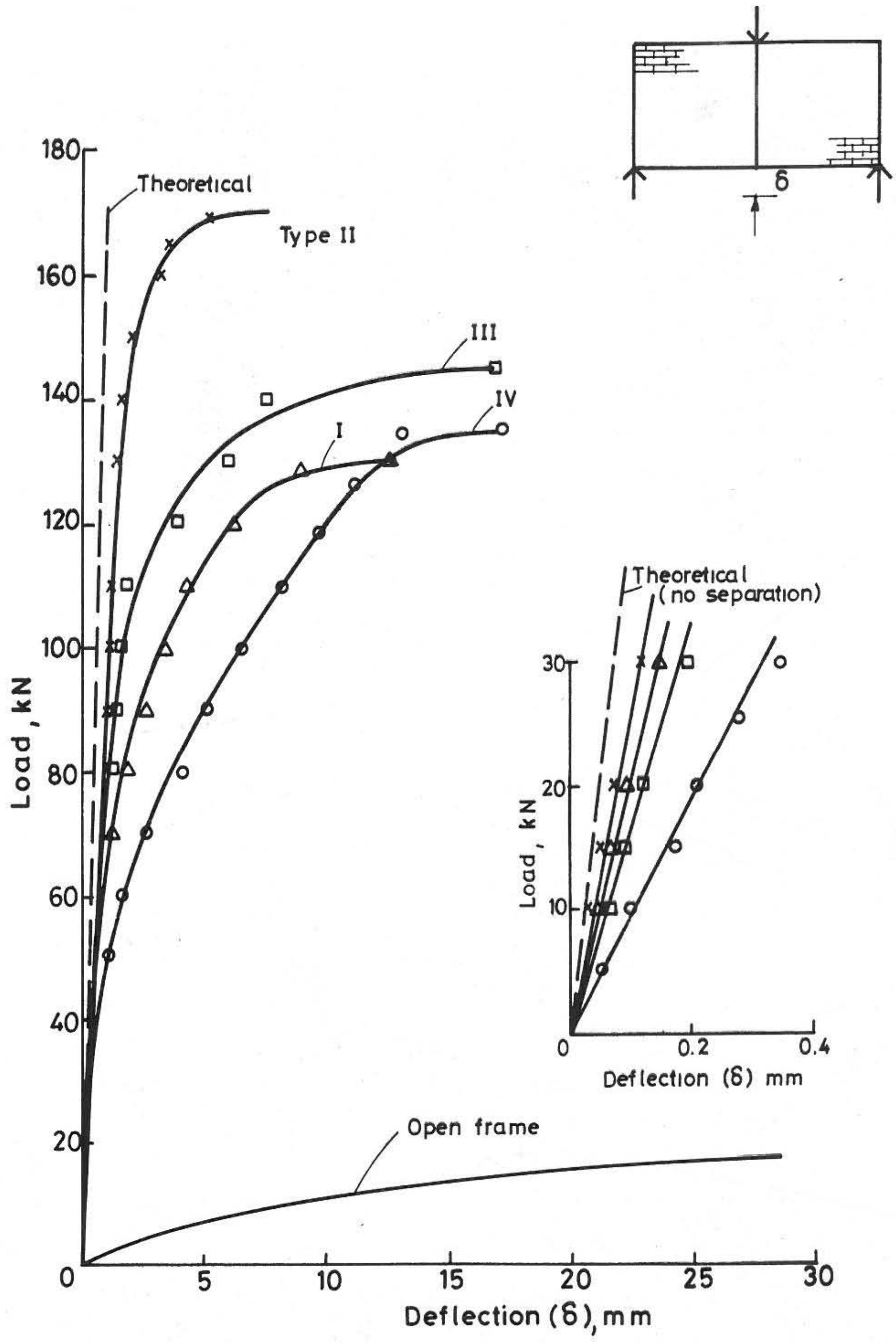


FIG. 2. EFFECT OF TYPE OF CONSTRUCTION ON THE BEHAVIOUR OF INFILLED FRAMES WITHOUT OPENINGS.

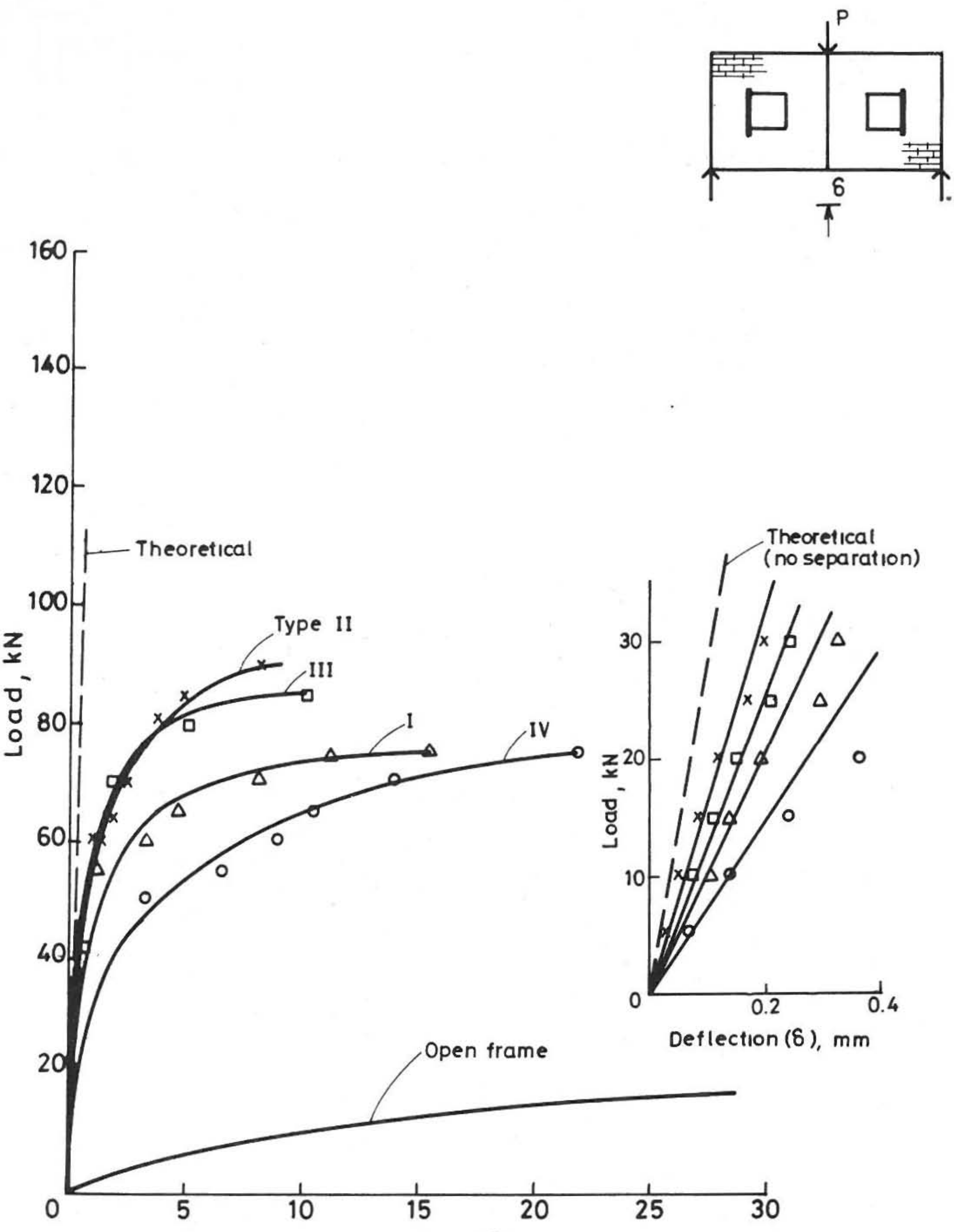
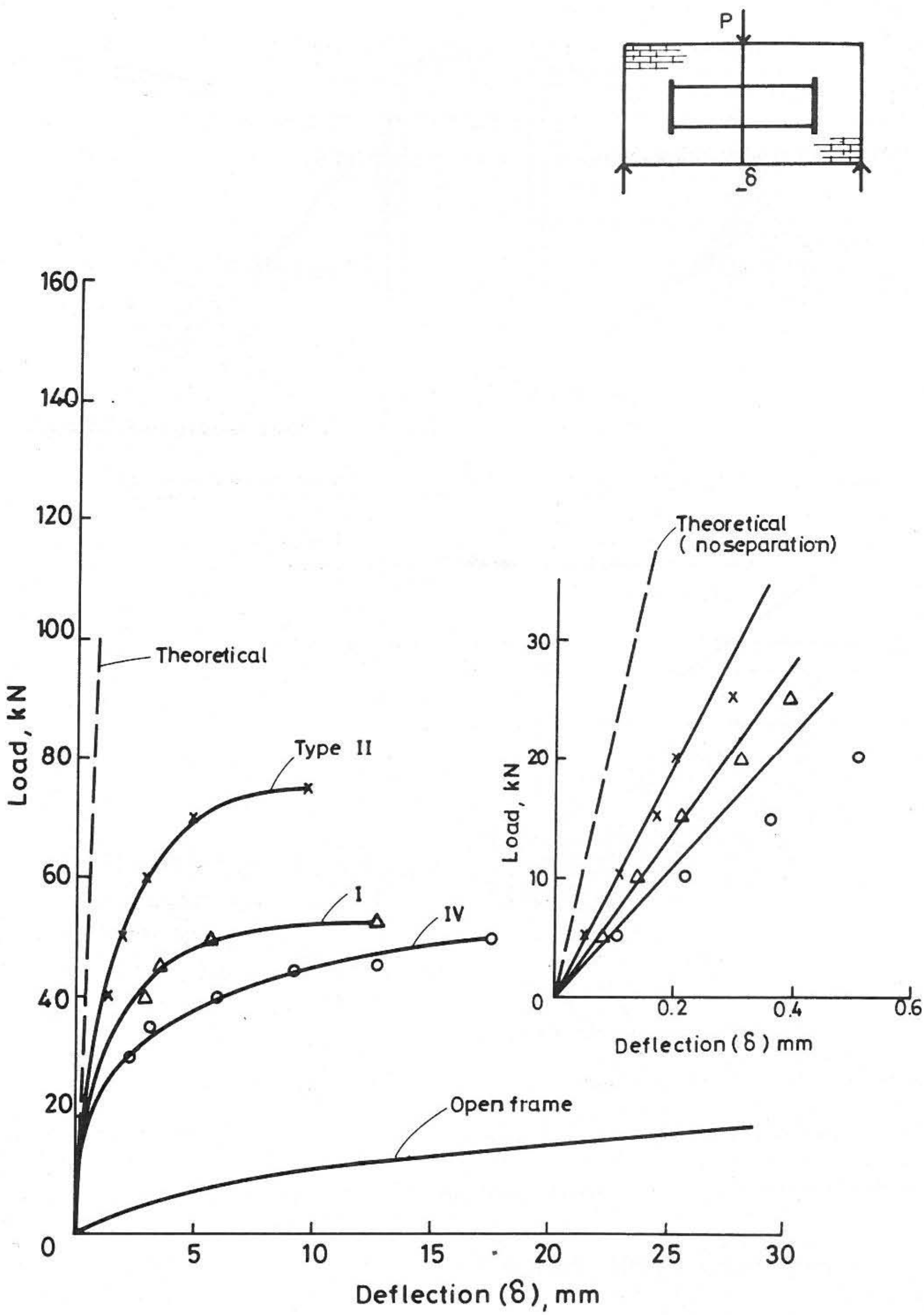


FIG. 3. EFFECT OF TYPE OF CONSTRUCTION ON THE BEHAVIOUR OF INFILLED FRAMES WITH WINDOW AND DOOR OPENINGS.



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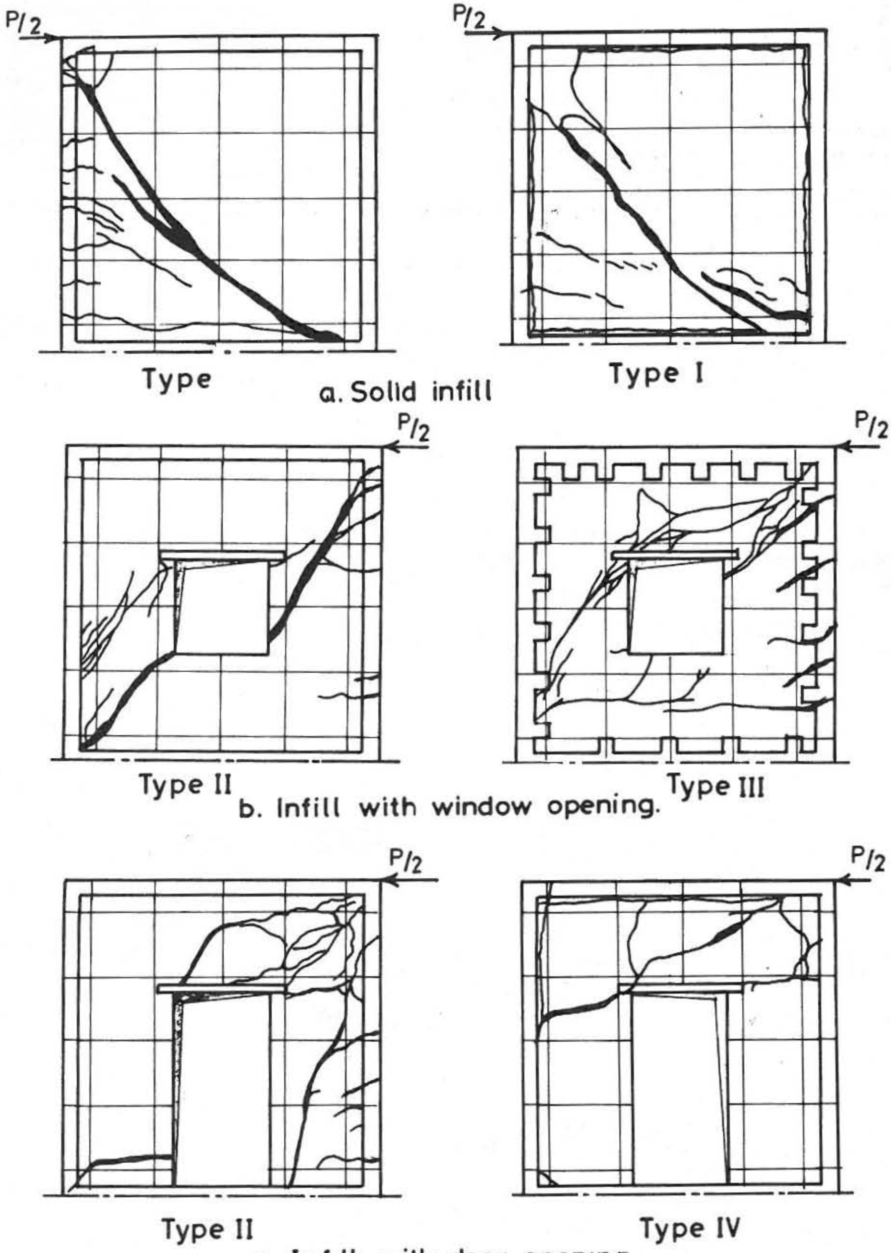

FIG. 4. FAILURE MODES OF INFILLED FRAMES.