THE BEHAVIOUR OF MASONRY INFILLED REINFORCED CONCRETE FRAMES SUBJECTED TO CYCLIC LATERAL LOADING

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SUMMARY

The behaviour of masonry infilled reinforced concrete frames subjected to cyclic lateral loading has been investigated. The effect of three different types of both unreinforced and reinforced infill on strength and ductility of the infilled frame has been studied. However, no significant effect of relatively small amount of horizontal infill reinforcement was observed. By means of this study, failure mechanisms have been defined and fundamental data for modeling the hysteretic behaviour of masonry infilled frame structures obtained. Simple formulae for calculation of the hysteresis envelope are proposed.

INTRODUCTION

In this paper the behaviour of masonry infilled reinforced concrete stiff frames, subjected to cyclic horizontal loading is discussed. An attempt has been made to define the phenomena of interaction between the reinforced concrete frame and various types of masonry infill, i.e. to obtain fundamental data for modeling the hysteretic behaviour of masonry infilled frame structures. Simultaneously the effect of infill reinforcement on strength and ductility of the infilled frame has also been studied.

DESCRIPTION OF TESTS

The series of tests reported here represents the first part of a two-year research project. Four types of specimens constructed in 1:2 reduced scale have been tested within this study:

- reinforced concrete frame with no infill (M1);
- reinforced concrete frame with unreinforced infill (M2);
- reinforced concrete frame with horizontally reinforced infill (M3);
- reinforced concrete frame with horizontally reinforced infill, anchored into the frame (M4).

Dimensions and configuration of specimens, as well as position of reinforcement, are shown in Fig.1.

M 15 grade concrete and deformed bars were used for construction of frame, and normal format perforated bricks laid in 1:1:6 (lime:cement:sand) mortar and plain bars for construction of infill. The mechanical properties of constituent materials are given in Table 1.

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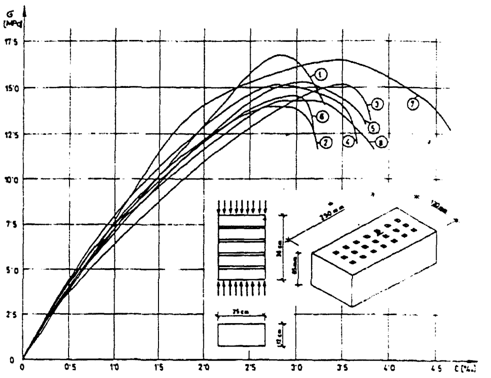
Table 1: Mechanical Properties of Constituent Materials

Reinforcement	Yield stress (MPa)	Strength (MPa)	$\delta_{10\%}$
ČBR 40-2 ø16 mm	456	750	16.4
ČBR 40-1 ø 8 mm	551	760	22.8
ČO 200 ø 6 mm	300	471	26.7
Concrete	Compressive strength (MPa)	Elastic modulus (MPa)	
	15.4	17 900	
Brick	Compressive strength : 28.5 MPa		
Mortar 1:1:6	Compressive strength Cube(MPa)	Compressive strength Prism(MPa)	Bending strength (MPa)
	11.5	12.9	2.8
Wall	Compressive strength (MPa)	Elastic modulus (MPa)	Shear modulus (MPa)
	15.2	8000	630



The specimens were fixed into the the testing floor and subjected to constant vertical load, acting on each column (100 kN) and cyclic horizontal load, acting on the beam. Horizontal load was applied by means of two hydraulic actuators, acting alternatively on either side of the beam. The test set-up is shown in Fig.2.

During the tests, the deformations of specimens were measured by means of LVDT-s, and strains of reinforcement by means of strain gauges. Specially designed electric resistance dilatometers were used for measuring the strains of masonry infill.

ANALYSIS OF TEST RESULTS

Relationships between the horizontal load and horizontal displacements at the mid-height of the beam, expressed also in terms of storey drift angle, are presented in Fig.3. The experimentally obtained hysteresis envelopes are compared to the calculated one in Fig.4.

The relationships between the horizontal load and strains of main frame reinforcement are shown in Figs.5 and 6, the relationships between the horizontal load and strains of infill reinforcement in Figs.7 and 8, and the relationships between the horizontal load and strains of infilled wall in Figs.9 and 10.

Finally, typical crack patterns after failure of specimens are presented in Fig.11.

Test results are synthesized in Table 2, where horizontal loads and displacements at visible cracking as well as the ultimate loads of all four tested specimens are presented.

Studying the propagation of cracks and comparing the measured horizontal load-strain relationships, especially the hysteresis envelopes of horizontal load-strains of main frame reinforcement, as shown in Fig.6, the mechanism of interaction between the frame and masonry infill can be defined. Before the occurrence of diagonal cracks in the infill, both reinforced concrete frame and masonry infill are acting monolithically, forming a unique structural system. After diagonal cracking of the infill, i.e. after the lateral resistance of the infill is reached, its contribution to the lateral resistance of the system is not diminished. The frame takes over a significant part of the lateral load, until its columns fail in shear.

Following this mechanism, an attempt has been made to predict the hysteresis envelope by calculation. Taking into account the mechanical properties of materials as given in Table 1, estimating the equivalent cross-sectional area of the infilled panel, and using the equations for calculation the lateral resistance and stiffness of masonry walls, as given in Ref.3, satisfactorily good correlation between the calculated and measured hysteresis envelopes has been obtained (Fig.4).

As it can be seen from test results, no significant effect of relatively small amount of horizontal infill reinforcement on the lateral resistance and ductility of the infilled frames has been observed. An increase of lateral resistance has only been obtained by means of anchoring the infill reinforcement into the frame.

CONCLUDING REMARKS

The following conclusions can be drawn when analyzing the test results:

-when subjected to cyclic lateral loading, masonry infilled reinforced concrete stiff frame behaves as an unique structural system until diagonal cracks occur in the infill. After cracking, the contribution of the infill to the lateral resistance of the infilled frame system is not diminished. However, the frame takes over a significant part of the lateral load, increasing the lateral resistance of the system, until its columns fail in shear.

-based on the observed failure mechanism, simple formulae for calculation of hysteresis envelope have been proposed, and sufficiently good correlation between the measured and calculated values obtained.

-no significant effect of relatively small amount of horizontal infill reinforcement (ρ=0.2%) on the lateral resistance and ductility of the infilled frame was observed. An increase in lateral resistance only has been obtained by means of anchoring the infill reinforcement into the frame.

ACKNOWLEDGEMENT

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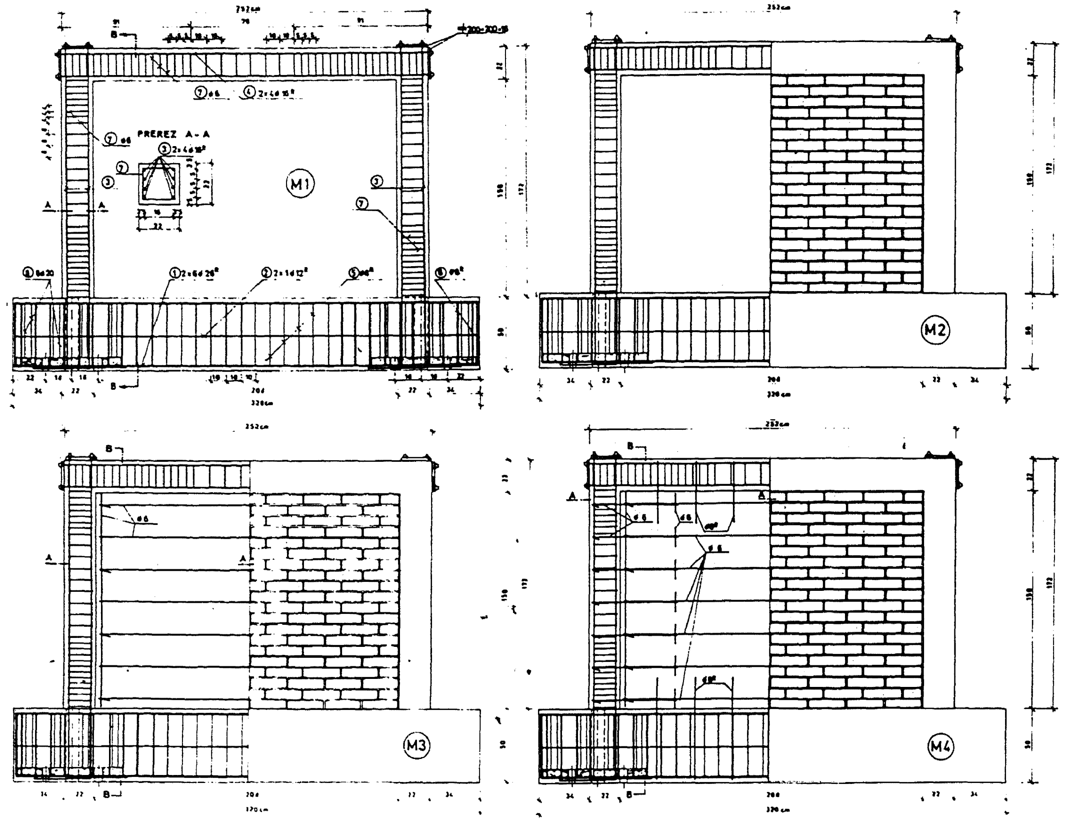


Fig.1 Configuration and Dimensions of Test Speciments

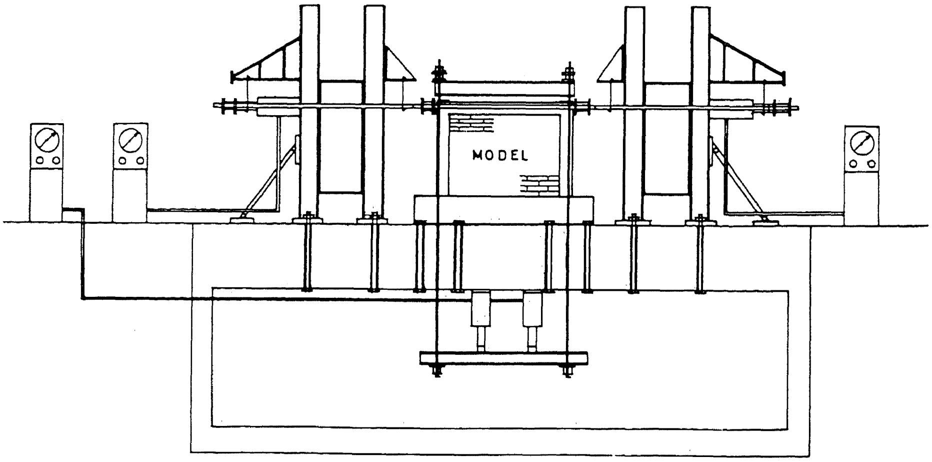
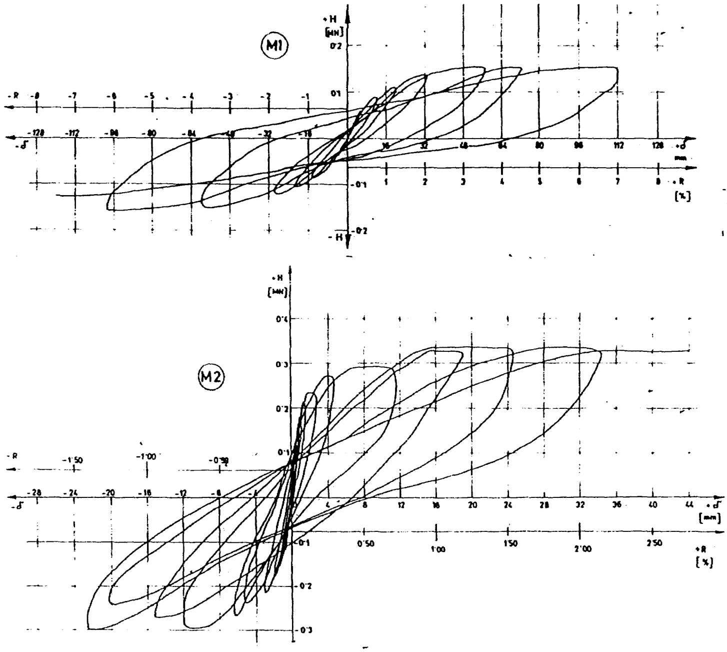


Fig.2 Test Set - Up



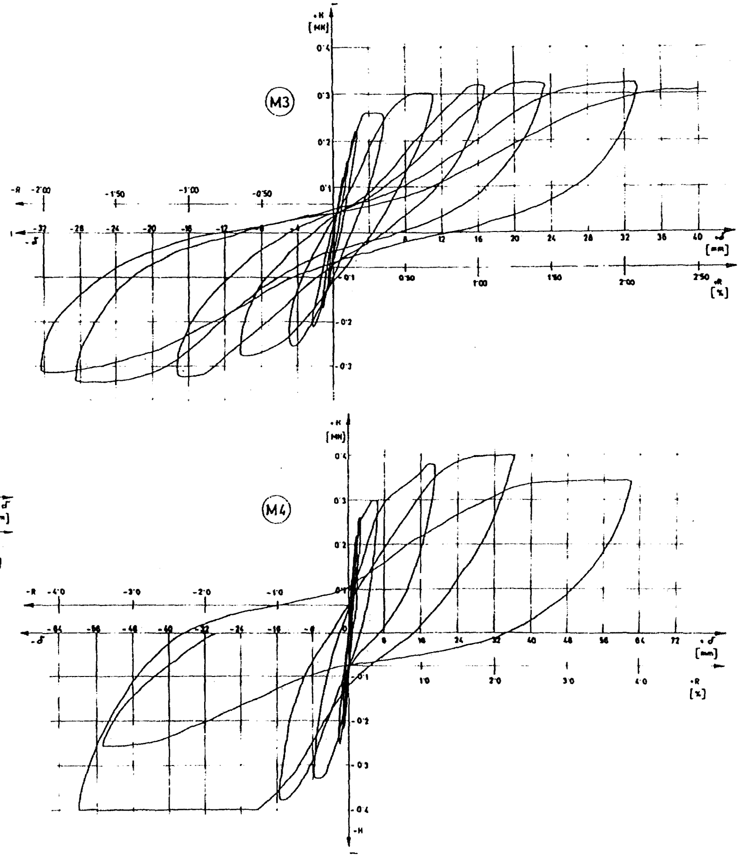


Fig.3 Horizontal Load - Displacements Relationships

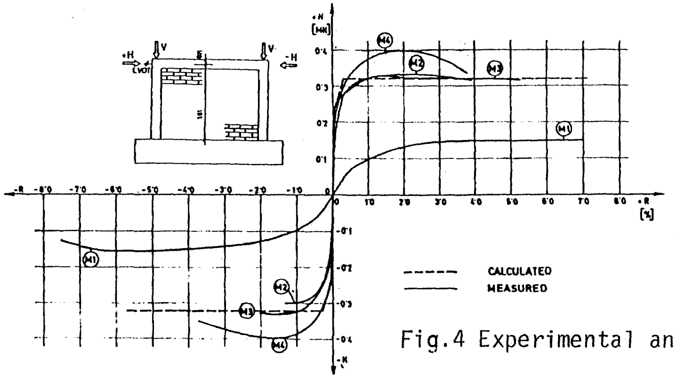


Fig.4 Experimental and Calculated Hysteresis Envelopes

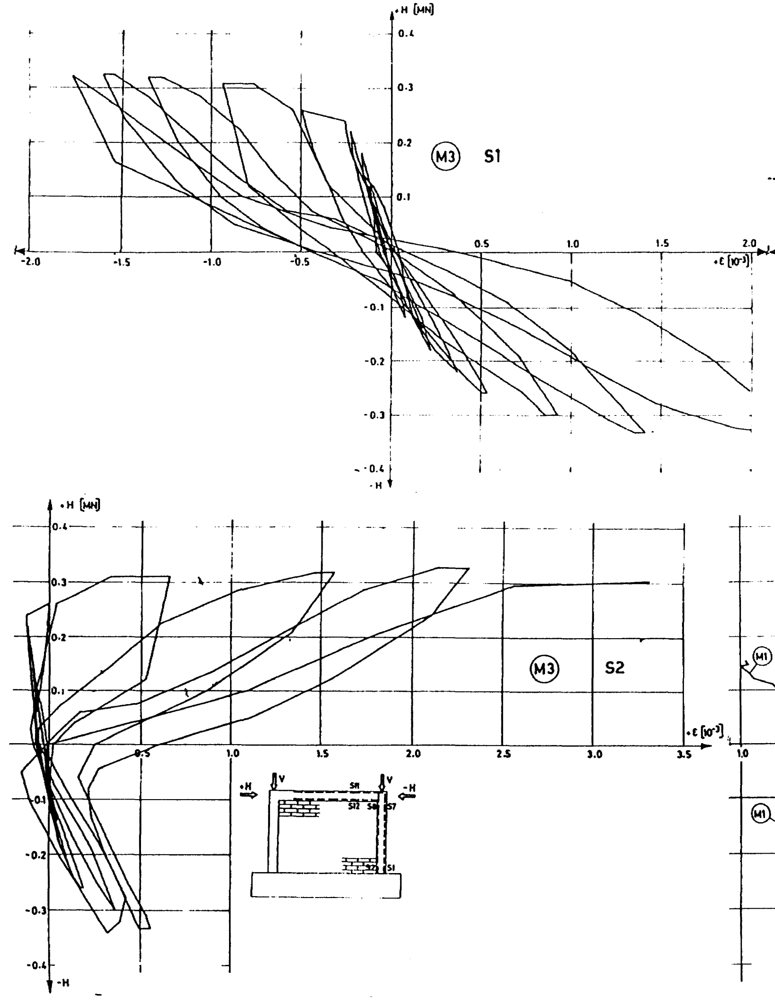


Fig.5 Horizontal Load - Column Reinforcement Strain Relationships

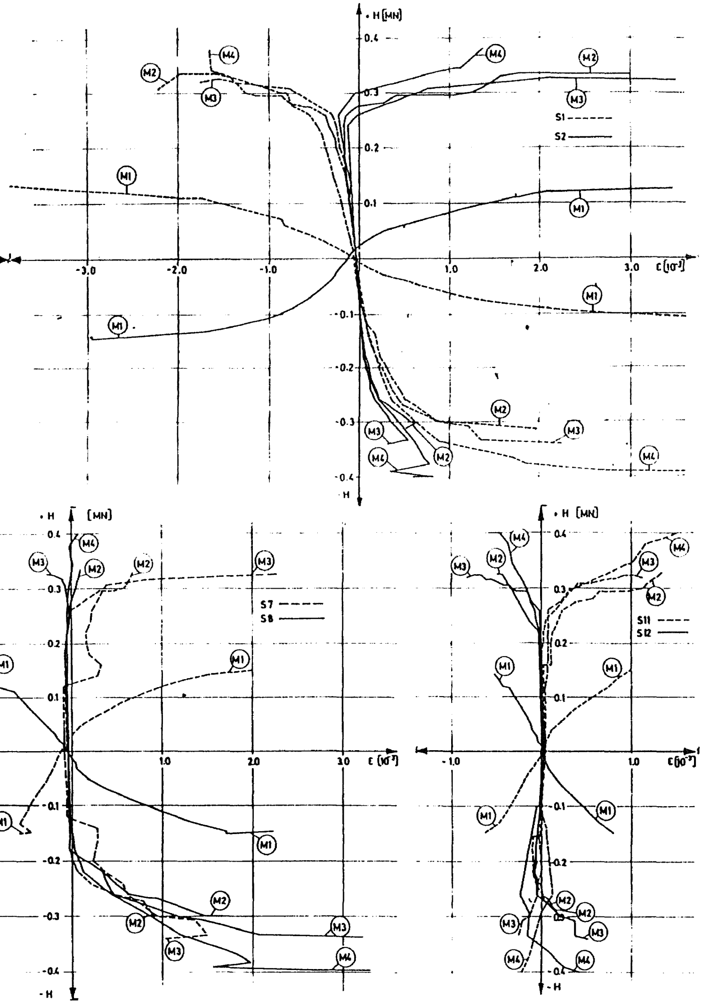


Fig.6 Horizontal Load - Column Reinforcement Strain Hysteresis Envelopes

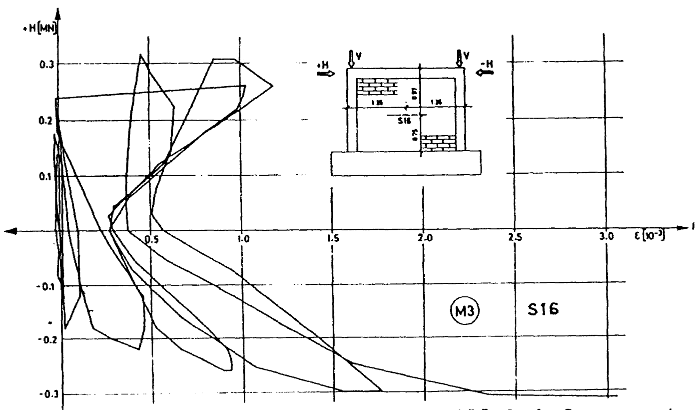


Fig.7 Horizontal Load - Infill Reinforcement Strain Relationships

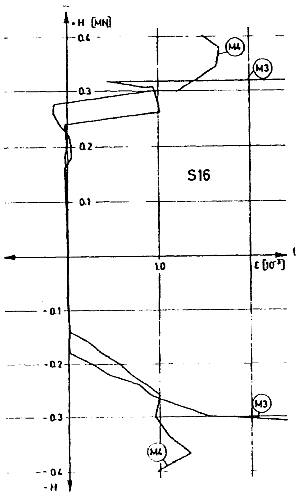


Fig.8 Horizontal Load - Infill Reinforcement Strain Hysteresis Envelopes

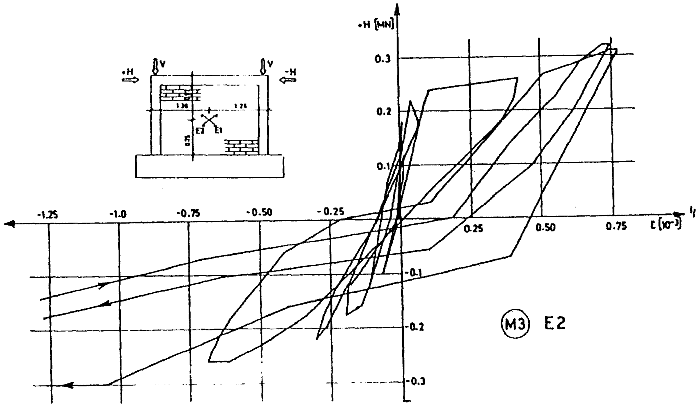


Fig.9 Horizontal Load - Infill Wall Strain Relationship

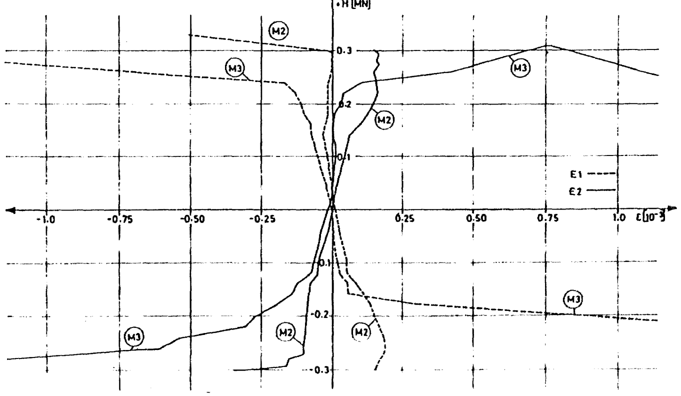


Fig.10 Horizontal Load - Infill Wall Strain Hysteresis Envelopes

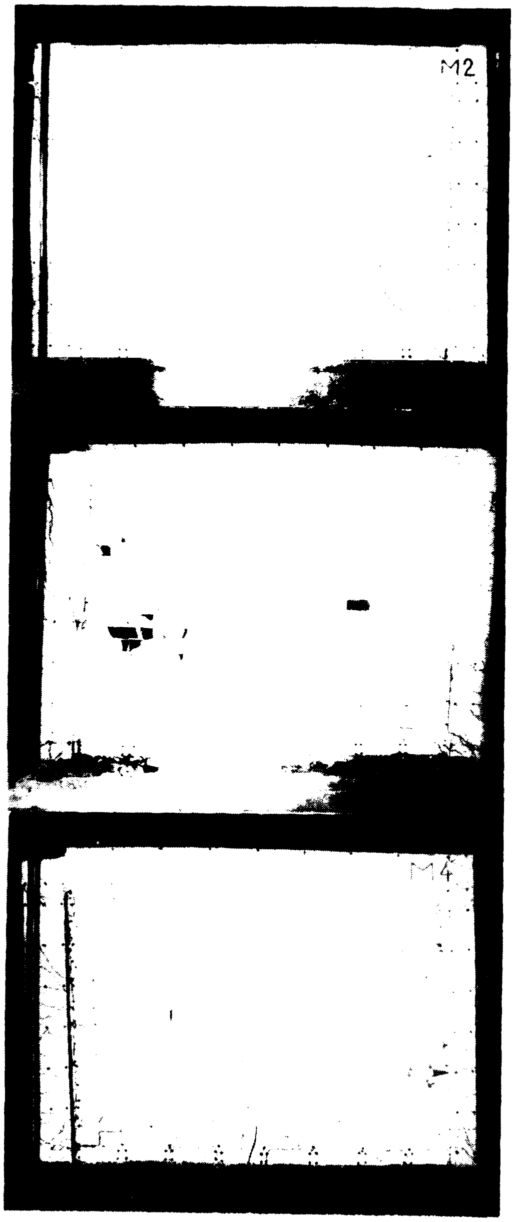


Fig.11 Crack Pattern after Failure

Table 2 Test Results

	Specimen				Cal.
	M1	M2	M3	M4	
Cracking Load H_{cr} (kN)	60	240	260	260	240
Displacement at cracking δ_{cr} (mm)	4.3	1.8	3.3	2.7	0.7
Ultimate Load H_u (kN)	151	335	340	398	324

APPENDIX

Calculation of Idealized Hysteresis Envelope

Cracking Load:

$$H_{cr} = A_w \frac{f_{t,w}}{b} \sqrt{\frac{\sigma_o}{f_{t,w}} + 1}$$

$$\sigma_o = \frac{3}{2} \frac{H_{cr}}{A_w} \frac{h_w}{l_w}$$

Ultimate Load:

$$H_u = H_{cr} + A_s f_y$$

Initial Stiffness:

$$K = \left(\frac{h^3}{3E_w I_e} + \frac{\kappa l_w}{G_w A_e} \right)^{-1}$$

$$A_e = 2A_c \frac{G_c}{G_w} + A_w$$

Stiffness After Cracking:

$$K_{cr} = \frac{24E_c I_c}{h^3}$$

where:

A_w, A_c, A_s - cross-sectional area of masonry infill, column, and active transverse reinforcement, respectively,

A_e - effective cross-sectional area of infilled frame,

E_w, E_c - elastic modulus of masonry infill and concrete, respectively,

G_w, G_c - shear modulus of masonry infill and concrete, respectively,

I_e - effective moment of inertia of infilled frame,

I_c - moment of inertia of one column,

$f_{t,w}$ - tensile strength of masonry infill,

f_y - yield stress of transverse reinforcement.