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The behaviour of infilled reinforced concrete frames under horizontal cyclic loading

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ABSTRACT: This paper reports an experimental work, concluded at National Laboratory for Civil Engineering at Lisbon, aiming at analysing the behaviour, under horizontal cyclic loading, of reinforced concrete frames infilled with brick masonry walls.
Seven models in a scale of 2:3 were tested, of which six consisted of one-storey, one-bay reinforced concrete frames infilled with brick masonry walls and one consisted of the bare frame. Alternated horizontal displacement were imposed at the level of the beam centerline and vertical forces were applied at the top of columns. Materials and construction-techniques normally used in Portugal were applied.

1 INTRODUCTION

The importance that infill walls (usually considered non-structural elements) may have as regards the overall behaviour of buildings with reinforced concrete frames is a fact stated by many authors. Several experimental and analytical works developed with the major aim of studying phenomena of interaction between infill walls and frames are already available (E. Vintzeleou 1987).

This paper presents the results of an experimental study carried out at LNEC (Felicita Pires 1990) aiming at analysing the behaviour, under alternated horizontal actions, of reinforced concrete frames infilled with brick masonry walls as usual in Portugal.

2 MODELS AND TESTING PROCEDURE

The experimental models consisted of a series of six (M2 to M7) one-storey, one-bay reinforced concrete frames in a scale of 2:3 infilled with brick masonry walls of the type usual in Portugal. One bare frame (M1) was used as reference model.

The influence of the following parameters was investigated:

- Connection conditions between the reinforced concrete frame and the infill.

  In three models (M2, M3 and M6), the reinforced concrete frame was built before the wall, contrary to what occurred with the remaining three (M4, M5 and M7) whose frame was built after the construction of the wall which served as a lateral form work.

- Anchorage conditions of the longitudinal reinforcement of beam to columns.

  In five models (M1, M2, M5, M6 and M7), this anchorage was done complying with the development lengths defined in the Portuguese Code for Reinforced and Prestressed Concrete Structures (REBAP 1983) for the restrained connections whereas in the remaining models (M3 and M4) the anchorage adopted does not comply with those lengths.

- The existance of hoops at the frame joints and spacing of hoops and stirrups in zones contiguous to the joints.

  In frames of models M1, M2, M5, M6 and M7 hoops were placed at the joints and spacing of hoops and stirrups was reduced at the ends of beams and columns, whereas in frames of models M3 and M4 joints were not provided with hoops and spacing of transverse reinforcement remained constant along the beams and columns.

- Longitudinal reinforcement ratio in columns.

  Columns in models M6 and M7 were reinforced with half the longitudinal bars used in the other models.

- Mechanical characteristics of masonry infills.

  Although all infills were built with 30 cm x 20 cm x 15 cm horizontal hollow bricks, usual in Portugal, bedded using mortars with the proportion 1:4 in volume (cement: river sand), following good construction practice, as a result of large dispersion of results of the mechanical

TABLE 1 - MECHANICAL CHARACTERISTICS OF MATERIALS

Material	Strength (MPa)	Models						
		M1	M2	M3	M4	M5	M6	M7
Bricks	Compressive strength		3.5					
Mortars	Compressive strength		6.3	6.5	7.4	8.9	9.9	8.6
Masonry	Compressive strength		2.1	2.1	2.2	2.2	2.5	2.2
	Shear strength		0.27	0.27	0.41	0.50	0.51	0.41
Concrete	Compressive strength	33.1	28.3	33.2	38.5	32.5	35.2	31.2
Reinforcing Bars Ø4.0 mm	Ultimate strength	552						
Reinforcing Bars Ø8.0 mm	Ultimate strength	519						

TABLE 2 - COMPARISON BETWEEN PARAMETERS OF STRENGTH AND DEFORMABILITY OF INFILLED AND BARE FRAMES

Model	Maximum strength $\frac{r_{máx\,Mn}}{r_{máx\,M1\,or\,M1'}}$	Initial stiffness $\frac{K_{o\,Mn}}{K_{o\,M1}}$
M2	3.0	23.1
M3	2.6	22.0
M4	3.9	51.3
M5	4.7	67.9
M6	5.4 *	51.5
M7	6.2 *	60.1

* Strength of models M6 and M7 was compared with that of fictitious model M1' whose strength was assumed to be 28% lower than that of model M1 under test.

TABLE 3 - CAUSES FOR EARLY INTERRUPTION OF TESTS ON MODELS M4 TO M7

Model	Half-cycle	Causes for early interruption of tests
M4	38	Shear failure at base of column P1
M5	30	Shear failure at top of column P2
M6	38	Bending failure of column P1 at 3/8 height measured from the base
M7	31	Shear failure at base of column P1 between 5/8 and 3/4 height, measured from the base.

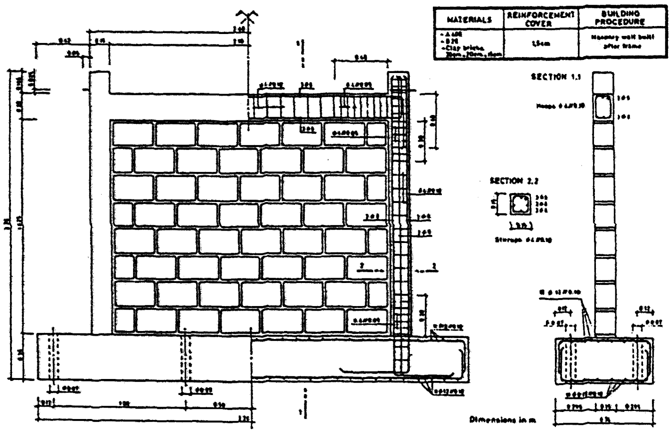

Fig. 1 - Model M2. Geometrical characteristics and reinforcements

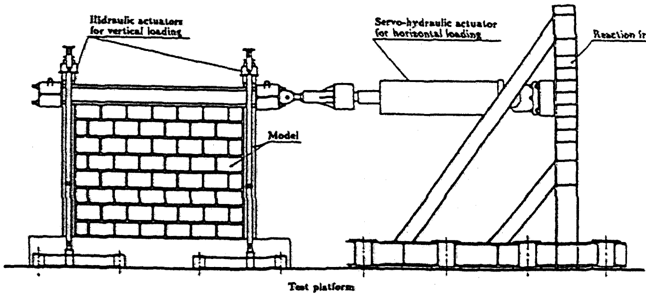

Fig. 2 - Scheme of the test set-up

characterization tests on masonries, it became necessary to consider the influence of mechanical characteristics over models behaviour.

The mechanical characteristics of the materials used are given in Table 1. Fig. 1 illustrates the geometry and reinforcement of concrete elements of model M2.

Upon the beam centerline of the models a "history" of alternate symmetrical displacements was imposed up to failure of columns or up to the maximum displacement foreseen of $\delta = 100$ mm. Before beginning each model test, a 100 kN vertical load was applied at the top of columns. Fig. 2 illustrate the test set-up used. The assessment of the behaviour of the frames was performed on the basis of failure mechanisms, strength, initial stiffness and energy dissipation.

3 TEST RESULTS AND CONCLUSIONS

Tests results are illustrated by the envelopes of the horizontal force-displacement (F-δ) diagrams, which are grouped in accordance with the construction procedure used (Fig. 3). Fig. 4 illustrate the horizontal force-displacement (F-δ) diagrams of model M2 whose frame was built before the wall and of model M5 whose frame was built after the construction of the wall.

Table 2 makes a comparison between some strength and deformability parameters of the models with infilled frames (M2 to M7) and the same parameters for the models with bare frame (M1 and M1'). M1' stands for a fictitious model, that reproduces the behaviour of frames of models M6 and M7 whose strength was estimated at 28 % below that of model M1, on account of the lower percentage of longitudinal reinforcement of its columns.

From the analysis of tests results the following main conclusions may be drawn:

- *Failure mechanisms*

  In general, after the first cracking occurred in the infill, it became divided into two zones which behaved as two or three compressed "bars", one oriented along the diagonal of the infill and the position of the others varying according to the evolution of cracking in that element.

  The construction procedure for the models conditioned the failure mechanisms. A more marked tendency to brittle failure by shear in columns was found in models in which frames were concreted against the infill wall (Table 3).

- *cracking in models*

  In general it can be noticed that the construction procedure and the shear strength of the infills influence the level of distortion at the first cracking.

  The differences in the reinforcement of the models did not appear to influence the first cracks.

- *Maximum strength*

  The parameters that influenced the maximum strength of models were the construction procedure and the shear strength of the infills.

  Differences in the reinforcement of frames did not appear to influence their maximum strength.

- *Initial stiffness*

  The initial stiffness basically depends on the shear strength of the infills. The constructios procedures used for the models also influences such parameter.

  Reinforcement differences in the model frames did not appear to influence their initial stiffness.

Results of this experimental study made possible to conclude that the infills always have influence on the behaviour of frames, which may be positive or negative.

The influence of the infills may be positive when their presence, in addition to increasing significantly the energy dissipating capacity and the strength of reinforced concrete frames, also permits that those structures reach so high distortion levels as those that might occur if the infills did not exist, without failure of columns. This behaviour was observed on the models whose infills were built subsequently to the frames and where simultaneously the corresponding masonry showed less shear strength.

The influence of the infills may be negative when, owing to their interaction with the frame, they induce shear failure in columns, the more so as its location is difficult to forseen.

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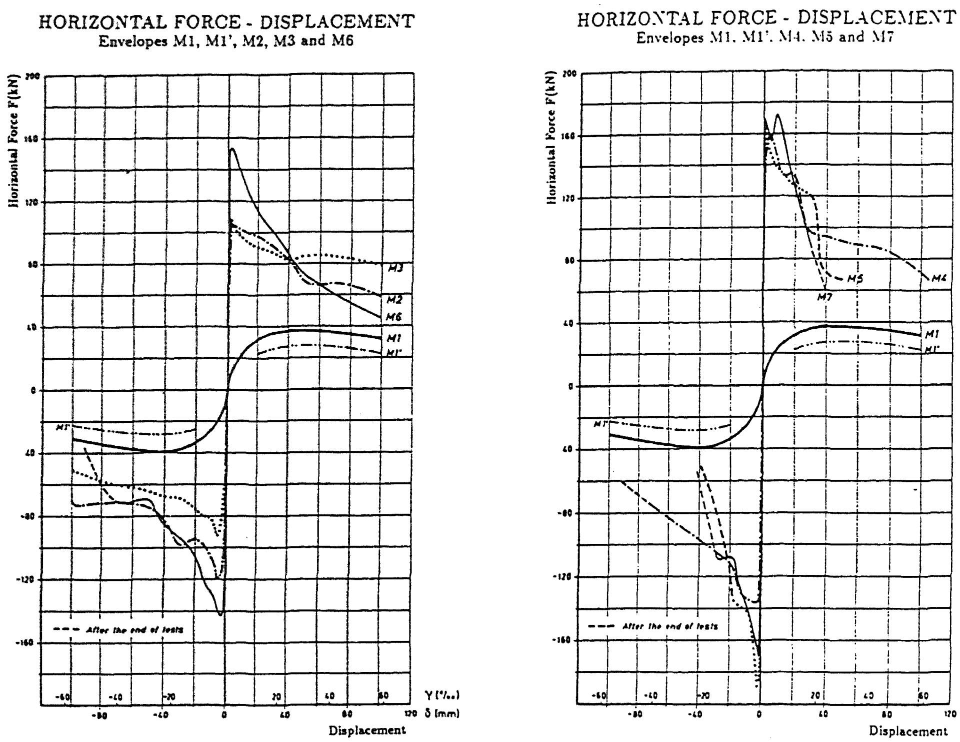

Fig. 3 - Models M1 to M7. Envelopes of diagrams (F-δ)

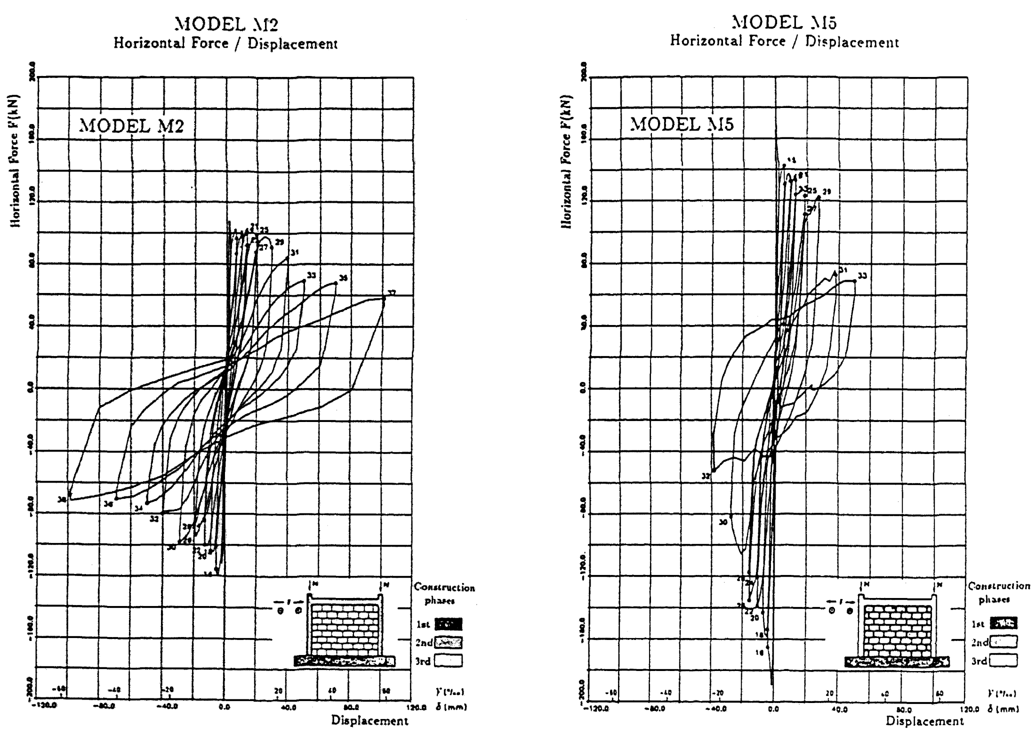

Fig. 4 - Models M2 and M5. Horizontal force-displacement diagrams (F-δ)