The 13th Edition of TIMIŞOARA ACADEMIC DAYS

THE BEHAVIOUR OF RC FRAMES WITH MASONRY INFILL

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- TIMIķOARA, 24 MAY 2013 -

ABSTRACT

- This paper presents an experimental study on the behaviour of the masonry infilled reiforced concrete frames subjected to horizontal loads, as compared with bare frames.

- As the masonry infill walls have an important influence on the total shear resistance of the whole structural system, this direction of research is of major interest.

- The walls of the tested frames were made from three different masonry unit types: cellular concrete blocks, ceramic blocks with vertical hollows and solid bricks.

- Conclusion: the structural system consisting of reinforced concrete frame and masonry infill wall is a **wall-equivalent dual system.**

INTRODUCTION

ž From the classification of structural systems according to EN 1998-1-2004 (Eurocode 8), the following systems were taken into account in the present study :

1. **Frame system,** ñin which both the vertical and lateral loads are mainly resisted by spatial frames whose shear resistance at the building base exceeds 65% of the total shear resistance of the whole structural systemò;

2. **Dual system,** ñin which support for the vertical loads is mainly provided by a spatial frame and resistance to lateral loads is contributed to in part by the frame system and in part by structural walls, coupled or uncoupledò.

- According to the above-mentioned classification there are two different types of dual systems:

2a. **Frame-equivalent dual system**, ñn which the shear resistance of the frame system at the building base is greater than 50% of the total shear resistance of the whole structural systemò;

2b. **Wall-equivalent dual system**, ñn which the shear resistance of the walls at the building base is greater than 50% of the total shear resistance of the whole structural systemò

- The present study has the aim to find the proper system for RC frames with masonry infill, according to upper classification.

- The reported experimental program refers to a reinforced concrete frame with one span and one level, tested either as a reference frame, i.e. a frame without masonry infill, or as a frame provided with a masonry infill wall.

- The described structures were loaded with vertical and alternating horizontal forces, applied in the frame plan. The shear resistance and the drift were measured in each case.

EXPERIMENTAL PROGRAM

ž Two different reinforced concrete frames were tested:
- a reference frame without reinforcement for masonry anchorage (Fig.1);
- a frame with horizontal reinforcement bars for coupled masonry.

Fig. 1 Reference frame

ʓ The uncoupled infill walls were made of three different masonry unit types:
- cellular concrete blocks (Fig.2);
- ceramic blocks with vertical hollows;
- solid bricks.

Fig.2 Cellular concrete masonry infill wall

- The coupled infill walls were erected using two different masonry unit types:

- ceramic blocks with vertical hollows (Fig.3);
- solid bricks (Fig.4).

Fig.3 Ceramic blocks with vertical hollows masonry infill wall

Fig.4 Solid bricks masonry infill wall

TEST RESULTS

- The mechanical properties of the materials:

  Mortar (7 days age):

  - the compressive strength : fc = 93.5 N/mm^2;

  - bending tensile strength: ft = 0.82 N/mm^2.

  Concrete:

  - properties are presented in Table 1.

Concrete properties — Table 1

Age	7 days	28 days
Density ρ_c, kg/m^3	2,341	2,285
Compressive strength fcm, N/mm^2	22.9	33.2

- The graphic representations of experimental horizontal load versus deflection at the top of the frame are illustrated in **Figure 5** and **Figure 6** for all six tests.

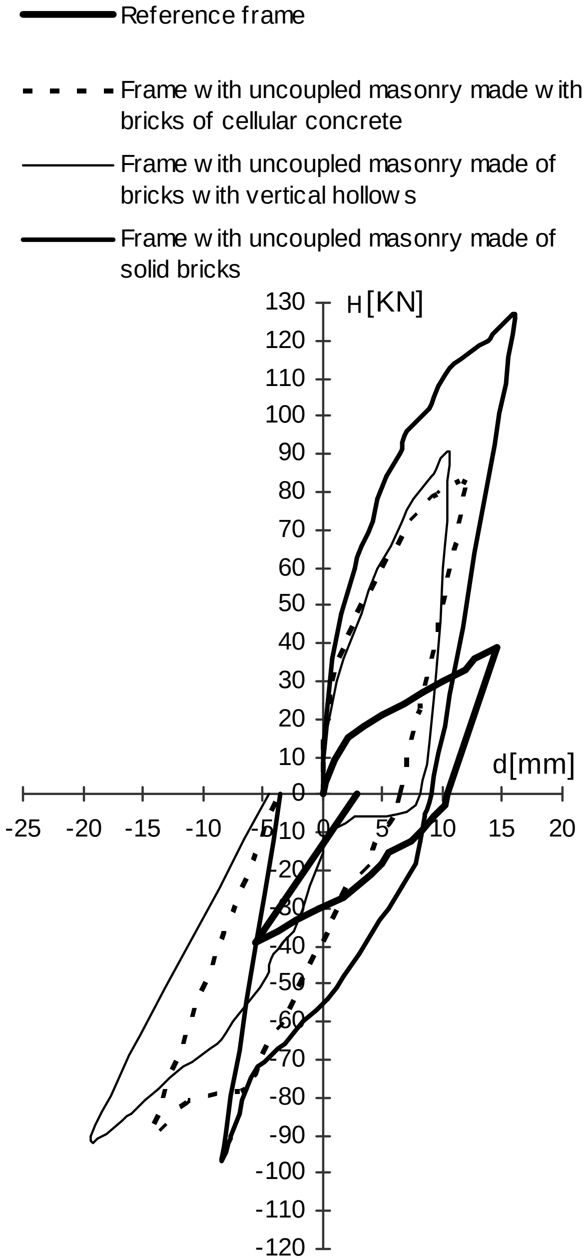

Fig.5 Reference frame, uncoupled cellular concrete masonry infilled frame, uncoupled ceramic blocks with vertical hollows masonry infilled frame, uncoupled solid bricks masonry infilled frame

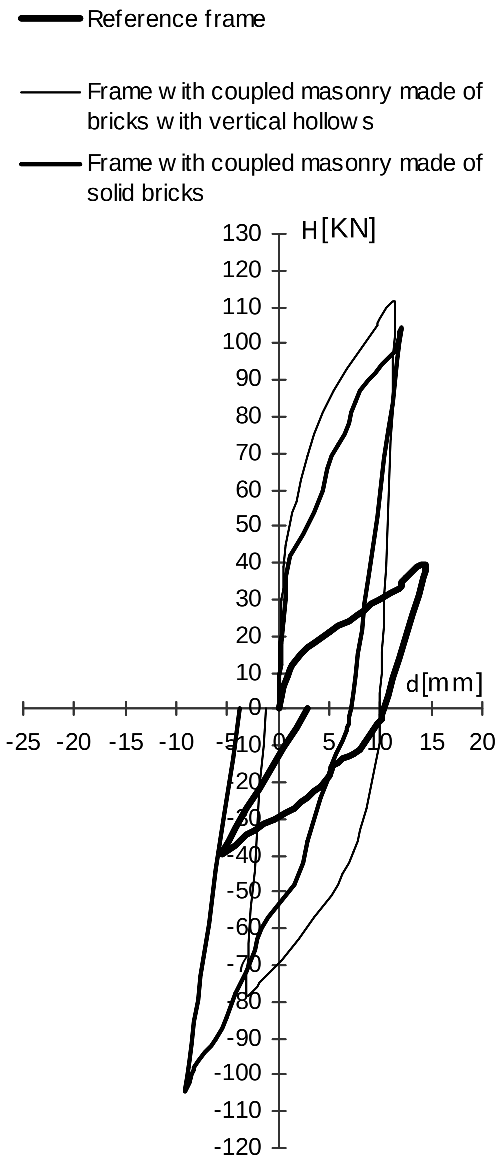

Fig.6 Reference frame, coupled ceramic blocks with vertical hollows masonry infilled frame, coupled solid bricks masonry infilled frame

- The maximum horizontal action was taken depending on inter-storey drift limitation (EN 1998-1-2004), i.e.:

-$d_{ra}^{SLS} \leq 0.005 \cdot h = 0.005 \times 1{,}725$ mm = 8.63 mm for buildings having non-structural elements made of brittle materials atached to the structure,

-$d_{ra}^{SLS} \leq 0.0075 \cdot h = 0.0075 \times 1{,}725$ mm = 12.94 mm for buildings having ductile non-structural elements

and

-$d_{ra}^{SLS} \leq 0.01 \cdot h = 0.01 \times 1{,}725$ mm = 17.25 mm for buildings having non-structural elements fixed in a way so as not to interfere with structural deformations, or without non-structural elements.

- The results from the alternating horizontal loads and the average values of these results are presented in Table 2.

Experimental data Table 2

No	Structure	Horizontal action applied	Main characteristics obtained from tests				
			H [KN]		K [KN/mm]		D [KNmm]
			at exper. value	at 13 mm	at exper. value	at 13 mm	
1.	Reference frame	left-hand	39	37	2.71	2.85	274
		right-hand	39	34	2.44	2.62	204
		mean value	39	35.5	2.57	2.73	239
2.	Frame with uncoupled masonry made of cellular concrete bricks	left-hand	81	81	6.78	6.78	503
		right-hand	87	78	4.22	6.00	681
		mean value	84	79.5	5.50	6.39	592
3.	Frame with uncoupled masonry made of bricks with vertical hollows	left-hand	90	90	8.54	6.92	530
		right-hand	90	49	4.66	3.77	596
		mean value	90	69.5	6.60	5.35	563
4.	Frame with uncoupled masonry made of solid bricks	left-hand	126	118	7.82	9.08	1,050
		right-hand	96	68	11.26	5.23	675
		mean value	111	93	9.54	7.15	862.5
5.	Frame with coupled masonry made of bricks with vertical hollows	left-hand	111	111	9.73	9.73	868
		right-hand	78	78	5.95	5.95	657
		mean value	94.5	94.5	7.84	7.84	752.5
6.	Frame with coupled masonry made of solid bricks	left-hand	104	104	8.58	8.58	586
		right-hand	104	89	6.40	6.85	657
		mean value	104	96.5	7.49	7.71	622
Legend : H - horizontal action, K - structure stiffness, D - structure ductility.							

ž The tests showed an increase of the shear resistance of the masonry-infilled RC frame at itȏs base, as compared to the reference frame.

A significant increase in both the stiffness and ductility of the dual structure was also recorded.

ž The increase of the above mentioned main characteristics as compared to the reference structure are presented in Table 3.

Table 3

The increase of main characteristics as compared with the reference structure

No.	Structure	Ratios at d_{ra}^{SLS} of the mean values					
		Horizontal force		Structure stiffness		Structure ductility	
		H/H^{ref} (δ, [%])	æ[%]	K/K^{ref} (δ, [%])	æ[%]	D/D^{ref} (δ, [%])	æ[%]
2.	Frame with uncoupled masonry made of cellular concrete bricks	2.24 (124)	55.3	2.34 (134)	57.2	2.48 (148)	59.6
3.	Frame with uncoupled masonry made of bricks with vertical hollows	1.96 (96)	48.9	1.96 (96)	48.9	2.36 (136)	57.5
4.	Frame with uncoupled masonry made of solid bricks	2.62 (162)	61.8	2.62 (162)	61.8	3.61 (261)	72.3
5.	Frame with coupled masonry made of bricks with vertical hollows	2.66 (166)	62.4	2.87 (187)	65.1	3.15 (215)	68.2
6.	Frame with coupled masonry made of solid bricks	2.72 (172)	63.2	2.82 (182)	64.5	2.60 (160)	61.6

Legend :H, K, D - characteristics of the dual system, from test
H^{ref}, K^{ref} , D^{ref} - characteristics of the reference frame, from test
δ, æ- the increase of the characteristic values as compared with the reference frame

ȝ Several important ideas can be underlined from **Table 2** and **Table 3**:
a). Shear resistance/horizontal force at the structure base as compared with the reference frame is higher by 1.96 to 2.72 times; it means that the shear resistance of the walls at the building base is almost equal or higher than 50% of the total seismic resistance of the whole structural system (48.9% ÷ 63.2%). These data demonstrate that the dual system is ñ**wall-equivalent dual system**ò

b). The increase of the structure stiffness as compared to the reference frame stiffness is in the same range as the increase of the horizontal force: 48.9% ÷ 65.1%. The stiffness was calculated as the ratio between the lateral load and the limited inter storey drift.

c). The ductility of each structure was calculated as the surface inside of charge-discharge curves for the horizontal action in both directions: left-hand and right-hand. The increase in ductility of the dual system as compared with the reference frame is only slightly more than the increase in stiffness of the structure: 57.5% ÷ 72.3%.

d). From presented tests, conducted at service limit state, it comes out that the contribution to lateral load, stiffness and ductility increase of coupled masonry as compared with uncoupled masonry is positive for structure made with vertical hollows blocks and with small increase or a decrease for structure made with solid bricks: 36% for lateral load, 46.5% for stiffness, 33.7% for ductility and respectively 3.8%,7.8% and -27.9%.