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VERTICAL FLEXURAL BEHAVIOUR OF BED JOINT REINFORCED BRICK MASONRY

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ABSTRACT

This paper speaks about the vertical flexural behaviour of bed joint reinforced walls. This reinforcement is formed by two longitudinal wires separated and soldered between them by other diagonal wire in zigzag soldered in a same plane. With this object have been designed different types of walls in which it was studied the influence of several factors: depth of the neutral axis, reinforcement quantity, reinforcement's overlap etc.

A comparative analysis of the experimental values and the theoretical values has been realised, considering two types of breaking that have been produced in the test: By flexural or by shear efforts, according to different quantities of reinforcement.

It is possible to conclude that the behaviour of the bed joint reinforced brick masonry subjected to vertical flexural stress is satisfactory; the masonry behaves really as reinforced cross section. It is this manner when the diagonal wire is considered in the theoretical calculation.

Key words: *Masonry, bed joint reinforcement, Murfor reinforcement, flexural behaviour, shear behaviour.*

1. INTRODUCTION

This report is the result of the compilation of several studies realised by "Laboratorio Central de Estructuras y Materiales del Centro de Estudios y Experimentación de Obras Públicas" (CEDEX). It has been developed in the frame of two projects, the first with Department of Construction and Architectural Technology of E. T. S. of Architecture of Polytechnic University of Madrid, HISPALYT, N. V. and BEKAERT, S. A. with the title" Tests on ceramic bricks and lightened blocks reinforced masonry", the second of title: "Comparative study of the qualitative increment of the reinforced masonry in relation to unreinforced masonry", it is inserted in the summons of financial helps and subsidies of Commission Interministerial of Science and Technology of 11th July 1994, corresponding to Projects of Investigation of the National Program of materials, forming part of the project of title :"Physical and mechanical behaviour of the reinforced ceramic masonry by bed joint reinforcement", being the general coordinator of the investigation D. Josep Mª Adell Argilés.

In the works have participated different technical teams of the "Laboratorio Central del Centro de Estudios y Experimentación de Obras Públicas": "Division de Tecnología de Hormigones", "División de Análisis Experimental de Estructuras" and "Sector de Estudios de Estructuras".

2. OBJECTIVE

A) To analyse the flexural behaviour of the masonry, taking into account the influence of the depth of the neutral axis, the quantity of reinforcement, the overlap of wires and the shear behaviour masonry.

B) To compare the experimental results of the prisms in several tests and the results obtained by numerical calculation.

3. TRIALS PROGRAM

Table I. Designation and types of masonry brick walls

WALLS	DIMENSIONS (m)	TYPE AND NUMBER OF REINFORCEMENTS
M-1	3,00 x 0,60 x 0,115	RND.4-80 mm - 1 TRUSS IN THE 1st LAYER
M-2	3,00 x 0,60 x 0,115	RND.4-80 mm - 1 TRUSS IN THE 3rd LAYER
M-3	3,00 x 0,60 x 0,115	RND.4-80 mm – 2 TRUSS IN THE 2nd AND 4th LAYERS
M-4	3,00 x 0,60 x 0,115	RND.4/ZINC-50mm – 2 TRUSS IN THE 2nd AND 3rd LAYERS WITH OVERLAPS OF 150 mm
M-5	3,00 x 0,60 x 0,115	RND.4/EPOXY-50mm - 2 TRUSS IN THE 2nd AND 3rd LAYERS
M-6	3,00 x 0,60 x 0,115	RND.4/EPOXY-50mm - 2 TRUSS IN THE 2nd AND 3rd LAYERS WITH OVERLAPS OF 250 mm
M-7	3,00 x 0,60 x 0,115	RND.4/ZINC-50mm – 1 TRUSS IN THE 2nd LAYER
M-8	3,00 x 0,60 x 0,115	RND.4/ZINC-50mm – 2 TRUSS IN THE 2nd AND 3rd LAYERS
M-9	3,00 x 0,60 x 0,115	RND.4/ZINC-50mm – 3 TRUSS IN THE 2nd, 3rd AND 4th LAYERS
M-10	3,00 x 0,60 x 0,115	4RND-80 mm - 4 TRUSS IN THE 1st, 2nd, 3rd AND 4th LAYERS

3.1. Design of the test system and of the load aplication system

The load is transmitted from the actuator by a metallic element (IPN-160) in horizontal position. In order to realise the support of the metallic beam in two points over the wall, two cylindrical elements of diameter 40 mm have been placed in order to guarantee the transmission of loads across an only line. As reinforcement of the horizontal surface of the wall and support of the cylinders, it is disposed a base plate of reduced thickness of the same length that the cylinder. The horizontal support of the wall on the floor is realised by similar cylinders preceding and disposing the adequate plates.

With this system, the load is concentrated in two points situated to 1/3 of the span approximately. The separation between supports is 2,70 m and the load is applied to 0, 90 m of the supports.

It may be considered that the specimens are only subjected to bending moment in middle third and they are subjected to shear stress of constant value in the lateral thirds. This solicitation permits a comfortable comparison of the experimental results obtained in the walls, because it exists a central ample zone in which it is produced the maximum bending moment of constant value, and other extreme ample zones put to the maximum shear effort.

3.2. Monitoring

- ACTUATOR SERVOCONTROLLED: An actuator of 50Tn of maximum capacity has been utilised.

- DISPLACEMENT TRANSDUCER (LVDT): The displacement in the span middle of the specimens has been measured with a LVDT marks MTS, of ±125mm range.

- STRAIN GAGES: In order to measure the strain in the reinforcement it was utilised strain gages: Marks HBM, of 4 mm of length of grid and 120 Ohmios ± 0,35 % of resistance, in all cases.

4. DEFINITION OF MATERIALS

Two types of perforated ceramic brick (dimensions 240 x 115 x 52 mm) have been utilised marks Cerámica La Oliva and Malpesa.

The Murfor reinforcement are formed by two longitudinal wires separated and soldered between themselves by other diagonal wire in zigzag soldered in a same plane, in such a way that they conform a lattice truss, whose total thickness doesn't exceed the diameter of the longitudinal wires. The following Murfor reinforcements types have been employed: RND.4/Z-80 mm, RND.4/ ZINC-50mm

and RND.4 /EPOXY-50mm, with longitudinal wires of 4 mm of diameter, separated 8 or 5 cm between themselves according to the cases and they are united by a diagonal wire of 3, 75 mm of diameter.

In the construction of the specimens was employed mortar M-8 (Compressive strength of 8 N/mm^2) elaborated "in situ" and tested to guarantee an adequate resistance. Cement type P- 350 was utilised.

5. STUDY OF THE VERTICAL FLEXURAL BEHAVIOUR OF MASONRY

5.1. Description of the development of fissures and of the type of breaking of specimens

In all the specimens that have broken to flexure it was observed that a vertical fissure appears approximately in the centre of the wall. This fissure appears in the brick and the mortar, which indicates a very good adherence between both materials. In nearly all the cases the fissure reaches until the 7th or 8th layer leaving a compression zone in the superior part of the wall.

In the case of the two walls with overlapped reinforcements, the breaking is produced in the middle third, bat not as symmetrical as in the preceding case. In this case the breaking plane is placed near to one of the two overlaps (walls 4 and 6).

The walls most reinforced have broken by shear stress, it was produced a major number of fissures of minor size and parallel to the main central fissure. Finally it was developed a craft that beginning approximately in one of the supports of the wall, it's continued until the superior part, shaping an angle of 45º.

5.2. Results obtained

Table II. Load, vertical desplacement in the wall and strain in the reinforcements

WALLS	RUPTURE TYPE	RUPTURE LOAD (T) (mm)	LOADED DESPLACEMENT	MAXIMUM STRAIN (mm/mm 10^{-6})	TENSILE STRESS (N/mm^2)
M-1	FLEXURE	3,17	4,91	6.076,0	779,2
M-2	FLEXURE	2,27	6,40	13.371,6	779,2
M-3	FLEXIURE	4,80	10,93	9.685,8	779,2
M-4	FLEXURE	4,20	6,51	2.809,0	578,7 (*)
M-5	FLEXURE	6,19	10,70	6.566,6	779,2
M-6	FLEXURE	4,44	7,05	1.771,9	365,0 (*)
M-7	FLEXURE	4,46	11,76	7.164,7	779,2
M-8	SHEAR	5,26	11,55	5.112,8	779,2
M-9	SHEAR	9,54	11,80	4.823,8	779,2
M-10	SHEAR	6,21	12,12	3.703,2	740,6
(*) It is not reached the breaking tension of the reinforcement in spite of that the walls have broken. These are the walls that they had overlaps in your reinforcements.					

5.3. Analysis or results

The following mechanics characteristics have been considered:

- Compressive strength of masonry (compression in bed joint direction) fhk = 2, 5 N/mm^2
- Tensile strength of the steel (elastic limit) = fyk= 677 N $/mm^2$ and fyk = 779, 2 N / mm^2

5.3.1. Flexural breaking

They are compared the values of bending moment obtained in the trial (Me) with the values of characteristic theoretical bending moment: (M, Mm and Mg) and the design bending moment Md corresponding to the characteristic M.

The bending moment of the trial is defined by Me = PL/ 6, being P the rupture load and L the span between supports. The theoretical moment it's determined following the simplification of the rectangular diagram that proposes EC-6. In this analysis they are posed 3 different hypothesis:

1st HYPOTHESIS: They are considered the compressive strength (compression in bed joint direction) of the masonry indicated in the Murfor manual (fhk = 2,5 N/mm^2; fhd = 2,5 / γ) and tension strength of the steel in accordance with the average values of test facilitated by the manufacturer (fyk = 677 N/mm^2; fyd = 677 / γ). The values obtained are indicated in the tables III and IV.

As the results obtained in the trial are greater than the theoretically possible values utilising the materials and the disposition of the reinforcements posed in the first hypothesis, they are considered the 2 next hypothesis:

2nd HYPOTHESIS: It is considered that the compressive strength (compression in bed joint direction) is superior to the predetermined value in the 1st hypothesis. That is a logical supposition taking into account that the compression strength (compression in bed joint direction) of a piece of brick is approximately 50 N $/mm^2$. It's determined a bending moment (Mm) considering all the compression concentrated in the superior zone (z = 0, 95 d, maximum value admitted by EC-6), and the tensile strength of the steel in accordance with the maximum value of test facilitated by the (fyk= 779, 2 N $/mm^2$. (table V)

3rd HYPOTHESIS: To consider the collaboration of the diagonal reinforcement, which represents a quantity of reinforcement of a 40 % approximately respect to the total. Therefore it's determined a bending moment (Mg) that it keeps in mind this consideration. Just as the preceding hypothesis: z = 0, 95 d and fyk = 779,2 N / mm2 (table V)

Table III. Calculation of the theoretical bending moment

Specimens	width b (m)	Height h (m)	Traction reinforcement	Traction overlap (cm)	effective depth d (cm)	characteristic Theoretical moment (mt)
M – 1	0,115	0,60	2 F 4	6	54	0,88
M – 2	0,115	0,60	2 F 4	18	42	0,67
M – 3	0,115	0,60	4 F 4	12	42	1,25
M – 4	0,115	0,60	4 F 4	12	45	1,35
M – 5	0,115	0,60	4 F 4	12	45	1,35
M – 6	0,115	0,60	4 F 4	12	45	1,35
M – 7	0,115	0,60	2 F 4	12	48	0,78

Table IV. Analysis of reslts (flexure breking) I

Walls	Bending moment test Me (mt)	Theoretical bending moment Md (mt)	Theoretical characteristic bending moment M (mt)	Me/Md	Me/M
M-1	1,42	0,71	0,88	2,00	1,61
M-2	1,02	0,53	0,67	1,92	1,52
M-3	2,16	0,88	1,25	2,45	1,73
M-4	1,89	0,97	1,35	1,95	1,40
M-5	2,78	0,97	1,35	2,86	2,06
M-6	2,00	0,97	1,35	2,06	1,48
M-7	2,01	0,62	0,78	3,24	2,58

Table V. Analysis of reslts (flexure breking) II

Walls	Bending moment test Me (mt)	Rupture bending moment Mm (mt)	Bending moment with diagonal reinforcement Mg (mt)	Me/Mm	Me/Mg
M-1	1,42	1,02	1,44	1,39	**0,99**
M-2	1,02	0,79	1,11	1,29	**0,92**
M-3	2,16	1,58	2,23	1,37	**0,97**
M-4	1,89	1,70	2,42	1,11	**0,78**
M-5	2,78	1,70	2,42	1,64	**1,15**
M-6	2,00	1,70	2,42	1,18	**0,83**
M-7	2,01	0,91	1,29	2,21	**1,55**

Considering the greatest resistances of the reinforcement and of the masonry, all experimental values are superior than the theoretical values.

If furthermore, in the theoretical calculation is included the collaboration of the diagonal wire, the result is the following:

- Walls 1, 2 and 3. The resistances of trial and theoretical are practically equal.
- The walls 4 and 6 resist less in the trial than by theoretical calculation. This walls had overlaps in everyone of your reinforcements. Is possible that it has had influence in the effective collaboration of the diagonal wires.
- Wall 5 and 7 resist more in the trial than by theoretical calculation.

It is verified that keeping in mind the diagonal wire, there is a great similitude between the theoretical values and the experimental values.

In other hand, it is not possible to insure the correct working of the overlaps, it was observed the following:

- The rupture plane of the walls placed near to the overlaps.
- The tension of the reinforcements measured by strain gages (they placed approximately in the centre of the walls) have been less than the ultimate tensile strength. It is possible that the reinforcements didn't break where were placed the strain gages or the overlaps didn't work correctly or both things.
- The two walls that had overlaps in the reinforcements (4 and 6) have resisted less than by theoretical calculation, considering the diagonal wire (Me < Mg).

5.3.2. Shear breaking

They're compared the results of test (Ve) with the theoretical characteristic shear values (V) and with the design shear values (Vd). The test shear is calculated by V = P / 2, being P the breaking load. The design shear resistance of the masonry without transversal reinforcement (art. 4.7.2.2. of the EC- 6) is calculated by Vd = bdf_{vk} / γ_M, being f_{vk} the characteristic shear resistance of the masonry.

Table VI. Theoretical shear designed in brick masonry

WALLS	f_{vk} (N/mm^2)	b (mm)	d (mm)	THEORETICAL SHEAR	
				DESIGN Vd (T)	CHARACTERÍSTIC V (T)
M-8	0,2 (EC-6, mortar 8,5 N/mm^2)	115	450	0,42	1,05
	0,45 (MURFOR)			0,95	2,37
M-9	0,3 (EC-6, mortar 12,9 N/mm^2)	115	420	0,59	1,48
	0,45 (MURFOR)			0,89	2,21
M-10	0,3 (EC-6, mortar 12,1 N/mm^2)	115	450	0,63	1,58
	0,45 (MURFOR)			0,95	2,37

Table VII. Analysis of reslts breaking shear

WALLS	SHEAR TEST Ve (T)	THEORETICAL SHEAR		Ve/Vd	Ve/V
		DESIGN Vd (T)	CHARACTERÍSTIC V (T)		
M-8	2,63	0,42	1,05	6,26	2,50
		0,95	2,37	2,77	1,11
M-9	4,77	0,59	1,48	8,08	3,22
		0,89	2,21	5,36	2,16
M-10	3,81	0,63	1,58	6,05	2,41
		0,95	2,37	4,01	1,61

All walls broken by shear resist more in the trial than by theoretical calculation.

6. CONCLUSIONS

The obtained results and the realised analyses show the following:

- The bed joint reinforced brick masonry behaves really as a reinforced cross section, it is demonstrated by the similitude of the theoretical values with experimental results. It is in this manner when the diagonal wire is considered in the theoretical calculation

- It is not possible to insure the correct working of the overlaps, in these cases are unsafe to consider the collaboration of the diagonal wire in the bending strength.

- In all the cases, the shear resistance of trial is greater than the theoretical shear; for that reason, the security is good. In fact, this situation is similar in other reinforced material more studied.

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TC-76- LUM LOAD BEARING UNIT MASONRY: General recommendations for methods of testing load-bearing unit masonry. LUM.B.2. FLEXURAL STRENGTH OF WALL SPECIMENS.

Figure 1. Detail of the monitoring and preparation of the walls.

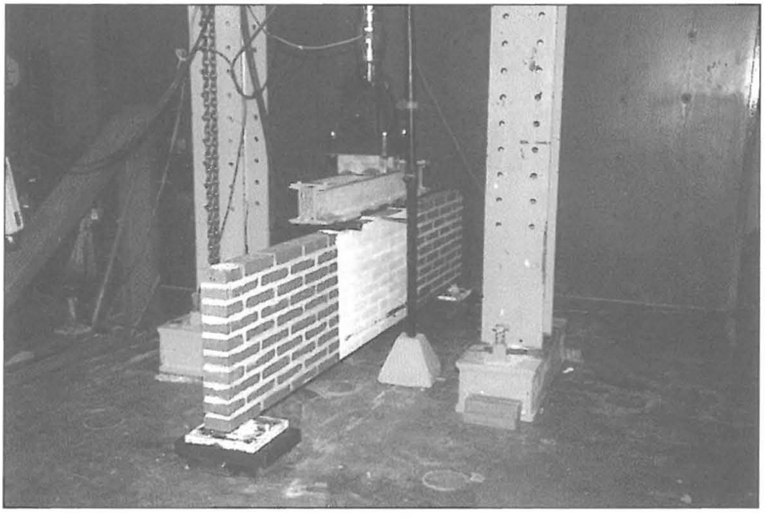

Figure 2. Detail of the flexure breaking after the trial.

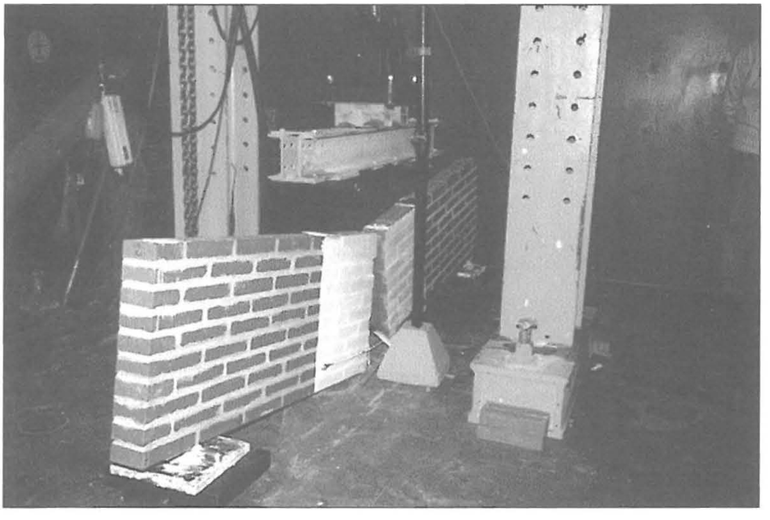

Figure 3. Detail of the shear breaking after the trial.