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Vertical Flexural Bending in Lintels of Bed Joint Reinforced Clay Masonry in Spain

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ABSTRACT
Masonry using perforated clay bricks and lightweight clay blocks with truss type prefabricated bed joint reinforcement, has been tested as 0.6m shallow lintels and 1.4m deep lintels, both 2.7m span. This investigation differs in that, in Spain, various bed joint reinforcements are placed side by side in the same mortar layer, which increases the strength possibilities of the masonry. The investigation also considers blockwork with no mortar in the vertical joints.

1. INTRODUCTION

The study was carried out within the framework of the agreement "Testing of bed-joint reinforced masonry composed of clay bricks and lightweight clay blocks", May 1993, signed by the Department of Construction and Architectural Technology at the Architectural College at the Universidad Politécnica de Madrid, Hispalyt, N.V. Bekaert, S.A. and the Centre of Research and Experiment (CEDEX) of the Ministry of Public Works, Transport and Environment (MOPTMA). These tests are included within the research topic "The physical and mechanical behaviour of masonry", initiated in December 1992, at the Department of Construction and Architectural Technology at ETSAM (The College of Madrid Architects) by the author.

This study into vertical bending forms part of the investigation "Reinforced masonry composed of clay brick and blockwork and prefabricated bed joint reinforcement", which, at a later stage, will also consider horizontal bending and the bond between components. It aims to establish the response of the new composite masonry material to the different combinations of material employed and the different stresses to which it is subjected.

The results recorded for the theoretical composite material (standard quality masonry materials combined with Murfor bed joint reinforcement) may be compared with experimental results obtained when using specifically Spanish materials, such as perforated clay brick (considered generically) and a lightweight clay block, (LCB), as patented by Termoarcilla (and of specific characteristics). In this study, bed joint reinforced masonry is taken to be Malpesa Perforated Clay Brick or "Termoarcilla" Light Clay Block, reinforced with Murfor (4 and 6) truss type reinforcement embedded in the horizontal bed joints.

Bed joint reinforced masonry prevents and controls cracking and also improves the technical qualities of the masonry. In Spain this type of reinforced masonry has broadened its field of application thanks to the Calculation Principles and Tables established by Professor LAHUERTA, and published in Bekaert's Murfor Manual for Spain[1] and in HISPALYT'S "Brick Wall"[2]. According to these tables, lintels of bed joint reinforced masonry are capable of bearing the loads of floor slabs as well as their own dead weight. When forming a lintel in this manner, it is necessary to reinforce the lower courses of the lintel and even place several truss type reinforcements within the same layer (if the thickness of the wall so permits). This reinforcement provides a greater capacity to withstand tensile stress, provided that compressive strength of the masonry is not exceeded.

Microcracking may be accepted in bed joint reinforced mortar, in the same way that it occurs in reinforced concrete, without the cracks being actually visible, and, thereby greatly increasing the technical possibilities of the masonry. If microcracking is not permitted, then it is sufficient to limit the design tensile strength of the reinforcement to 200N/mm^2, in accordance with EC-6[3].

From the individual and overall analysis of the results and their comparison with the tables, it can be established whether any particular aspect requires a more exhaustive and statistical study, prior to coming to any definite conclusions. On the other hand, if certain aspects of the study do not contradict the calculation, then this may be taken as confirmation.

2. OBJECTIVES

The overall objectives of the study are as follows:

(i) To establish the experimental behaviour of Murfor reinforcement, when applied specifically to Spanish materials, testing lintels and masonry walls composed of perforated bricks and lightweight clay blocks (LCB) subjected to vertical bending.

(ii) Characterise the mechanical properties of the materials employed: reinforcement, mortar, vertically perforated brick, lightweight clay block.

(iii) Study the behaviour of the LCB as a component of bed joint reinforced masonry.

(iv) Compare the strengths obtained from the standard compression test and compression in the direction of the mortar layer, on brickwork and blockwork, to establish the individual resistance of each, in accordance with the anisotropy of the component parts, and to predict the behaviour of reinforced masonry made with these materials.

(v) Compare the influence of vertical joints, filled and unfilled, on the behaviour of bed joint reinforced LCB.

(vi) Analyse the influence of the length of overlap in accordance with the type of corrosion protection used on the reinforcement.

(vii) Observe the influence of the wall thickness/slenderness ratio.

(viii) Determine the effect of concentrating reinforcement on one area or bed joint.

(ix) Verify the degree of safety offered by the calculation tabulated in the Murfor Manual, with regards to the special characteristics of clay materials employed in Spain, in order to establish the degree of safety offered with respect to these characteristics.

(x) Compare the experimental results obtained from specifically Spanish clay materials with tests carried out in other European countries using other units and criteria.

3. TEST PLAN : STAGES

3.1 General

The investigation is considered as the first experimental evaluation of Spanish bed joint reinforced masonry, and as such, rather than trying to obtain an in depth and meticulous knowledge of some of the aspects, the aim is to examine the more common materials in order to gain a general idea of their suitability, in accordance with the theory developed, or, on the other hand, to see whether it is necessary to make some recommendations regarding their use. The proposed test plan will, therefore, study the more common situations, testing for standard compression and compression in the direction of the mortar layer and vertical bending, and will consider the range of variables that are presented in this type of construction. The test plan considers tests on unreinforced units and masonry as well as on bed joint reinforced brickwork and blockwork.

In order to make a subsequent analysis of the results, with respect to the theoretical calculations, the geometry and reinforcement of the walls have been constructed so that comparison may be made with the values given in the tables[1]. Two bands, the upper and lower quarters, have been selected from the tables. That is to say, the lintel depths are set at 0.60m and 1.40m, while in the tables these depths appear as 0.40, 0.60, 0.80, 1.00, 1.20, 1.40 and 1.60. All the walls tested were 3m long. The aforementioned heights were also considered for horizontal bending. All walls were single leaf, the thickness being that of brick or block width, and all were built in M-80 mortar made on site.

3.2 Vertical bending - Termoarcilla (LCB)

The following variables were considered:

- The effect of thickness of block employed (and that of the wall).
- The variations in the amount of reinforcement placed in the same layer.
- The type of vertical joint, with or without mortar.
- The effect of the depth of beam or wall lintels.

Details of the specimens tested are given in Table 1. In addition Wall 3 (IPSW) Wall 4 (IPCW) overturned on first test.

3.3 Vertical bending - brick

The following variables were considered for this type of wall:

- The influence on strength of different types of Murfor reinforcement with different corrosion cover.
- The discontinuity of the reinforcement, with the corresponding length of overlap.
- The effect of the depth of beam or wall lintels.

Details of the specimens tested are also given in Table 1. In addition Wall 21 (EZNW) and Wall 22 (3ZRW) have still to be tested.

3.4 Horizontal bending

This stage has not yet been carried out. Table 16 of the Murfor Manual "Vertically Supported Walls with Wind Action" was used as a reference.

The following variables were considered:

- The effect of the thickness of the unit employed
- The effect of the thickness of the wall
- The different widths of Murfor bed joint reinforcement
- The variations in the number of reinforced bed joints and the amount of reinforcement
- The type of vertical joint, with or without mortar

The key to the specimens is the same as Table 1 plus:

- U reinforced layers, every one 200mm high
- D reinforced layers, every two 400mm high

The specimens are: 2PCD, 2PCU, 2PSD, 2PSU, 2GCD, 2GCU, 2GSD, 2GSU.

3.5 Compression tests of brick and blockwork

This stage consists of support tests to the investigation and considers the bricks and blocks as units and as masonry. In the latter situation, filled and unfilled vertical joints are taken into consideration. The unit tests are compressive and transverse strength. The M-80 mortar will also be tested to verify the strength of the mix. The list below does not contain all types of specimen.

- 1.a **FL** Brick masonry prism : 500 x 500 x 115mm
- 1.b **FB** LCB block masonry prism : 600 x 600 x 190mm
- 2.a **C** Compression perpendicular to bed joint
- 2.b **H** Compression parallel to bed joint

Total : 4 different prisms : 4FLC, 4FLH, 4FBC, 4FBH.

4. CHARACTERISATION OF MATERIALS AND MASONRY

The characteristics of the materials are given below, defining the characteristic and design strengths. The following ratios were considered for the strength reduction of the materials:

- steel 1.15 (according to the Spanish Code EH-91)
- masonry 2.5 (according to Spanish Code NBE-FL-90[4]

4.1 Murfor reinforcement

Bed joint reinforcement is regulated by the standard CEN-prEN845-3: Specifications for ancillary components for masonry - Part 3: Bed joint reinforcement[5], and is considered in EC6[3]. The reinforcement, complying with the specifications of EH-91, has a guaranteed elastic limit of 500N/mm^2, and a minimum unit load of 550N/mm^2.

Murfor reinforcement is prefabricated and consists of two longitudinal wires which are welded to a continuous zigzag cross wire to form a lattice truss configuration, the overall thickness being that of the longitudinal wires. Murfor RND. 4/-50mm reinforcement was employed for vertical bending, the longitudinal wires being 4mm in diameter, 50mm apart and connected by a 3.75mm diameter cross wire. Two types of corrosion protection were used in these tests: Zinc (/Z) and zinc + epoxy coating (/E). (The actual reinforcement itself was not tested).

4.2 M-80 Mortar

It is difficult to find a mortar with a pre-established strength in accordance with the specifications of the Spanish standard[4]. The results for strength, when mixed by volume, are very varied. The strength results obtained for the mortar employed were generally slightly above 8N/mm^2 except in Walls 8 and 18, where values of 6N/mm^2 and 6.6N/mm^2 respectively were recorded. It is of note that the Murfor Manual stipulates a minimum characteristic strength of 8N/mm^2.

4.3 Perforated clay brick

The perforated clay bricks were supplied by Malpesa and have a guaranteed strength of >20N/mm^2. The INCE seal of approval guarantees a 10N/mm^2 characteristic compressive strength for the brick. The calculations in the Manual consider the characteristic compressive strength of a perforated clay brick to be 10N/mm^2.

4.4 Brick masonry

The brick masonry is relatively isotropic when compared to other materials and, although the bricks are small, because of the nature of the perforations, they become full of mortar when the brick is laid, making them more solid and resistant. These circumstances, together with the quality of the Malpesa bricks employed, meant that a special study into this aspect was not necessary. The behaviour of the perforated clay brick is assumed to be very homogeneous, without great variations in strength in the two directions of the test, and this is beneficial for the correct behaviour of this type of bed joint reinforced masonry.

The design compressive strength may be evaluated from Table 5.3 of FL-90[4]. With a 20N/mm² brick, M-80 mortar and a joint thickness of between 10 and 15mm a design compressive strength perpendicular to the mortar layer of 2.8N/mm² is obtained. According to the Murfor Manual[1], the design compressive strength perpendicular to the course should be 1.8N/mm², while parallel to the course this should be 1.0N/mm². The design strength can be found by dividing the characteristic strength by the partial safety factor for the strength of the masonry, taken as 2.5 in the Manual calculations.

4.5 Lightweight clay block : Termoarcilla (LCB)

This block has great thermal and strength properties. Adjacent blocks are connected by the tongue and groove sides and, therefore, do not require mortar in the vertical joint. The block is 300mm long by 190mm high and the width can vary, being 140, 190, 240 and 290mm. The compressive strength, perpendicular and parallel to the course, were determined in the laboratory for nine 290mm blocks. The tests were carried out in accordance with the standard PNE 67.046 and the parallel faces of the load plates were faced with cement mortar.

The characteristic compressive strength of the block is guaranteed as over 10N/mm². Tests carried out on 6 blocks gave very similar results and showed a characteristic strength of 16.0N/mm² which exceeded the stipulated strength. However, compression in the direction of the mortar layer on 3 blocks gave varied and inferior results and, therefore, it is recommended that more specimens of different widths be studied in order to ascertain this particular value.

4.6 LCB masonry

The different compression tests on LCB masonry were carried out on 600 x 600mm sections, made up of three courses of blockwork unreinforced set in M-80 mortar. Sections were tested both with and without mortar in the vertical joints. (In this investigation the mortar was placed over the whole surface of the course).

The compressive strength obtained for these sections hardly varied between those with and without mortar in the vertical joints. The average results for two specimens of each type were 5.8N/mm² and 5.7N/mm² respectively. This small effect had been already shown experimentally by VILLEGAS[6]. So, the compressive strength easily complied with the characteristic strength of 1.8N/mm² established in the Murfor Manual for lightweight clay blockwork which is equivalent to a characteristic strength of 4.5N/mm².

However, the compressive strength, parallel to the course, of lightweight clay blocks was higher in those sections that contained mortar, being 1.2N/mm² as opposed to 0.9N/mm² in those sections without vertical mortar joints. In both cases the masonry gives higher values than that of the individual blocks, but these values are below 1.0N/mm², stipulated in the Manual for the design compressive strength of the masonry which is equivalent to a characteristic strength of 2.5N/mm².

The reason for the increase in compressive strength of masonry with regard to individual blocks may lie in the mortar layers, as on vertical testing, as in the tested sections, these are not as thick as the individually tested blocks, which implies a small proportion of cells in relation to the contribution of the continuous outer walls.

The different behaviour of the block in the two directions of the test was clearly seen in the manner in which the LCB units or sections failed. This is due to the slanting internal webs of the blocks, in relation to the direction in which the load was applied. The design shear strength given in the Murfor Manual is 0.18N/mm².

It seems logical to recommend that the block be designed in such a way that, in addition to being sufficiently resistant and insulating, the rubs within the blocks are capable of transferring the stresses on the horizontal plane of the masonry. This is especially important if the masonry has to bear horizontal stresses produced by seismic effects.

If a "seismic resisting" LCB is to be designed, then consideration should be given to allowing the addition of vertical reinforcement, and the joints should be designed to receive mortar. The Italian Murfor Manual[7] which examines reinforced masonry in seismic conditions may serve as an example.

5. VERTICAL BENDING

5.1 Geometry and construction

The geometry and construction of the walls is as previously described under the sections for block and brick. Here the effect of several variables was studied in accordance with the objectives. The walls and the position of the instrumentation are shown in Figures 1 and 2.

In order to make the task of the designer easier when deciding upon the strength properties of the reinforced masonry, obtained by using one material or another, the calculations and tests were made on masonry which was arranged by placing the first reinforcement to the lintel on an overhang of less than 100mm, independent of the vertical height of the different masonry courses. The reinforcement of the following courses was applied so that it was in accordance with the height of the brick or block employed.

Using clay block masonry implies the use of half blocks (cut horizontally), while brick masonry requires reinforcement as from the second course, if the bricks are placed flat as in this case, (this does not prevent reinforcement being placed on the first course for factors of safety), or on the first layer of a soldier course, with a 150mm overhang.

The manual recommends Murfor LHK lintel hangers (84 or 44mm long) for both materials, set on the first reinforcement of the course and placed in the perpend joints every 400mm maximum to provide support to the bottom course of masonry over an opening. When constructing the lintels the Recommendations given in the Manual [1] were followed for each type of masonry (with the exception of the masonry without vertical mortar joints) and the type of reinforcement employed.

In order to verify the influence of the variables considered, the walls were compared in pairs in accordance with their characteristics, as previously described in the test plan stage.

In the light of the first test results, CEDEX thought it necessary to change Walls 23 (3ZNW) and 24 (3ENV) (which were considered to analyse the behaviour of discontinuous and lapped reinforcement), for Walls 23 (3ZINV) and 24 (3Z3NV) with "1" and "3" Murfor reinforcements respectively, in order to verify the behaviour of the brick masonry when withstanding greater or lesser stress than that covered by the manual[1]. In this way the composite material was studied by taking it to extreme limits of failure, through tensile failure of the steel ("1" reinforcement), or by compression of the masonry in the direction of the courses in the upper central section ("3" reinforcement).

5.2 Types of wall

Twelve walls have been tested in vertical bending: six LCB walls and six perforated brick walls. All walls were 3m long, but were

0.60m high for beam lintels and 1.40m high for wall lintels. The thickness of the wall depended on the type of unit used in each case, the reinforcement being as indicated previously with all its variations (Table 1).

5.3 Load application method and instrumentation

Walls were tested after 28d. In walls subject to vertical bending the load was concentrated at two points placed at ⅓ of the span. The separation between supports was 2.70m and the loads were applied 0.90m from the supports. If we ignore the dead load, which is relatively small in comparison to the load borne, the wall is almost entirely subject to bending. This stress, though detrimental, enables one to make an easy comparison between the different elements, as there is a large area where maximum bending moment occurs, which under a uniformly distributed load is reduced to one point. However, in laboratory testing it is difficult to apply a uniformly distributed load as the beam cannot easily rest on all points of the wall.

The load was applied by one or two hydraulic jacks, with different load capacities, depending on the case. DEMEC gauges, with a 200mm gauge length and a precision of $\pm$ 6 x 10^{-6}mm, were used to measure microdeformations and subsequent small horizontal movements. Deflection gauges with a resolution of 0.01mm were placed on the supports to measure any small vertical movements since these would be taken into consideration when determining the bending moment at the centre of the span. The deflection of the lintel was measured by LVDT with a range of $\pm$ 250mm. To enable the tensile stress in the reinforcement to be calculated the extension was measured by transducers 10mm long connected by a compensating device to minimise the effect of heat on the measurements.

The geometry and instrumentation were based on earlier tests [8,9] allowing correlation to be made, and demonstrating the applicability of reinforced masonry in Spain as elsewhere[7,10].

6. ANALYSIS OF RESULTS ON LCB LINTELS

The results so far available are given in Table 1. The formulae given in EC6 were used to calculate the design shear. The shear strength of the masonry is considered to be 0.18N/mm^2, and 10% of the compressive strength as indicated by the FL90[4]. The shear values obtained by test V_e were compared with the theoretical shear values obtained with non-diminished strengths V and diminished strengths V_d (see Table 2). Although the investigation is not exhaustive from a statistical point of view, it aims to give an overall impression of the validity of the calculations. It will be used as a point of reference for a further testing programme by CEDEX which will examine a sufficient number of specimens in order to obtain more specific, values.

In bed joint reinforced LCB masonry, failure always occurred due to shear, though in some cases this may have been induced by an insufficient length of anchorage of the tensile reinforcement. In 600mm thick walls, the results are lower than those theoretically deduced from EC6[3] criteria, when considering the shear capacity of the section with diminished strength characteristics. The test results for shear in 600mm walls with vertical mortar joints were greater than those theoretically deduced when considering the shear capacity of the section with both diminished and undiminished strengths. In these walls failure often occurred due to loss of bond between the mortar and the blocks (Walls 1,2 and 5, Figure 3), and in other cases the blocks themselves broke (Wall 6,7 Figure 4), thus showing that the quality of workmanship has an important bearing on the results in accordance with the bond obtained. The mortar in Wall 6 was also seen to be much stronger, 17.4N/mm^2, than that employed in Wall 1, 13.5N/mm^2.

In 140mm walls failure occurred in the blocks themselves revealing the more monolithic structural behaviour of the element. The experimental values were greater than those obtained through calculation, when considering both diminished and undiminished strengths. In all cases the walls constructed with vertical mortar joints showed a higher shear strength than those constructed without mortar.

7. ANALYSIS OF RESULTS OF BRICK LINTELS

Reference should be made to Table 9a of the Murfor Manual[1]. Walls that had failed through shear and those that had failed through bending (Figures 5, 6) were analysed. In the former the shear values obtained in test, V_e, were compared with the theoretical values obtained with undiminished strengths V and diminished strengths V_d. In the second case, the bending values obtained in test, M_e, were compared with the theoretical values for the bending moment obtained with undiminished strengths M and diminished strengths M_d, (Tables 2 and 3).

In the calculation of the theoretical shear the masonry was considered to have a strength of 0.18N/mm^2. Formulae from the EH91 and EC6[3] were used for the calculation of the bending moment. The characteristic strength of steel is taken to be f_{yk} = 690N/mm^2 and the compressive strength of the masonry in the direction of the course is taken as f'_m = 2.5N/mm^2.

The brick masonry failed by shear stress and by bending moments under greater values than those deduced theoretically from EC6 criteria, when considering the shear capacity of the masonry without diminishing the strength.

The test with "3" reinforcement instead of the two recommended in the Manual[1] shows that, as in other aspects of perforated brick, when the masonry is fairly homogeneous and resistant, and with very close mortar joints, as is the case here, the technical qualities of this masonry can increase considerably. However, if the reinforcement is decreased, as is the case for the test with "1" reinforcement, the reduction in load is not excessive but the reinforcement eventually fails, and subsequently there is the danger that the lintel might collapse.

It should be noted that, in the transfer of stresses of the lapped reinforcement (where the zigzag cross wire and its welding to the longitudinal wires help significantly), in determined lengths of overlap, the strength of the mortar is of great importance. It is recommended that at least M-80 mortar be used. The second stage of the programme will investigate these aspects.

The cracking prior to failure appeared towards the centre and was almost vertical with no sharp changes. The lintel with "1" reinforcement is the only one where the wall was split vertically in two when the steel failed (Figures 5, 6). In that with "3" reinforcements it was the masonry that failed in the compressed area.

In all cases the reinforcement prevented the brittle failure of the masonry (with the exception of that of "1" reinforcement as was planned), even under large deformation towards the end of the test. On no occasion did the bricks, held by lintel hangers, fall away. The tests carried out with "1" and "2" reinforcements show the peculiarities of the composite material of bed joint reinforced masonry, where the vertical separation between horizontal joints typical of each type of masonry unit, means the reinforcement is spaced at different vertical distances apart so the safety factors vary according to unit height. The problem may be partially offset by using reinforcement of different section - with 4 or 5mm diameter wires.

All things considered, in certain cases, while trying to make the calculation more exact, if the construction technique used in practice is not taken into consideration, with regards to the strength properties, size and form of the material employed, then it may be almost impossible to adjust the theory to correct construction practice.

8. CONCLUSIONS

1. In the brick lintels the values for failure by both shear and bending were higher than those deduced theoretically in accordance with EC6 and EH91 criteria, when considering both diminished and undiminished strength. This has been verified considering specific variables:
   - galvanised zinc, and epoxy coated, reinforcement
   - continuous reinforcement and jointed reinforcement
   - greater or lesser quantities of reinforcement
2. In all cases the LCB lintels failed as a result of shear. In 600mm walls the shear values obtained in the tests were lower than the theoretical values with undiminished strengths. Therefore there is no correlation between the theoretical and experimental values for this masonry. This is possibly due to both the insufficient length of anchorage of the specimens and the lack of uniformity of the lintels with a high ratio of block thickness/lintel thickness. This proves the need for an in depth study of the behaviour of these elements under bending and shear through further testing.
3. In the 1.40m lintels the experimental values are greater than the theoretical, and therefore there is no discrepancy.

It should be noted that the tests carried out should really be compared with those using the same masonry but without reinforcement, in order to appreciate the great increase in possibilities offered by reinforced masonry as opposed to traditional masonry, the architectural benefits and effective control of cracking[11-14]

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Table 1
Details of 3m long lintels V 600mm deep and walls W 1400mm high reinforced with Murfor 4/Z-50mm and test results
All shear failures except 18, 19, 20, 23 bending failures

Specimen		Reinforcement		Results at Ultimate	
No.	Type	No. of Courses	No. of Pieces	Load N	Deflection mm
LCB					
1	1PSV	2	2	140	16.61
2	1PCV	2	2	295	19.53
5	1GSV	1	4	377	2.49
6	1GCV	1	4	1015	10.55
7	1GSW	3	9	4173	6.08
8	1GCW	3	9	4726	6.56
Clay Brick					
17	3ZNV	2	2	526	11.55
18	3ZRV	2	2	420	6.51
19	3ENV	2	2	619	10.70
20	3ERV	2.	2	444	7.05
23	3Z1NV	1	1	446	11.76
24	3Z3NV	3	3	954	11.80

Key:
- P small LCB 300 x 140 x 190mm (l x w x h)
- G large LCB 300 x 290 x 190mm
- S without vertical mortar joints
- C with vertical mortar joints
- V lintel 3 courses LCB, 10 courses brick (3 x w x 0.6m)
- W wall lintel 7 courses LCB, 23 courses brick (3 x w x 1.4m)
- Z reinforcement zinc galvanised
- E Epoxy coated reinforcement
- N continuous reinforcement
- R lapped reinforcement (length of overlaps: zinc, 150mm; epoxy, 250mm)

Specimen widths: LCB = 290mm except 1 and 2 = 140mm
Bricks = 115mm

Table 2
Analysis of results of vertical bending : failure by shear

Spec. No.	Exptl. V_e N	Theoretical		V_eV_d	V_e/V
		V_d N	V N		
LCB 1	7.8	10.3	25.8	0.75	0.30
2	15.6	10.3	25.8	1.51	0.60
5	20.5	21.3	53.2	0.96	0.38
6	52.4	21.3	53.2	2.46	0.98
7	209.2	64	160	3.27	1.30
8	236.9	64	160	3.70	1.48
Bricks 17	27.3	8.5	21.2	3.20	1.29
24	48.7	8.5	21.2	5.73	2.30

Table 3
Analysis of results of vertical bending in brick masonry: failure by bending

Spec. No.	Test bending moment M_e m.Tn	Theoretical bending moment* M_d m.Tn	Theoretical bending moment* M m.Tn	M_e/M_d	M_e/M
18	1.99	0.80	1.39	2.49	1.43
19	2.88	0.80	1.39	3.60	2.07
20	2.09	0.80	1.39	2.61	1.50
23	2.10	0.80	1.67	2.62	1.26

* calculation made with reinforcement actually placed

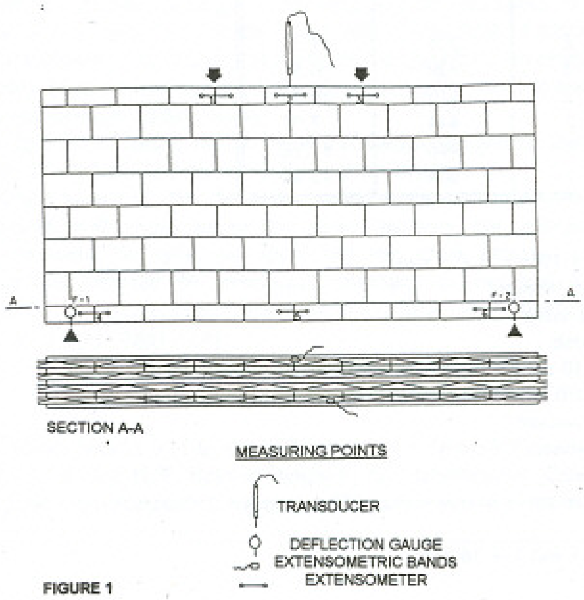

Figure 1-Instrumentation of Walls 7 and 8

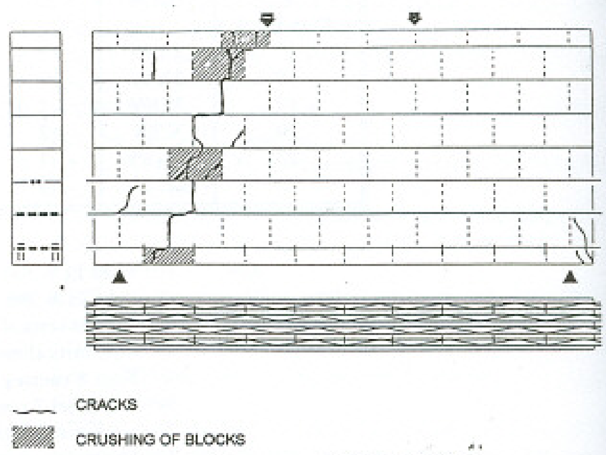

Figure 4-Damage to LCB Wall 7

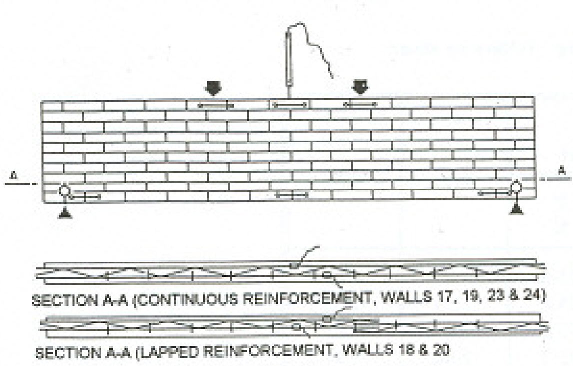

Figure 2-Instrumentation of Walls 17, 18, 19, 20, 23 and 24

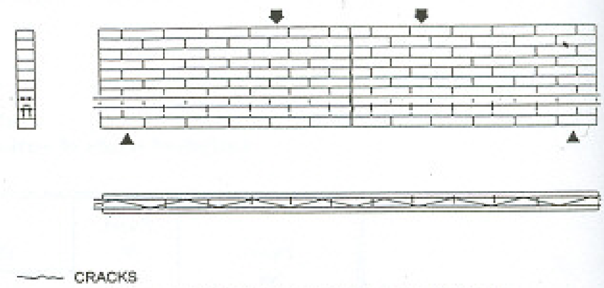

Figure 5-Crack pattern brick Wall 19

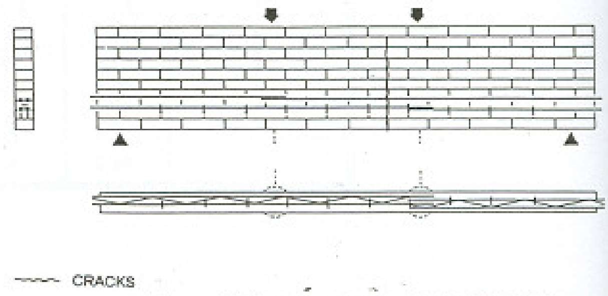

Figure 6-Crack pattern brick Wall 20

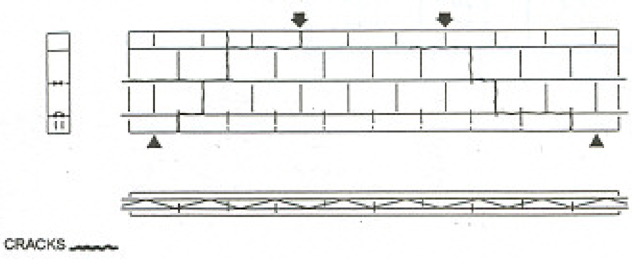

Figure 3-Crack pattern LCB Wall 2