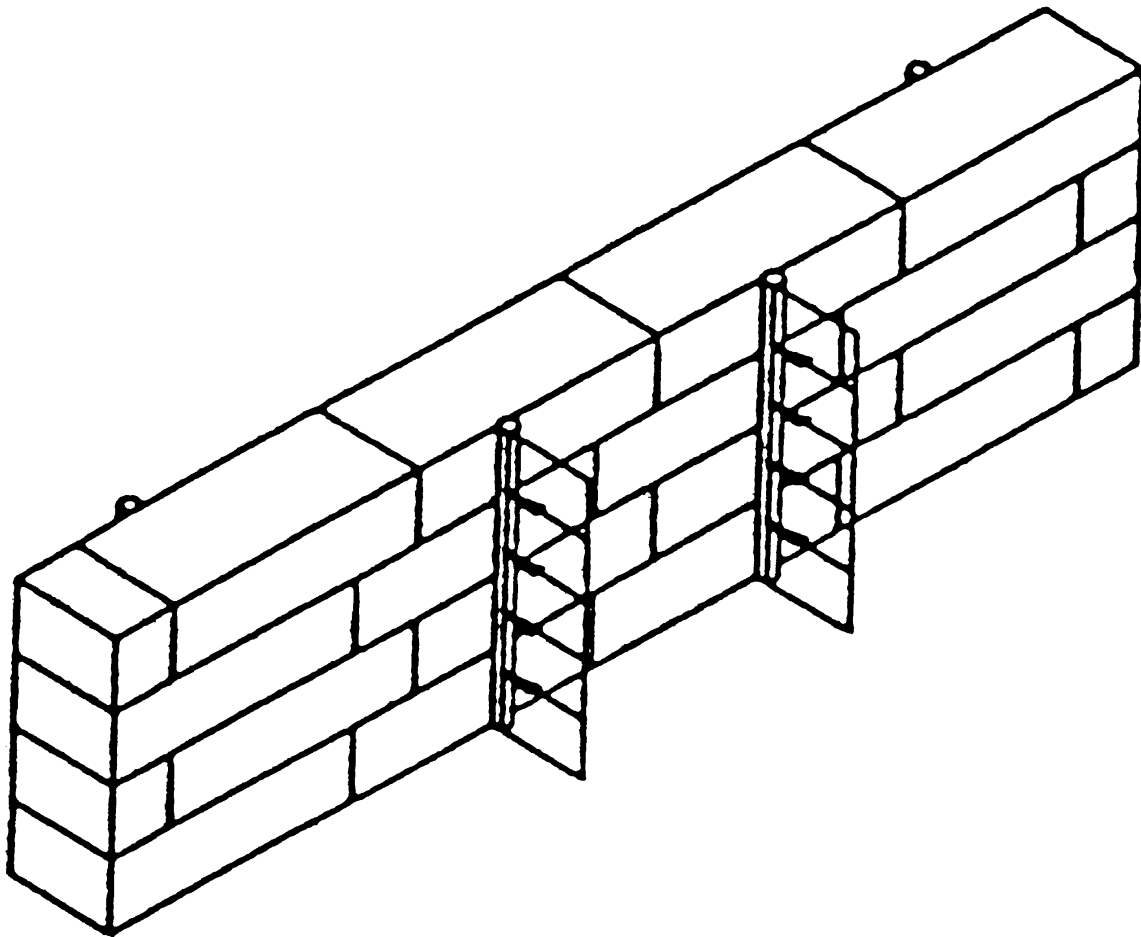


Bending and Shear Tests with Masonry



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Bending and Shear Tests with Masonry

Klavs Feilberg Hansen



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Foreword

The tests described in this bulletin are part of a test program about the bending properties of masonry walls. The Danish Technical Research Council financed the work and the Danish Masonry Information Council paid for the test specimens.

*Danish Building Research Institute
Division of Building Technology and Productivity, September 1999
Jørgen Nielsen, Head of Division*

Forord

De forsøg, der beskrives i denne meddelelse, indgår i en forsøgsrække vedrørende murværks bøjningsegenskaber. Statens Teknisk-Videnskabelige Forskningsråd har finansieret arbejdet og Murerfagets Oplysningsråd har givet midler til forsøgsmaterialer.

*Statens Byggeforskningsinstitut
Afdelingen for Byggeteknik og Produktivitet, september 1999
Jørgen Nielsen, forskningschef*

Introduction

Masonry is in general considered a brittle material. In spite of this it is used to make rather large unreinforced structures especially in countries like Denmark where the risk for a significant earthquake is practically non-existent. These structures have generally behaved well and this indicates that they must possess some ductility and that the toughness of masonry is not insignificant.

The aim with the tests described in this bulletin is to investigate the strength and toughness (brittleness) of masonry walls subjected to bending by means of deformation controlled tests as a function of brick type mortar type and of the bond used.

The bulletin deals with deformation controlled tests of 3 different kinds

- Bending tests with masonry walls about an axis normal to the bed joints
- Bending tests with masonry walls about an axis parallel to the bed joints
- Shear tests with a precompressed single bed joint between two bricks.


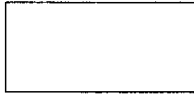
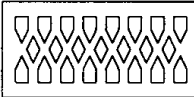
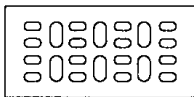
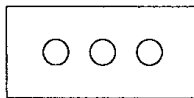
These tests together with similar tests reported in [1] and [2] forms the basis for a paper [3] with the title "Bending properties of Masonry walls" submitted for publication in Masonry International

This bulletin only contains information about how the tests are carried out and presents the results. The interpretation of the test results and the conclusions, which can be drawn, can be found in [3].

2. Bricks and mortars used

In the tests five different clay bricks and two different mortars are used. In table 1 is given the brick properties and in table 2 the mortar properties.

Table 1.

Brick type	Mean compressive strength N/mm ²	Suction rate Kg/m ² /mm	Geometry
Solid S	26	2.8	
Solid O	26	3.2	
Perforated P	46	2.9	
Perforated Y	47	2.0	
Perforated G	66	2.5	

All the bricks are of Standard Danish size 228 × 108 × 55 mm.

Table 2. Mortar properties

Type	A	B
Composition		
<i>Cement</i>	40 kg	65 kg
<i>Lime</i>	60 kg	35 kg
<i>Sand</i>	850 kg	650 kg
Compressive strength	3.8 N/mm ²	11.5 N/mm ²
Tensile flexural strength	1.51 N/mm ²	3.65 N/mm ²

Three professional bricklayers who were instructed to follow the recommendations given in the Danish masonry code DS 411 made all test specimens.

3. Bending tests with masonry walls about an axis normal to the bed joints

3.1 General

In the Danish masonry code the test specimen used to determine the bending properties of masonry walls subjected to bending about an axis perpendicular to the bed joints is a 4-course high wall as shown in Figure 1.

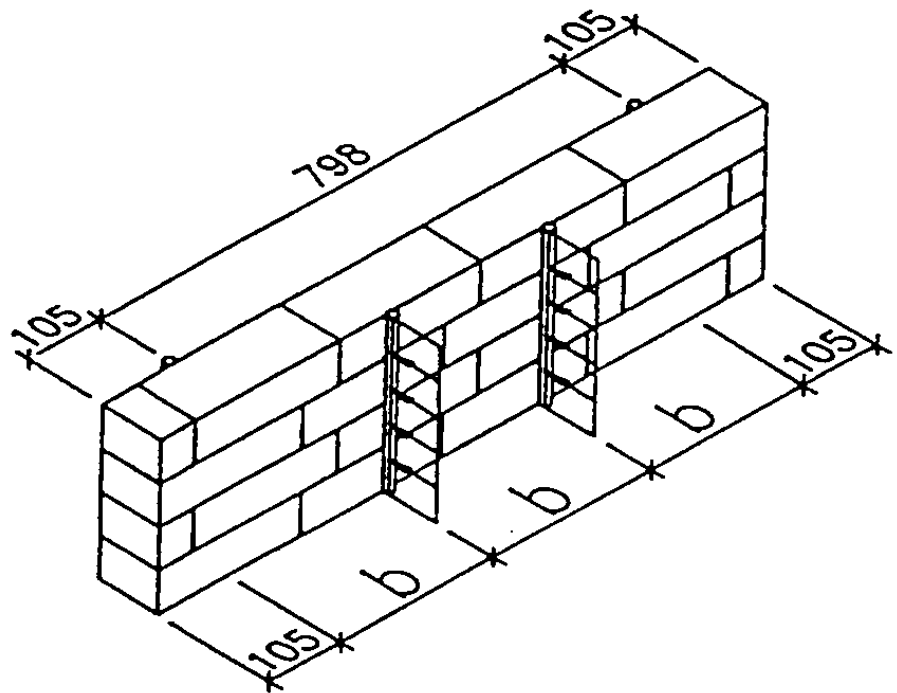


Figure 1. Test specimen and loading arrangement for the determination of the bending properties of masonry walls.

It is expected that the number of courses as well as the bond type have an effect on the bending properties. These two parameters are therefore included as variables in the tests.

3.2 Principle

The principle of the test setup is shown in Figure 2.

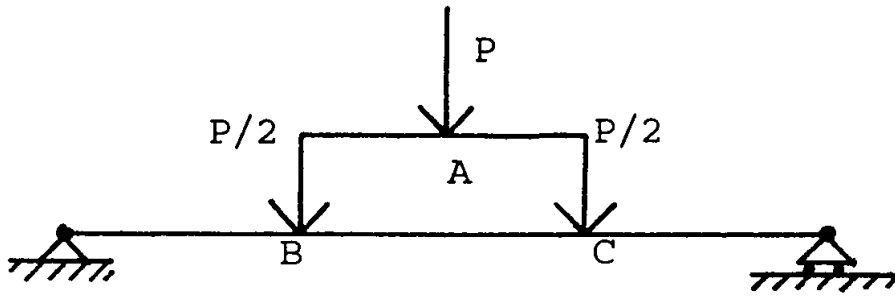


Figure 2. Principle of the test setup.

Forcing point A downward at a constant rate provides the loading. A force transducer measures the load P. The loading arrangement is designed to be approximately 10 times as stiff as the test specimen in order to be able to capture the post-peak behavior.

3.3 Testing equipment

Figure 3 shows the test setup.

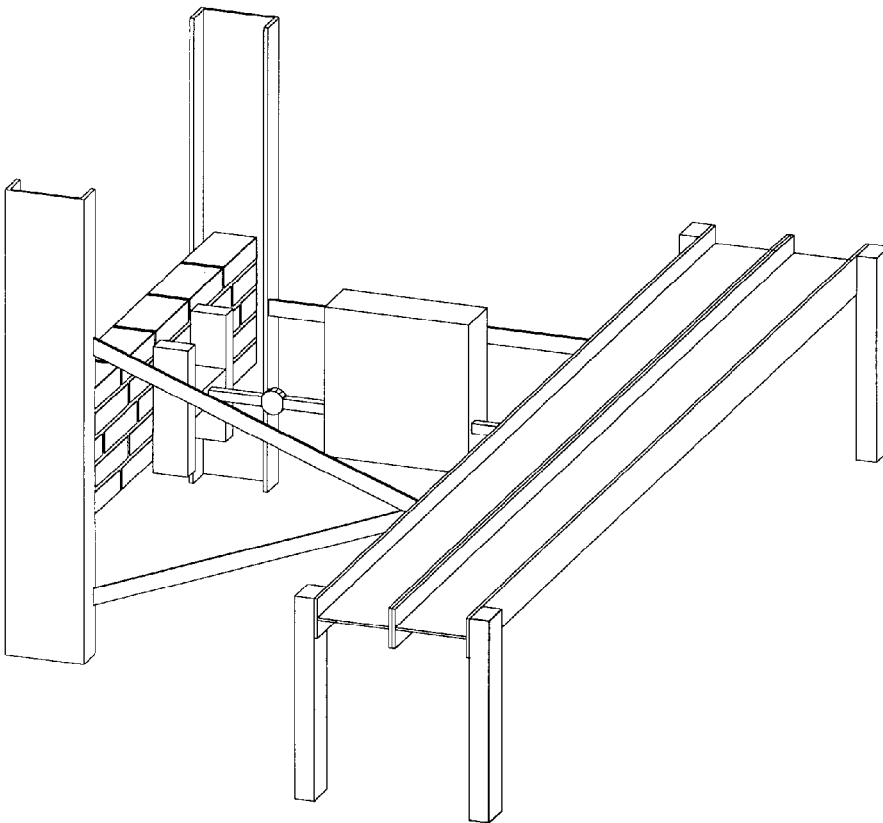


Figure 3. Test setup.

Each course in the test specimen is fastened to two U-profiles by means of adjustable *bolts* as shown in Figure 4.

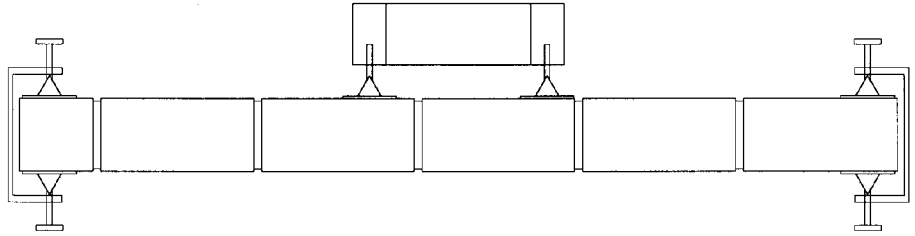


Figure 4. Fastening of the test specimen to the U-profiles.

The U-profiles are supported by rollers on the floor and connected via three bars to a double I-profile acting as a vertical strong floor.

The load is transferred from the double I-profile to the test specimen via an H-shaped frame containing adjustable bolts spaced one course such that the load is applied in a uniform manner. The H-shaped frame is supplied with a hinge at C in Figure 3 allowing the two legs to rotate independently of each other about a horizontal axis.

The load is supplied by a loading unit capable of producing a constant displacement rate (A in Figure 3), and the load is measured by a load transducer (B in Figure 3).

The lateral deflection of the test specimen is measured by electrical displacement transducers located at the non-visible face of the test specimen.

The test specimen is also equipped with electrical displacement transducers measuring changes in the height of the test specimen as shown on Figure 5.

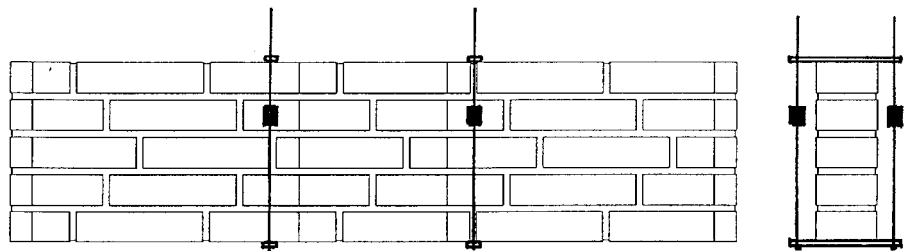


Figure 5. Measurement of change in height of test specimen.

3.4 Test procedure

The test is performed at a displacement rate of 0.4 mm/minute. During the tests the displacements and the load are recorded one time per five second.

The test is terminated when the load has dropped to a low constant value or zero.

4. Bending tests with masonry walls about an axis parallel to the bed joints

These tests are made similar to the tests with bending about an axis normal to the bed joint except that the test specimen is turned 90° as shown on Figure 6.

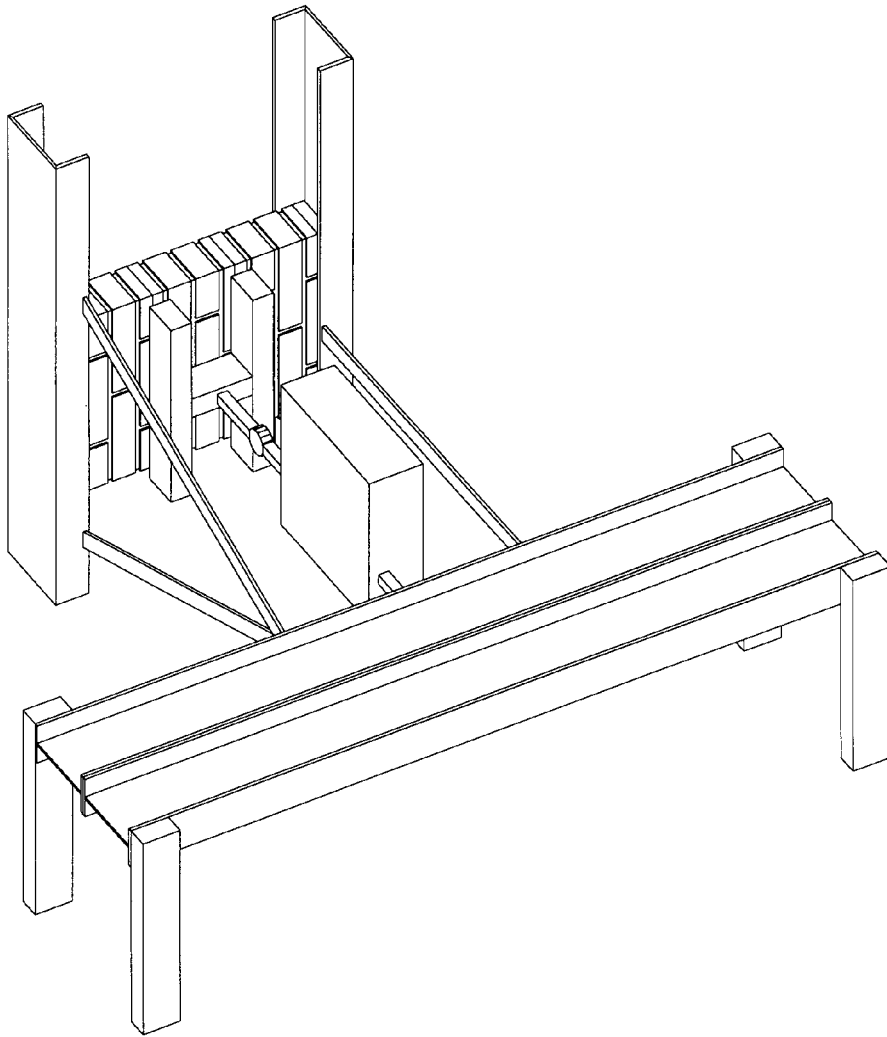


Figure 6. Test setup for bending tests with a bending axis parallel to the bed joints.

5. Shear tests

5.1 General

In the literature several papers dealing with the shear properties of bed joints can be found, see e.g. [4] – [9].

Five different loading arrangements are used in these papers each having its advantages and disadvantages.

In [9] four of these five loading arrangements have been analyzed using the finite element method to find the shear and normal stress distribution in the joint assuming linear elastic behavior. None of the arrangements produce a completely uniform shear and normal stress distribution in the joint and this makes the interpretation of the test results more difficult.

The effect of an uneven stress distribution should, however, be judged in relation to the brittleness of the joint and in relation to the uniformity of the material properties along the joint. Only for very brittle joints with an almost uniform distribution of material properties along the joint can it be expected that the non-uniformity, of the stress distributions will produce test results, which will underestimate the strength of the joint.

Since mortar joints are expected to possess some degree of ductility and do not have a completely uniform distribution of material properties along the joint it is believed that none of the stress distributions corresponding to the different loading arrangements shown in [9] would lead to a significant underestimation of the strength properties of the joint. This, however, does not mean that a striving toward a uniform stress distribution is not worthwhile.

The loading arrangement used in this bulletin is similar to the one described in [4]. In [9] it is shown that the normal stress distribution produced by this loading arrangement is non-uniform due to bending in the L-shaped moulds shown in Figure 7. In the used loading arrangement the L-shaped moulds are designed to be as stiff as possible in order to reduce the non-uniformity in the normal stress distribution without making them too difficult to handle.

5.3. Principle

The principle of the test setup is shown in Figure 7.

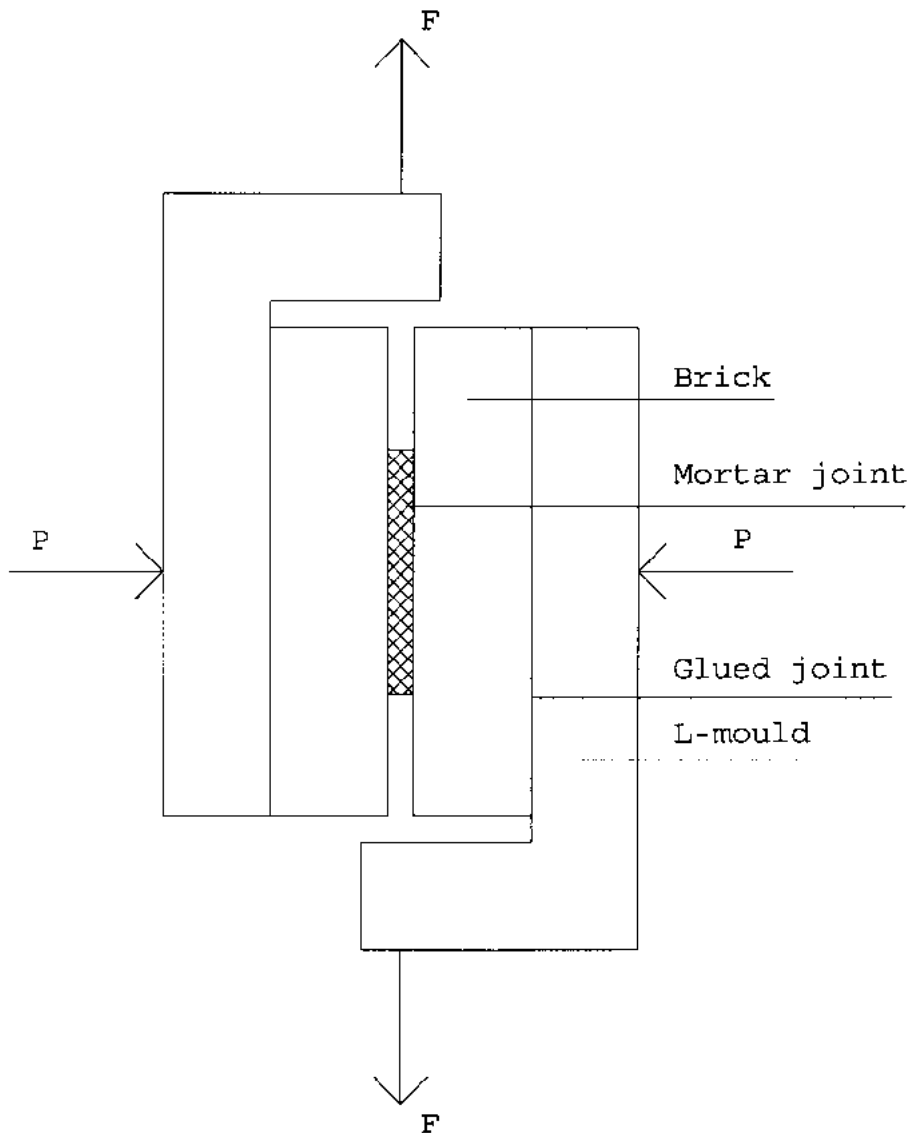


Figure 7. Principle of test setup.

P = Precompression force.

F = Shear force.

From Figure 7 it is seen that a test specimen consists of two bricks and a single mortar joint. The shear force is transferred to the test specimen through a glued joint between the bricks and the L-shaped moulds. This arrangement secures that the shear force is applied at the centre line of the joint, so that pure shear is attained in the centre of the joint. The test is carried out in tension, which gives a stable test setup that is little affected by initial eccentricities of the test specimen.

This test setup is similar to the one used by Rob van der Pluijm [4] and by Finn R. Gottfredsen [10].

In order to minimize the risk of brick failure only half of the joint is filled with mortar.

5.3. Testing equipment

In Figure 8 it is shown how the L-shaped moulds are made.

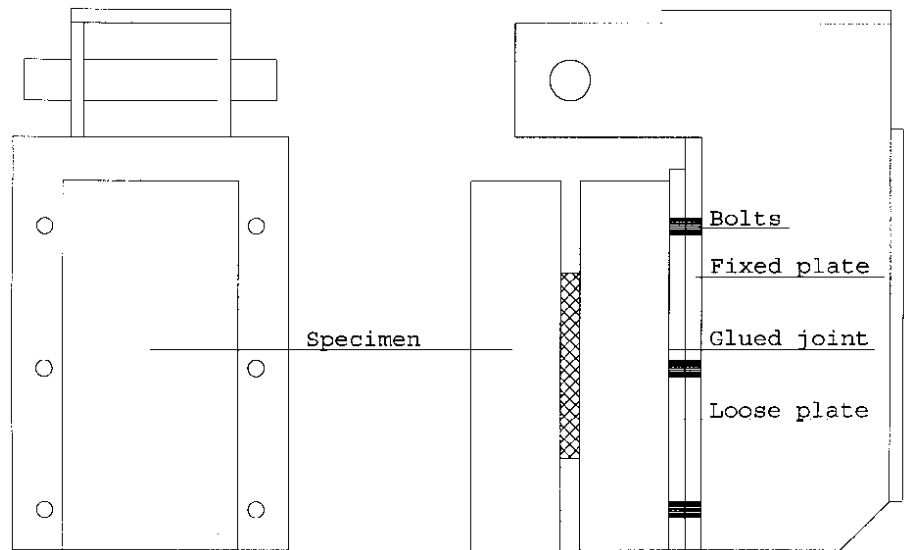


Figure 8. View of one of the L-shaped load application moulds.

As indicated in Figure 8, a loose plate is first bolted to each of the two L-shaped moulds. Then the test specimen is glued to the moulds so that the test specimen after the test can be removed from the moulds mechanically.

The assembled testing arrangement ready for testing is shown in Figure 9. The stiffness of the springs should be so that a deformation of the test specimen of approximately 0,5 mm in the direction of the two steel rods will not change the precompression force more than 10 percent.

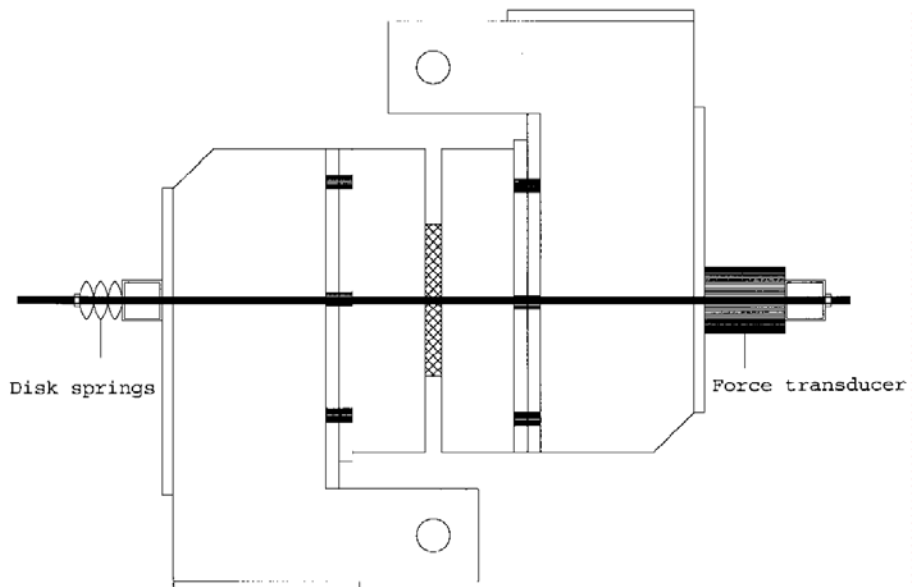


Figure 9. Test specimen ready for testing.

During a test the following parameters are measured:

- Shear displacement of joint (d)
- Dilatation of joint (w)

- Precompression force (P)
- Shear force (F)
- Time.

The shear displacement of the joint is measured with two displacement transducers on each side of the joint as shown in Figure 10.

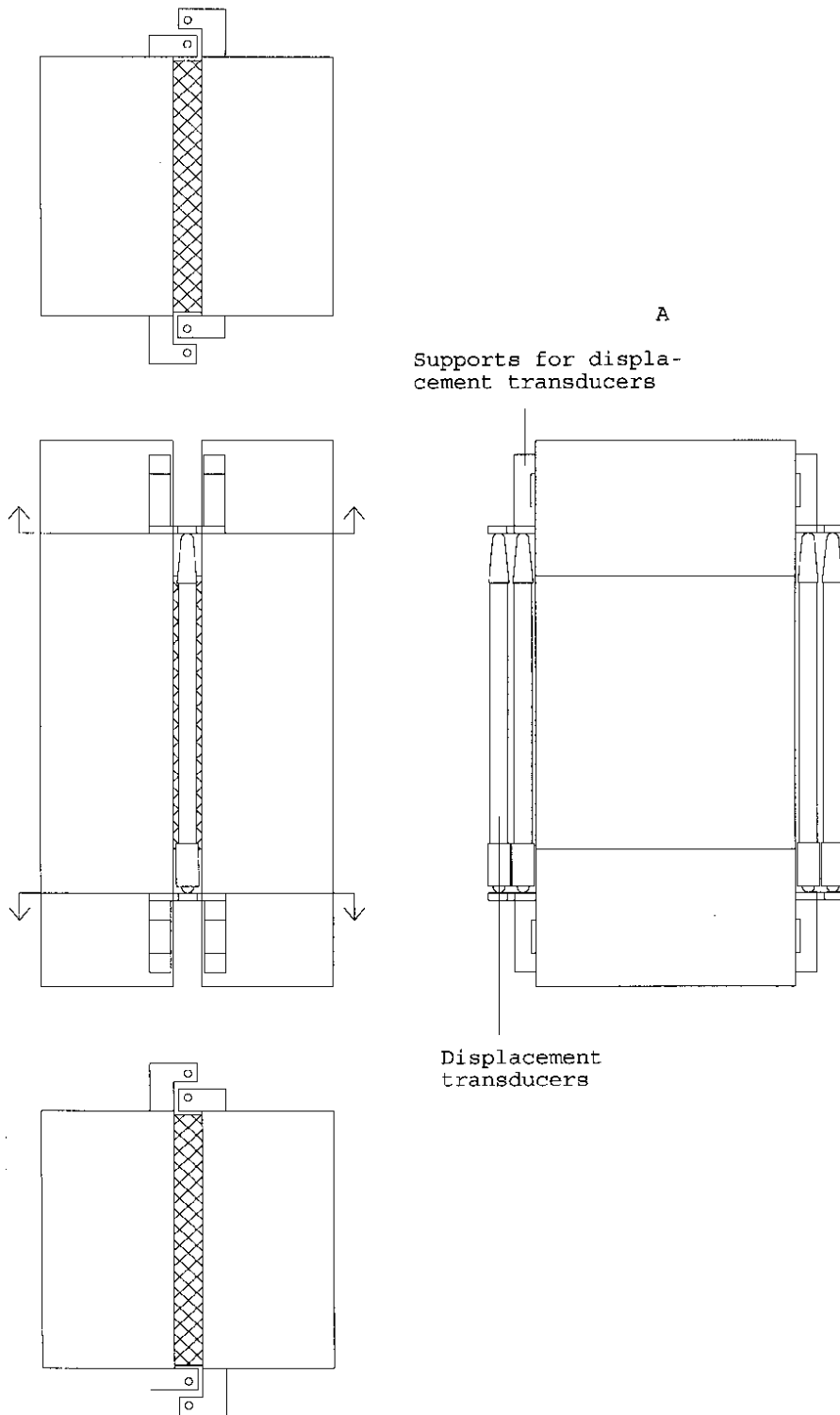


Figure 10. Arrangement for measuring the shear displacement of a joint.

The shear deformation of the joint can be found from the readings of the four displacement transducers shown in Figure 10 as

$$d = ((L_{ri} - L_{ro})/2 + (L_{lo} - L_{li})/2)/2 \quad (1)$$

where L_{ri} and L_{ro} are the readings of the inner and outer displacement transducers on the right side (Figure 10, A) of the test specimen and L_{lo} and L_{li} are the readings from the displacement transducers on the left side of the specimen.

The supports for the displacement transducers are placed near the end of the units as close to the joint as possible. They are designed so that they can be glued to the units in two separate points as shown in Figure 10 in order to avoid angular movements of the supports due to shear deformations in the units.

The parameter d is used as the controlling parameter in the test, which means that the growth rate of the numeric value of this parameter is kept constant during a test.

The use of two displacement transducers on both sides of the test specimen means that an elongation or a shortening of the test specimens due to an uneven shear distribution in the glued joint between the test specimen and the L-moulds has no effect on the measured shear deformation d .

The shear deformation found by (1) includes a contribution from the shear deformation of the units because the supports for the deformation transducers are glued to the units at a small distance from the interface between the units and the mortar. If the shear modulus for the units is known this contribution can be estimated. Normally this contribution is so small that it can be neglected.

The dilation w of the joint is measured as shown in Figure 11. The result is given as the mean value of the two readings.

Displacement transducer for measuring the dilatation in the mortar joint

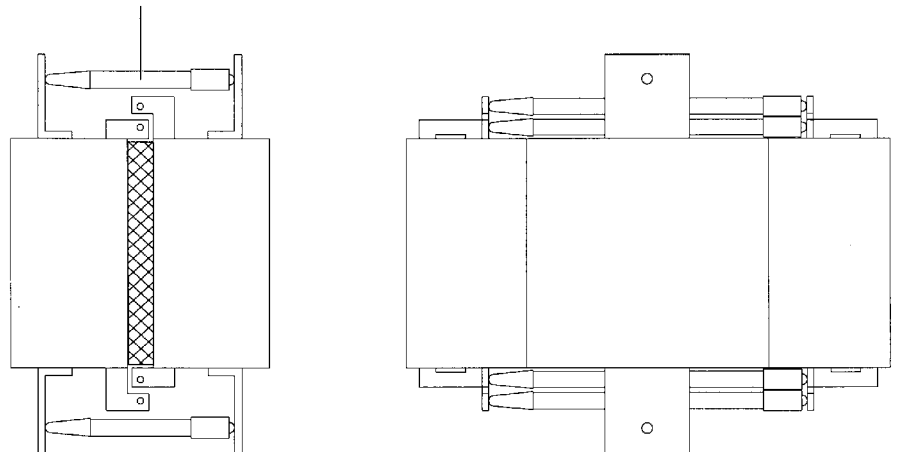


Figure 11. Determination of the dilatation in the middle of the joint.

The precompression force P is measured by a force transducer as shown in Figure 9 and the shear force F is measured by the testing machine which is servo-controlled with the shear deformation d as the controlling parameter.

5.4. Test procedure

The test specimen assembled with the two L-moulds is placed in the testing machine as shown in Figure 12.

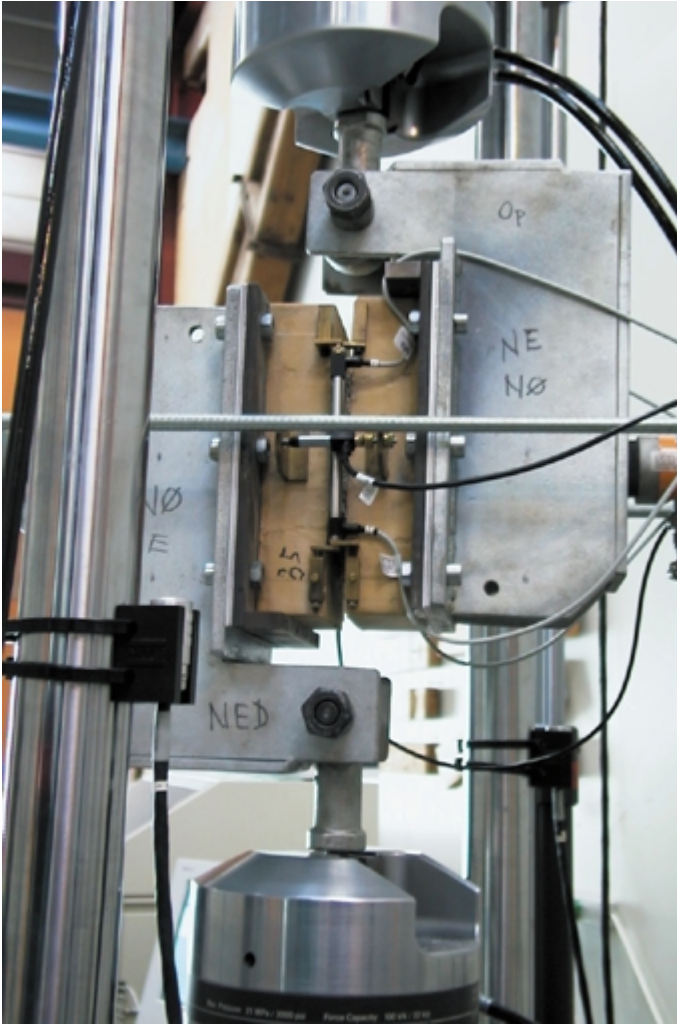


Figure 12. The test setup.

The test is carried out in tension and the movement of the pistons is controlled by the shear displacement d so that the growth rate of the numeric value of this parameter is kept constant at 2 mm/hour. During the test all measurements are recorded two times per second. The test is stopped when the parameter d has attained a value of approx. 1 mm.

6. Test results

6.1. Results from bending tests with a bending axis normal to the bed joints

In Figure 13 is shown the test specimens.

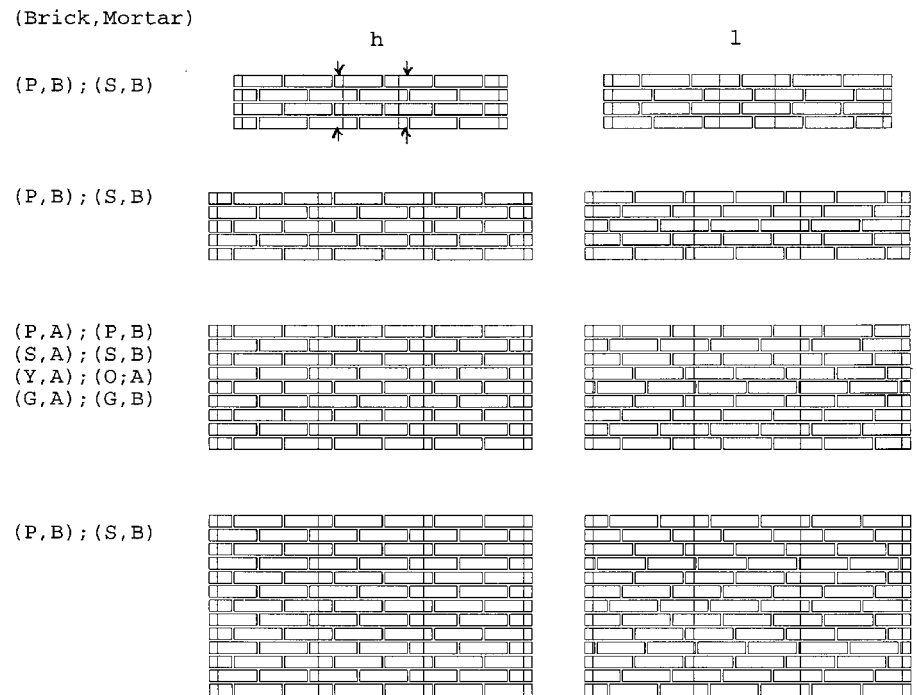


Figure 13. Test specimens used in bending tests about an axis normal to the bed joints.

A corresponds to KC 60/40/850 mortar

B corresponds to KC 35/65/650 mortar

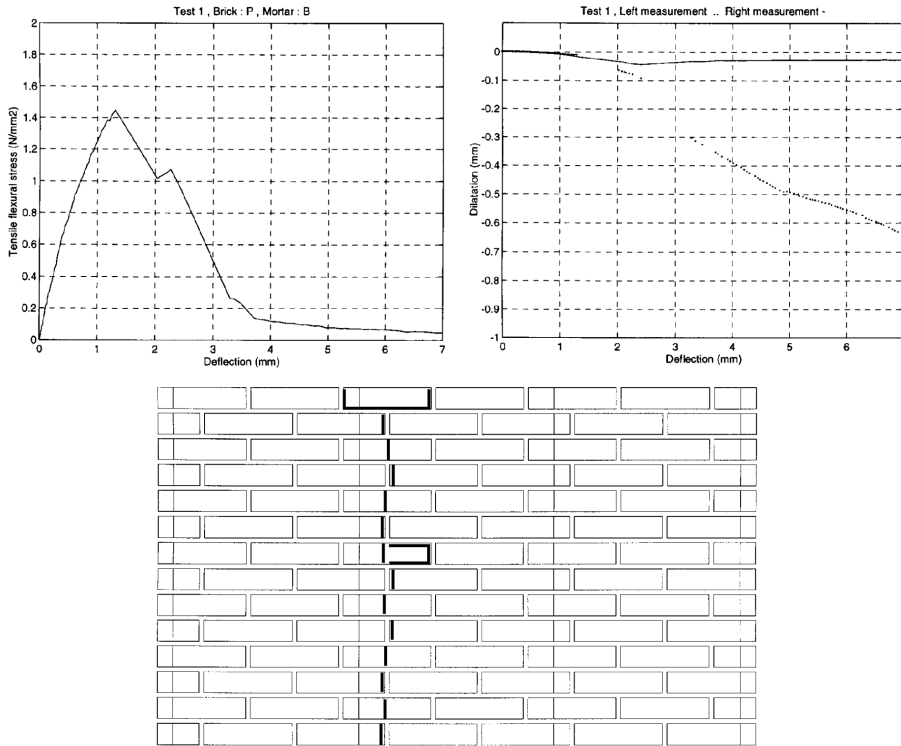
The arrows (only shown on one test specimen but placed similar on all test specimen) indicate sections where changes in height are recorded.

In Figure 14 is given tensile flexural stress as a function of the normalized deflection for all 28 specimens.

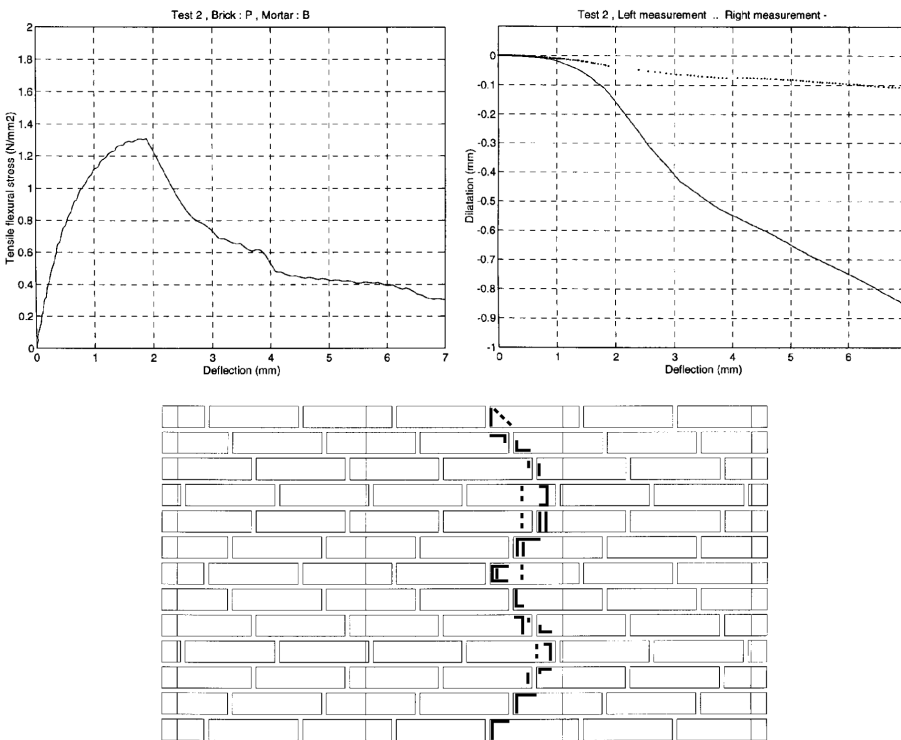
The tensile flexural stress is calculated assuming linear elastic behavior of masonry using ordinary beam theory. Normalization of the deflection means that for a given load and deformation measurement the stiffness of the test specimen regarded as a beam is calculated. The stiffness is used to compute the deflection of a 13 course high and 1.5 m long beam loaded in the third pints so that the maximum moment/m in this beam is the same as in the test specimen. The deflection refers to that of the mid-point.

Also given is the crack pattern at ultimate failure in all specimens on the tension face. The cracks at the interface between bricks and mortar are marked on the bricks. The dotted lines correspond to cracks traversing the brick on the compression face of the specimen. The changes in height of the test specimens were only measurable when the failure involved one or more bed joints and when the

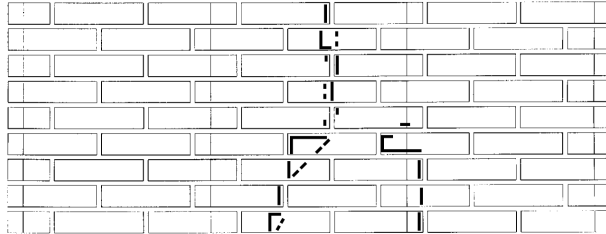
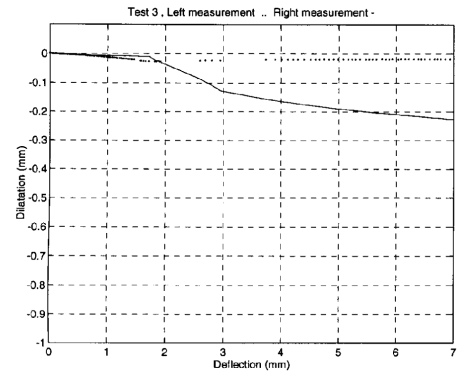
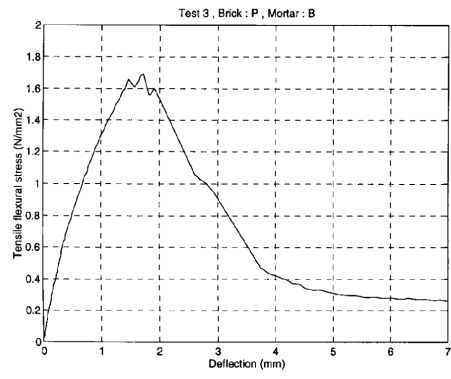
failure occurred close to the section where changes in height were measured. The variations in heights is shown as a function of the normalized deflection.



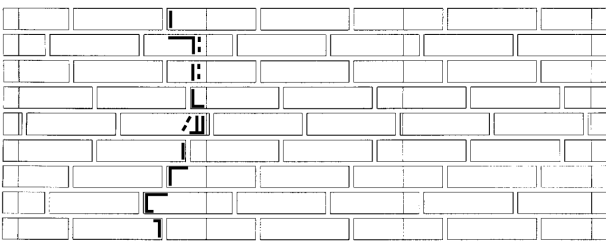
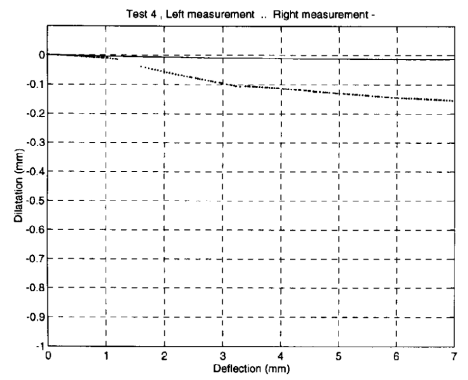
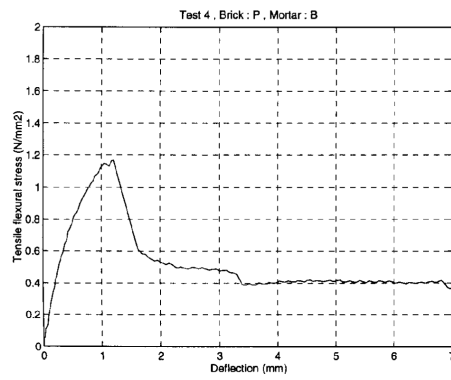
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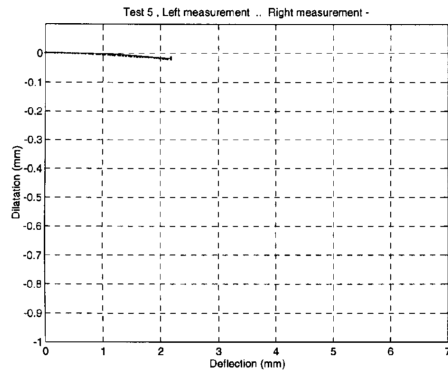
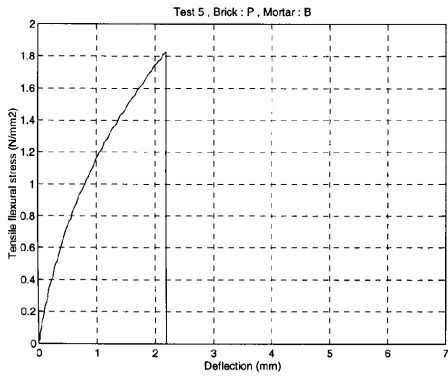
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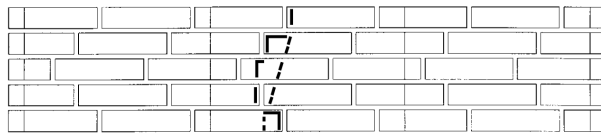
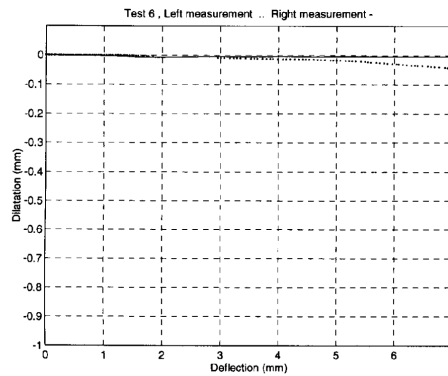
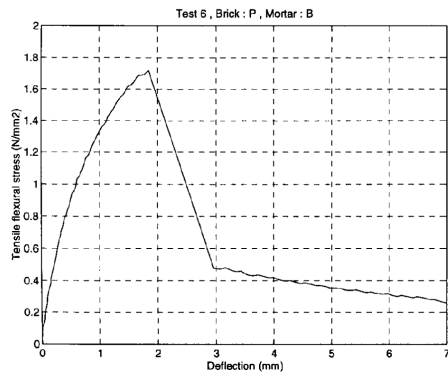
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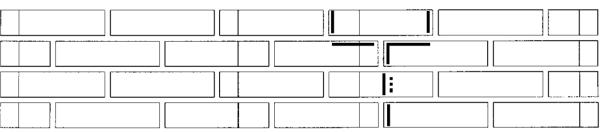
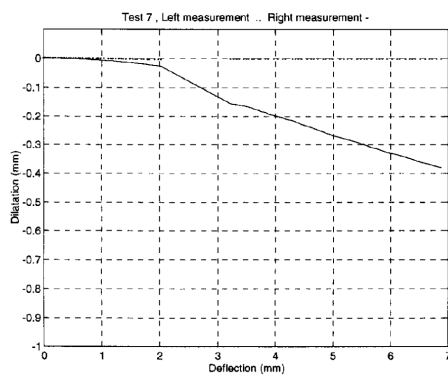
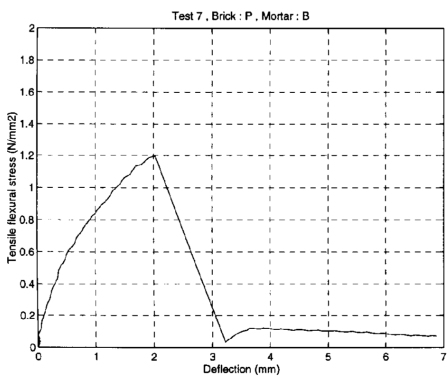
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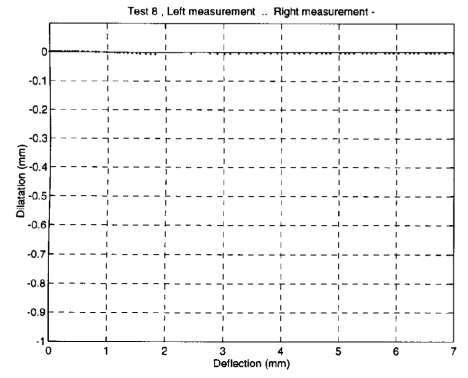
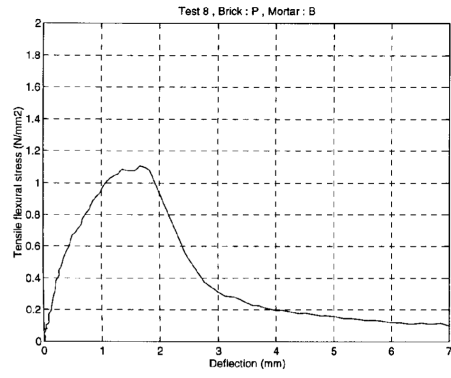
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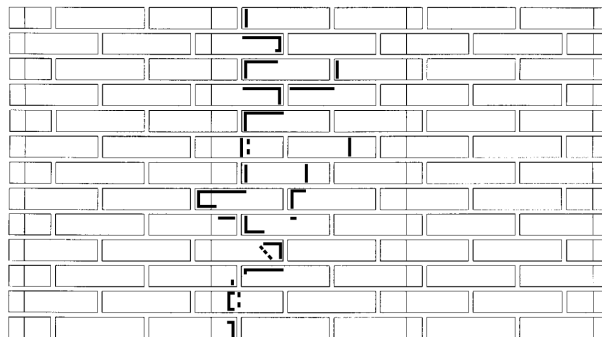
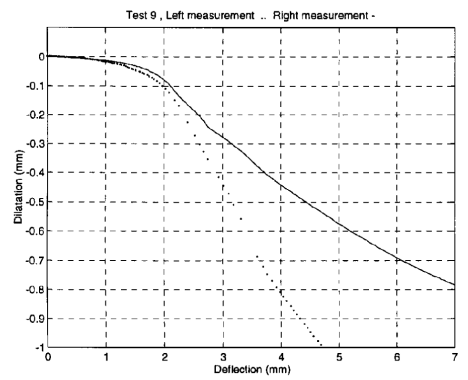
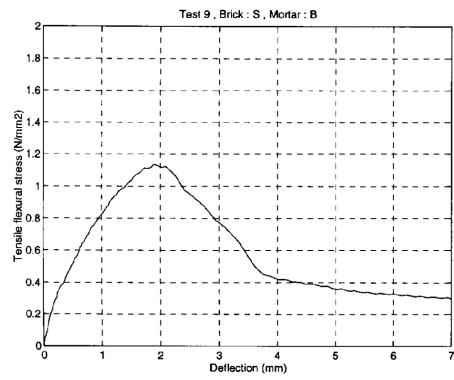
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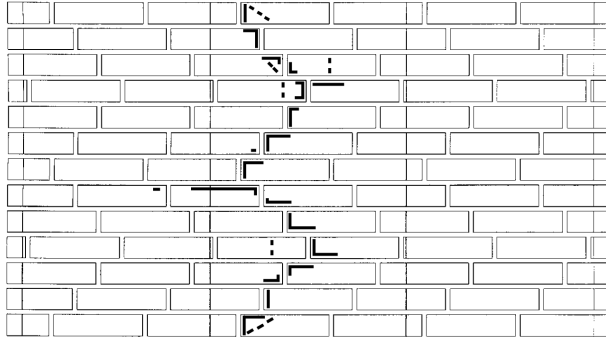
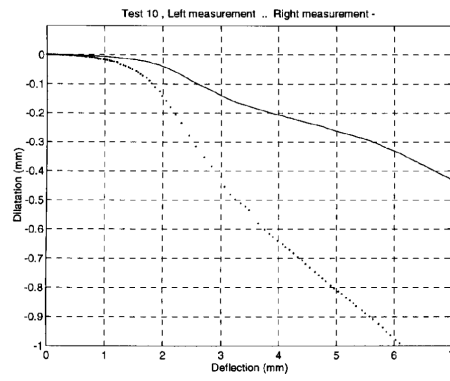
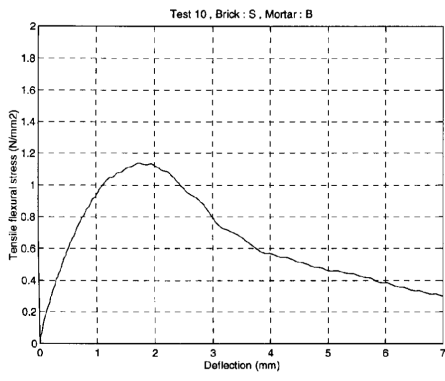
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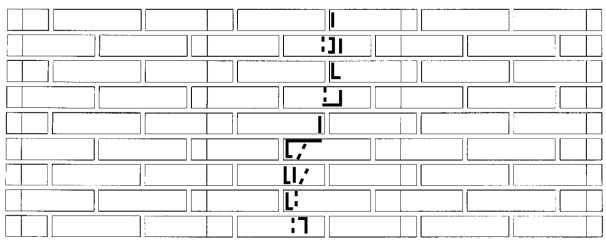
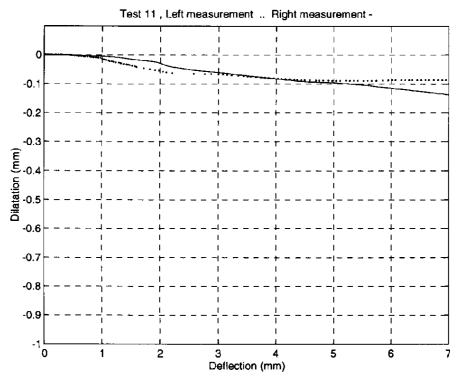
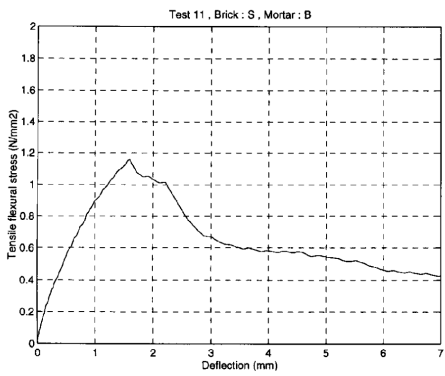
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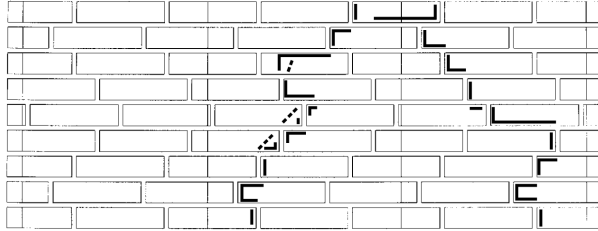
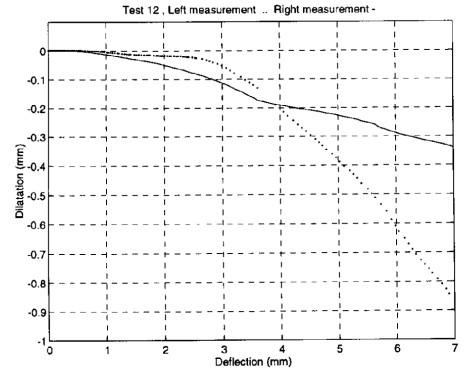
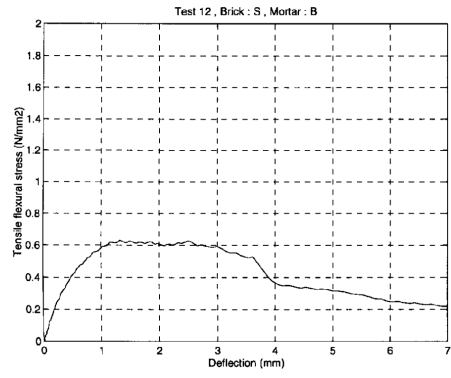
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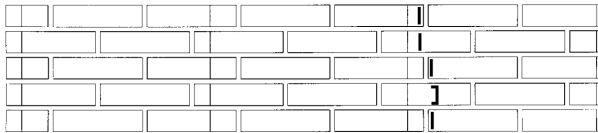
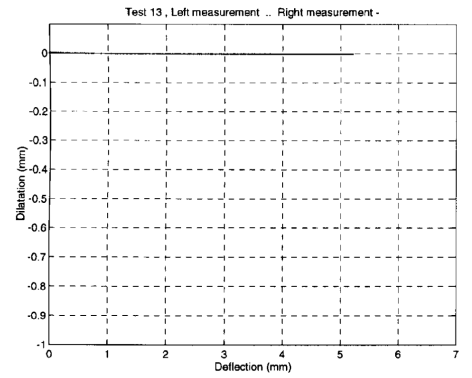
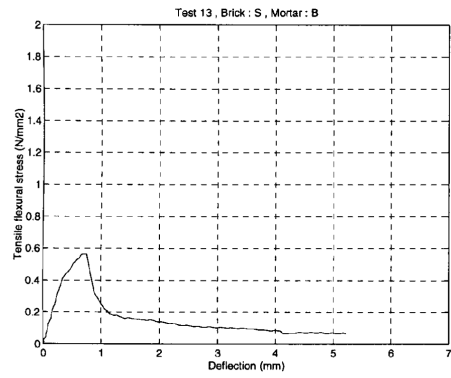
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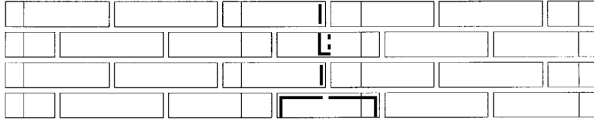
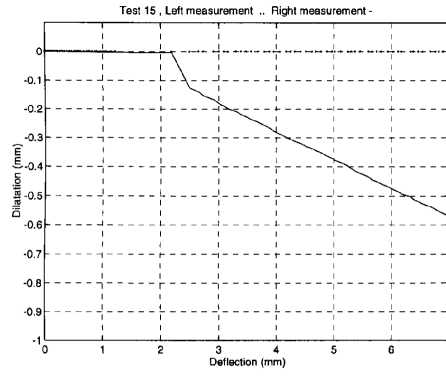
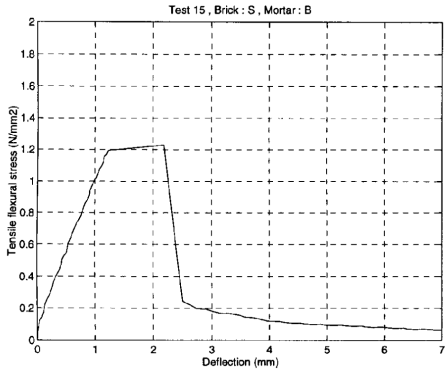
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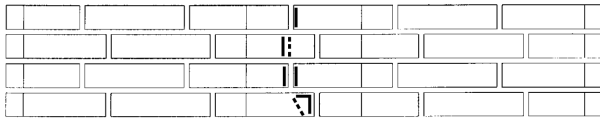
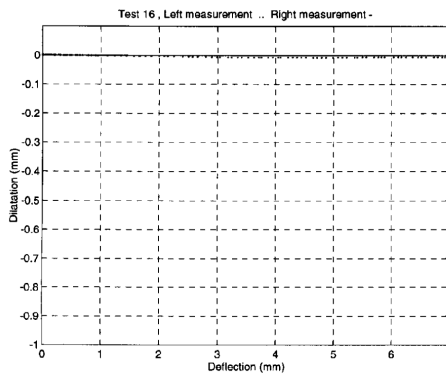
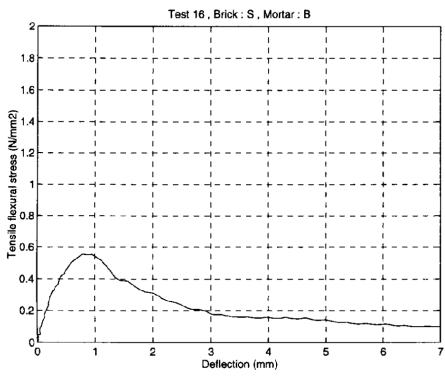
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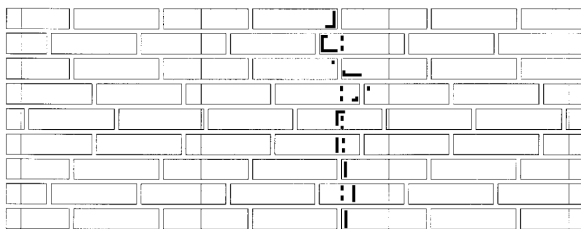
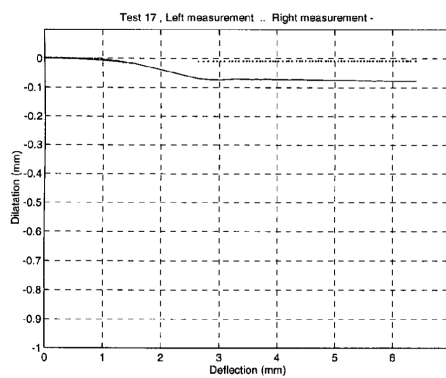
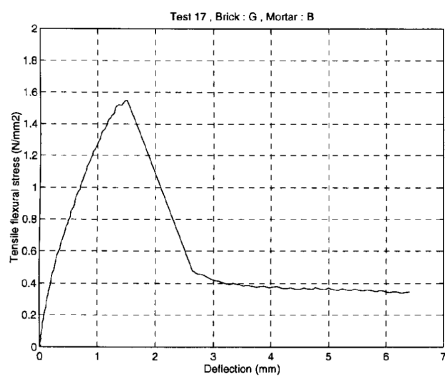
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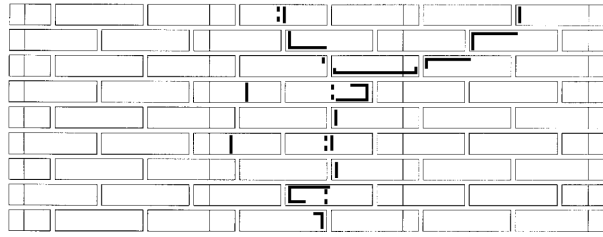
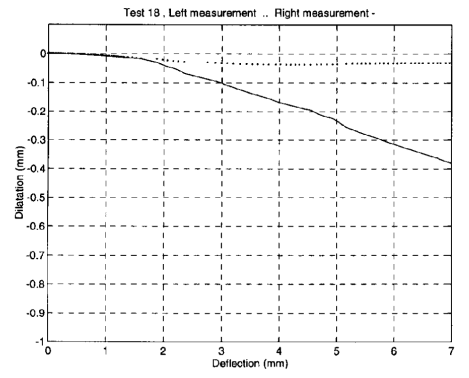
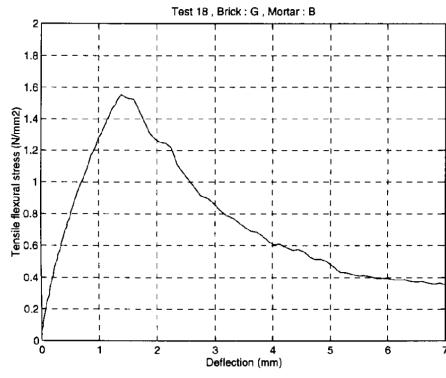
Test 15



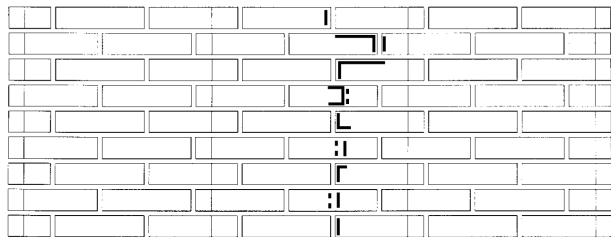
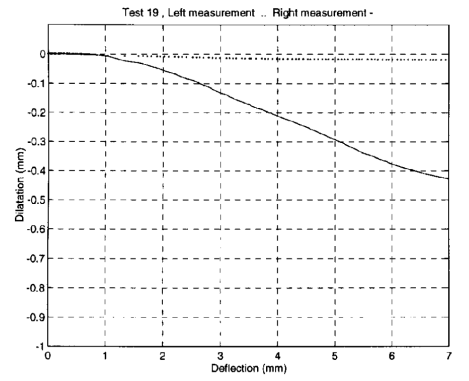
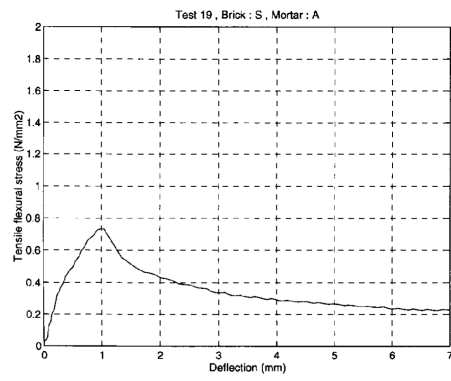
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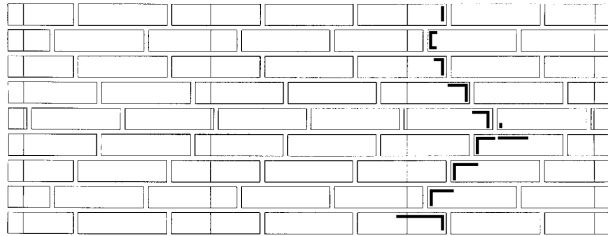
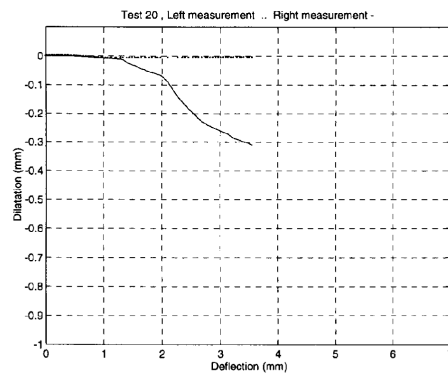
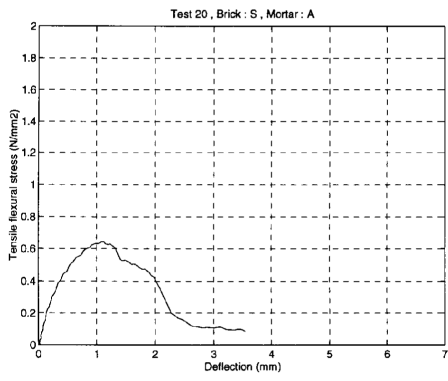
Test 17



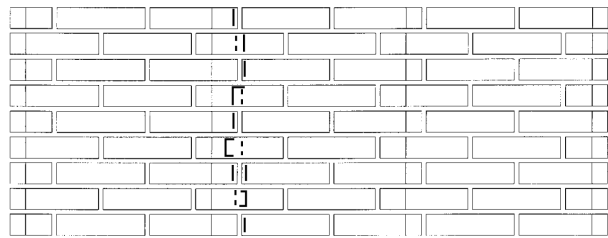
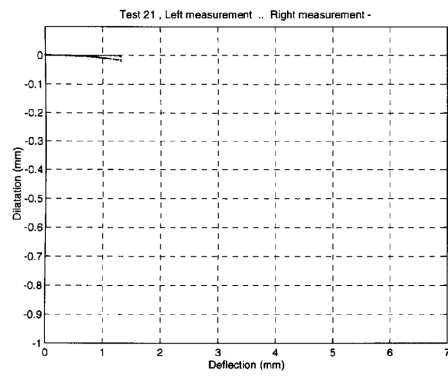
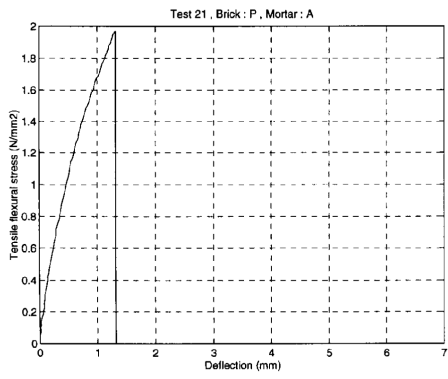
Test 18



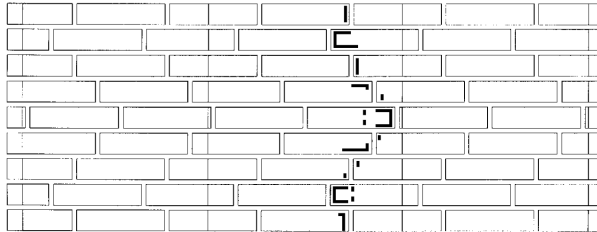
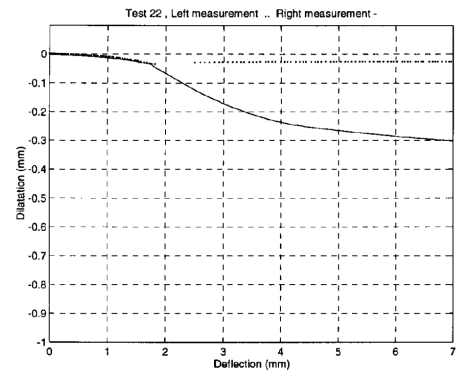
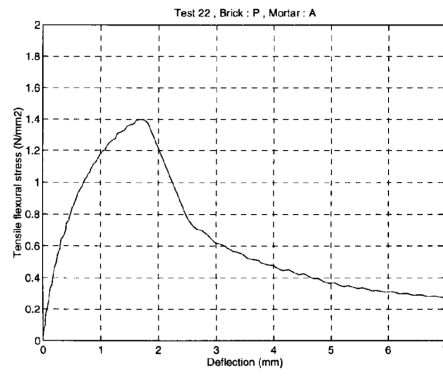
Test 19



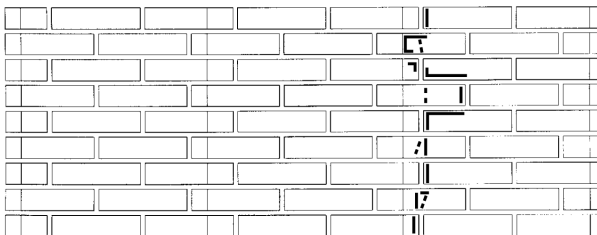
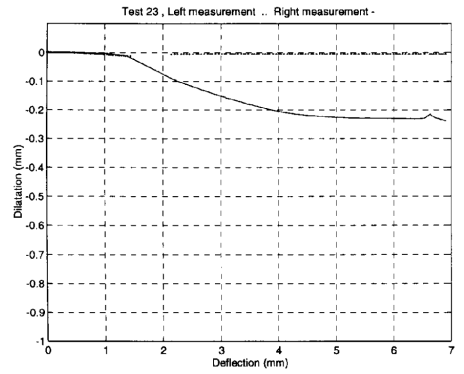
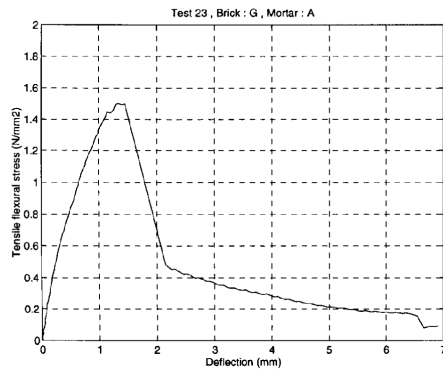
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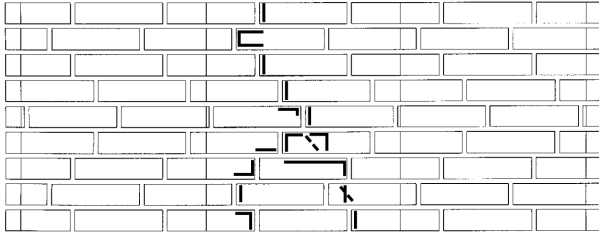
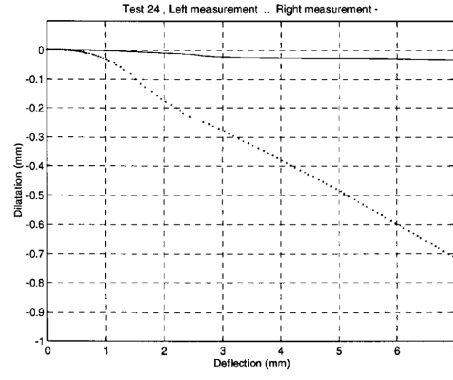
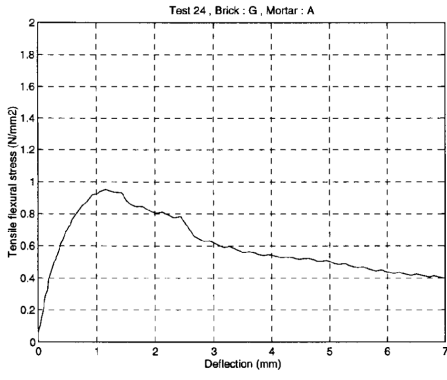
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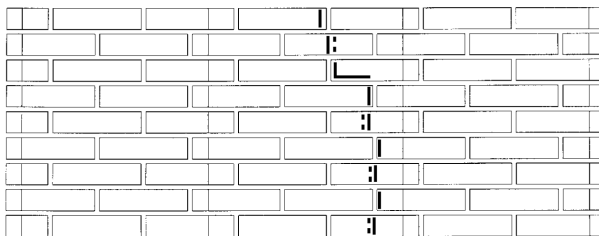
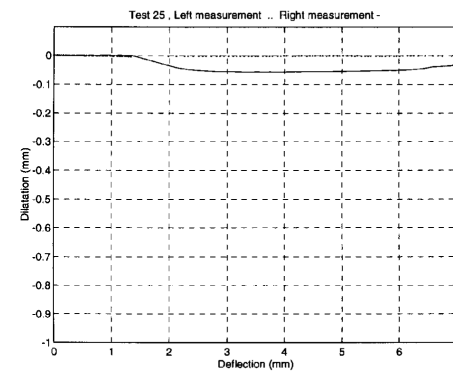
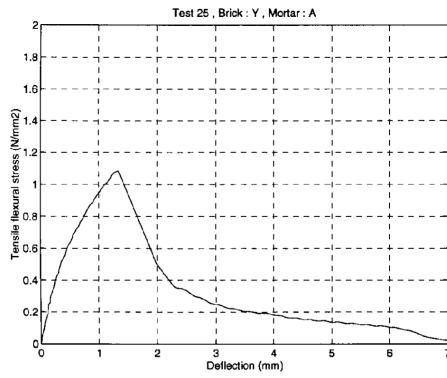
Test 22



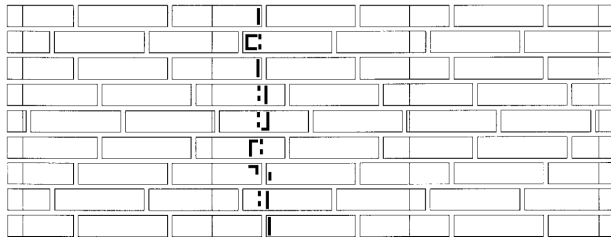
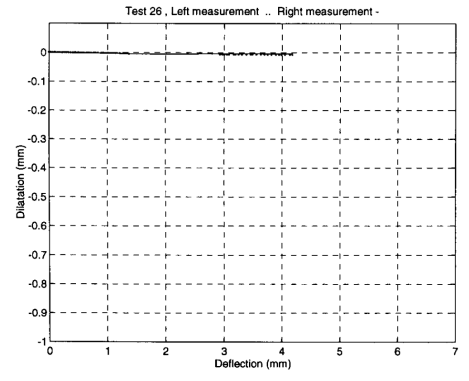
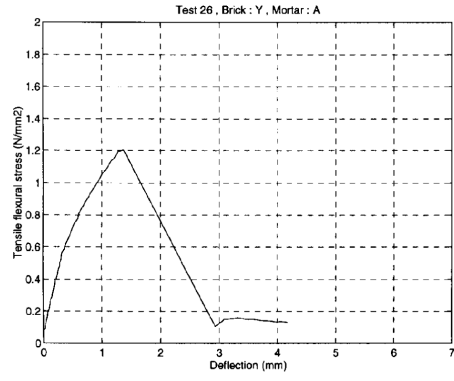
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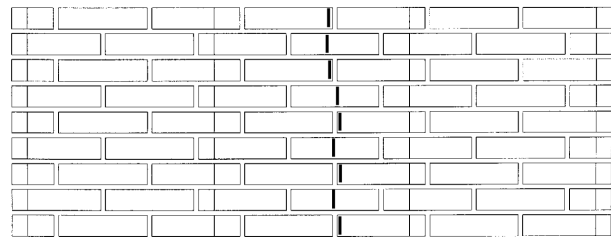
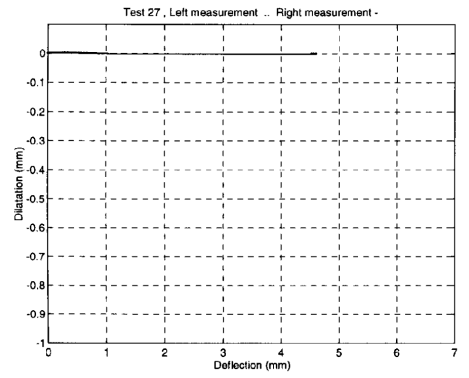
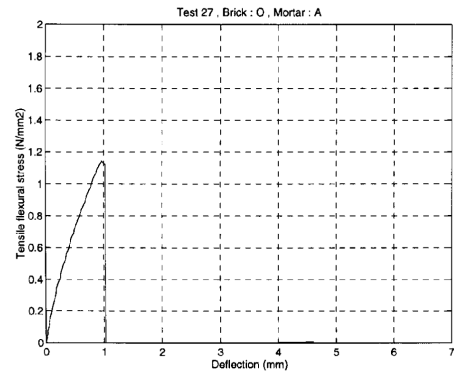
Test 24



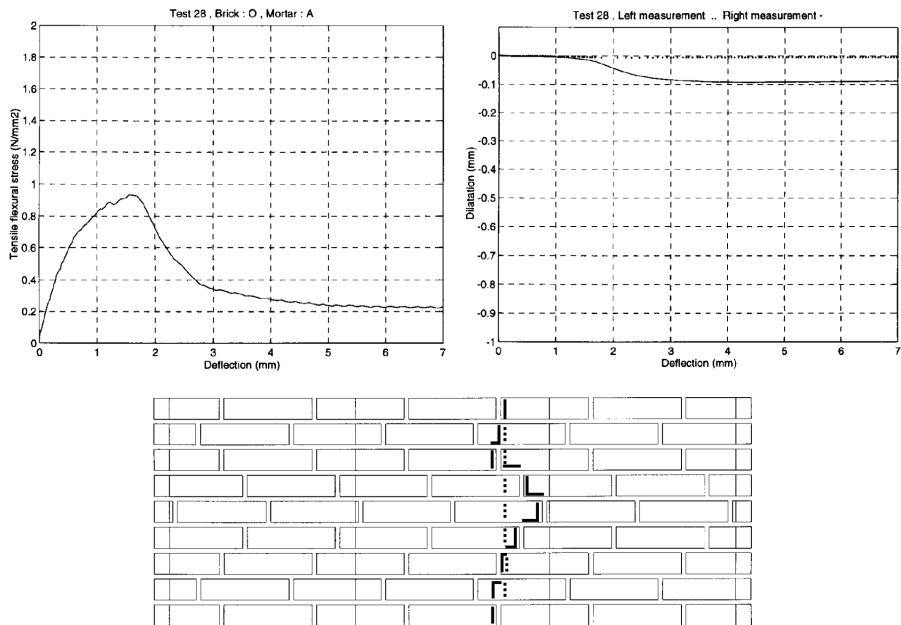
Test 25



Test 26



Test 27



Test 28

Figure 14. Results from bending tests about an axis normal to the bed joints.

6.2. Results from bending tests with a bending axis normal to the bed joints

In Figure 15 are shown the test specimens

(Brick, Mortar)

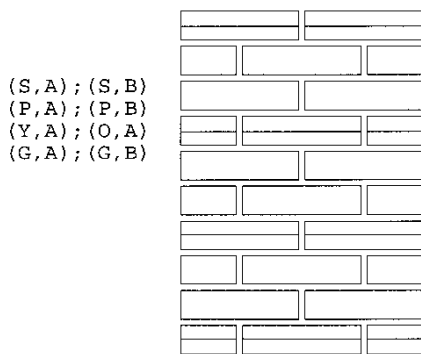
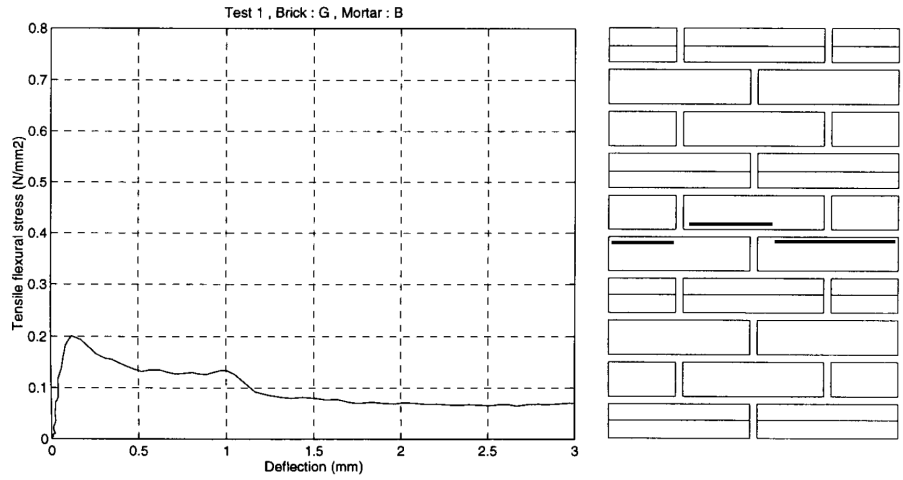
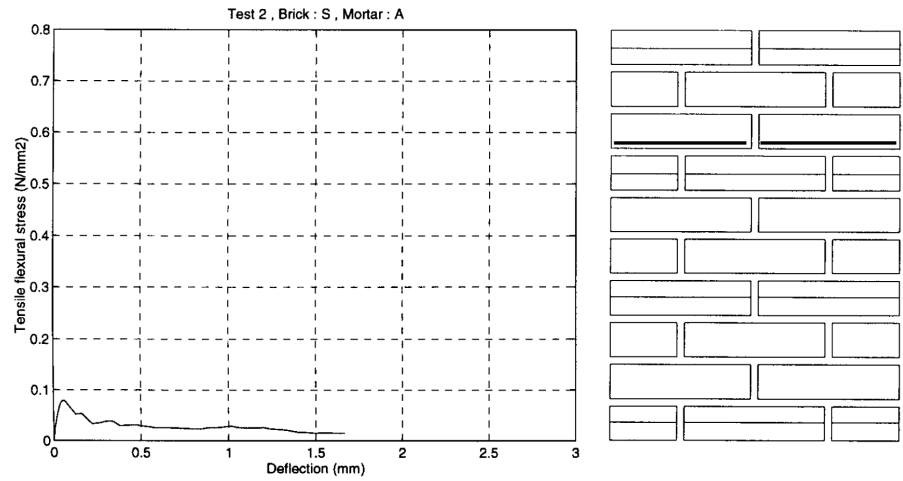


Figure 15. Test specimens used in bending about an axis parallel to the bed joints.

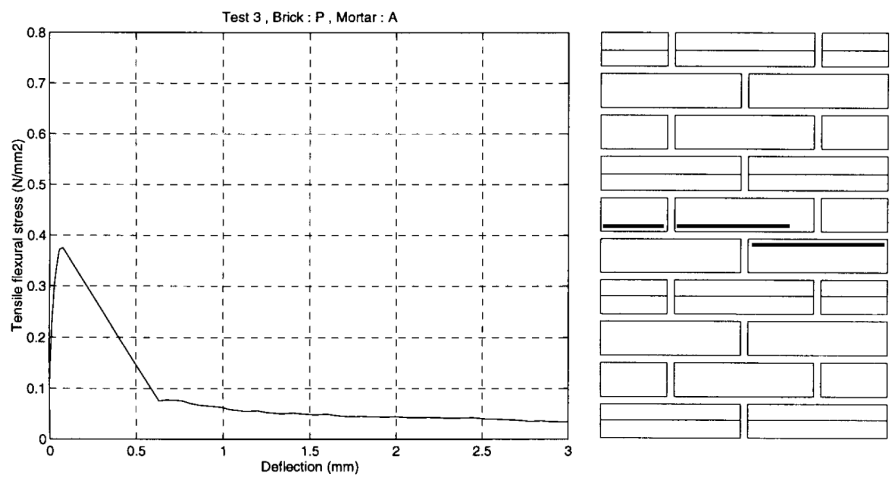
In Figure 16 is given the tensile flexural stress as a function of the deflection of the midpoint of the specimen. Also given is the crack pattern at ultimate failure on the tension face.



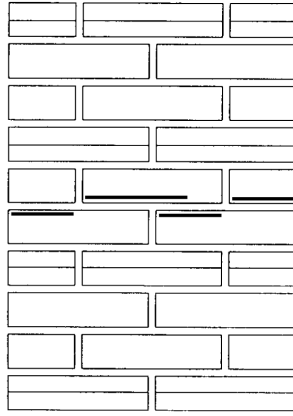
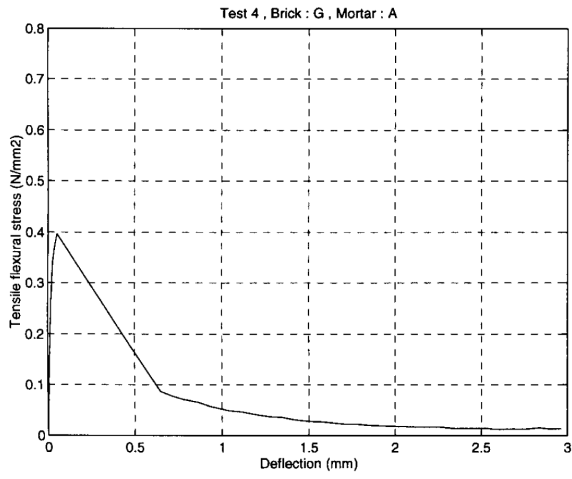
Test 1



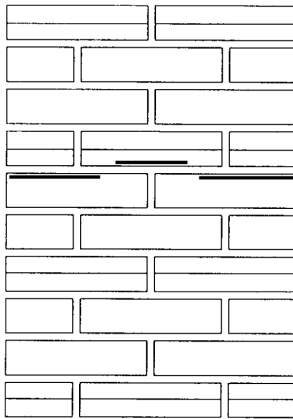
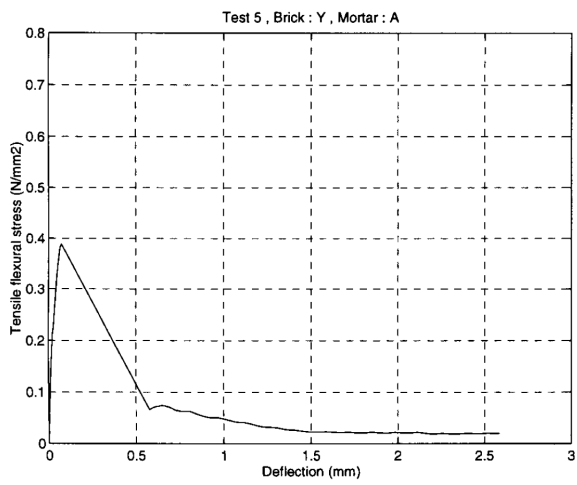
Test 2



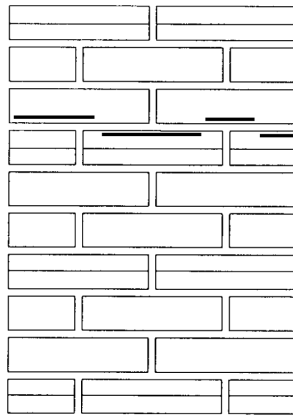
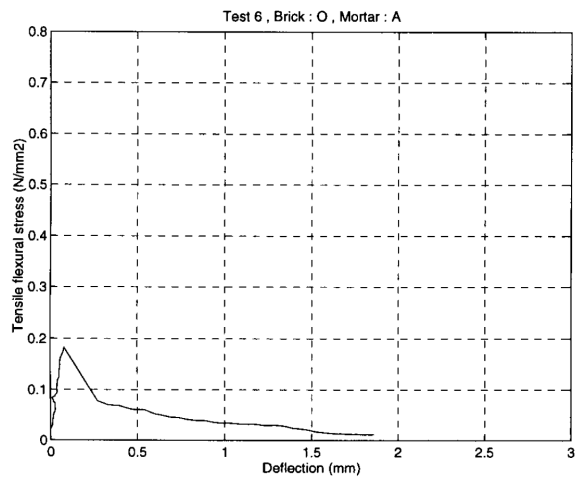
Test 3



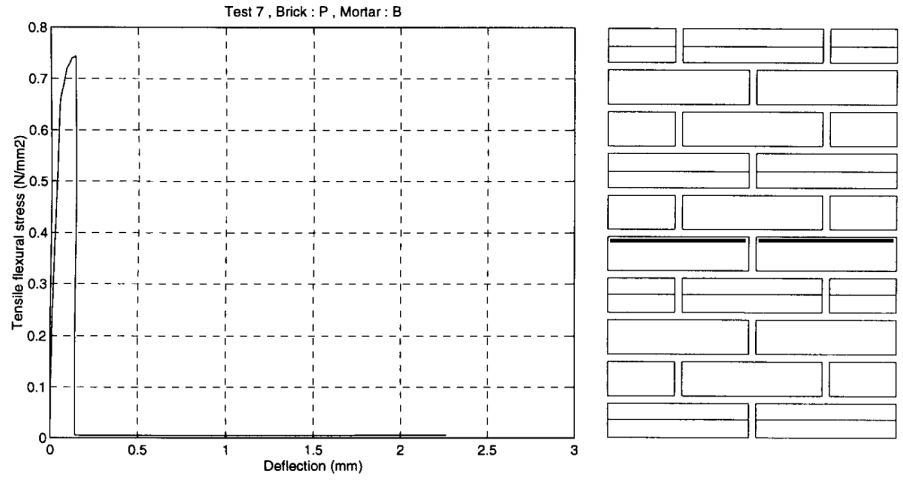
Test 4



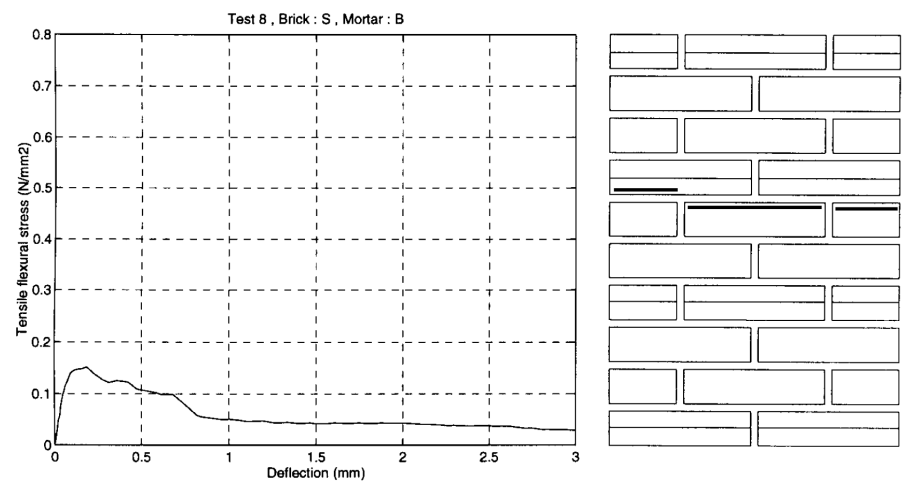
Test 5



Test 6



Test 7

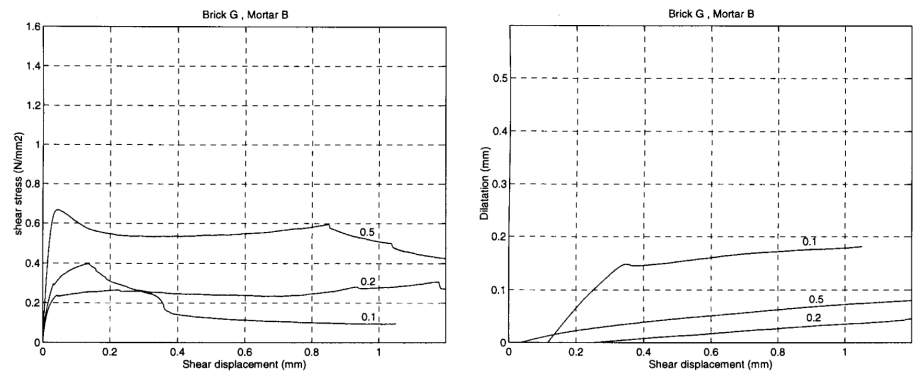


Test 8

Figure 16. Results from bending tests about an axis parallel to the bed joints.

6.3. Results from shear tests with of single bed joint

In Figure 17 the results of the tests are given as shear stress, assuming uniform stress distribution, versus shear displacement curves and as joint dilatation versus shear displacement curves.



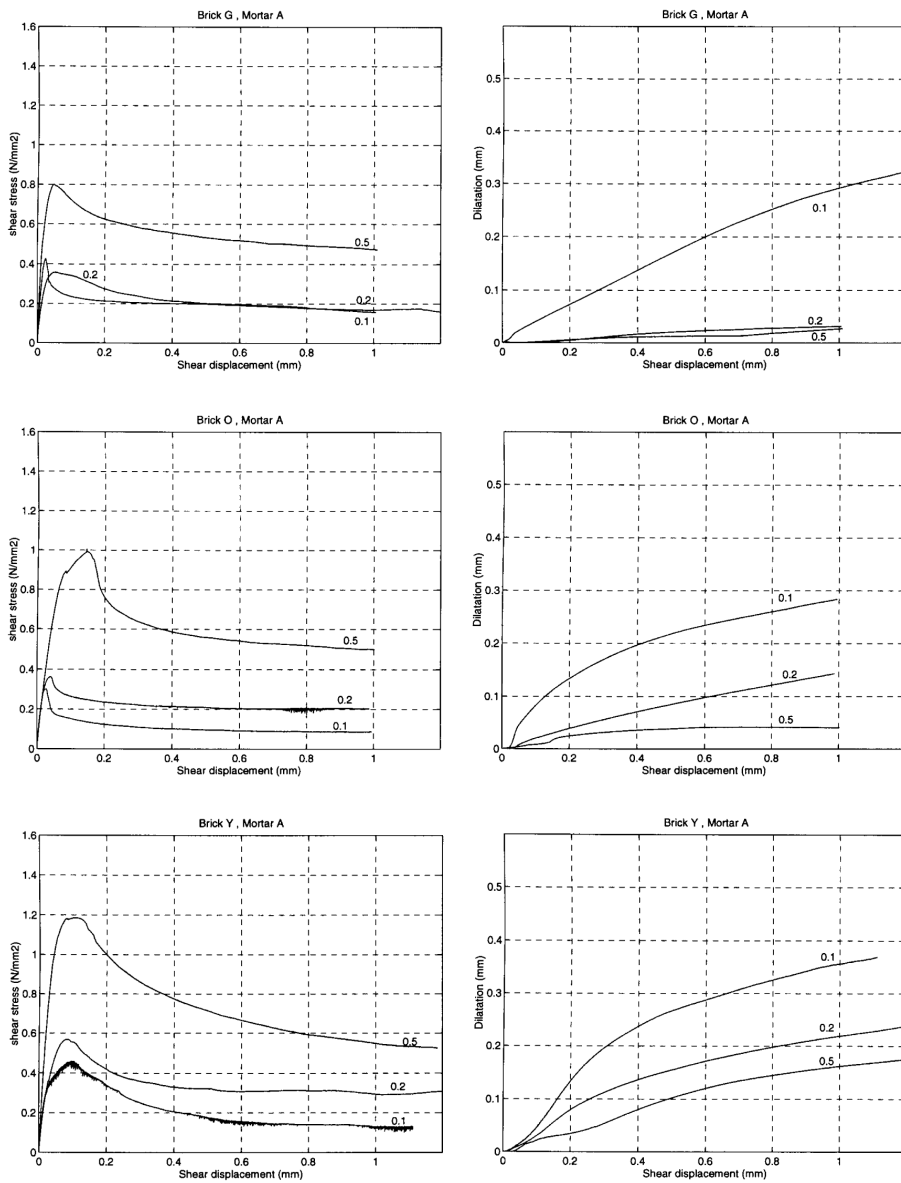


Figure 17. Results from shear tests with a single bed joint. The number associated with each curve gives the precompression stress in N/mm²

Resume

Bøjningsegenskaberne af murværk er bestemmende for bæreevnen af murede vægge. Denne meddelelse indeholder resultater fra deformationsstyrede forsøg med murværk til bestemmelse af disse egenskaber.

Evaluering og konklusioner baseret på disse forsøg er præsenteret i "Hansen, K.F, Bending properties of Masonry Walls. Indgivet til publicering i Masonry International."

References

- [1] Hansen, K.F. Strength and Deformation Capacity of Laterally Loaded Masonry. *Masonry* (8). Proceedings of the 5th International Masonry Conference, London 13th-15th October, 1998.
- [2] Hansen, K. F., Nykänen, E., Gottfredsen, F.R. Shear behavior of bed joints at different levels of precompression. *Masonry International* Vol. 12, nr. 2, 1998.
- [3] Hansen, K. F. Bending properties of Masonry Walls. Submitted for publication in *Masonry International*.
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- [6] Amadio, C. & S. Rajgelj. (1991). *Shear behaviour of brick-mortar joints*. *Masonry International*, 5(1). pp. 19-22.
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- [8] Riddington, I.R. & Jukes, P (1994). *A masonry joint shear strength test method*. Proc. Instu. Civ. Engrs. Structs. & Bldgs., 1994, 104, Aug. p.p. 267 - 274.
- [9] Riddington, I.R., Fong, K.H. and Jukes, P. Numerical study of failure initiation in different joint shear tests. *J.Brit. Mas. Soc. Masonry International*, 11 (2). pp 44 - 50. 1997.
- [10] Gottfredsen, F. R. (1996). *Laterally loaded masonry*. Danish Building Research Institute. Hørsholm, Denmark. Ph.D-Thesis.

This bulletin is primary directed towards research groups or others with special interest in the full documentation of a test series about the bending properties of masonry walls.