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**TNO report**

**2004-CI-R0171**

**Shear tests on masonry panels; Literature survey  
and proposal for experiments**

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Date	October 21, 2004
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Copy no	
No. of copies	
Number of pages	36
Number of appendices	
Sponsor	
Project name	ESECMaSE
Project number	006.42213/01.01

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## Contents

<b>1</b>	<b>Shear tests on masonry .....</b>	<b>3</b>
1.1	Introduction .....	3
1.2	Two types of shear tests .....	3
1.3	Discussion of the overviews in [2, 3, 4] .....	4
<b>2</b>	<b>Inventory of experiments on in-plane loaded masonry panels .....</b>	<b>8</b>
2.1	Introduction .....	8
2.2	Benjamin and Williams (1958) [11] .....	8
2.3	Hinkley (1966) [15] .....	12
2.4	Porter, Ahmed and Wolde-Tinsae (1983/1985) [16, 17] .....	14
2.5	Galegos and Casabone (1983) [18] .....	15
2.6	Richardson and Dawe (1986) [19] .....	16
2.7	Woodward and Rankin (1985) [21] .....	17
2.8	Various publications from Japan (1986) [22, 23] .....	19
2.9	Jiango and Jinqian (1986) [24] .....	20
2.10	Li, Chen and Hunang (1986) [25] .....	21
2.11	Huizer and Shrive (1986) [26] .....	22
2.12	Ganz (1984) [27] and Lurati and Thürlimann (1990) [38] .....	23
2.13	Pook and Dawe (1986) [28] .....	24
2.14	Seible and Hegemeier (1987) [29] .....	25
2.15	Shing et all (1987/1989) [30,33] .....	26
2.16	Matsumura (1987/1990) [31, 36] .....	27
2.17	Johal and Anderson (1988) [32] .....	28
2.18	Abrams and Epperson (1989/1990) [34, 37] .....	29
2.19	Larbi and Harris (1990) [35] .....	30
<b>3</b>	<b>Discussion of the various test methods .....</b>	<b>31</b>
<b>4</b>	<b>References .....</b>	<b>33</b>

# 1 Shear tests on masonry

## 1.1 Introduction

The shear behaviour of masonry can be investigated at different levels. At the lowest level, the micro-level, the joint and the bricks are considered separately (Figure 1a). TNO Building and Construction has made an inventory of different loading schemes that can be applied for performing such a shear test on the bed joint. If the shear behaviour of a relatively small part of the masonry is considered, and no distinction is made between bricks and joint, this is called the meso-level (Figure 1b). For the experiments on wall panels dimensions of approximately 1 m times 1 m are considered, so that the masonry is studied at the meso-level. Finally, when considering the behaviour of a one-storey high wall panel with possible openings, we speak of the macro-level. This report discusses experiments on both the meso-level and the macro-level.

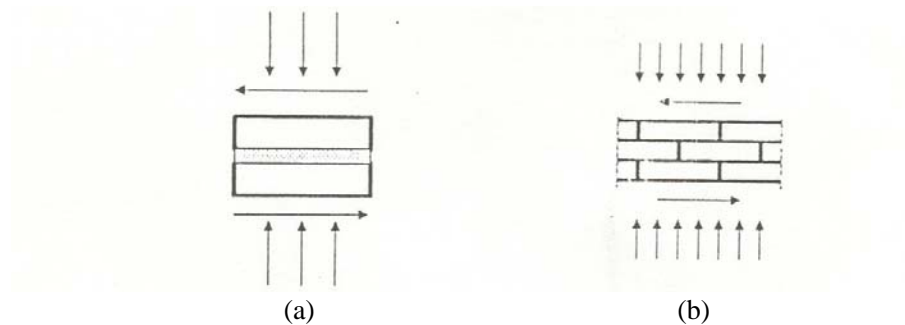


Figure 1 Shear tests on masonry; micro (a) and meso (b) level

An overview with respect to shear tests on masonry is given in literature by among others Trautsch [2], Müller [3] and Van de Haar and Van Leeuwen [4] in 1971, 1974 and 1978 respectively. In paragraph 1.3 a summary of these references will be given. In chapter 2 a number of individual investigations will be discussed.

## 1.2 Two types of shear tests

When studying literature with respect to shear tests on masonry, different types of test are found. In this report two types of test will be distinguished, that are characterised by the way in which the load is applied.

### *Shear test type 1:*

The loading is applied by means of a compression force only. Since the bed joints are at an angle with the loading direction, the masonry is loaded by a combination of normal compression and shear. Tests according to this principle can be found in [5, 6, 7, 8, 9, 10] (see Figure 2). In the shear test of Monk [9] the specimen is enclosed by a frame with open corners, consisting of steel [-sections. By means of hinges the external compression forces are decomposed in shear components.

In this report no further attention will be paid to this type of test.

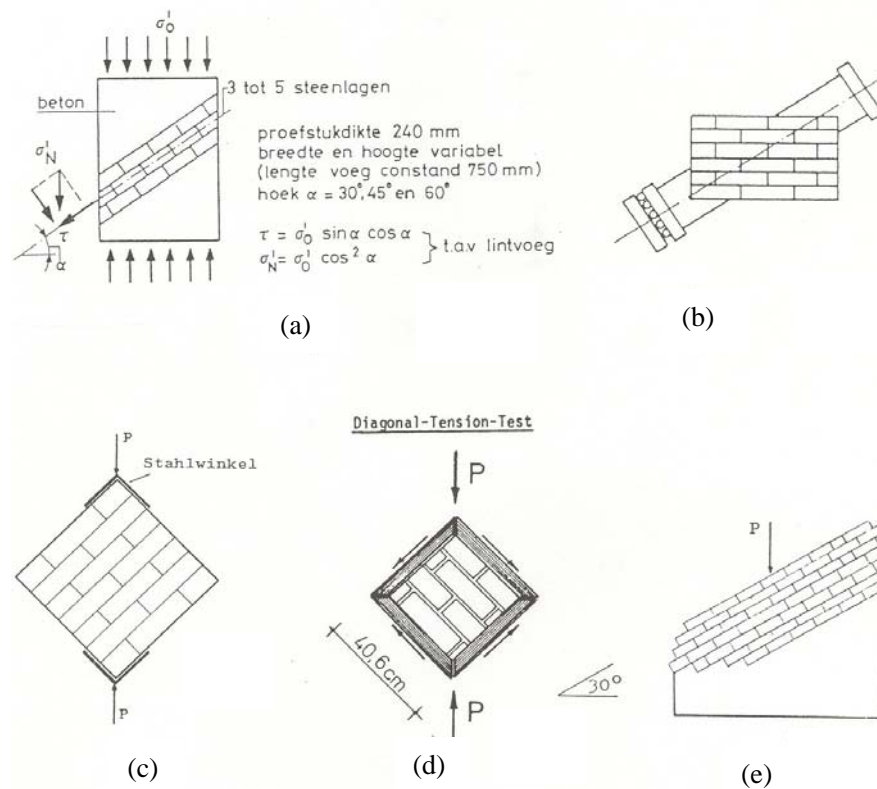


Figure 2 Shear tests by means of compression tests

#### Shear test type 2:

A masonry wall panel with bed joints in horizontal direction is supported at the lower side, and at the upper side loaded in-plane by a horizontal force. At the upper side of the wall panel different boundary conditions can be applied. Also the way in which the horizontal force is introduced can vary.

The shear tests on masonry that are discussed in this report, are of type 2. In the discussion attention will mainly be paid to:

- the applied boundary conditions, including the way in which the load is introduced;
- the principle of the test set-up.

For certain cases, also interesting results like for instance a crack pattern will be shown.

### 1.3 Discussion of the overviews in [2, 3, 4]

Besides variations in wall panel dimensions, brick type and mortar quality, the various test methods mainly differ by the way in which the load is introduced [3].

Benjamin and Williams [11] performed tests like shown schematically in Figure 3 (see also 2.2). With respect to the surrounding frame three alternatives were tested:

- a frame of reinforced concrete
- a steel frame
- no frame

Wood [12] used a comparable test set-up.

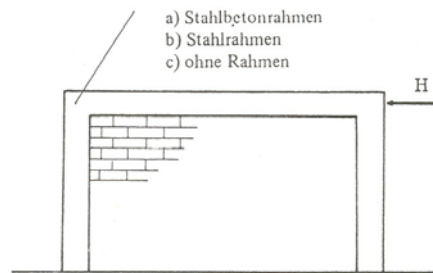


Figure 3 Test set-up of Benjamin and Williams [11] and Wood [12]

Monk [9] carried out three different types of shear test on wall panels (Figure 4). The first type concerns the standard shear test (“Standard Racking test”), proposed by ASTM E 72-61. The force  $N$  prevents rotation of the panel. In this set-up the vertical force  $N$  cannot be controlled. In a second test series (Figure 4b) rotation of the panel was prevented by vertical steel strips attached at both sides of the panel. In this way boundary conditions were created comparable to those in the diagonal tension test (Figure 2d). Finally, by means of four pairs of bars that were somehow connected to a hydraulic actuator with a capacity of 300 kN, a vertical force was introduced as is shown in Figure 4c. This type of test concerned a proposal by SCPRF (Structural Clay Products Research Foundation).

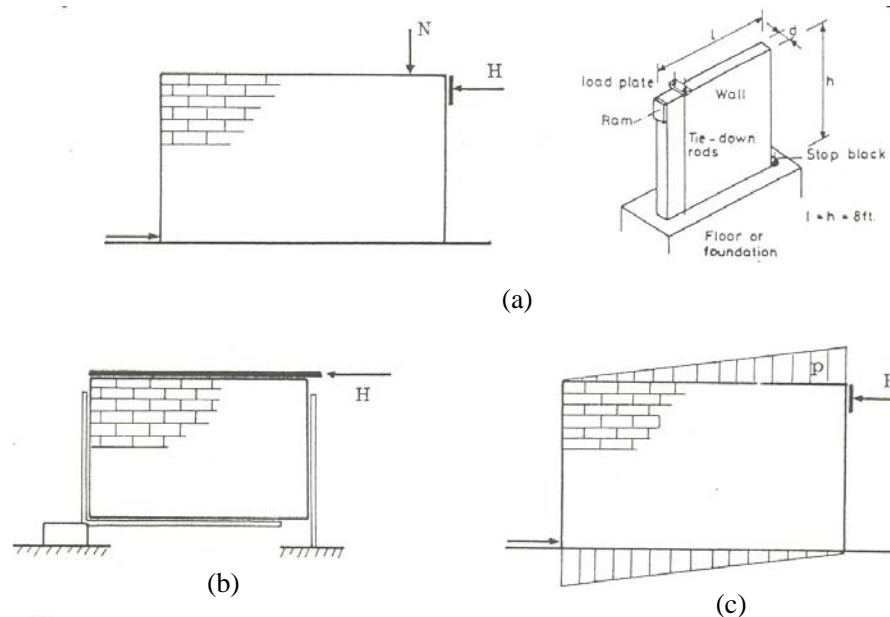


Figure 4 Shear tests by Monk [9]

Simms [13] also carried out tests in which equilibrium was obtained by a vertical reaction force (Figure 5a). In a second series of tests equilibrium was obtained by means of a vertical preloading (Figure 5b).

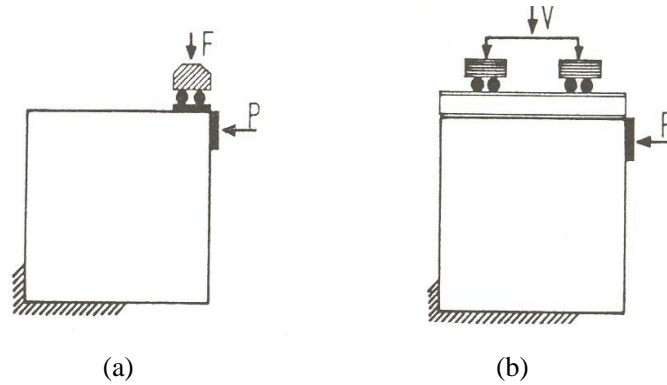


Figure 5 Shear tests by Simms [13]

In Figure 6 the loading principle of Murthy's tests is shown schematically. One-storey high wall panels with stiffening walls were built at a scale of 1:6. Both the horizontal and vertical load were introduced through a reinforced concrete slab.

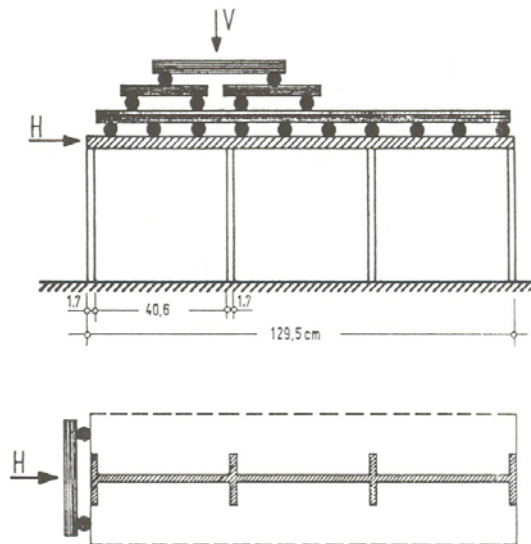
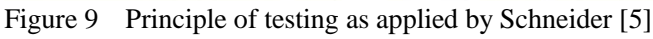
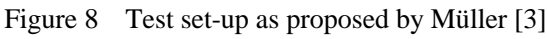
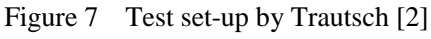


Figure 6 Test set-up by Murthy [14]

The tests by Trautsch deviate from the other tests because the horizontal force was not introduced at the upper side of the wall, but at half height (see Figure 7).

By Müller [3] a test on a masonry panel of 1 m times 1 m was proposed, in which by means of a simple mechanism every separate brick was loaded by the desired normal and shear force (see Figure 8). It was not shown in which way this should be achieved.

Schneider [5] applied the shear force and the vertical load by means of beams that were glued to the edges (Figure 9).



## 2 Inventory of experiments on in-plane loaded masonry panels

### 2.1 Introduction

In this chapter a number of researches that have been found in literature, will be discussed in short. Starting point is to get an impression of the way in which a shear test has been carried out. This concerns for instance:

- the applied boundary conditions
- the applied loading frame
- the type of test panel that has been used
- the dimensions of the masonry panel that was tested

For a number of cases also a specific result will be shown.

As for the test panel, unreinforced, reinforced and pretensioned wall panels can be distinguished. Furthermore, stand alone masonry walls have been tested as well as masonry infilled frames.

Remark: for a number of publications only the test set-up is shown by means of a figure or a photograph.

### 2.2 Benjamin and Williams (1958) [11]

#### *Experimental set-up*

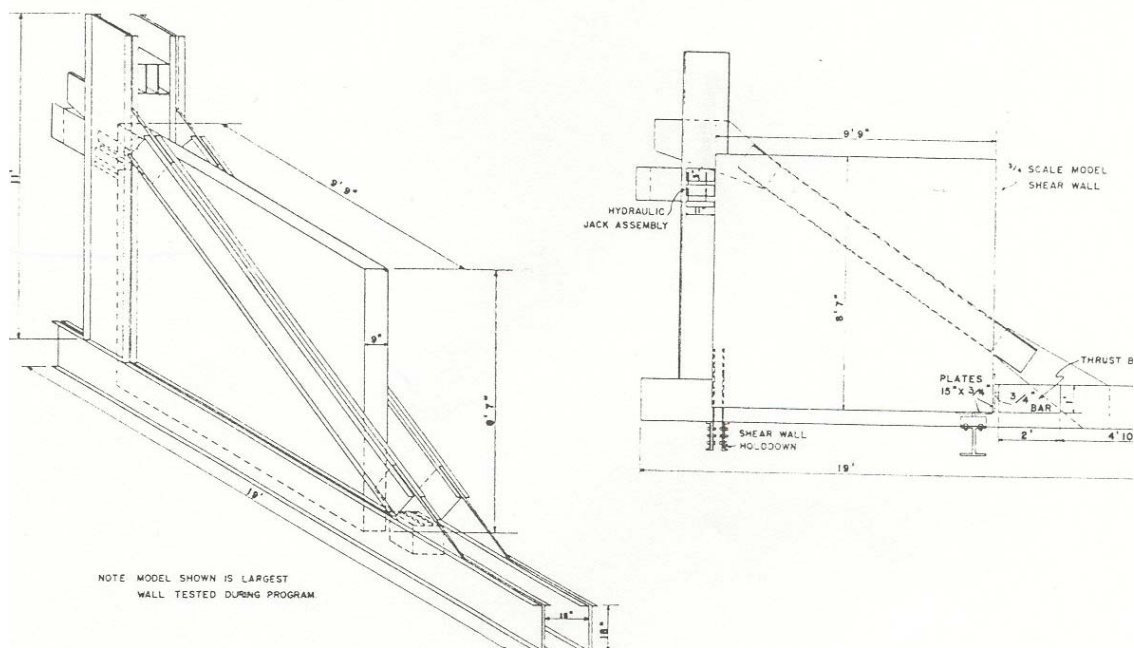


Figure 10 Test set-up (see also Figure 3)



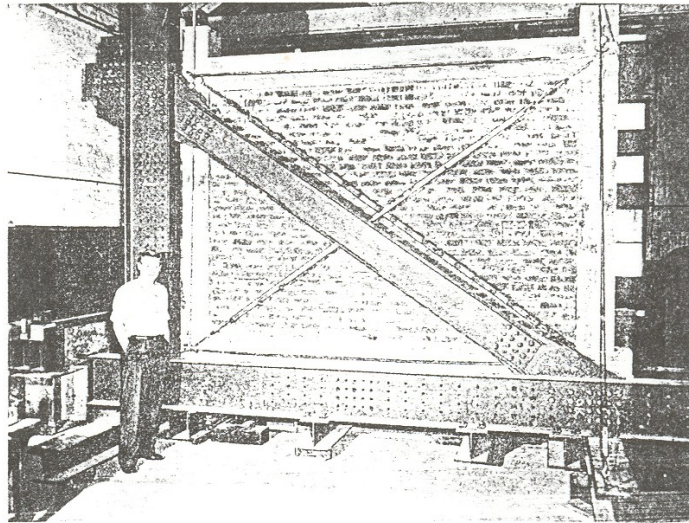


Figure 11 Picture of the set-up for loading

#### *Type of test panel*

One-storey high, unreinforced masonry panels were tested, and the following three types were distinguished:

1. Masonry panel without frame
2. Masonry panel within a frame of reinforced concrete (Figure 12)
3. Masonry panel within a steel frame, including a panel with an opening (Figure 13).

#### *Dimensions*

Panels with several dimensions have been tested. The dimensions (width\*height\*thickness) were 6.65 m \* 2.28 m \* 0.20 m. Because of the investigation of possible size effects also tests on smaller panels have been carried out, with scale factors of 0.34 and 0.75 respectively. In addition, also panels with scale factors of 0.25 and 0.42 were tested.

#### *Some results*

Failure of the panels without a frame (1.47 \* 0.85 m) appeared in most cases to be tensile failure of the connection between the panel and the concrete foundation. The maximum load that could be exerted was 9 kN and 27 kN respectively (large scatter!). Crack patterns of two panels enclosed by steel frames are shown in Figure 14 and Figure 15.

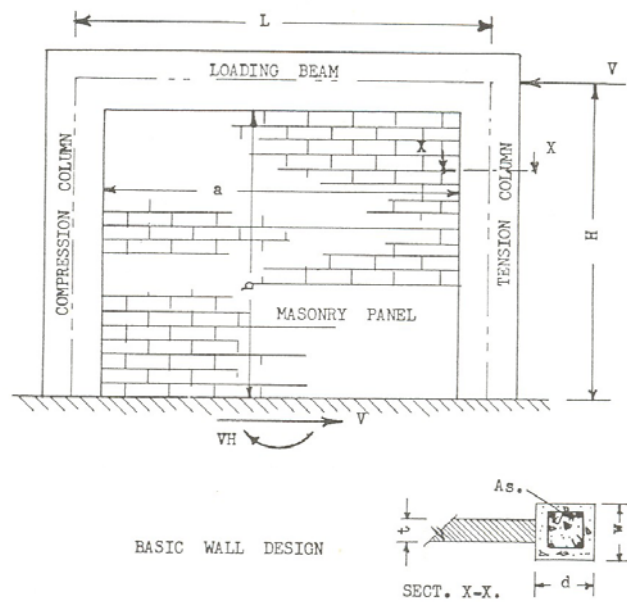


Figure 12

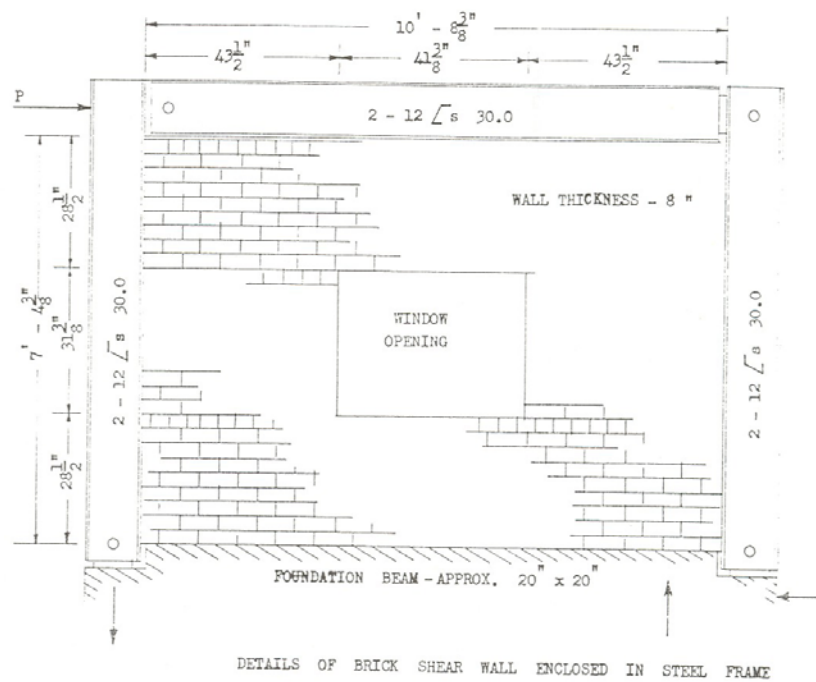


Figure 13

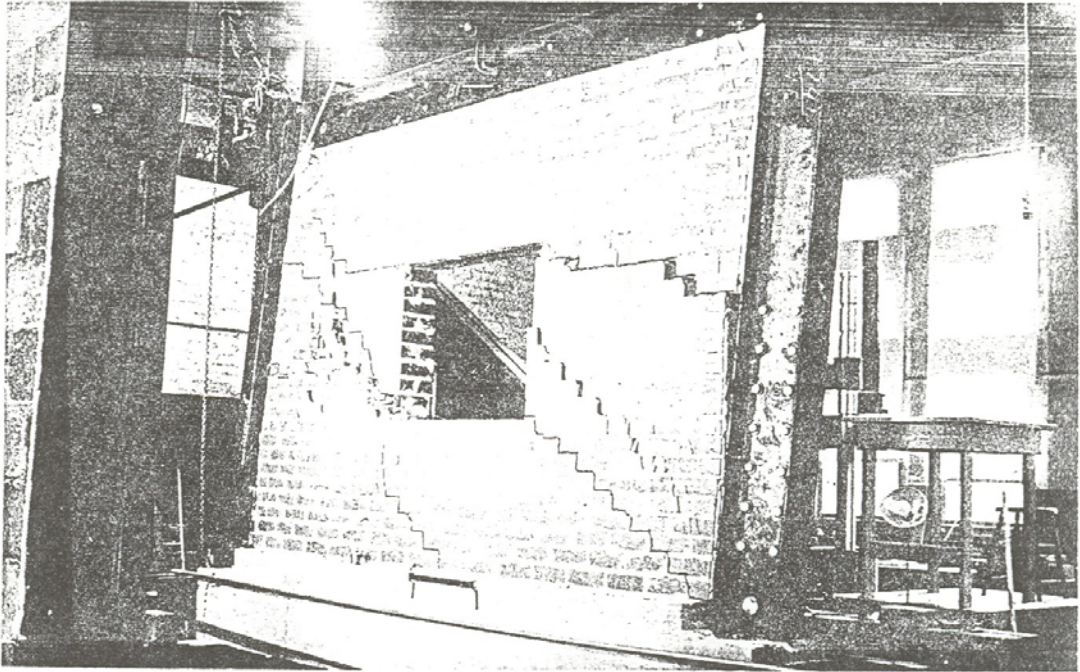
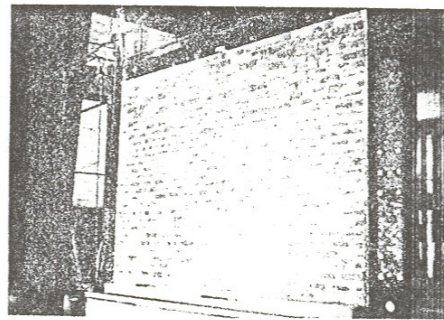
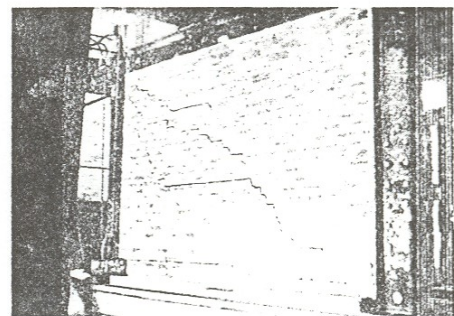


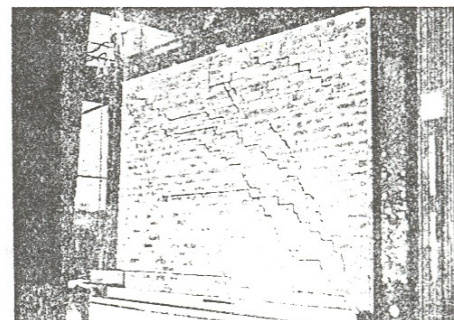
Figure 14 Failure of brick wall with opening and steel framing members, Specimen SF-1



$V = 0^k$   $\Delta = 0.0 \text{ in.}$



$V = 92^k$   $\Delta = 0.60 \text{ in.}$



$V = 140^k$   $\Delta = 1.44 \text{ in.}$

Figure 15 Progressive failure of brick wall with steel frame

## 2.3 Hinkley (1966) [15]

### *Experimental set-up*

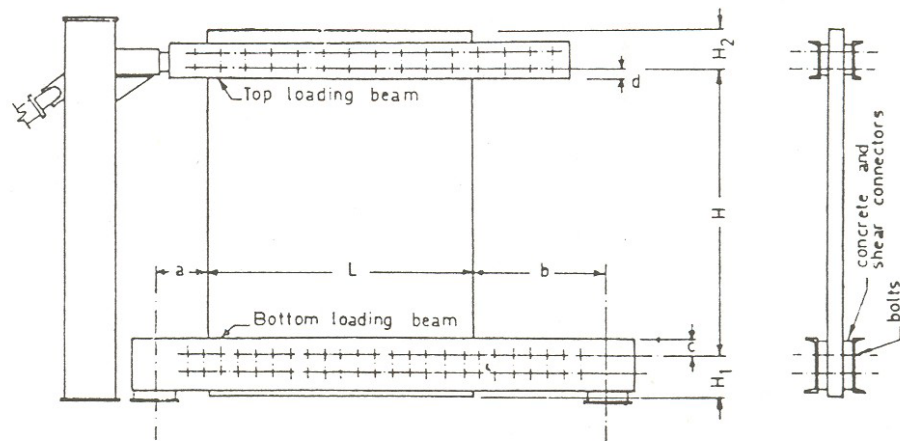


Figure 16

### *Type of test panel*

The wall panels were loaded with and without vertical prestressing. The prestressing was applied by means of prestressing wires running through the middle of the wall panel. This became possible by applying bricks with a hole in the middle.

### *Dimensions*

Two different sizes (in m) were applied for the wall panels.

	square	rectangular
L	1.57	2.08
H	1.57	1.37

### *Some results*

During loading the loads in the subsequent prestressing wires changed, which can be seen in Figure 17. The crack pattern at failure of a rectangular wall panel with an equally distributed preloading is shown in Figure 18.



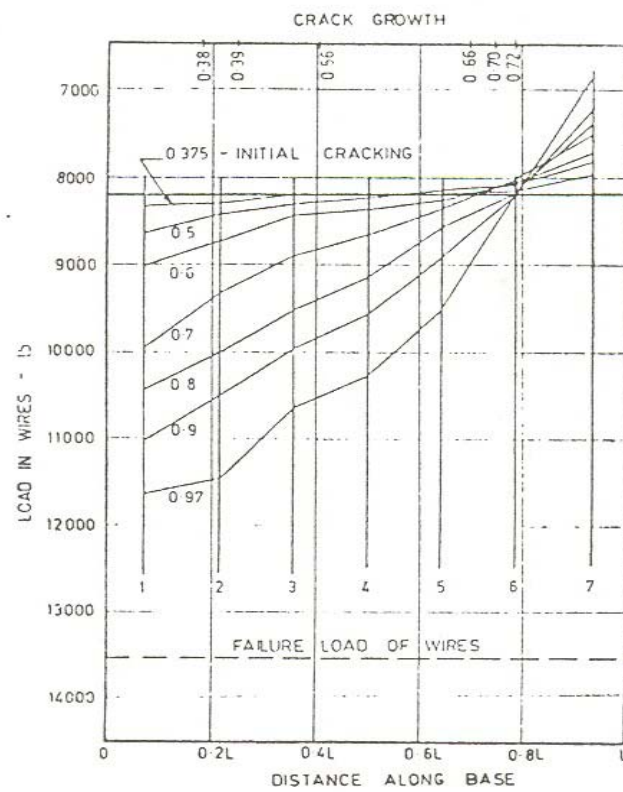


Figure 17 Load in the prestressing wires

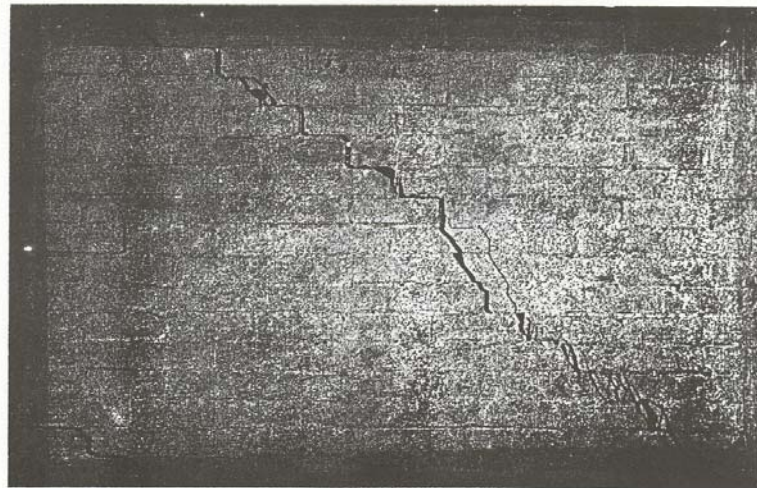


Figure 18 Crack pattern at failure

## 2.4 Porter, Ahmed and Wolde-Tinsae (1983/1985) [16, 17]

### *Experimental set-up*

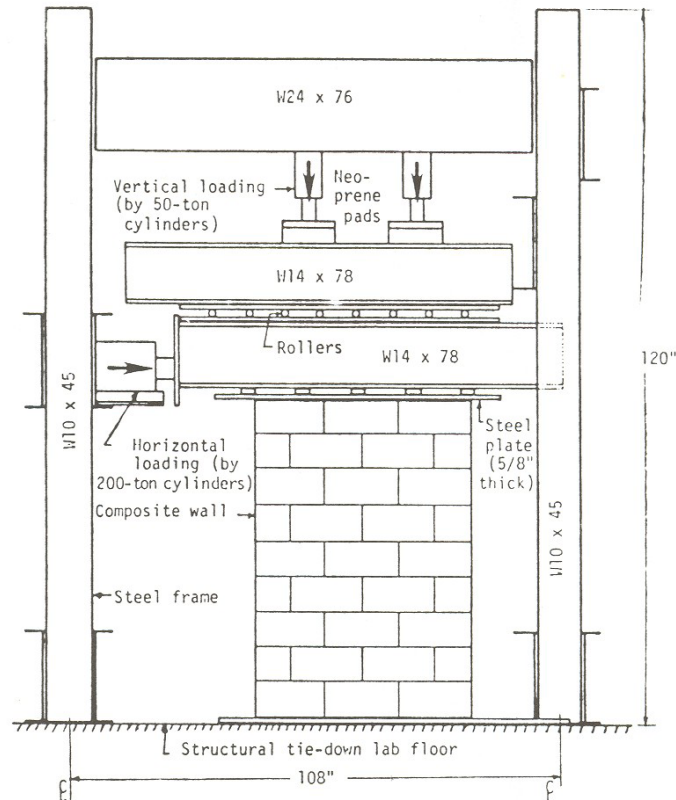


Figure 19 Test set-up

The loads in vertical and horizontal direction are applied distributed along the upper side of the wall panel. First the vertical load is applied, which is then kept constant while applying the horizontal load. The lower side of the wall was connected directly to the floor of the laboratory.

The maximum capacity of the horizontal hydraulic actuator was 2000 kN, for the vertical loading two actuators with a capacity of 500 kN each were used.

### *Type of test panel*

The wall panels were constructed from two planes that were set with bricks. In between the planes was a space with a width of 51 mm, filled with mortar in which reinforcement was placed. The planes were set with bricks (57 mm \* 92 mm \* 194 mm) and blocks (92 mm \* 194 mm \* 397 mm) respectively, both containing three holes. Composite brick-to-brick as well as composite brick-to-block wall panels were used.

### *Dimensions*

Width \* height \* thickness: 1.22 m \* 1.83 m \* 0.23 m

## 2.5 Galegos and Casabone (1983) [18]

### *Experimental set-up*

Cyclic loading in horizontal direction was applied to the upper side of the wall panel under deformation control. The horizontal loading was applied on a heavily reinforced beam at the upper side of the wall. The frame that has been used to apply the horizontal loading was not described.

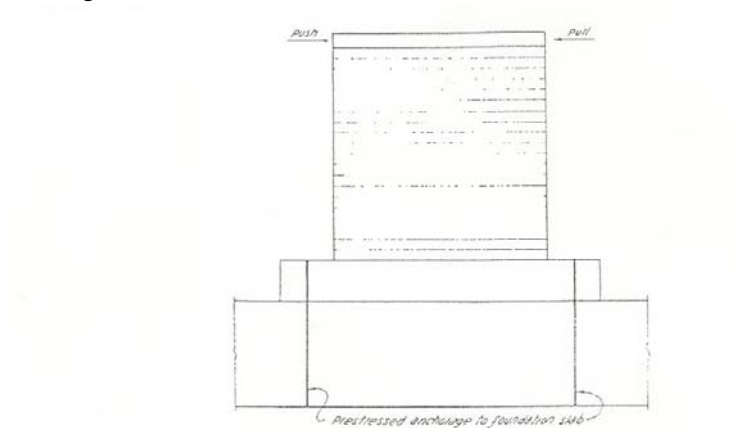


Figure 20 Schematic loading system

### *Type of test panel*

Tests on three types of reinforced masonry wall panels are described. The three types of panels can be characterised by the way in which the reinforcement was applied, namely:

1. inside a concrete frame surrounding the wall panel
2. inside the hollow bricks that were injected afterwards
3. inside the mortar that was used as cavity filling

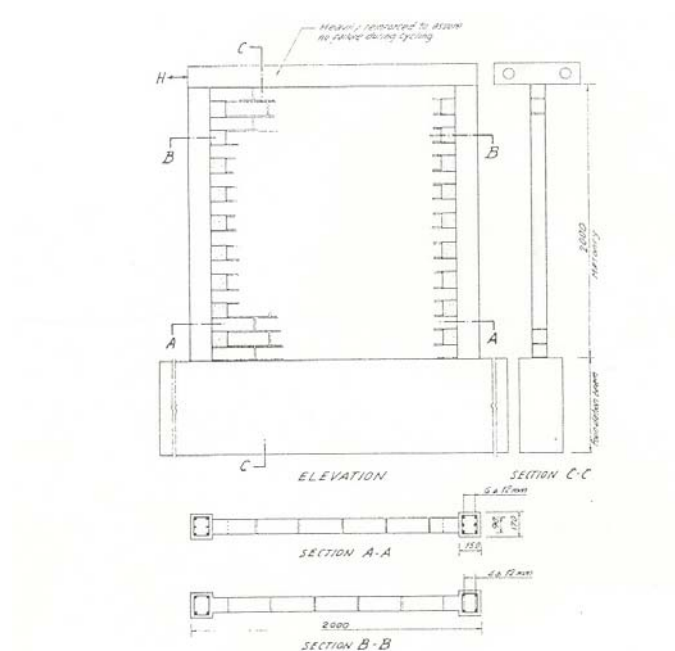


Figure 21 Test panel type 1

### *Dimensions*

Width \* height: 2 m \* 2 m

## 2.6 Richardson and Dawe (1986) [19]

### *Experimental set-up*

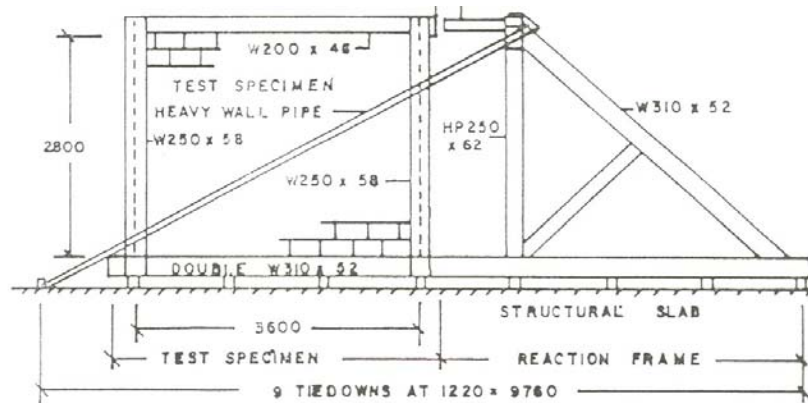


Figure 22 Test set-up

### *Type of test panel*

A masonry infilled steel frame was loaded both quasi-statically and cyclic in horizontal direction. The wall panel was constructed with 200 mm \* 200 mm \* 400 mm blocks.

### *Dimensions*

Width \* height: 3.6 m \* 2.8 m

### *Result*

Amos and Waugh [20] used the same test set-up for the investigation of the effect of openings in masonry in steel frames. A result is shown in Figure 23.

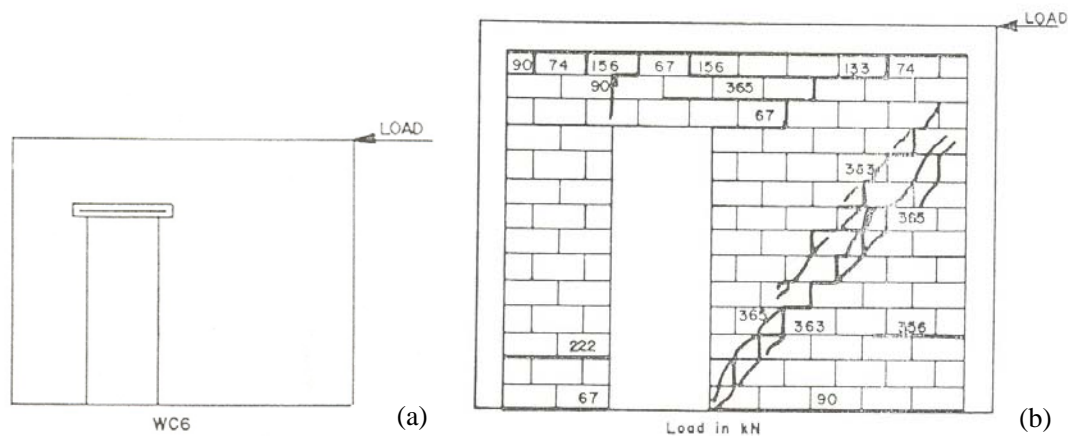


Figure 23 Geometry (a) and crack pattern for WC6 (b)



## 2.7 Woodward and Rankin (1985) [21]

### *Experimental set-up*

A test set-up was used with which at the upper side of the test panel both loads and deformations could be controlled. The lower side was connected rigidly. The machine is three dimensional (Figure 24), meaning that all six degrees of freedom (rotations and displacements/normal forces and moments) can be controlled. In the shear test on the wall panel a deformation was applied as is shown in Figure 25. The position of the displacement transducers is shown in Figure 26.

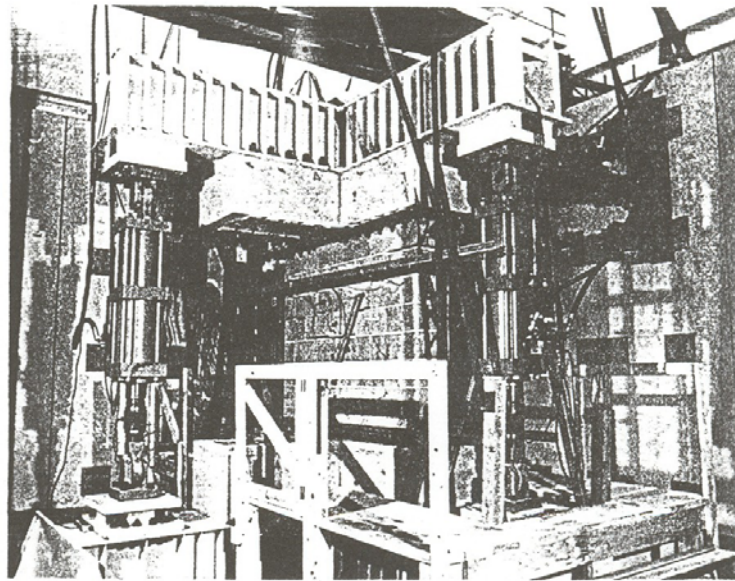


Figure 24 Picture of the test set-up with a test panel

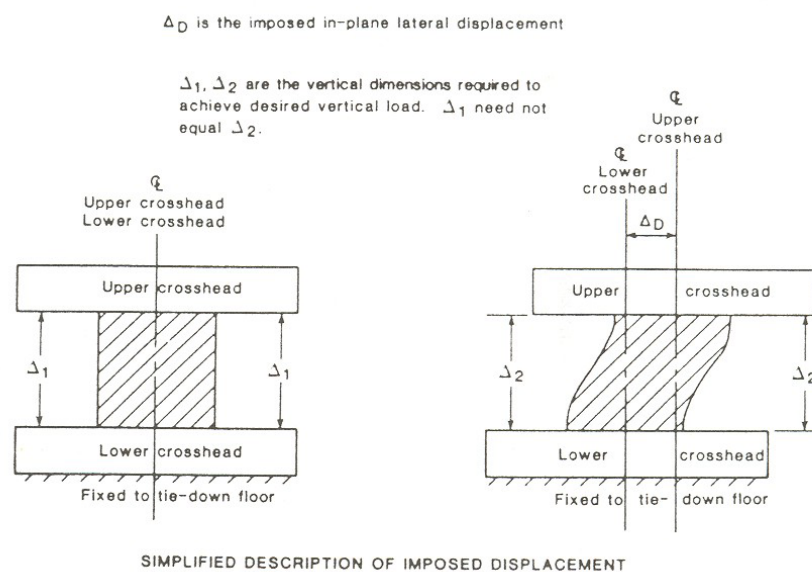


Figure 25 Imposed displacement

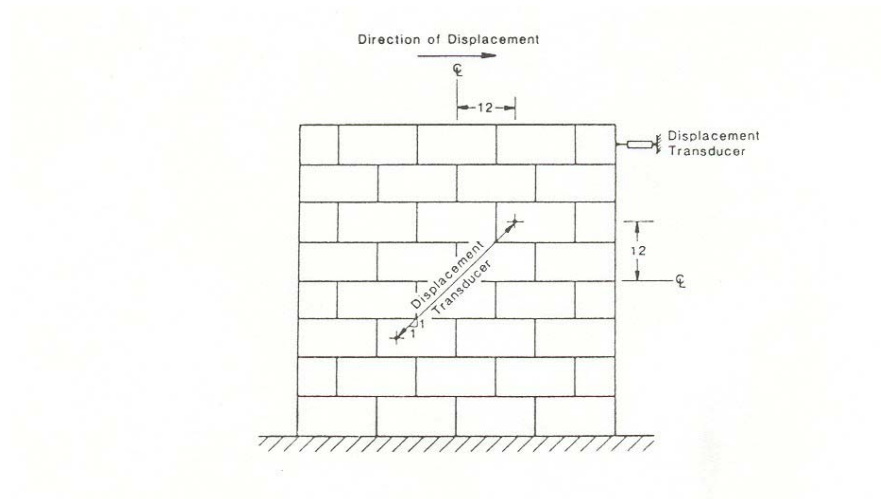


Figure 26 Position of the displacement transducers

#### *Type of test panel*

Unreinforced masonry was tested, set with hollow concrete blocks. The wall panels were loaded vertically with a stress varying between  $0.7 \text{ N/mm}^2$  and  $3.4 \text{ N/mm}^2$ .

#### *Dimensions*

The height and the thickness of all wall panels tested was 1.63 m and 0.20 m respectively. As for the width, four dimensions were applied, namely 1.22, 1.63, 2.03 and 2.44 m.

#### *Some results*

Since the test was deformation controlled, the wall panel could be loaded beyond the ultimate shear load (see Figure 27). The crack pattern for a wall panel with a width of 2.44 m can be seen in Figure 28.

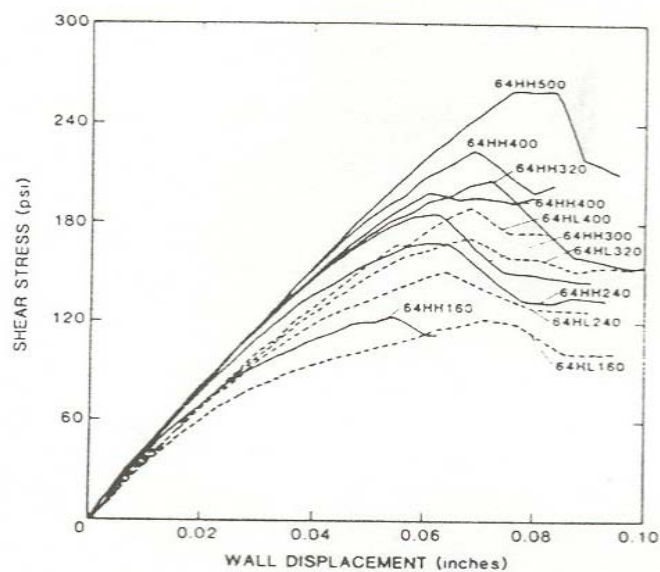


Figure 27 Examples of measured shear stress – displacement curves

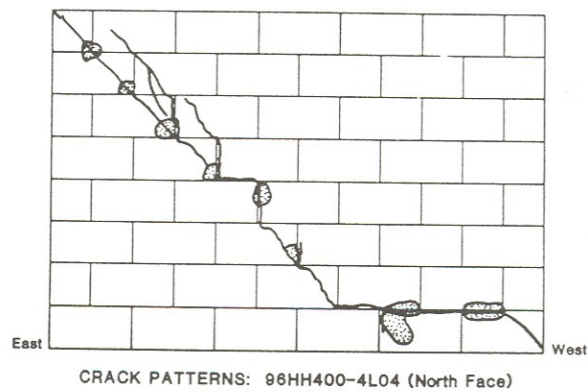


Figure 28 Example of a crack pattern

## 2.8 Various publications from Japan (1986) [22, 23]

The proceedings of the “4<sup>th</sup> Canadian Masonry Symposium – 1986” contain contributions of several Japanese authors (among others [22, 23]) that all carried out experiments using the same test set-up. These investigations focussed on the behaviour of reinforced masonry panels under earthquake loading. Here, only the experimental set-up will be shown.

### *Experimental set-up*

The principle of the used experimental set-up is the same as for the set-up of Woodward and Rankin [21].

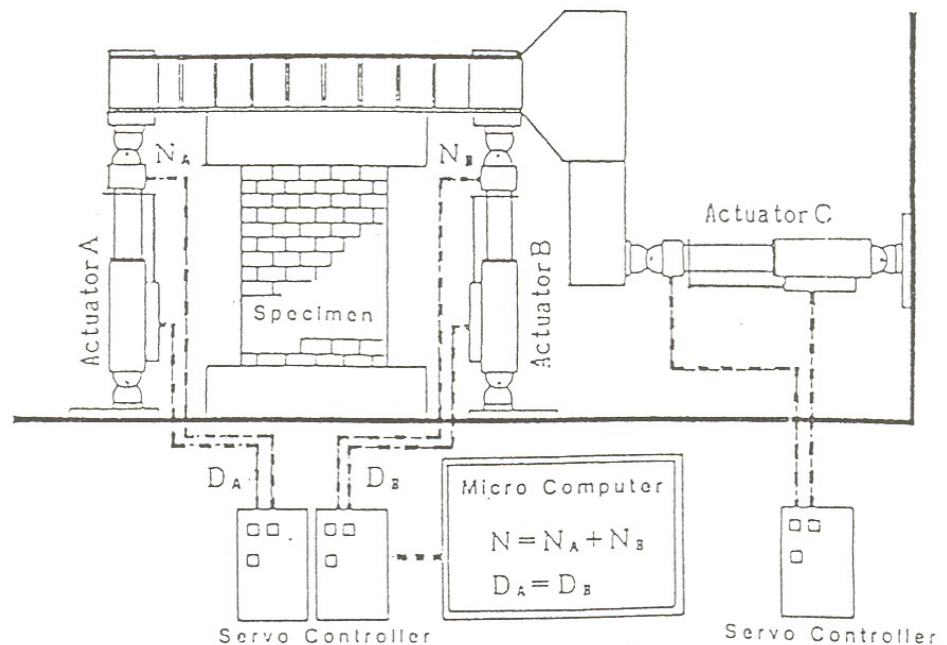


Figure 29 Experimental set-up

## 2.9 Jiango and Jinqian (1986) [24]

### *Experimental set-up*

Two types of test set-up were used. One in which the upper side can rotate freely (Figure 30a) and one in which that rotation was prevented (Figure 30b).

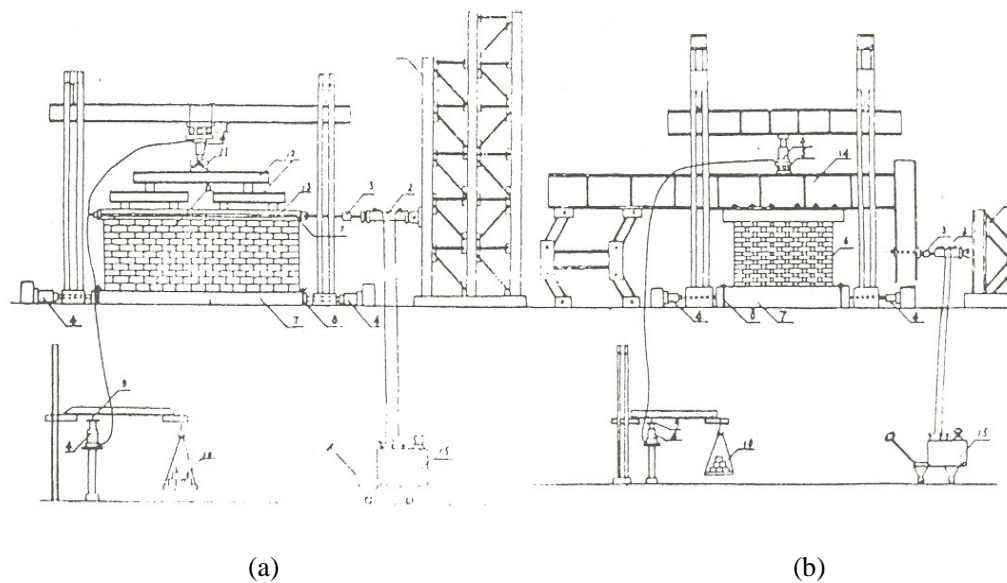


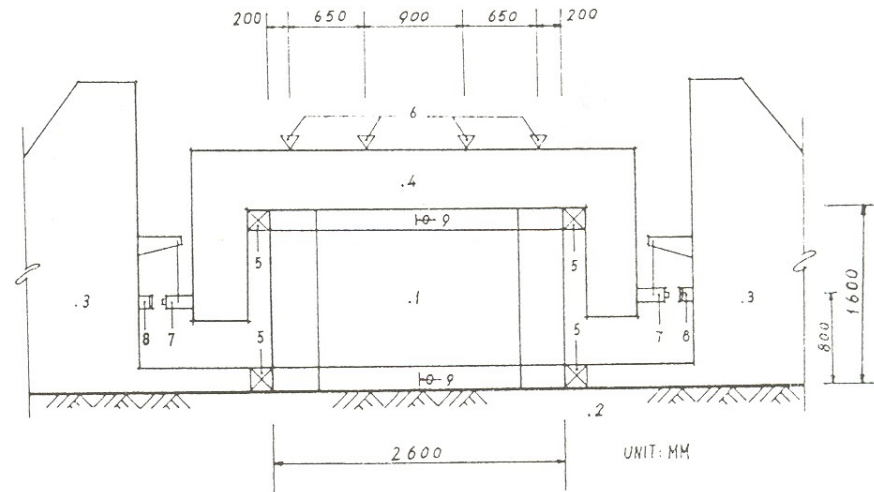
Figure 30

### *Dimensions*

Thickness: 0.24 m  
 Width: 1.25 to 3.50 m  
 Height: 0.40 to 1.80 m

## 2.10 Li, Chen and Hunang (1986) [25]

### *Experimental set-up*



- 1--Test Specimen
- 2--Test Bed
- 3--Reaction Systems
- 4-- Shape Steel Frame
- 5--Steel Blocks

- 6--Lever Loading Points
- 7--500KN Hydraulic Jacks
- 8--500KN Load Cells
- 9--30MM Displacement Cells

Figure 31 Experimental set-up

## 2.11 Huizer and Shrive (1986) [26]

### *Experimental set-up*

The paper does not contain a schematic presentation of the loading frame. A schematic presentation of the wall panel can be seen in Figure 32. The horizontal load was applied by means of a hydraulic actuator, over the height of two bricks at the right upper side of the wall panel. The horizontal load was measured by means of a 500 kN load cell. The wall is post tensioned in both horizontal and vertical direction. The position of the post tensioning, the post tensioning loads and the position of the displacement transducers are also shown in Figure 32.

### *Type of test panel*

As can be seen in Figure 32 a wall panel with an opening was tested.

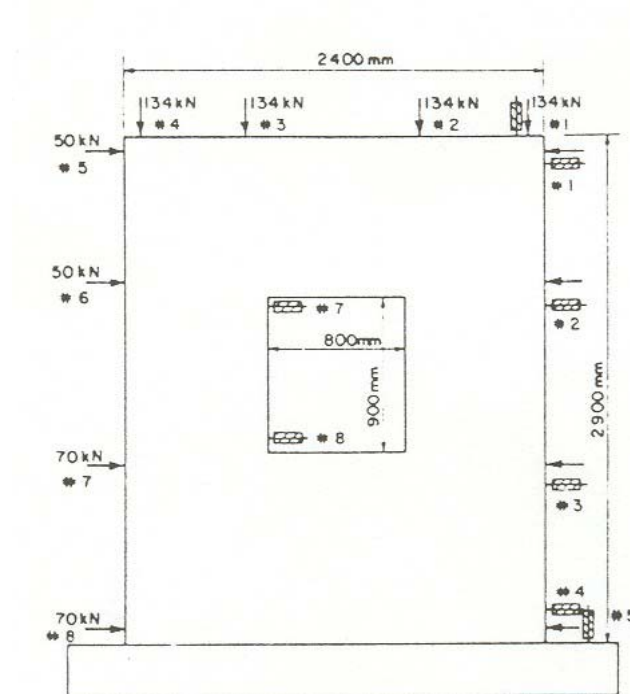


Figure 32 Test panel



## 2.12 Ganz (1984) [27] and Lurati and Thürlimann (1990) [38]

### *Experimental set-up*

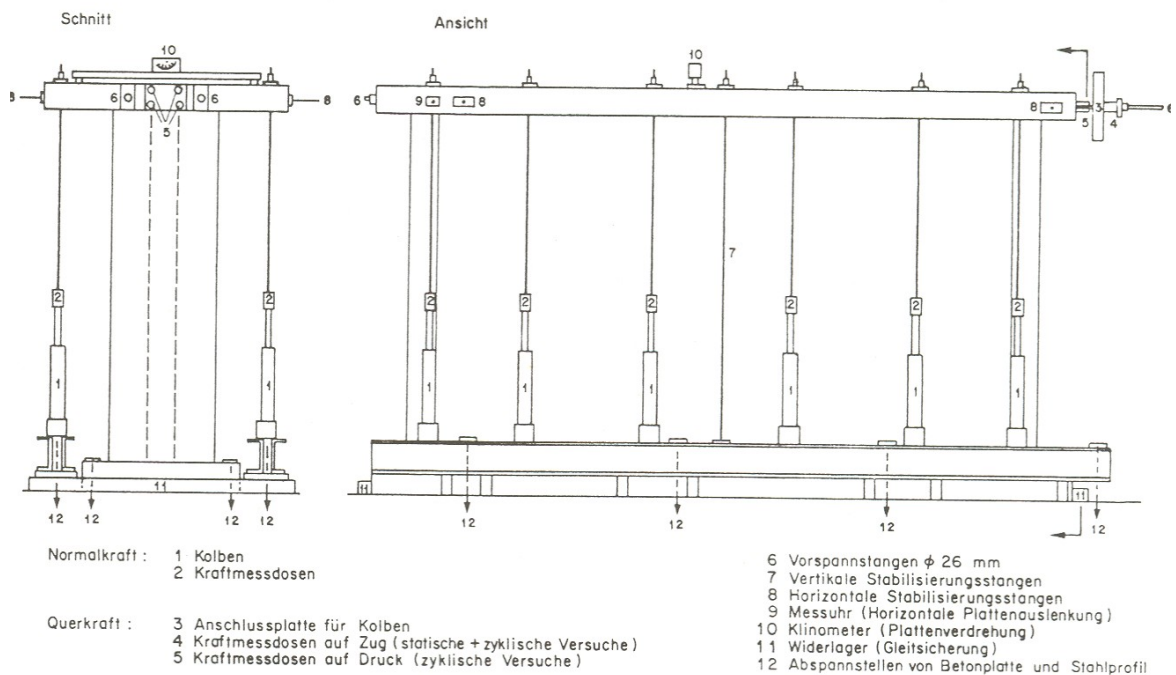
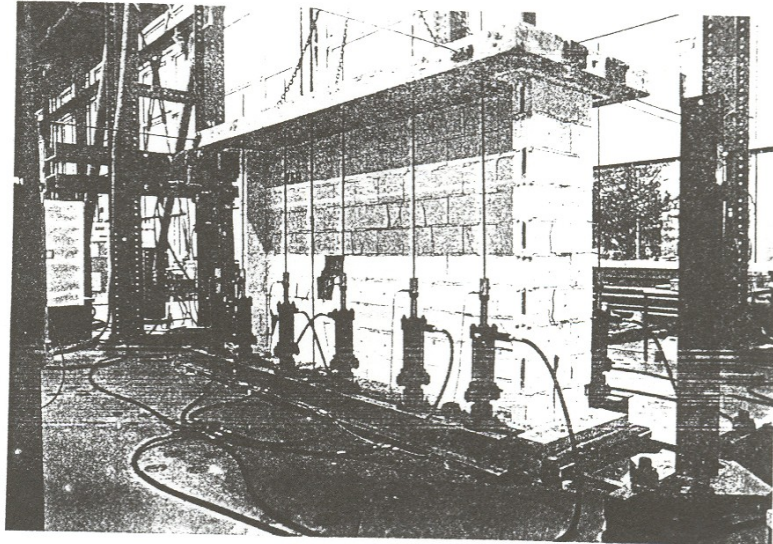


Figure 33 Picture and schematic representation of the test set-up





## 2.14 Seible and Hegemeier (1987) [29]

The paper addresses the experimental phase of the “U.S.-Japan Coordinated Masonry Building Research Program” in the United States. The shear tests on storey high wall panels by Shing et al [30], as discussed in paragraph 2.15, belong to the same program. Also shear tests on two and three storey high wall panels however, are part of the experimental program. Despite the fact that it is not intended to build such a test set-up in the Netherlands, a schematic representation of the set-ups is shown in Figure 35.

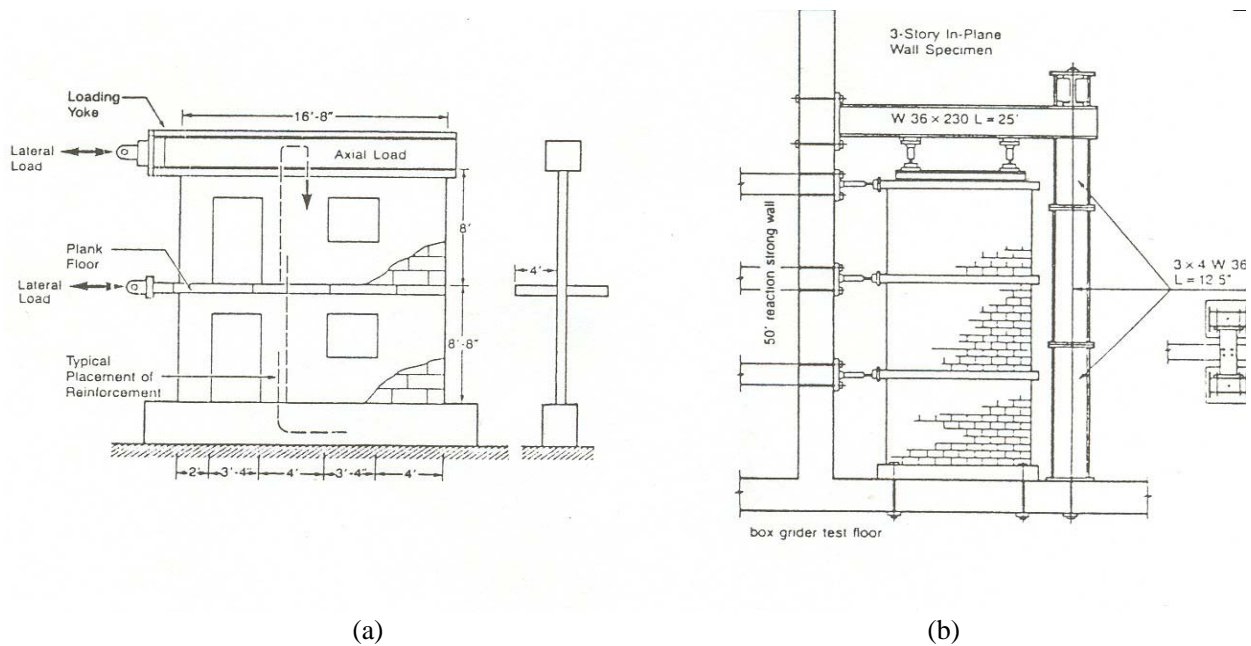


Figure 35 Shear tests on two- and three storey high wall panels

## 2.15 Shing et al (1987/1989) [30,33]

### *Experimental set-up*

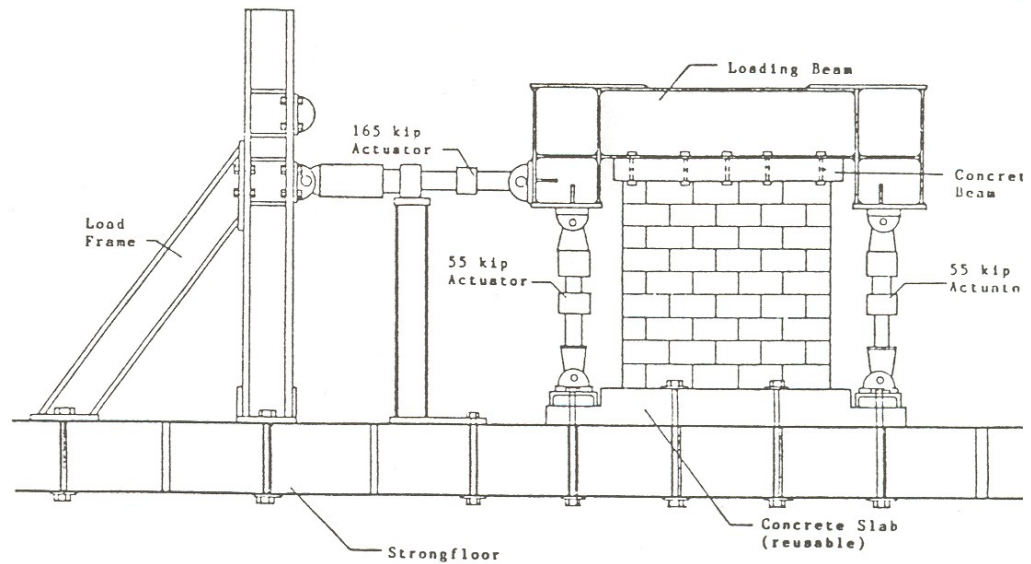


Figure 36 Test set-up

In total 21 displacement transducers were used (see Figure 37).

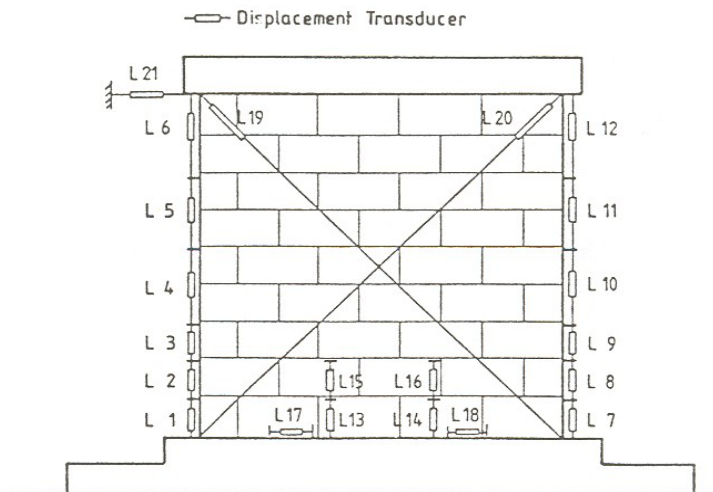


Figure 37 Positions of the displacement transducers

### *Type of test panel/dimensions*

Reinforced masonry / width \* height: 1.82 m \* 1.82 m

## 2.16 Matsumura (1987/1990) [31, 36]

### *Experimental set-up*

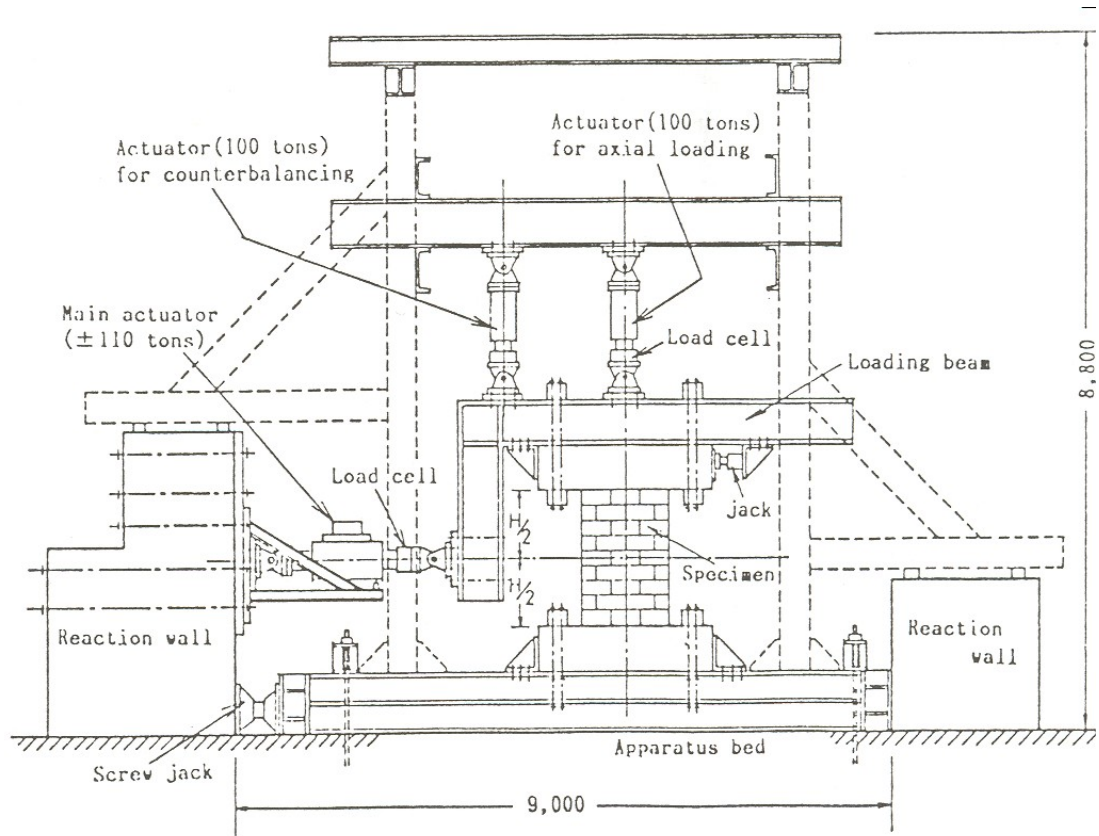


Figure 38 Test set-up

## 2.17 Johal and Anderson (1988) [32]

### *Experimental set-up*

The way in which the shear load was introduced differs from most other experimental set-ups. A pier of masonry was made between two reinforced masonry beams. By means of a hydraulic actuator and tension bars, a diagonal compression force was introduced in the test panel. The resolved force in horizontal direction gave the shear force in the pier. Two braces compensated the resolved force in vertical direction, one on each side of the pier (see Figure 39b), so that no resulting normal stress was present in the pier. The forces in the two vertical hydraulic actuators were kept equal. Hence, the pier was purely loaded by a combination of shear stress and bending. Since the tension bars were placed along both diagonals of the test panel, alternate loading could be applied. The position of the displacement transducers d1, d2, h1 and h2 can be seen in Figure 39c.

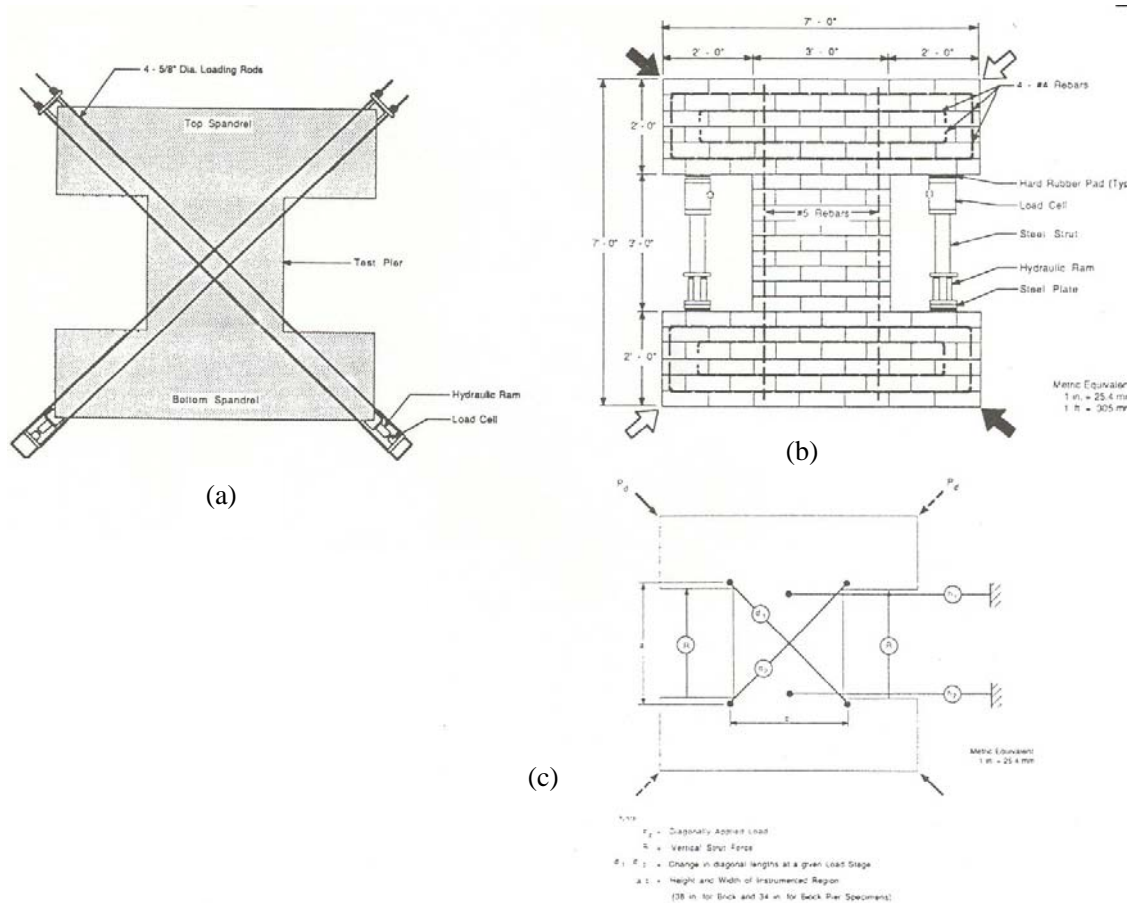


Figure 39 Test set-up

### *Dimensions*

Pier: 0.91 m \* 0.91 m





## 2.19 Larbi and Harris (1990) [35]

### *Experimental set-up*

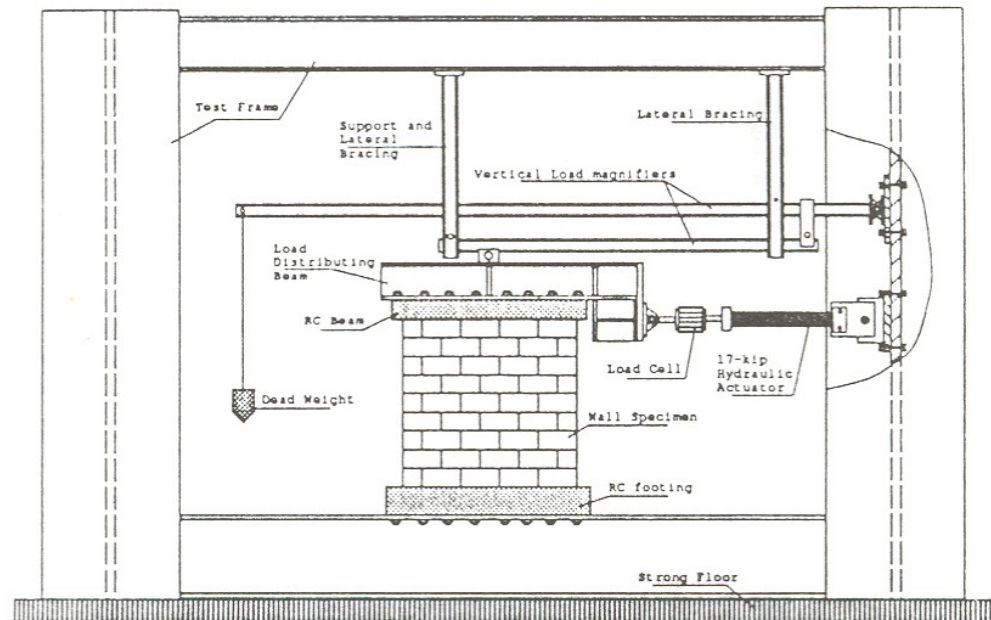


Figure 42 Test set-up

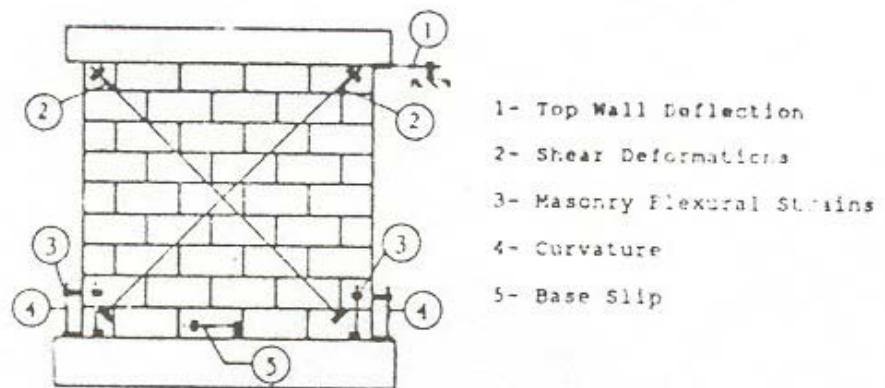


Figure 43 Position of the displacement transducers

### *Dimensions*

Scale 1:3 was applied.

Width \* height: 0.61 m \* 0.61 m

### 3 Discussion of the various test methods

First of all it is mentioned that many variations have been found in the tests on masonry wall panels. These variations concern:

- the applied brick or block type
- the possible presence of openings in the wall panel
- the presence or absence of reinforcement
- the presence or absence of a frame surrounding the wall panel
- the way in which the load is spread
- the boundary conditions at the upper side
- the presence or absence of a vertical preloading
- the type of loading (monotonic, cyclic or impact)

Hereafter, as for the applied boundary conditions, it will be attempted to structure the variety of information as found in literature. First of all, it can be stated that for shear in principle a deformation state occurs as is shown in Figure 44. The upper edge has moved in horizontal direction with respect to the lower edge, while remaining parallel to that edge.

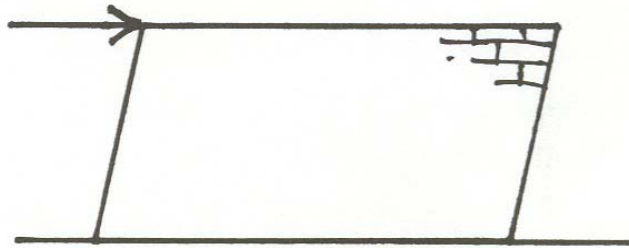


Figure 44 Deformed shape for shear loading

For the shear loading of a wall that is fixed for rotation at the lower edge, in first instance it is necessary to apply somehow at the upper edge an in-plane horizontal force. In several experiments this horizontal force is applied:

1. as a concentrated force at the side of the wall (Figure 45a);
2. by means of a very stiff beam at the upper side of the wall, thus creating a uniform shear stress along the upper side of the wall panel (Figure 45b);
3. using a beam with a low stiffness compared to the wall panel, thus creating a situation in between 1 and 2;
4. on to a frame that surrounds the complete wall panel (Figure 45c).

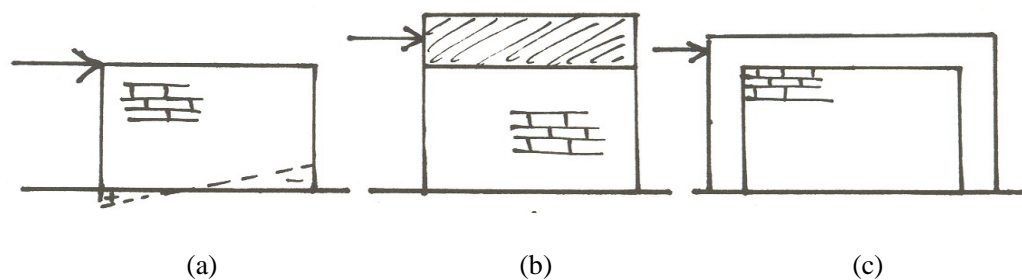
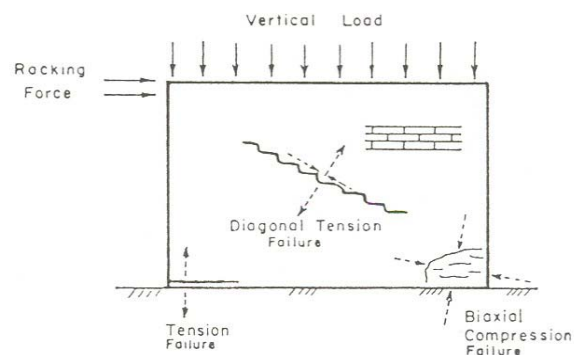


Figure 45 Different ways in which the horizontal load can be introduced

Because of the horizontal force the wall panel is loaded in shear. From equilibrium however, follows that at the foot of the wall a moment equal to the horizontal force times the height of the wall must be counteracted. (see Figure 45a). This only applies to situations 1, 2 and 3. For situation 4 the frame strongly attributes in counteracting the aforementioned moment. In many cases failure of the wall panel will occur because the tensile strength in the foot of the wall is exceeded (see Figure 46). It will be clear that in this situation the upper edge of the wall does not remain parallel to the lower edge, which means that not the desired shear loading is introduced. In a number of cases a load is applied on top of the test panel (see for instance Figure 5b and Figure 6). Doing so indeed reduces the tensile stress in the lower edge, or transforms it into a compressive stress, but again does not create the desired shear loading. Apart from that, the wall panel will now possibly fail because the compressive strength in the lower edge is exceeded (see Figure 46).



MODES OF FAILURE FOR A SHEAR WALL

Figure 46 Modes of failure for a wall panel loaded in shear [42]

To prevent rotation of the upper edge, in several test set-ups supports were more or less introduced in vertical direction. Often this is done by applying vertical rebars running from the upper side of the wall panel to the bottom side. In the ASTM standard shear test (Figure 4a) this is the case at one spot (because of the fact that the lower edge is not fixed for rotation that “support” is for that matter necessary for obtaining equilibrium). In other tests (for instance Hinkley [15] and Ganz [27]) the same thing has been done but now smeared, by applying several rebars along the length of the wall panel. In the latter case the rebars were often used to apply the vertical load. Although rotation of the upper edge is prevented, this situation still does not provide the desired shear loading. To a large extent this is caused by the relatively low stiffness of the tensile rebars.

In various experiments wall panels have been tested that were surrounded by a steel or reinforced concrete frame. The reason for such investigations was that in the field such masonry infilled frames were applied. However, the frames also more or less forced the masonry to deform as shown schematically in Figure 44.

Finally, test set-ups exist in which the upper edge is forced to remain parallel to the lower edge by means of two vertical deformation controlled hydraulic actuators (for instance Woodward and Rankin [21]). The desired shear test can be carried out using such a test set-up, which will result in a crack pattern with a diagonal shear crack.



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