ESECMASE - SHEAR TEST METHOD FOR MASONRY WALLS WITH REALISTIC BOUNDARY CONDITIONS

E. FEHLING

Professor of Civil Engineering
Institute of Structural Engineering
Chair of Structural Concrete
University of Kassel
Kassel, Germany

D. SCHERMER

Research Engineer
Institute for Concrete and
Masonry Structures
Technische Universität München
Munich, Germany

SUMMARY

Within the European research project ESECMaSE a shear test method for masonry walls with realistic dimensions and boundary conditions was developed and numerous wall tests were carried out using this method.
The test method considers the restraint due to the floor slabs by a vertical pair of forces on top of the wall. Furthermore the load history for these tests is shown.

INTRODUCTION

The experimental characterisation of the behaviour of masonry wall panels under shear loading can be carried out in different ways. The investigations can take place by testing a representative small test specimen – e.g. compression test on a masonry wall panel in a specified angle to the bed joints or a diagonal compression resp. tension test – or by the application of a horizontal load on the cap of a large or full scale masonry wall panel with realistic boundary conditions both at the cap of the wall and at the wall edges.
In the following, a method for the determination of the shear load bearing capacity and the deformation behaviour is described. The tests should be performed on a full scale masonry wall with load application at the top of the wall simulating the boundary conditions in real structures.

BACKGROUND

The behaviour of masonry wall panels under in-plane loadings, i.e. combined N-M-V-action, depends on several parameters. To investigate these effects, the execution of real tests is necessary, because a numerical simulation often largely depends on the material models and the selection of the modelling approach.

BOUNDARY CONDITIONS IN COMMON STRUCTURES

With regard to shear walls in multi-storey structures it should be noted, that the slabs may lead to significant restraint effects. In the consequence, the boundary conditions at the cap and the bottom of the wall can be described by the three load parameters:

- vertical compression force N (assumed to be constant along the height of the wall)
- in-plane bending moment at the top M_{cap} and the bottom M_{bottom} of the wall
- horizontal shear force V

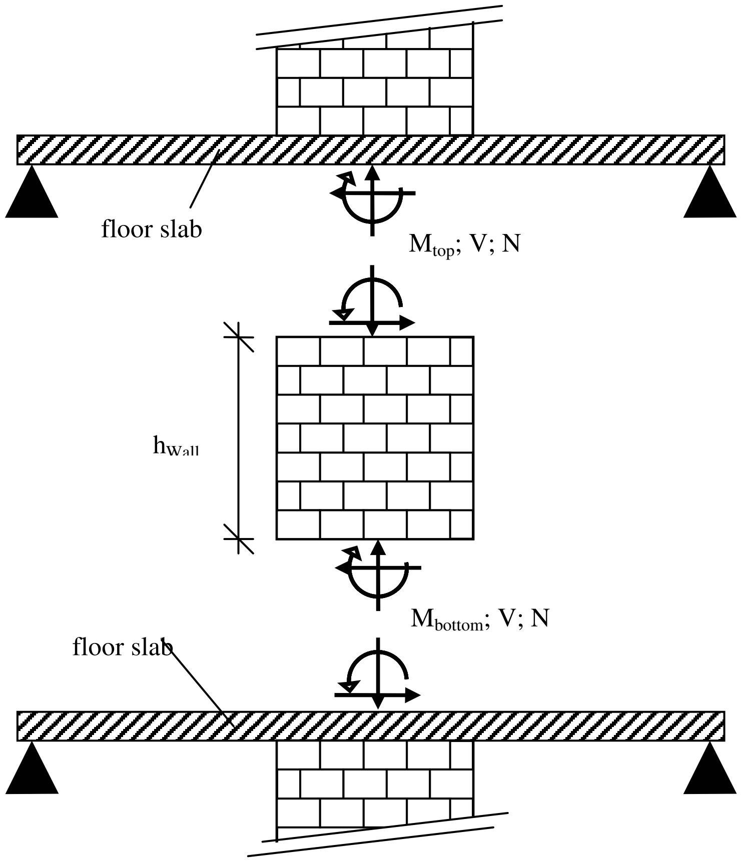


Figure 1. Shear wall in a multi-storey structure with loads acting at the top and the bottom of the wall

A parametric study with spatial FEM-calculations on typical multi-storey masonry structures – including material non-linearities – led to the description of the stress distribution in shear walls in dependency of the several parameters. It was found, that under high horizontal loads the compressed area of the walls was significantly reduced. The eccentricity at the top of the wall was found to be close to the eccentricity at the bottom of the wall – mirror-inverted to the centre of the wall (Fig. 1), described by an almost absolute rigid restraint in the floor slabs occurred. The level of the restraint depends on the stiffness of the wall in relation to the bending stiffness of the slab, i.e. level of the restraint reduces with increasing length of the wall. As in reality the design of short walls is relevant and decisively, the test-method is mainly focused on short walls. Nevertheless the test-method is also suitable for long walls, but then corrections have to been done concerning the h/l- or M_{top}/M_{bottom}-ratio.

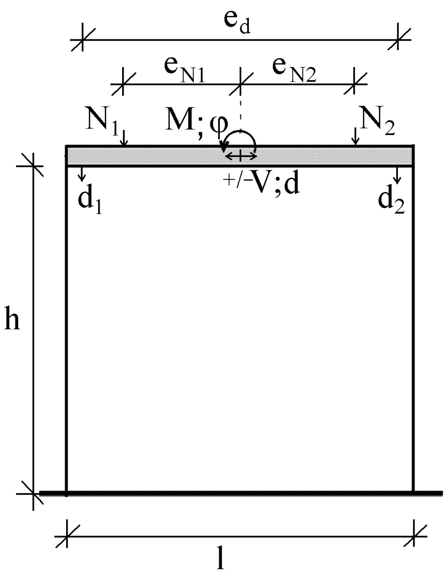
TEST-METHOD

Test specimen

The tests should be performed on full-scale masonry walls to cover size and other above-mentioned effects. The height and the length of the tested walls should be selected close to real structures, i.e. a height between 2.25m and 2.75m.

The test specimen has to be built up on a stiff foundation beam. At the top of the wall the application of a stiff beam is proposed to ensure a proper distribution of the applied loadings.

The test set-up has to ensure the application of the given loadings to the test specimen with a sufficient accuracy. Care should be taken, that the vertical load applied on the wall remains constant during the test and no parasitic loads appear (Fig. 2).



$M = N_1 * e_{N1} - N_2 * e_{N2}$

$\varphi = (d_1 - d_2) / e_d$

$N = (N_1 + N_2)$

Figure 2. Test specimen with loadings.

Load application

The application of the horizontal load (or displacement, respectively) should ensure a uniform displacement on top of the wall.

The vertical forces applied on the test specimen represent the axial force and also the bending moment. In order to model the distribution of the bending moment and eccentricities across the wall height, the ratio between M_{top}/M_{bottom} is fixed to be 1.0 – mirror-inverted to the centre of the wall (Fig. 3). That means for a full rotation restraint that the eccentricity of the resulting force in the mid height of the wall equals zero and no relative rotation between cap and bottom of the wall should occur. It is proposed to use a set of boundary conditions for the comparison of the behaviour of shear walls with different aspect ratios, normal force and materials.

$$M_{cap} = N \cdot e = V \cdot \frac{h_{Wall}}{2} = -M_{bottom} \quad (1)$$

Where: N is the vertical compression force
V is the horizontal shear force
M is the in-plane bending moment (at the top reps. the bottom of the wall)
h_{wall} is the (effective) height of the wall

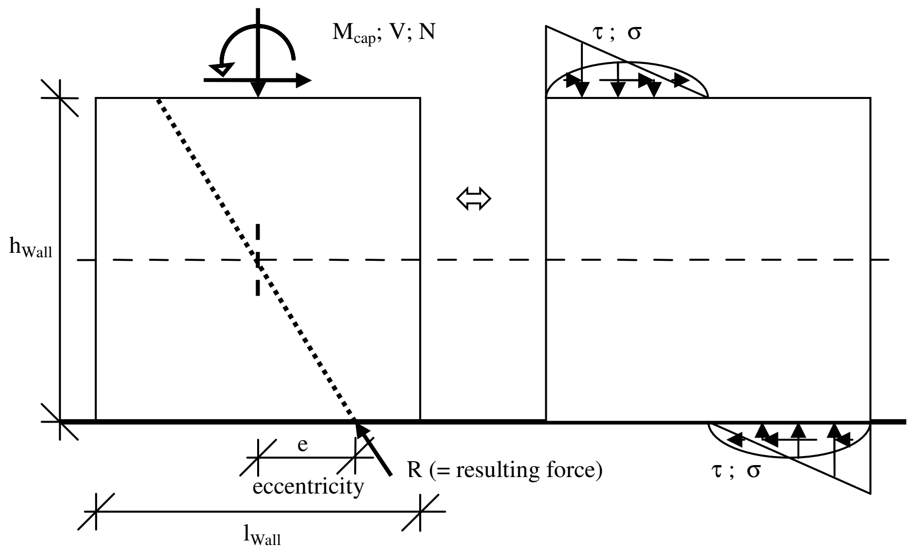


Figure 3. Idealised loadings on shear walls under combined N-M-V-loadings.

The normal force N has to remain constant during the test. That means that mechanical fixations to block cap rotations are not suitable at all, since then additional parasitic vertical forces are activated due to the unavoidable uplift of the wall under bending deformations. Though, the vertical load application must be ensured by computer-controlled actuators and must be measured continuously.

The horizontal load application has to ensure a uniform cap-displacement along the wall. The adjusting shear stress distribution at the cap of the wall depends on the vertical stresses in the compressed part and the geometric properties of the wall in general. To fulfil this demand, a very high longitudinal stiffness of the wall placed directly on the cap of the beam is necessary.

For the standard determination of the shear load bearing capacity of a wall, the horizontal load has to be increased continuously in the tests until the collapse of the wall is reached. To cover also the post-peak and post-crack behaviour (see table below: Load Levels B and C), the application of the horizontal load has to be carried out displacement controlled. Generally, at the beginning of the tests, when the horizontal low load level ensures that no cracks (shear or bending) occur at all, the horizontal load also can also be applied force controlled (see table below: Load Level A).

As the bending moment depends on the horizontal load V, the eccentricity varies during the test and a variable real-time controlling system has to ensure the above mentioned equation. To cover also the post-crack behaviour (where a non symmetric bending-stiffness-reduction in positive a negative direction may occur by shear cracks), it might also be useful, to switch from force-control of the cap moment to a displacement-control, where no relative rotation of the cap is permitted.

For the execution of static-cyclic tests the application of horizontal compression and tension forces should be possible.

Test set-up

In the following figures the test set ups at TU München (D) (Fig. 4) and Kassel University (D) (Fig. 5) are shown. Within the research project ESECMaSE a test set-up has been constructed also at Pavia University (I).
The forces and the displacements are applied computer-controlled. The measurements cover the relevant horizontal and vertical displacements and the forces N_1, N_2 and V.

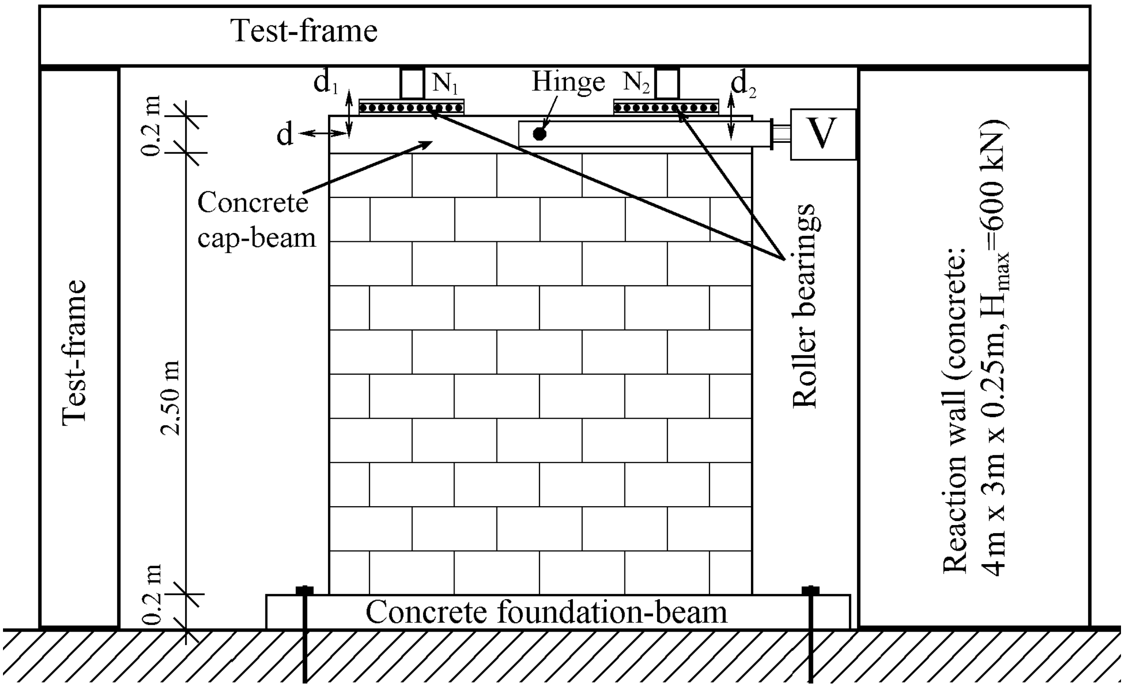


Figure 4. Test set-up at TU München.

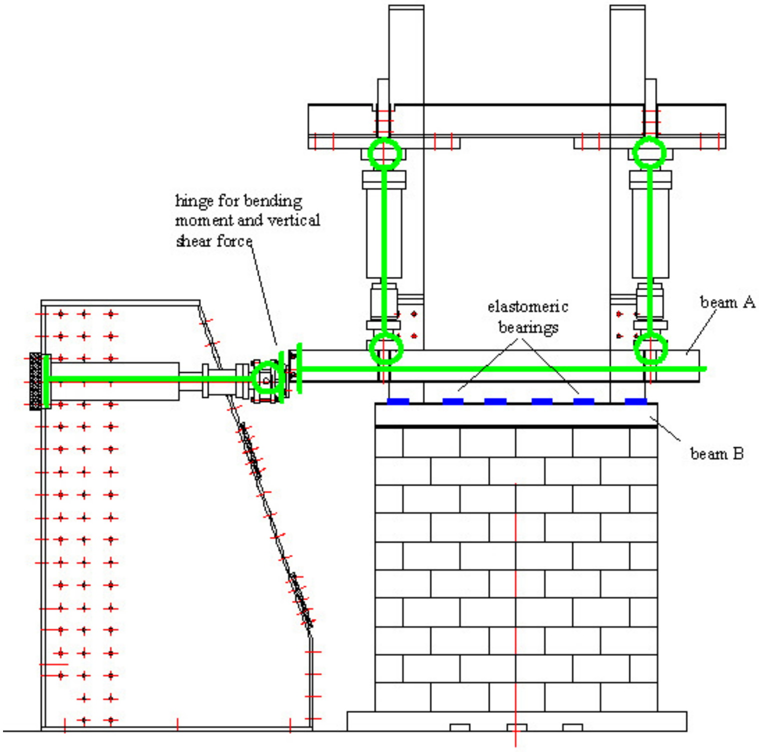


Figure 5. Test set-up at the University of Kassel

LOAD HISTORY

Monotonic tests

For the determination of the shear load bearing capacity of a wall, the execution of a monotonic test is sufficient. These tests are carried out under a constant vertical load N and a monotonic increasing displacement d at the top of the wall. The boundary conditions at the top of the wall have to be fulfilled as lined out. The velocity of the application of the displacement d is calculated from the intended duration of the test of 30 minutes in total.

Static-cyclic tests

These tests are carried out under a constant vertical load N and alternating displacements ±d at the top of the wall. The boundary conditions have to be fulfilled according to the demands, too, as mentioned above.
At the beginning the following values must be estimated, either based on the results of preliminary tests, taken from a data base or from numerical calculations:

- d_{cr} : horizontal displacement where the first cracks are assumed to appear
- $d_{V,max}$: horizontal displacement at the maximum shear load V_{max}
- V_{cr} : horizontal shear load where the first cracks are assumed to appear

The test execution is divided into three load levels
- Level A: no relevant cracks are assumed to appear, i.e. $d < d_{cr}$ resp. $V < V_{\mathrm{cr}}$
- Level B: post-crack, i.e. $d_{cr} < d < d_{V,max}$ resp. $V_{\mathrm{cr}} < V < V_{\mathrm{max}}$
- Level C: post-peak, i.e. $d_{V,max} < d$ resp. $V_{max} < V$

Each load level is subdivided into several steps with an increment of
- $\Delta d = 0.25 \cdot d_{cr}$ (Load level A / almost linear-elastic behaviour assumed)
- $\Delta d = 0.50 \cdot d_{cr}$ (Load level B / post-crack)
- $\Delta d = 1.25 \cdot d_{cr}$ (Load level C / post-peak).

At each load step 3 single cycles of horizontal displacements $\pm d$ are applied on the specimen in form of a sinus-function (Fig. 6).

The maximum velocity of the sinusoidal application of the displacement d is determined to $\mathrm{d_{cr}}$ / 2 min.

Table 1. Applied displacements *d* at the top of the shear wall within a static-cyclic test.

Load level / Step		Displacement	Increment steps
A1	$d \leq d_{cr}$	$\pm 0,25 * d_{cr}$	$\Delta d = 0,25 * d_{cr}$
A2	$d \leq d_{cr}$	$\pm 0,50 * d_{cr}$	
A2	$d \leq d_{cr}$	$\pm 0,75 * d_{cr}$	
A4	$d \leq d_{cr}$	$\pm 1,0 * d_{cr}$	
B1	$d < d_{V,max}$	$\pm 1,5 * d_{cr}$	$\Delta d = 0,50 * d_{cr}$ (*)
B2	$d < d_{V,max}$	$\pm 2,0 * d_{cr}$	
B3	$d < d_{V,max}$	$\pm 2,5 * d_{cr}$	
Bn	$d < d_{V,max}$	…	
C1	$d \geq d_{V,max}$	$\pm d_{V,max}$	$\Delta d = 1,25 * d_{cr}$ (*)
C2	$d \geq d_{V,max}$	$\pm(d_{V,max} + 1,25 * d_{cr})$	
C3	$d \geq d_{V,max}$	$\pm 0,25 * d_{cr}$	
C4	$d \geq d_{V,max}$	$\pm 0,50 * d_{cr}$	
Cn	$d \geq d_{V,max}$	$\pm 0,75 * d_{cr}$	

(*)Variations from the above mentioned load history are generally possible – especially to fit the number of cycles in load levels B and C, e.g. by factorising Δd with 0.5 up to 2.0.

Related to time the displacement can be plotted as:

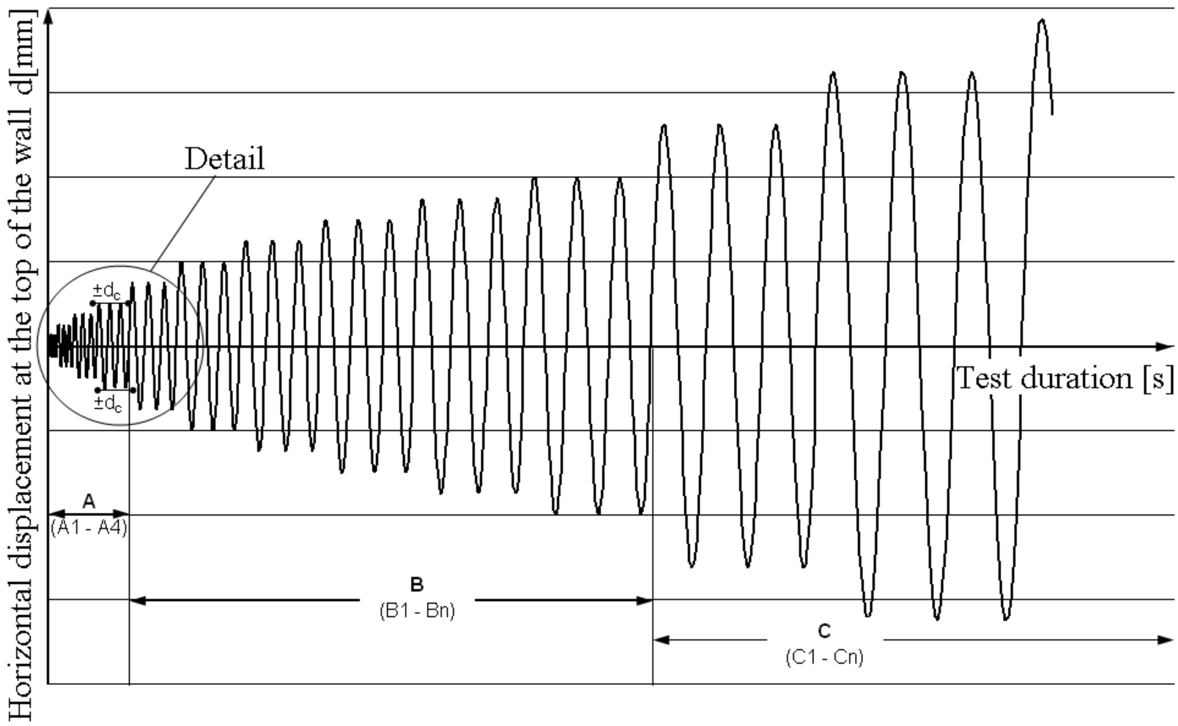


Figure 6. Applied displacements *d* at the top of the shear wall within a static-cyclic test

Slight deviations from the above mentioned load history are generally possible, when no relevant differences are expected.

CONCLUSION

A test set-up for masonry walls with realistic dimensions and realistic boundary conditions is shown. The described approach should be the basis for a test standard of wall tests under horizontal loading.

ACKNOWLEDGEMENTS

The authors would like to thank the European Commission for granting the research project ESECMaSE and generously funding it for three years.

REFERENCES

E. FEHLING: Analysis of Terraced House. ESECMaSE. Enhanced safety and efficient construction of masonry buildings in Europe. Workpackage D3: Theoretical Investigation on Stress States of Masonry Structures Subjected to Static and Dynamic Shear Loads (Lateral Loads)

D. SCHERMER: Analysis of Apartment House. ESECMaSE. Enhanced safety and efficient construction of masonry buildings in Europe. Workpackage D3: Theoretical Investigation on Stress States of Masonry Structures Subjected to Static and Dynamic Shear Loads (Lateral Loads)

D. SCHERMER: Development of a realistic shear test method. Proceedings of the 7th International Masonry Conference, 30.10. – 1.11. 2006, British Masonry Society, London.

N.N.: Development of test methods for the determination of masonry properties under lateral loads in WP 7, incl. test methods for European Standardisation. ESECMaSE. Enhanced safety and efficient construction of masonry buildings in Europe. Workpackage D6: Theoretical Investigations on Shear Test Methods)