SHEAR STRENGTH OF CLAY BRICK MASONRY INCLUDING DAMP PROOF COURSE

D.R.W. MARTENS[1], G. BERTRAM[2]

[1] Professor, [2] Assistant Professor
Department of Architecture, Building and Planning
Unit Structural Design and Construction Technology
Eindhoven University of Technology
The Netherlands

SUMMARY

In the Netherlands, damp proof course (DPC) material is required to prevent groundwater rising in masonry.
In order to calculate the resistance of a wall to wind loading, the value of initial shear strength needs to be determined. For masonry without DPC, the equations and the table given in the European Standard EN 1996-1-1:2005 (EC6) may be used. For masonry including damp proof course material experimental tests, according to European Standard EN 1052-4:2000, are required.
In order to evaluate the effect of a damp proof course on the shear strength of clay brick masonry, 6 series of 4 specimens each of shear tests have been carried out on small masonry specimens with and without damp proof courses, in accordance with European standards EN 1052-3:2002 and EN 1052-4:2000.
Based on the results of this research the characteristic value of initial shear strength and the angle of internal friction were calculated and a proposal was made for the calculation of the characteristic shear strength of masonry with DPC.

INTRODUCTION

In winter, it is very cold in the Netherlands, while in summer, it is often wet. Consequently damp proof course material (DPC) is needed to prevent groundwater rising in masonry (Martens 2006).

In order to design a wall subjected to wind loading, the value of initial shear strength should be determined. In European Standard 1996-1-1:2005 (EC6), either values from tests (in accordance with EN 1052-3 and 1052-4) or values from specified equations and a table are given to determine the characteristic shear strength of masonry. However, the equations and table may be used only for masonry without DPC, while for masonry including damp proof course material experimental tests are required.

This research is focused on the design rules given in EC6 which are not applicable for earthquake loading. For seismic design the shear strength should be calculated based on a friction coefficient determined from displacement controlled tests conducted at realistic sliding velocities (Trajkovski et al 2002).

The goals of this research were:
1. To get more insight into the effect of DPC on the shear strength of masonry and;
2. To evaluate whether the equation in EC6 is also applicable for masonry with DPC and in particular, to determine what the angle of internal friction is appropriate.

In order to evaluate the effect of a damp proof course material from DIBA, 6 series of shear tests, with and without damp proof courses, have been carried out. Each series consisted of 4 small clay brick masonry specimens. The specimens were tested in double shear with 3 different loads of pre-compression perpendicular to the bed joints, in accordance with European Standards EN 1052-3:2002 and EN 1052-4:2000.

SPECIMENS

In the experimental research the specimens were prepared according to the European standard EN 1052-4:2000, for the determination of shear strength masonry including damp proof course. The plain masonry specimens without DPC were also made according to this standard, for comparison. Accordingly, the specimens had to be of length between 400 mm and 700 mm and the height to width ratio (h/w) had to be greater than 2. In addition there had to be at least one vertical joint per course. The specimens used were 430 mm long with h/w equal to 3 (height =300 mm, width = 96 mm.)

The specimens were 2 bricks long and 5 courses high (430 x 300 x 96 mm^3), as shown in Figure 1. The fired clay bricks had a size of 206 x 96 x 50 mm^3. The mortar used in this research was a dry, pre-mixed mortar of strength class M 7.5 - type II/III, according to the Dutch Standard NEN 3835:1991. Tests on the mortar showed an average compressive strength of 14 N/mm^2 or strength class M10-M20. In the Appendix the material properties of the mortar and bricks are given in Table 3.

The damp proof course was sandwiched between mortar layers with a yielding joint thickness of 12.5 mm, which meets the requirements of the standards (range 8 to 15 mm). A polyethylene foil made by DIBA, 500 μm thick and 100 mm wide, with a double-sided ribbed texture (diamond-shaped ribs of 40 x 10 mm) was used as damp proof course.

Immediately after building the specimens were covered in plastic, to prevent drying out during hardening. According to EN 1052-3 and EN 1052-4 each specimen should be pre-compressed using a uniformly distributed mass to give vertical stresses between 2.0 x 10^{-3} and 5.0 x 10^{-3} N/mm^2. By putting four wet bricks on the top of each specimen, a pre-compression of 4.0 x10^{-3} N/mm^2 was introduced (Figure 1).

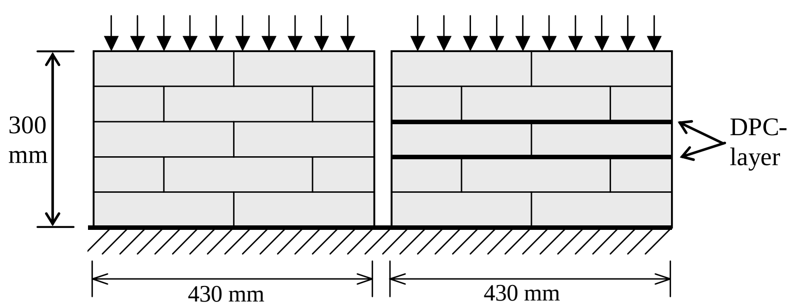


Figure 1. Specimens with pre-compression

TEST SET-UP

The test rig was built with HE160B European steel sections in a Schenck-Trebel 100 kN compression testing machine. The specimens were put in the test set-up, turned 90^{o} in respect of the position they were made in (see Figures 2 and 3), according to EN 1052-3:2002. The specimens with damp proof course were also tested according to this standard, for comparison. The outline of the test set-up is shown in Figure 2:

1. HE160B Steel sections
2. Straw-board
3. Small steel plate
4. LVDT

F_{pi}. Pre-compression load (Figure 3.a.)
F_i. Shear load (Figure 3.c.)

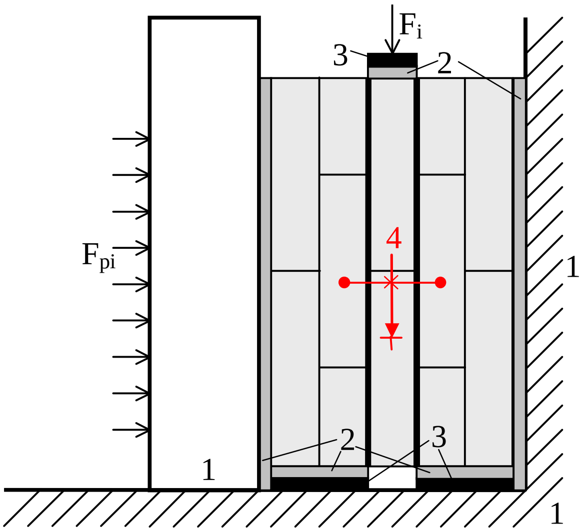


Figure 2. Test set-up

Three pre-compression loads, approximately 8, 24 and 41 kN, which gave pre-compression stresses of approximately 0.2, 0.6 and 1.0 N/mm^2 , were used. The shear stress was increased at a rate of approximately 0.2 N/mm^2 per minute (or a load of 8 kN/min).

During testing the shear load, the pre-compression load and the deformation were measured using a Linear Variable Differential Transducer (LVDT, nr. 4 in Figure 2 and b. in Figure 3).

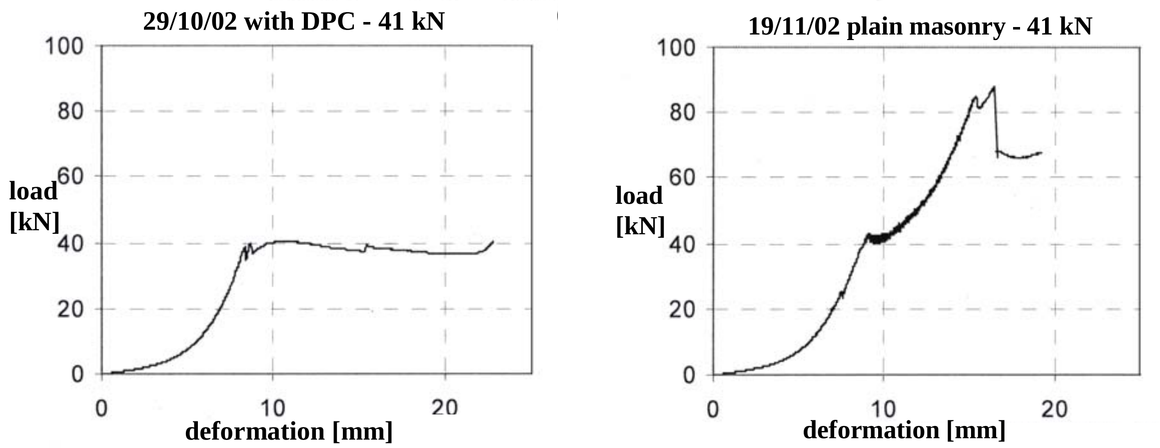
a. Introduction of pre-compression load **b**. LVDT **c**. Introduction of shear load

Figure 3. Pictures of the test set-up

TEST RESULTS

The specimens were tested at an age between 28 and 38 days. Figure 4 shows the deformations of the specimen as a function of the shear load, for a representative specimen. In Figures 4.a and 4.b the results of a specimen with and without DPC, respectively, are represented. Both specimens were loaded with a pre-compressive load of approximately 41 kN.

The graphs show a slow increase in the load until first cracking. For both types of specimens this crack occurs at almost the same value of shear load. For the specimens with damp proof course (Figure 4.a.) this was also the maximum load, which could be resisted to, which means that the adherence between the mortar and the damp proof course is very small. Beyond the maximum, the load remains almost constant, equalling the friction resistance of the masonry with damp proof course. The plain masonry specimens (Figure 4.b.) show a further increase of the load after the first crack until the second and third crack, due to bonding between bricks and mortar. After de-bonding the load bearing capacity decreases to an almost constant value, the dry friction.



a. Graph of specimen with damp proof course **b.** Graph of plain masonry specimen

Figure 4. Deformations of specimens under shear loading

Per specimen the friction resistance (f_{fri} in N/mm^2), the shear strength (f_{vi} in N/mm^2) and the pre-compressive stress (f_{pi} in N/mm^2) are calculated from equations (1), (2) and (3), respectively:

$$f_{fri} = \frac{F_{fri}}{2 \cdot A_i} \qquad (1)$$

$$f_{vi} = \frac{F_{i;\max}}{2 \cdot A_i} \qquad (2)$$

$$f_{pi} = \frac{F_{pi}}{A_i} \qquad (3)$$

where:
A_i = cross-sectional area of the specimen [mm^2]
F_{fri} = friction load [kN]
$F_{i;max}$ = maximum load [kN]
F_{pi} = pre-compression load [kN]

In Table 1 an overview of the measured mean friction resistance and mean values of the shear strength i.e. maximum shear resistance are given, for both plain masonry specimens and specimens with DPC. The friction resistance is a factor 2-2.5 higher and the shear strength is a factor 2-3 higher for plain masonry than for masonry with DPC-material.

Table 1. Mean value of shear strength (f_v) and friction resistance (f_{fr})

Damp proof course material	Pre-compressive stress f_p [N/mm^2]	Shear strength f_v [N/mm^2]	Friction resistance f_{fr} [N/mm^2]	#
No	1.0	1.12	2.0	4
	0.6	0.91	1.5	5
	0.2	0.52	0.6	4
Yes	1.0	0.48	0.9	4
	0.6	0.36	0.6	4
	0.2	0.17	0.2	4

EVALUATION

For the evaluation of the test results, the individual shear strength and pre-compressive stress of each specimen are plotted in Figure 5 and trend lines are determined from linear regression analyses.

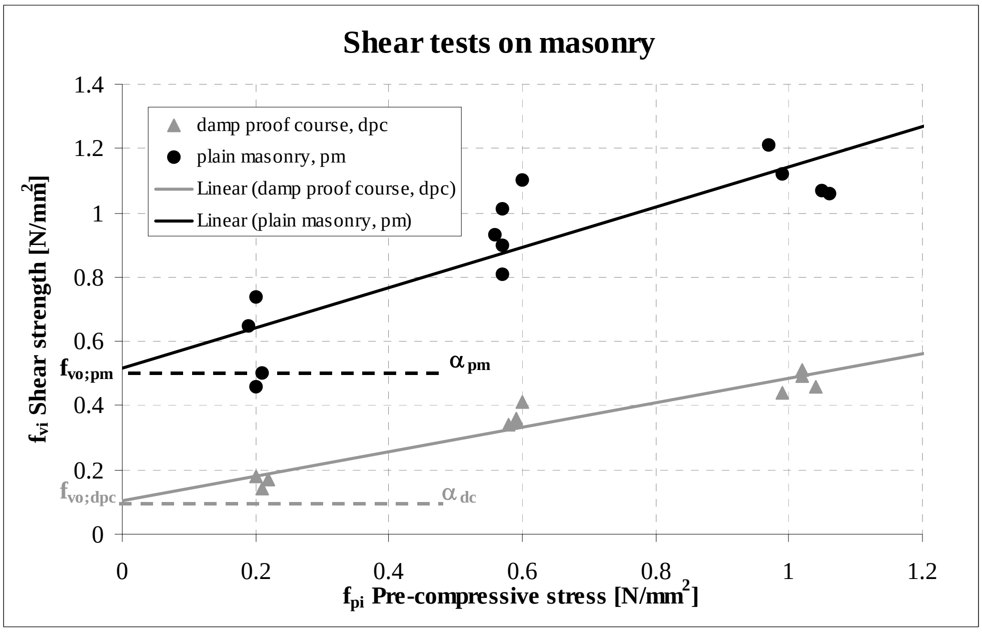


Figure 5. Graph of individual shear tests results and trend lines

According to EN 1052-3 and EN 1052-4, the characteristic value of the initial shear strength is f_{vko}, where $f_{vko} = 0.8\ f_{vo}$ and the characteristic angle of internal friction is taken from $\tan \alpha_k = 0.8 \tan \alpha$. These test and characteristic values for masonry with and without damp proof course, as well as the equations of the trend lines are given in table 2

Table 2. Trend lines for f_v and f_{vk} (EN 1052-3 and 1052-4)

Damp proof course material	f_{vo} [N/mm^2]	$\tan \alpha$ [-]	trend line f_v [N/mm^2]	f_{vko} [N/mm^2]	$\tan \alpha_k$ [-]	trend line f_{vk} [N/mm^2]
No	0.51	0.63	$0.51 + 0.63 \cdot f_{pi}$	0.41	0.50	$0.41 + 0.50 \cdot f_{pi}$
Yes	0.10	0.38	$0.10 + 0.38 \cdot f_{pi}$	0.08	0.31	$0.08 + 0.31 \cdot f_{pi}$

According to EC6 the characteristic shear strength (f_{vk}) for plain masonry with all joints filled, may be taken from equation (4) (equation 3.5 in EC6).

$$f_{vk} = f_{vko} + 0.4 \cdot \sigma_d \qquad (4)$$

where:

f_{vko} = characteristic initial shear strength under zero compressive stress
f_{vk} = characteristic shear strength
σ_d = design compressive stress perpendicular to the shear

The characteristic initial shear strength (f_{vko}) in this equation has to be determined from tests according to EN 1052-3:2002 or be determined from either a database or the values given in table 3.4 in EC6.
In this table a value of 0,3 N/mm^2 is found for the initial shear strength (f_{vko}) of masonry with clay bricks and general purpose mortar of strength class M10-M20, yielding the following equation for the characteristic shear strength:

$$f_{vk} = 0.30 + 0.4 \cdot \sigma_d \qquad (5)$$

In figure 6 different trend lines for the characteristic shear strength (f_{vk}) are put together in one graph.

As could be expected for plain masonry the initial shear strength (f_{vko}) from the table in EC6 is lower (0.3 N/mm^2) than what was determined from the tests (0.41 N/mm^2). Also the angle of internal friction in the equation of EC6 is a conservative value (0.4) compared to the test results (0.5). As a result the calculation of the shear strength (f_{vk}) according to equation (5) gives a lower bound value for the actual shear strength.

For masonry with damp proof course, the angle of internal friction determined from the tests is 0,31. For such masonry the equation from EC6 (Equation (4)) is obviously not applicable. In addition it should be borne in mind that the DPC-material that was used had a double-sided diamond-shaped ribbed texture, yielding a higher friction resistance than for smooth DPC-foils.

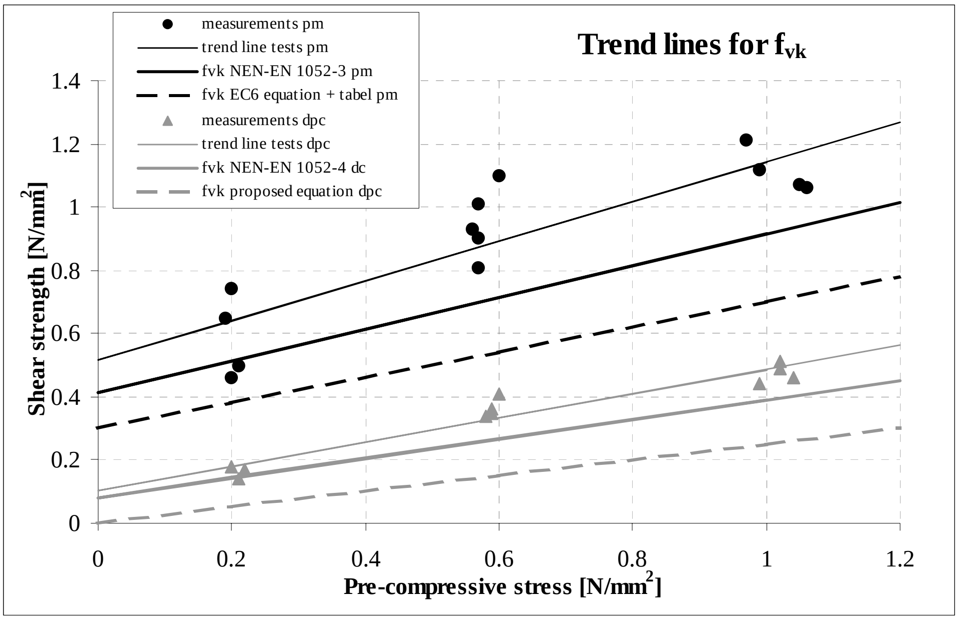


Figure 6. Trend lines for the characteristic shear strength (f_{vk})

PROPOSAL FOR LOWER BOUND VALUE FOR MASONRY WITH DPC

According to EC6 the characteristic shear strength shall be determined from the results in accordance with EN1052-3:2002 and EN 1052-4:2000. In practice, it is not always practical to perform such expensive tests. In such cases, a lower bound calculation method is very useful. For masonry without DPC, Equation 3.5 of EC6 yields reliable results.

In the case of masonry including DPC-materials, no such equation has been established. Based on the test results in this research, Equation (6) below, is proposed as a lower bound approximation for the shear strength of masonry with DPC-material with a double-sided diamond-shaped ribbed texture combined with a mortar with a strength class M10-M20 (see Figure 6).

$$f_{vk} = 0,25 \cdot \sigma_d \qquad (6)$$

CONCLUSIONS

1. There is a difference in preparing and testing the specimens in EN 1052-3 and EN 1052-4.
2. The EC6-equation and table for the calculation of the characteristic shear strength is a reliable lower bound approximation for plain masonry.
3. The masonry specimens with (DIBA) damp proof course show almost no adherence between the mortar and the DPC-material, resulting in a characteristic initial shear strength of approximately zero ($f_{vko} = 0$).
4. The equation given in EC6 for the calculation of the characteristic shear strength of plain masonry is not applicable for masonry with DPC-material.
5. An evaluation of a database on the results of tests on the initial shear strength of masonry with damp proof courses is needed.

APPENDIX

Table 3. Mean material properties

	density fresh mortar [kg/m^3]	density [kg/m^3]	flexural strength [N/mm^2]	compressive strength [N/mm^2]
mortar	2000	1800	3.7	14
bricks	-	1600	-	25

REFERENCES

CEN, “EN 1996-1-1:2005, Eurocode 6 - Design of masonry structures - Part 1-1: General rules for reinforced and unreinforced masonry structures”, 2005 (European standard).

CEN, “EN 1052-3:2002, Methods of test for masonry - Part 3: Determination of initial shear strength”, 2002 (European standard).

CEN, “EN 1052-4:2000, Methods of test for masonry - Part 4: Determination of shear strength including damp proof course”, 2000 (European standard).

NEN, “NEN 3835:1991, Mortels voor metselwerk van stenen, blokken of elementen van baksteen, kalkzandsteen, beton en gasbeton”, 1991 (Dutch standard in Dutch).

Martens, D.R.W., Chapter 1, “Typical masonry wall enclosures in Belgium and the Netherlands”, Enclosure Masonry Wall Systems Worldwide, 2006.

Trajkovski, S., Totoev Y.Z., “Shear Strength of Masonry Including Damp Proof course: Experimental Determination at Different Strain Rates”, Proceedings of the 6th International Masonry Conference, Nº 9, London, November 2002.