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EN 846-9. An alternative approach:2005

1. Preface

The aim of this paper is to show that the method of calculation of brick lintels used by the Danish Brick Industry is consistent and conservative compared with the result achieved by using EN 846-9 and therefore can be used as an alternative to EN 846-9.

2. The calculation method

The method of calculation of brick lintels used by the Danish Brick Industry is referred to as the "calculation method".

"Eurocode 6: Design of masonry structures - Part 1-1: General rules for reinforced and unreinforced masonry, EN 1996-1-1" is referred to as the "Eurocode 6".

The calculation method is introduced in Denmark in April 1998 as a successor to a method not consistent with experimental results. Several theoretical methods were examined, but the design rules given in Eurocode 6 gave a convincing correlation between theory and experimental result.

The correlation was established from experiments of 102 composite lintels covering a great variety of parameters.

The parts of the calculation method given in Eurocode 6 that divert from simple statically rules are detailed referred in appendix 1.

The main parameter relevant for calculating the capacity of composite lintels is the initial shear strength of the masonry. This parameter is important when determining the shear-capacity, which is normally equivalent to the design capacity. The capacity of bending is normally higher than the capacity of shear, unless for composite lintels where the height/length ratio is very small (≤ 1/15).

The initial shear strength was not a parameter determined during the experiment. When comparing the calculation method with the experiments the initial shear strength was estimated taking into consideration the type of mortar, the mixture of mortar and the rate of initial suction of the bricks. The model for determining the initial shear strength is described in the paper "TEGL 24" (Danish version) and reference 1* (English version) in appendix 3. The model is not detailed described in this paper.

3. The experiments

The experiments were performed during the period: 1983-1998. They were all conducted using the same load-applying system as shown below:

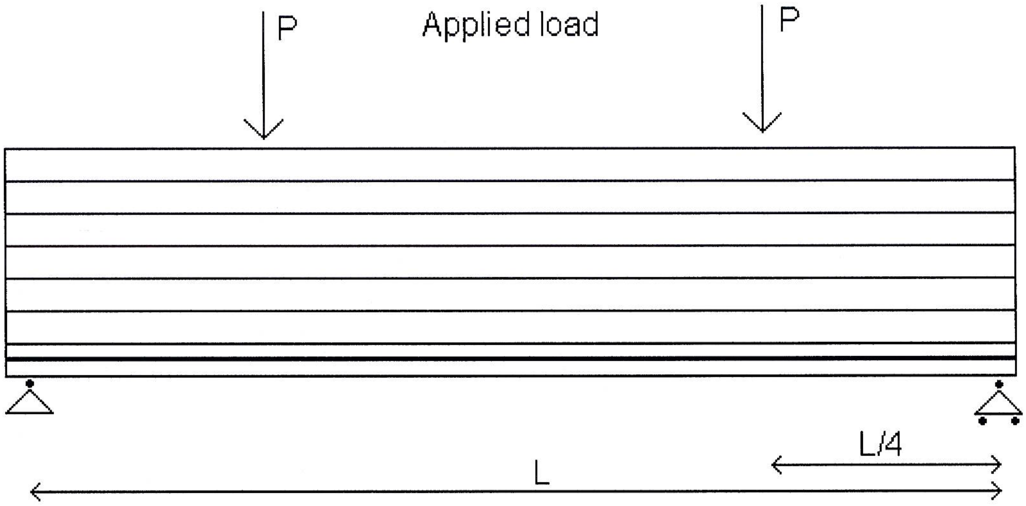

Figure 3.1. Load-applying system for composed lintels

This load-applying system gives the same shear-span as a uniformly distributed load.

The experiments were only conducted for prestressed and non-prestressed composite masonry lintels, fabricated using shell casing units made from clay. The formats of all the units were:

Height:	55 mm
Width:	108 mm

3.1 Span of parameters examined in the experiments

Values below were either estimated (indicated in a bracket) or measured during the experiments.

Height:	185 – 755 mm
Span:	970 – 3960 mm
Span/height:	1.4 – 12.7
Total load:	3.6 – 183.1 kN
Mortar - masonry: (corresponding to M3 – M20 according to EN 998 – 2)	CL 50/50/750 – C 100/400
Initial suction rate – masonry units:	1.3 – 6.39 kg/m^2
Compression strength – masonry units:	12.7 – 68.1
Compression strength – masonry: (estimated from EC6-1)	5.0 – 12.2 MPa
Diameter – reinforcement:	5 – 8
Number of reinforcement:	2 – 4
Prestressed:	0 – 450 MPa

Characteristic tensile strength:	550 – 1060 MPa
Characteristic initial shear strength: (estimated from reference 1)	0,10 – 0,30 MPa
Mortar – Lintel:	> M7

3.2 Comments to the parameters

The parameters relevant for the stress-strain distribution is:

- the minimum value for the span/height-ratio. Values smaller than 1.4 can produce different stress-strain distribution causing the calculation method to fail.
- the level of prestressing. Prestressing creates a very stiff bottom course and in combination with courses with lower stiffness a slightly lower capacity of the lintel is introduced (This subject is elaborated in appendix 4).

The minimum value for the height represents a relevant value for robustness. The value 185 mm is regarded as the minimum height for lintels.

The adhesion between:

- the reinforcement and the concrete infill and
- the concrete infill and the lintel

as a parameter is not represented in the calculation, and consequently the capacity for that part of the lintel shall by estimated differently. Recent research has shown that the value for the compression strength for the concrete infill shall exceed 10 MPa to obtain the necessary adhesion (when the lintels are made of clay). The diversion between M7 and the 10 MPa requirements is conservative. (This subject and the approach to other types of lintels (e.g. other materials) are elaborated in appendix 4.

3.3 Evaluation of results

For each item the design value for the shear and bending capacity was calculated and the minimum value extracted. This value was compared with the test result giving a factor 4 in average when the ratio of experimental value was compared with the design value. The result is shown in appendix 2. The correlation between experimental values and the design value is convincing, even though values for the initial shear and compression strength are estimated and not based on experiments.

4. EN 846 – 9

EN 846-9 is part of a set of standards related to: "Methods of test for ancillary components for masonry". Part 9 is titled: "Determination of flexural resistance and shear resistance of lintels". The reference to this test standard is from EN 845-2, which is now compulsory in the Danish complex of codes.

In the following section relevant issues to this comparison are extracted.

4.1 Extracts of essentials in EN 846-9

Extracts of essentials are listed below. Obvious demands, such as "the minimum number of specimens shall be three", "all relevant dimensions shall be measured", etc are not listed.

1) The standard specifies the following normative references (section 2):
   EN 772-1: Methods of test for masonry units – Part 1: Determination of compressive strength.
   EN 998-2: Specification for mortar for masonry – Part 2: Masonry mortar (The lintels may be bedded on mortar to EN 998-2).
   EN 1015-11: Methods of test for mortar for masonry – Part 11: Determination of flexural and compressive strength of hardened mortar.

2) The lintels are (only) simply supported in order to determine (section 2):
   a) flexural strength
   b) shear resistance
   c) deflection.

3) The loading system and the deflection monitoring equipment shall be accurate within +/- 2 % (section 6.2 and 6.3).

4) Simply support for the lintels shall be with a minimum end bearing of 100 mm (section 8.2).

5) Prevent the test specimen from drying out during the first 3 days after construction, e.g. by covering it with a polyethylene sheet and leave it uncovered in a laboratory environment until tested (section 8.3).

6) Use any convenient loading rate such that failure occurs at between 15 min. and 30 min. after commencing the test (section 8.5.1).

7) When testing the flexural resistance use a uniformly distributed load or alternatively, a series of point loads giving equivalent maximum shear and bending moment to that obtained from a uniformly distributed load (section 8.5.2).

8) Point loads should be applied through spreader plates of length between 50 and 200 mm (section 8.5.2).

9) When testing shear resistance, use a shear load applied to the lintel at a distance from the edge of the support equal to the height of the lintel plus 75 mm (section 8.5.3). The lintel length shall exceed 5 times its height (section 8.6.2).

10) Vertical deflection shall be measured at the mid leaf position (section 8.5.4).

11) Horizontal deflection shall be measured at the mid height of the lintel (section 8.5.4).

12) Flexural resistance. Increase the load until either (section 8.6.1):
(a) flexural failure occurs.
(b) the load at which further net mid-span deflection occurs without increase in load.
(c) the load at which web buckling or shear failure occurs.

13) Shear resistance. Record the failure load.

5. Evaluation of 846-9

It is not possible to make a comparison between EN 846-9 and the calculation method without evaluating the standard 846-9 it self. This will be done in this chapter 5 and 6.

5.1 Initial shear strength and other parameters of strength

As described in section 2 the main parameter relevant for determining the capacity of composite lintels is the initial shear strength (this parameter is important when determining the shear-capacity, which normally equivalent to the design capacity. The capacity of bending is normally higher than the capacity of shear unless for composite lintels where the height/length ratio is very small (≤1/15)).

This parameter, initial shear strength, is not included in EN 846-9 when material specification is stated in the test report. Instead is referred to:

- "EN 772-1 Determination of compressive strength". The compressive strength of the units is related to the compressive strength of the masonry, which has influence on the bending moment. The influence from the compressive strength of the masonry on the bending moment is very low.

- EN 1015-11: Determination of flexural and compressive strength of hardened mortar. The flexural strength of hardened mortar is not related to the capacity of the lintel at all. The compressive strength of hardened mortar is related to the bending capacity in the same way the compressive strength of the units is. This implies a similar low influence on the bending moment.
- The initial shear strength is approximately proportional to the shear loadcapacity and shall not be measured – according to EN 846-9.

5.2 Distinction between shear load and bending load capacity

Since the shear-capacity is normally equivalent to the design capacity it is very unfortunate to try to measure the bending capacity specifically. As it can be seen in this paper section 4.1.12) and 13) the manual of reporting is indicating this paradox:

- When testing for shear (in 13) the capacity found is set equal to the shear capacity.
- When testing for bending (in 12) the capacity found is either the bending capacity (a) or the shear capacity (c). This implies that a test result could have 2 different values for shear capacity in the probably incident that the measurement for bending capacity turns out to be a measurement for shear capacity. The standard does not describe which one is valid for declaration.

6. Comparison between EN 846-9 and the calculation method

The comparison takes into consideration that the calculation method is based on rules implemented in Eurocode 6 and a number of experiments as described in section 3. The items discussed below refer to the numbers in section 4.1 Extracts of essentials in EN 846-9.

1) The compressive strength for the units is measured in accordance with the previous Danish Standard DS 438-11 that differs slightly from EN 772-1. As described above in section 5.1 the compressive strength has a very low impact on the bending capacity (a fracture rather unlikely to occur). This difference is therefore neglected.

2) The calculation method was mostly based on experiments with simply supported lintels. The experiments were furthermore supplied with restrained lintels giving more detailed information.

The deflection was not measured during the experiments, partly because it is an irrelevant parameter related to the safety of the structure and partly because the value can be calculated. The established procedure for calculation of deflections has been shown consistent during some of the recently performed experiments.

3) The accuracy of the loading equipment exceeds the requirements given in EN 846-9.

4) The bearing was 100 mm fulfilling the requirements given in EN 846-9.

5) The specimen was stored before testing in 28 days in a conditioning room with a temperature of 20 +/- 2 degrees and a relative humidity of 60 +/- 5 %. The demand for conditioning in the standard was:

   "3 d, e.g. by covering it with a polyethylene sheet and then leave it uncovered in a laboratory environment until tested.

   A "laboratory environment" is undefined and can imply a wide range of temperature and relative humidity. The number of days is not specified in EN 846-9.

6) The demand in the standard was equivalent to the aim in the experiments.

7) The demand in the standard was equivalent to the aim in the experiments as shown in figure 3.1.

8) The requirement in the standard was fulfilled with a spreader with a dimension of 100 mm.

9) Specific experiments for evaluating the shear resistance were not performed. See discussions in section 5.2

10) See comments in 2) second paragraph.

11) Horizontal deflection is related to lateral buckling. Buckling is rarely a failure situation for composed lintels. In Eurocode 6 are given some very conservative restrictions related to buckling that is implemented in calculation method.

12) Consistent with the experiments performed.

13) Consistent with the experiments performed.

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7. Conclusion

When evaluating the consistency between EN 846-9 and the calculating method following conclusion is relevant:

The calculation method is regarded as a relevant alternative to EN 846-9 because:

- The calculation method takes the initial shear strength into account. Testing performed according to EN 846-9 does not prescribe examination of that parameter, leaving the test report without any clue to explain any result diverting from an expected value.
- The experiments performed to correlate the calculation method are consistent with all relevant parameters and procedures described in EN 846-9.
- The calculation method is only valid for the parameters fulfilling the requirement given in appendix 4 and 5.

Yours sincerely,
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The parts of the calculation method given in Eurocode 6 that divert from simple statically rules

The effective beam length is the clear span + Minimum (the bearing length, or the effective height).

In calculating the shear load, it is assumed that the maximum shear load occurs at a distance of ½ * (the effective depth) from the face of the support. This causes the shear load to be slightly less than the reaction.

The initial shear strength may be increased if the ratio of the shear span (a_v) to the effective depth (d) is less than 2, that is:

$$a_v/d < 2.$$

The initial shear strength may be increased by a factor:

$$2d/a_v \leq 4$$

If the initial shear strength is increased, however, the shear load is calculated at the face of the support. This means that for asymmetrical loads, the shear capacity can be different from the right and left side.

Furthermore, a criterion for the bearing capacity concerning strain in the tension area of the middle of the beam is introduced. The tensile strain in the lower bed joint must be below 0.5 ‰ for the bearing capacity to be assumed adequate.

The fixed-end moment at the ends is not to be calculated greater than half the actual positive moment, when the beam is considered to be simply supported, even when the moment bearing capacity at the ends is greater.

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Experimental values versus design values

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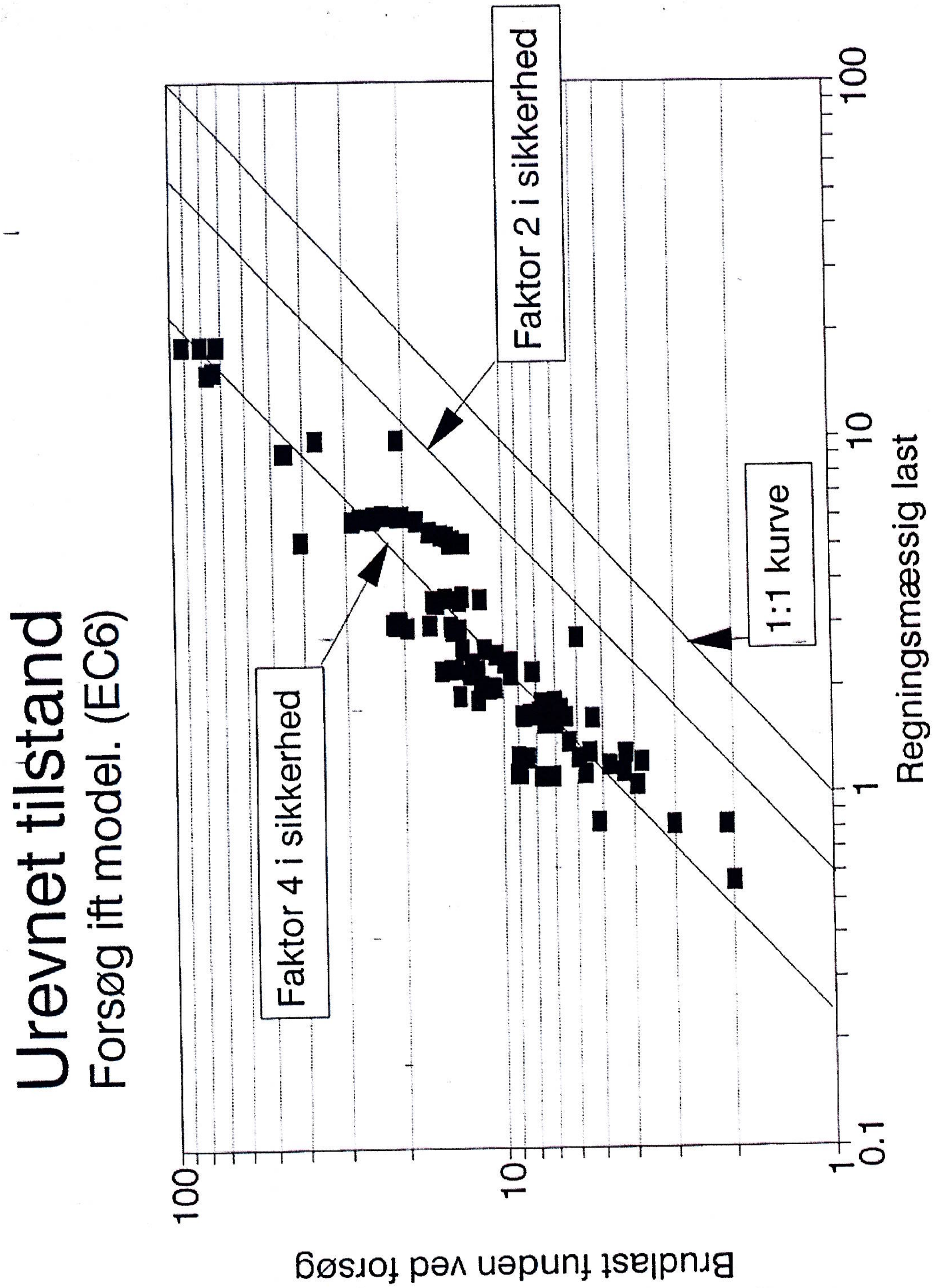


References

Reference 1*. Computer methods in structural masonry – 3. Edited by J. Middleton & G.N. Pande. Books & Journals International. Theoretical determination of flexural strength of unreinforced masonry.

Requirements for the lintels

The results in this report are valid for:
1 or 2 courses clay lintels with geometry as described in Appendix 5, configuration.

Other types of lintels can be divided into 2 categories.

1. Lintels where the stress-strain distribution differ from the presumed

E.g. lintels constructed with a vertical reinforcement either in concrete in-fill or in slits milled in the clay bricks.

These types of lintels must be tested separately according to EN 846-9. The method of calculation described in this paper is not valid for these type of lintels since the stress-strain distribution, the statically solutions, the fragility, etc differ.

2. Lintels where the stress-strain distribution are equivalent to the presumed, but the lintels differ in some way from the examined clay lintels.
E.g. lintels constructed with bricks of limestone or lintels constructed with bricks made of concrete with clay aggregate or other type of aggregate.

These lintels are similar to the examined lintels in all relevant areas (especially the main issue, that the initial shear strength in the horizontal section is weaker compared with all other directions)

These lintels can be calculated using the same model described in this paper when following conditions is fulfilled.

1) The parameters of strength should be known or determined using the relevant standards. Especially the initial shear strength determined from EN1053-3

2) A documentation that the adhesion between:
   - the reinforcement and the concrete infill
   - the concrete infill and the lintel

   is adequate should be made. I.e. the adhesion should be stronger than the corresponding cohesion in the reinforced lintel. (For clay bricks fulfilling the configuration stated in Appendix 5 this is achieved using concrete in-fill M10 or stronger)

3) The prestressed lintels used in combination with non-prestressed courses gives a slightly lower load capacity compared with non-prestressed lintels. This condition is included in the method of calculation. It can be shown that reinforcement that exactly matches the needs ($\sigma = f_{yd}$), when a shear fracture occur gives the highest load capacity. When using prestressed lintels (that differ

from the examined clay lintels) or lintels with a capacity in tension it will be necessary to secure that the modules of the elasticity in tension of the reinforced lintel does not exceed the modules of elasticity in compression of the masonry combined courses.

The limitations of the calculation method according to this analysis:

Span/Height > 1.4

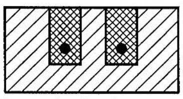
Height > 185 mm

Prestressed lintels:
Level of prestressing ≤ 18 kN per course prestressed
Limitations according to the range of lintels tested:

Principle:

Composite masonry lintels where the prefabricated part is fabricated using reinforced or prestressed concrete/masonry mortar and non-structural shell casing masonry units in accordance with the following:

Configuration:



½-stens tegloverligger, b = 108 mm

Definitions:

Shell casing masonry units according to EN 771-1

Mortar according to EN 998-2

Reinforcement

(The clay wall between the 2 steel bars can be omitted and replaced by concrete infill)

Reinforcement			
Dimensions:	Normal:	Ø 8 mm, profilet	
	Prestressed:	Ø 5 mm, profileret	
Placering:	Armeringsstængerne skal placeres symmetrisk i tværsnittet		
	Afstand fra underside overligger til armeringsstængernes midtpunkt		Mindst 20 mm
	Afstand fra yderside overligger til midtpunkt af de yderste armeringsstænger		Mindst 30 mm

Span of parameters, pre-fabricated part:
Shell-casing units: According to EN 771-1
Mortar – lintels: $f_{mor,c}$ > M10
Reinforcement: f_{yd} > 550 MPa
Reinforcement for pressing f_{yd} > 1060 MPa