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ABSTRACT

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INEXPENSIVE FLAT LINTELS WITH A COMPRESSION ZONE OF MASONRY

1 PROBLEM AND DECLARED AIM

In Germany the execution and design of lintels can be carried out either with the “Flat Lintel Directive” [1] or to German Standard Specification DIN 1053-3 [2]. The design rules in [1] – especially the shearing check – were based on the comprehensive tests inter al. in [3]. The two valid German systems of rules specify that the masonry above the flat lintel (in the calculated compression zone) should be designed with mortared joints. Masonry components today however are mainly designed with non-mortared perpend joints. The mortaring of the perpend joints in the pressure zone of brick-lined flat lintels requires an additional construction process. On the other hand the perpend joints in the compression zone are very often constructed without mortar by the builders and thus do not respect the rules. A subsequent improvement causes considerable extra costs. Moreover the two systems of rules limit the performance to specific units in regard to the minimum length of compressive strength or of the perforation volume. For flat lintels, which deviate from both systems of rules, permits are required from the building authorities. At the present time there are 9 general permits in existence for lintels approved by the building authorities, which however all prescribe mortaring of the perpend joints.

The aim of this research project was the development of a design approach for flat lintels with a compression zone without perpend joint mortaring. This is designed to create the basis for the adoption of flat lintels without perpend joint mortaring in German control systems.

2 PROCEDURE TO BE FOLLOWED

Within the scope of the research works and permit experiments a large number of tests were made on flat lintels both with and without mortared perpend joints in the brick-lined compression zone. The present test results are presented and evaluated. On the basis of the test results a design model was developed for flat lintels with brick-lined compression zone and non-mortared perpend joints. For verification or adaptation of the design model, laboratory tests were carried out on flat lintels with brick lining non-mortared perpend joints. The new laboratory test results – as well as the previous laboratory test results – are compared with results of the calculation model and evaluated.

3 TESTS CARRIED OUT AND RESULTS

3.1 Derivation of a calculation and design model

A large number of tests on flat lintels both with mortared and also with non-mortared perpend joints were carried out in the ibac with different test methods within the framework of various research works or permit experiments, sponsored by industrial customers. All the present test results on flat lintels with a brick lining in various unit-masonry-mortar combinations and non-mortared perpend joints were evaluated, assessed and formed the basis for the various types of the calculation and design models of the brick lining. The individual bearing structure models and the possible failure mechanisms are then explained below in principle. Basically with all lintels a bearing model with tensile and compression flanges as well as inclined struts for support was constructed as a basis. The following models with tensile and compression flanges and also inclined compression struts represent a necessary simplification of the design. The calculated lintel height employed should be limited to the separation of the beam theory from the plate construction theory. In the following design models therefore the internal lifting arm z should be limited as a function of the lintel width l_s, e.g. to $z \leq 0.5\ l_s$. Lintels with a single-layer brick lining and non-mortared perpend joints without reinforced concrete cover on top have no loadbearing capacity and are therefore not dealt with in the following paragraphs.

(1) Compression zone with one unit layer and reinforced concrete cover on top

In the brick lining with one row of units and a reinforced concrete cover on top, the compression flange is formed in the reinforced concrete cover, see Fig. 1.

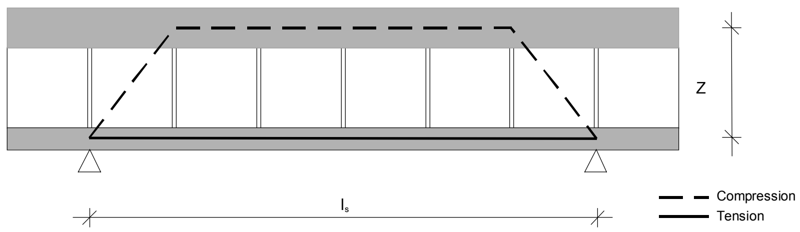

Fig. 1: Compression zone with one row of units and reinforced concrete cover

Deviating from the Flat Lintel Directive [1] and the basic static system given there, the inclined compression strut cannot be formed however as a function of the external lintel mass. In a brick lining without perpend joint mortaring the course taken by the inclined diagonal strut, as identifiable in Fig. 1, is governed by the arrangement or dimensions of the units. The diagonal strut runs through the next support unit, it can to be on the safe side – as in an opening – not run through an open perpend joint.

If the perpend joints are considered as small openings, the lintel should be shown as a beam with openings in the web. That is, in the area of the openings the compression flange to be on the safe side, should be capable of taking the shear force at this point alone. The decisive proof of the shear force of the compression flange (concrete cover) should thus be made at the next supporting perpend joint. To be on the safe side the proof should be made directly at the support with the full transverse force as otherwise the layout of the units of the brick lining has to be specified directly and a laying plan would then always be required.

Generally therefore proof has to be furnished for the following: the tensile flange (reinforcement for tension), the compression flange (concrete cover for compression) and the diagonal strut (shear proof masonry) and also in the area of the next supporting open perpend joint of the compression flange for shear (concrete cover for transverse force). The proof for the anchorage of the reinforcement should be made independently of the bearing model according to DIN 1045.

(2) Compression zone with two or more unit layers without reinforced concrete cover

In a brick lining of the flat lintels with two or more unit layers but without the joint action of a reinforced concrete cover, the following static system described can be installed as a basis (Fig. 2).

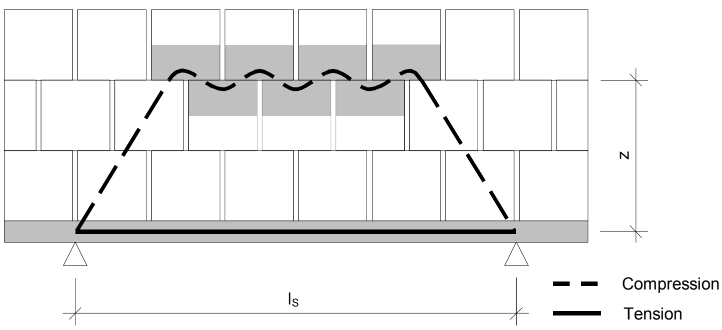

Fig. 2: Compression zone with two or more rows of units without reinforced concrete cover

The compression flange on the safe side is set only in the area of the top horizontal bed joint, joint action of the bed joint beneath is neglected, at this is only very slight. The system is likewise stable without deformation. The inclined diagonal strut is governed by the layout of the units. In the most unfavourable situation the diagonal strut thus passes through only one unit in every unit row.

As an extension of the proofs already described the compression flange in the system should not only show proof of compression (linear compressive strength of the units) but also of bending shear in the top bed joint (shear transfer between the individual units). The force of the compression flange must be capable of being sustained by the shear transfer between the individual units, i.e. as a function of the overlap.

(3) Compression zone with two or more brick layers and reinforced concrete cover on top

The following bearing model shown in Fig. 3 can be taken as an static system.

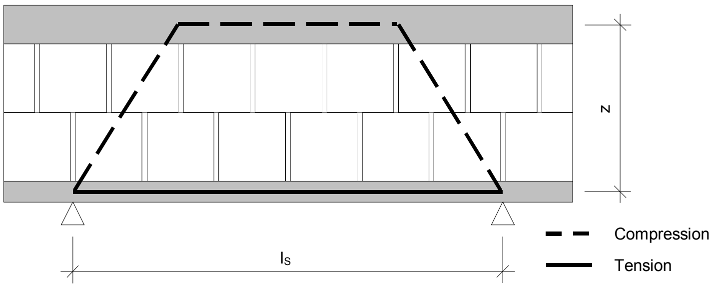

Fig. 3: Compression zone with two or more rows of units and concrete cover

With this system the bearing model should be employed in the same way as the brick lining with one row of units and reinforced concrete cover. The same calculated proofs are required. The system geometry is likewise dependent on the layout and size of the units.

No presentation of the individual Equations of the calculated proof is given here.

3.2 Experimental investigations

The test programme was prepared on the basis of the previous test results available. The aim was to cover a broad spectrum of possible masonry geometries, essentially with variation of the layout of the perpend joints, the support width and the number of unit layers. The tests were carried out on flat lintels with brick-lining of calcium silicate units, autoclaved aerated concrete units and vertically perforated clay units, both with and without concrete coated beams. Owing to the minimal scatter of the test results in the previous tests, one test specimen of every test series respectively was examined. Apart from the tests on building components, the essential unit and bonding properties were determined, inter al. the standard compressive strength of the units, the compressive strength in direction of the unit length and the adhesive shear strength.

The testing of the brick-lined flat lintels was made with test equipment developed at the ibac. With this test method the applied load was introduced via a water-filled special tube. The test equipment is shown in Fig. 4. The tube is adapted to the deformation state of the lintel; due to the hydrostatic pressure a uniform load is applied to the test specimen in every state of deformation. The test results are given in Tables 1 and 2. In tests with non-mortared perpend joints in the load-deflection-lines often before reaching the maximum breaking load an initial failure can be identified, in which the deflections increase disproportionately. The cause of this is normally failure of the adhesive bond. This “initial failure” does not as a rule lead to complete failure of the building component. After closing the perpend joints in some cases significant increases in load are still possible.

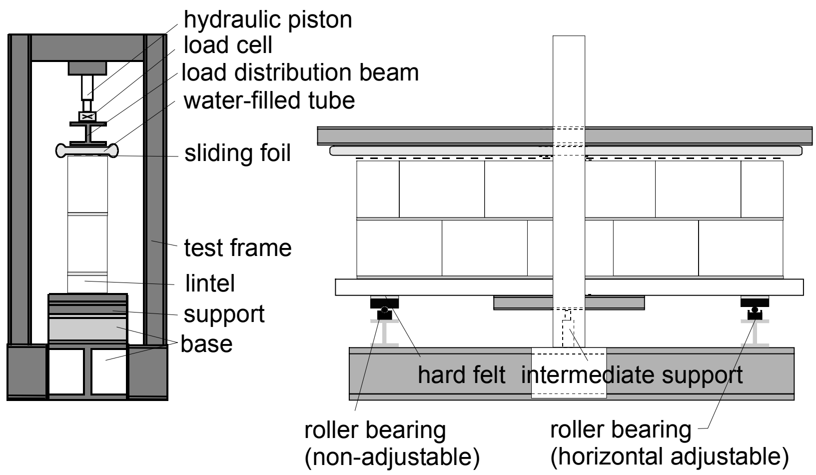

Fig. 4: ibac testing equipment for flat lintels

3.3 Comparison of the experimental loadbearing capacity with the calculated loadbearing capacity

For the different types of construction presented in Para. 3.1 the earlier and the more recent experimental tests the corresponding cases of failure – also to be checked in the design – were re-calculated. In the calculations carried out instead of using the calculated values from DIN 1053-1, the specific property values of the building material are used in the flat lintel tests. The safety coefficient is set here as $\gamma = 1$.

Table 1: Building material used for the flat lintel tests carried out
masonry units: type, dry row density ρ_d, compressive strength $\beta_{D,st}$, compressive strength in direction of unit length $\beta_{DL,st}$, unit tensile strength $\beta_{Z,st}$
masonry mortar: type, compressive strength $\beta_{D,mö}$, initial shear strength β_{HS}
flat lintel: dimensions, reinforcement, cross-section A_S

test series	masonry unit					masonry mortar			flat lintel			
	type	ρ_d	$\beta_{D,st}$	$\beta_{DL,st}$	$\beta_{Z,st}$ [1)]	type	$\beta_{D,mö}$	β_{HS}	l	b	h	A_s
-	-	kg/dm³	N/mm²			-	N/mm²		mm			mm²
1	2	3	4	5	6	7	8	9	10	11	12	13
I	KS L 20 - 1,4 - 8DF	1,27	24,8	6,66	0,99	NMIIa / DM	9,10 / 17,5	0,46 / 0,38	1485	115	71	78,5
II									2500	115	71	78,5
III	PP 2 - 0,40 - 8DF	0,39	2,49	1,55	0,45	DM	n.d.	0,38[2)] / 0,60[3)]	1400	115	125	66,5
IV												
V												
VI	HLz 12 - 0,9 – 9DF	1,32	12,6[4)]	1,63	0,38	NMIIa / DM	6,51 / 21,7	0,37[5)] / 0,38[5)]	2000	175	71	78,5
VII	PP 2 – 0,40 – 999 x 240 x 498	0,39	2,23[6)]	2,55[6)]	0,40	DM	14,7; 16,5	0,60	2000	2 · 115	125	133
VIII												

1) tensile strength calculated acc. to [6]
2) shear strength test specimen: masonry unit / masonry unit
3) shear strength test specimen: masonry unit / flat lintel
4) without shape factor
5) shear strength taken as in an earlier test series
6) determined on the cube (edge length: 100 mm)
n.d. = not determined

Table 2: Tests on brick-lined flat lintels
Perpend joint width b_{SF}, number of unit layers n_{SL}, height of brick-lining h_a, height of concrete beam h_b, used static height h_{stat}, width of lintels b, length of lintels l_S, anchorage length l_A, shear slenderness λ, load on initial failure F'_u, breaking load F_u, load $F_{1/500}$ on a deflection in the lintel centre of $l_s/500$, case of failure VF (see below), shear strength τ_u

Test series	b_{SF}	n_{SL}	$h_ü$	h_b	h_{stat}	b	l_S	l_A	λ	F'_u	F_u	$F_{l/500}$	VF[1)]	τ_u
-	mm	-	mm						-	kN			-	N/mm²
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
I	5	2	513	150	699	115	1232	127	0,42	(22,8)[2)]	≥74,3	≥74,3	(3F)[2)]	0,38
II	5	2	513	150	699	115	2270	115	0,80	52,5	75,1	60,4	3F	0,42
III	5	2	504	-	567	115	1000	200	0,37	59,3	70,2	≥70,2	3S	0,38
IV	5	2	504	-	567	115	1000	200	0,37	(8,8)[2)] 34,4	≥42,1	≥42,1	2F, 3F, 3S	0,23
V	5	2	504	150	717	115	1000	200	0,29	-	61,8	≥61,8	3S	0,27
VI	5	2	511	150	696	175	1650	115	0,58	114	161	86,4	3S, 3F	0,58
VII	5	1	500	150	713	240	1750	125	0,60	156	≥189	147	-	0,48
VIII	5	1	500	150	713	240	1750	125	0,60	118	181	132	3S	0,46

1) **VF** **Failure**
1 Failure of the tension flange (reinforcement for tension)
2F Failure of the compression flange: joint failure (initial shear strength unit/mortar)
3F Shear failure of the masonry: joint failure (initial shear strength unit/mortar)
3S Shear failure of the masonry: unit failure (tensile strength of units)
2) no definite failure

In Fig. 5 is represented the ratio value F'_u (load on initial failure) for the calculated breaking load cal F. F'_u was used, as loads exceed F'_u significant deflections and cracks occur, so that the suitability for use in general is not provided. In a few test series without definite initial failure F'_u – F_u was used.

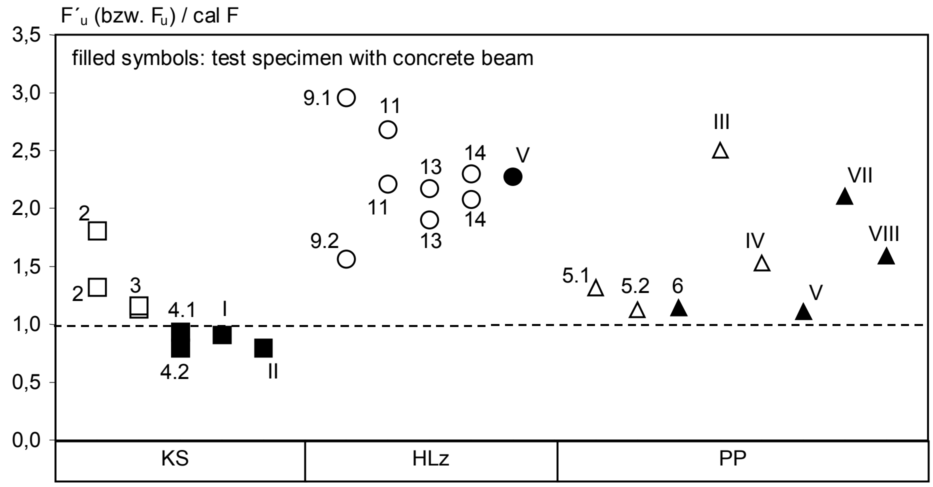

Fig. 5: Ratio value: Load on initial failure F'_u (or breaking load F_u) in the test and calculated bearing load cal F

It is evident in Fig. 5 that the test values – up to Test Series 4.1 and 4.2, I and II (calcium silicate units and concrete beams) – are above the calculated values. In the Test Series 4.2 a roofing felt was inserted between the concrete beam and the brick-lining. In the calculation steps taken however a combination between brick-lining and reinforced concrete cover was assumed. In the case of Test Series I the test was interrupted before the state of failure.

For the comparison of the calculated loadbearing capacity of the lintels using the building material characteristic values available in the tests with the test results, the design model appears to be suitable for the calculated proof of the loadbearing capacity of flat lintels with non-mortared brick lining.

If however instead of the specific building material properties the standardized calculated values of the building material parameters according to DIN 1053-1 are employed and the permissible applied load calculated, then very high safety values are obtained compared with the test values. As well as the use of the global coefficient $\gamma = 2.0$ according to DIN 1053-1 there occur also the safety factors contained in the calculated values of the building material parameters. The permissible applied loads are therefore comparatively small. For flat lintels with concrete cover on top, especially with thin walls and relatively large lintel lengths or slab span widths, the limits of application are rapidly reached. The design of lintels with a brick-lining without perpend joint mortaring, therefore in loadbearing walls under reinforced concrete covers is essentially limited to door and narrow window openings with relative short slab span widths or slab spanning parallel to the wall. For flat lintels without reinforced concrete cover on top the permissible applied loads, using the calculated value of the building material parameters given in DIN 1053-1, are extremely small. In most cases the empty weight in fact can be taken. This design alternative remains therefore confined e.g. to lintels in non-loadbearing walls with lintel widths of about maximum 2.0 m.

It should be noted however that in the tests the existing initial shear strength in some cases was definitely above the calculated values to be used according to DIN 1053-1. In particular with the autoclaved areated concrete units the actual unit tensile strength existing in the tests was about 5 times greater than the calculated value used for unit tensile strength according to DIN 1053-1, which corresponds to the current state of knowledge. By the application of calculated values for initial shear strength separated according the unit- and masonry mortar combinations an also due to a difference according to the types of unit in the calculation of the unit tensile strength the strength reserves can be used firmly founded and with safety.

Moreover the “initial failure” normally does not result in complete failure of the building component and after the closing of the perpend joints in some cases definite load increases are still possible in some cases. Within the scope of these investigations normally however the initial failure is used as the decisive bearing load. In the design for this failure preliminary warning, if necessary a lower coefficient of safety than the global safety coefficient of 2.0 can be used.

In tests with units in contact with the compression zone definitely lower deflections were found in the compression zone after initial failure compared with tests with 5 mm open perpend joints. With 5 mm wide, open perpend joints relatively large deformations up to a compressive force transfer via the front surface is required. Even if no definite differences in the load-deflection behaviour can be identified up to the initial failure, care should be taken in laying the units in contact with each other.

4 SUMMARY

The tests have shown that with the calculation models derived the loadbearing behaviour of flat lintels can be described with a compression zone of masonry without perpend joint mortaring. The high reserves of safety resulting in a comparison of the permissible applied loads compared with the test results are essentially to be attributed to the very low calculated values of the building material parameters in DIN 1053-1 compared with the actual strengths existing. Moreover the initial failure generally does not lead to failure of the building component, i.e. to a reduction in the global coefficient of safety is possible here if necessary.

5 LITERATURE

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