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Experimental Investigation Of The Behaviour Of Brick Lintels

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Abstract

Ceramic bricks are most frequently used for arranging the cladding layer of external layered masonry walls. The recent tendency has focused on a thinner cladding layer. Masonry lintels are used for making openings in the cladding layer. The article presents the results of experimental investigation in masonry lintels of 85 mm and 55 mm in width and 2 m long span. The experimentally established and calculated according to EC6 recommendations masonry lintels bearing load capacity has been compared.

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Keywords: masonry, brick lintel, reinforced bed joint.

1. Introduction

For erecting brick buildings, lintels have long been decorative accents on facades. Since ancient times masonry lintels have been applied: brick lintels, wedge-shaped and arched lintels. Brick lintels have the simplest structural solution. Brick lintels have been used for openings up to 2 m long. Their structural solution is also rather simple. Similar lintels are reinforced constructively applying to a wall thickness of 130 mm within the area of 0.2 cm^2 of reinforcement. Reinforcement is overlapped behind the wall and exceeds 250 mm. The main function of reinforcement is to withstand the weight of the lower rows of bricks. A 20-30 mm thick layer of mortar protects reinforcement from the impact of an aggressive environment. Recently, in many cases, prefabricated lintels of steel or reinforced concrete are used. The expansion of the stock of masonry products has assisted in putting into use blocks.

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An increase in using outer layered walls has resulted in the installed veneer layer applying ceramic bricks. Recently preserving the environment and reducing energy consumption in the production of materials, a tendency for thinning the veneer of layered walls is noticed. For setting up the veneer layer, ceramic bricks of 85 or 55 mm instead of those of 120 mm in width are applied. In this case, for making openings, new type of brick lintels are used. The bottom row of bricks hung on the longitudinal reinforcement of bed joint is the key distinguishing feature of mentioned type lintels. Thus, the heat insulating layer is covered and no any other inclusions (for example, precast reinforced concrete or steel lintel elements) in the veneer layer can be observed (Fig. 1). Building experience shows that, under the brick of 120 mm in width, brick lintels without additional intermediate fastenings can be used when the span is up to 2 m. When openings are larger, brick lintels are additionally suspended on special supports at certain distances.

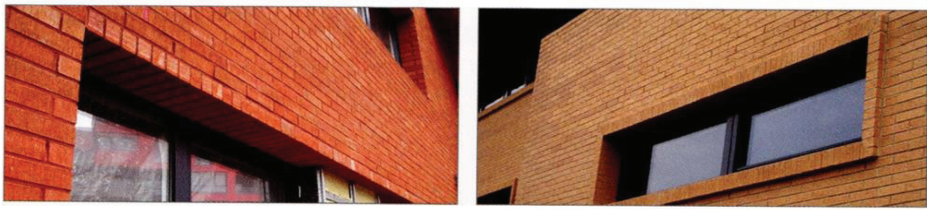

Fig. 1. Examples of the brick lintels.

Brick lintels are installed using bricks, specific bed joint reinforcement Murfor and special joints. A structural solution to the brick lintel is shown in Fig. 2 illustrating the principle of installing the lintel and fixing the bottom line of bricks to the bed joint reinforcement.

Fig. 2. A structural solution of brick lintels.

The lintels shown in Fig. 2 can be attributed to masonry wall beams according to EN 1996-1-1 (EC6) [1]. However, with reference to EC6, masonry wall beams make a part (stripe) of the wall above the opening the height of which is greater than $0{,}5l_{ef}$ (where l_{ef} – effective span of masonry wall beams). The height of the wall stripe of masonry lintels (Fig. 2) above the openings is frequently lower than $0{,}5l_{ef.}$, and therefore their bearing capacity can be calculated as that of the longitudinally reinforced masonry beam. Literature does not provide enough data on the behaviour of brick lintels of a narrower width (85 – 55 mm) under acting loads.

The article presents experimental investigation in the lintels made of small width ceramic bricks and draws a comparison between the calculation of the bearing load capacity of lintels according to EC6 and experimental research.

2. Experimental programme

For examining the behaviour of masonry lintels, two series of specimens were produced. The specimens (lintels) were built from ceramic hollow bricks. The first series of lintels (SP1) used the bricks of 85 mm while the second (SR2) – the bricks of 55 mm in width. The lintels were made using general-purpose mortar M10 and they were put by high skilled bricklayers in the laboratory. Murfor reinforcement of bed joints was used for specimens. The bottom area of the lintel is reinforced using six reinforcing bars of 4 mm in diameter. 3 lower bed joints are reinforced overlapping reinforcement on supports at 500 mm. The same amount of reinforcement was used for the lintels of both series. The thickness of bed and head-joints is 10-12 mm. The bricks of the bottom row of the lintels placed next to the reinforcement of the bed joints were hung using the reinforcement elements of the Baut system. Schemes for the specimens and a general view are shown in Figures 2 and 3.

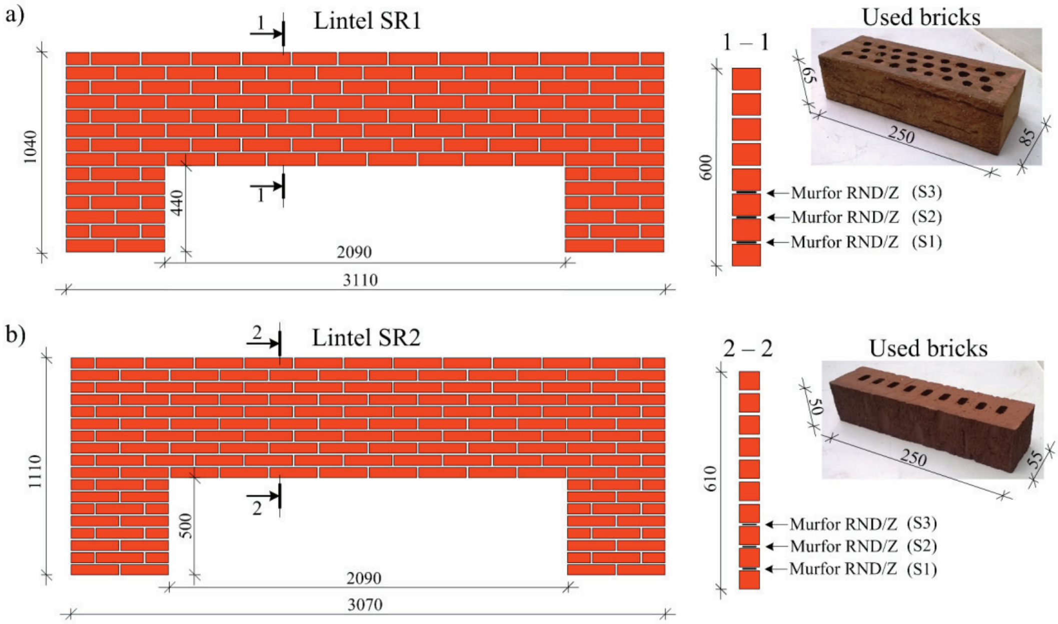

Fig. 3. A general view of the specimens of masonry lintels: (a) series SR1; (b) series SR2.

For examining the work of masonry lintels, they are tested with reference to the scheme for the two-span beam [6]. The authors of the article agree that the introduced scheme for testing does not reflect real work in the wall, because compressive stresses horizontally operating at the level of the bottom brick row in the support area have a huge impact. Figure 3 illustrates specimen geometry selected to repeat possible architectural solutions. A structural solution to the specimens meets the solution to the lintels next to the corner of the walls, i.e. This specimen type corresponds to the specimens used by other authors [7,8,9,10,14]. The research programme consists of three stages, including experimental investigation of masonry components (masonry, mortar and reinforcement), experimental investigation of masonry and research of lintels.

The compressive strength of masonry units was determined in accordance with requirements specified by standard EN 772-1:2001 [2] compressing bricks perpendicularly to and parallel with the bed-face. The scheme for testing bricks parallel with the bed-face meets their work in the compressive zones of the bent element. Control samples of mortar were made. The mechanical properties of mortar were established testing control samples according to the requirements set by standard EN 1015-11 [3]. The mechanical characteristics of the reinforcement of the bed joints were defined according to EN 15630-2 [11].

The compressive strength of masonry was determined in accordance with EN 1052-1 [5] requirements testing masonry fragments thus adding a load parallel to the bed joints (Fig.4). The introduced scheme for testing satisfies the work of masonry in the compressive zone of the bent element. The initial strength of the shear of masonry through the unbound masonry was identified according to the requirements specified for EN 1052-3 [4,13] standard. The results of research on the mechanical properties of materials are presented in Table 1.

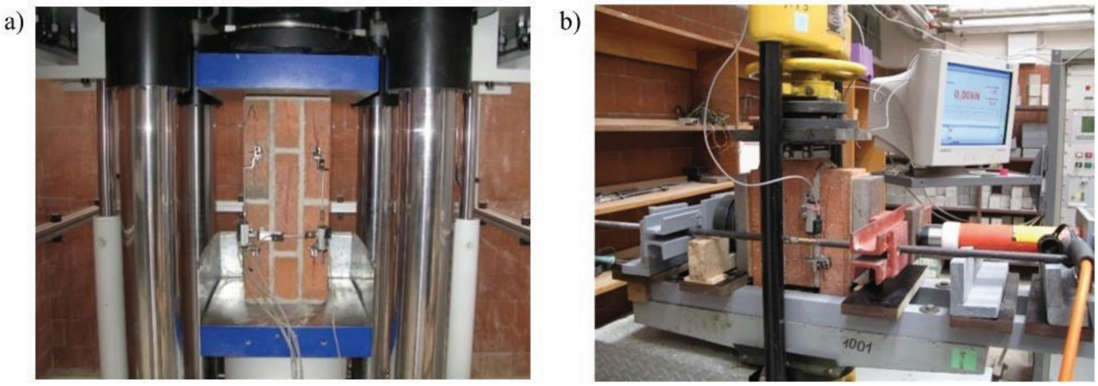

Fig. 4. A general overview of research: (a) compressive strength of masonry parallel with bed joints, (b) shear test.

Table 1. Material mechanical properties used for lintels.

Lintel type	Masonry units		Mortar Strength f_m [MPa]	Initial shear strength of masonry $f_{v0,m}$ [MPa]	Masonry compressive strength [MPa]	Reinforcement strength f_y [MPa]
	Dimensions [mm]	Strength f_b [MPa]				
SR1	250×85×65	32,7	12,9	0,55	9,14	679
SR2	250×55×50	26,1	10,3	0,61	9,0	679

3. Testing Mortar Lintels

The specimens were tested under a short-term static load. The load was attached via two concentrated forces accordingly to the scheme selected with reference to requirements for EN 846-9 [12] standards. The loading scheme and a general testing view are shown in Figures 5a and 5b. The scheme involves an effective span of the lintel accepted under the guidance of EC6 requirements (l_{ef}=1,15×l, where l – span length).

Lintel out of plane deformations was constrained by flexible ties (Fig. 5c). The content and layout of flexible ties met their actual content and layout fixing a veneer layer to the bearing layer of the wall.

The conducted tests measured lintel deflection and deformations in the vertical and diagonal cross-section. Also, a slip in the bed joint reinforcement was measured. There were three levels of reinforcement. The levels are indicated with letter S and showed in Fig. 5a. The moment of crack formation was recorded. A scheme for equipment arrangement is shown in Fig. 5a. Testing results are presented in Table 2.

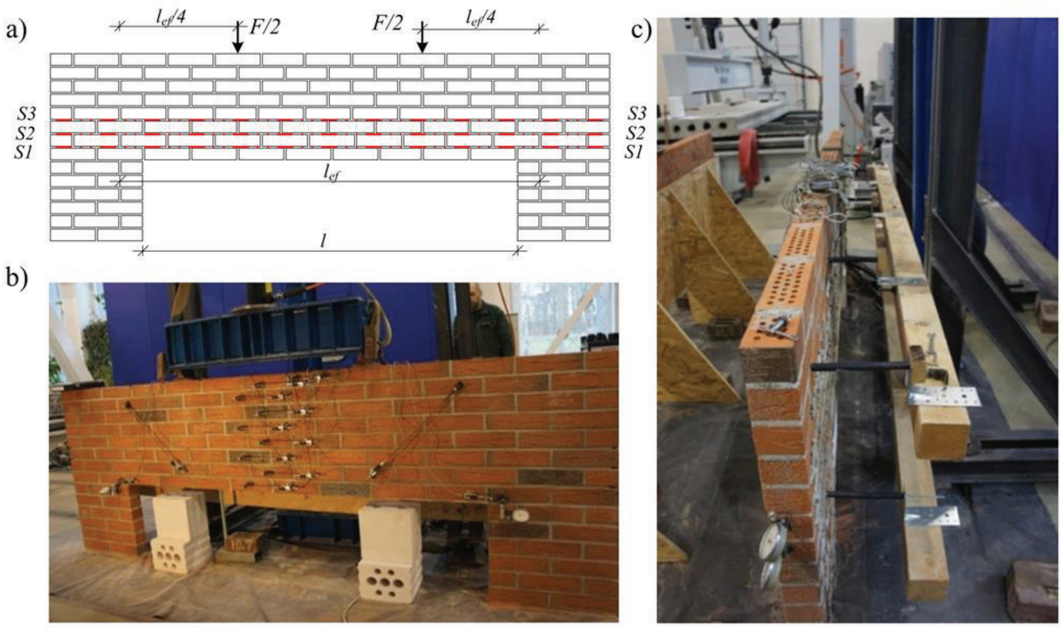

Fig. 5. Scheme for testing a masonry lintel: (a) loading scheme, (b) general view of arranged equipment, (c) solution of constraining the out of plane deformations of the lintel with flexible ties.

Table 2. Material mechanical properties used for lintels.

Series	Specimen	Load causing reinforcement slip, [kN]			Ultimate load	Forces conforming to F_u		Type of failure
		S1	S2	S3	F_u, [kN]	Bending moment $M_{u,obs}$, [kNm]	Shear force $V_{u,obs}$, [kN]	
SR1	SR1.1	50	50	90	108	36,7	53,8	Shear section
	SR1.2	20	80	70	113	38,5	56,5	Shear section
SR2	SR2.1	-	-	-	45,3	14,7	22,7	Shear section
	SR2.2	-	-	-	50,8	16,5	25,4	Shear section
	SR2.3	-	-	-	44,8	14,6	22,4	Shear section

The experimental investigation demonstrated that the bearing capacity of SR1 lintels was approximately 2 times higher than that of SR2 lintels. The effect was due to the fact that wider bricks of 85 mm in width were used for SR1 specimens. The masonry units of different width determined the rigidity of lintels. The charts of the deflection of the lintels are provided in Fig. 6. The results of measuring lintel deflections showed that, under a similar external load, the deflection of SR1 specimens was approximately 3 times smaller than that of SR2 specimens. The average deflections of lintels SR1 and SR2, when the load covers 60 % of limit load (0,6 F_u), makes 0,64 and 0,41 mm respectively. Thus, under the load close to an operational load (0,6 F_u), the deflection of lintels SR1 and SR2 makes approximately 1/3200 and 1/5100 of the lintel span. This shows that such type elements can be characterized as having high stiffness.

The lintels of both series have a similar failure character. Failure in SR1 specimens occurred in the diagonal cross-section. However, an intense formation of flexural cracks in SR1 specimens was observed. The first flexural cracks opened under 40 % of limit load (0,4 F_u). An increase in the level of load up to 50-60 % caused an intensive slip of bed joint reinforcement. This can be noticed from measuring deformations in the vertical cross-section (Fig. 7a).

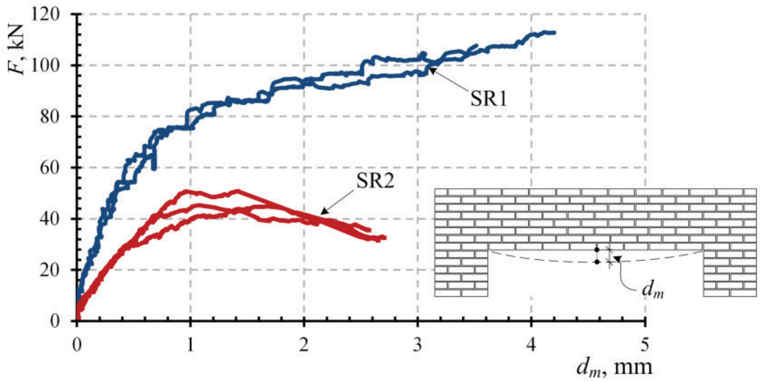

Fig. 6. Deflections of masonry lintels.

Failure in SR2 specimens also occurred in the diagonal cross-section. Nevertheless, an increase in the load did not cause flexural cracks, and therefore no slips of longitudinal reinforcement were noted (Fig. 7b). The general view of lintels failure is shown in Fig. 8. The cracks in the specimens can be divided into three types: the cracks of the first type appeared due to the impact of the bending moment; the cracks of the second type were formed when the element reached maximum bearing capacity F_u (ultimate load); and the cracks of the third type are post ultimate load behaviour cracks.

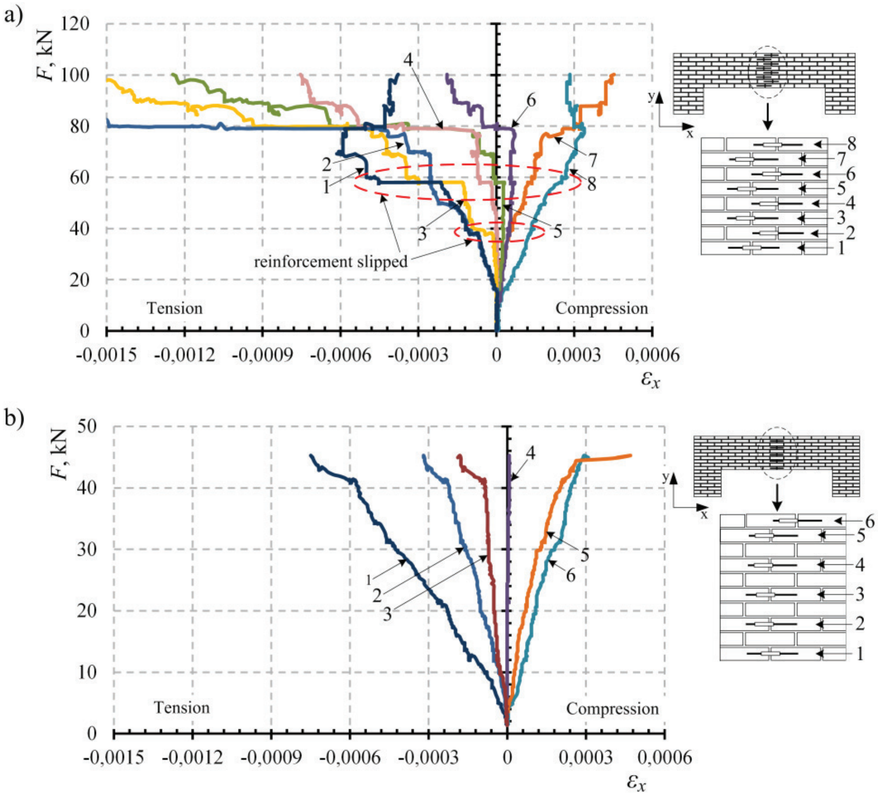

Fig. 7. Deformations of the lintel vertical cross-section: (a) series SR1, (b) series SR2.

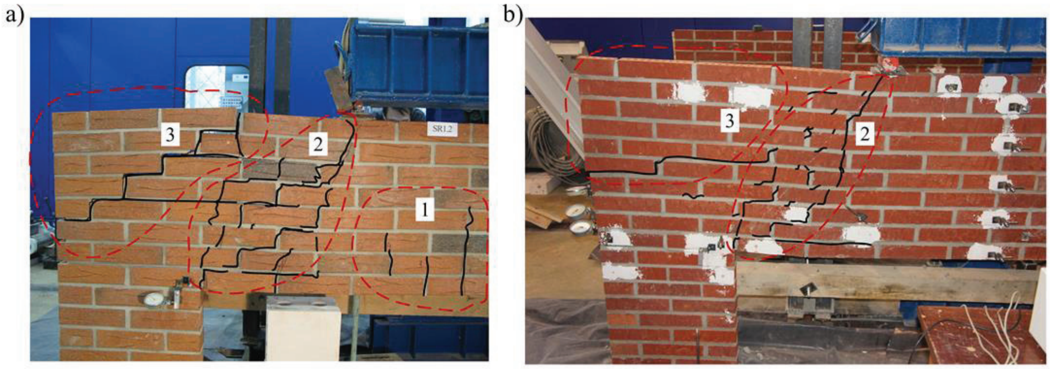

Fig. 8. A general view of lintel failure: (a) lintels SR1, (b) SR2.

4. Assessment of bearing load capacity according to EC6

The bearing capacity of the masonry lintel can be calculated as that of the bent reinforced masonry beam. According to EC6, the bearing capacity of the masonry lintel is sufficient if conditions (formula 1 and 2) are satisfied:

$$V_{Ed} \leq V_{Rd} = f_{vd} \cdot b \cdot d \tag{1}$$

$$M_{Ed} \leq M_{Rd} = \min \begin{cases} M_{Rd,s} = A_s \cdot f_{yd} \cdot z \\ M_{Rd,c} = \mu_{Eds} \cdot f_d \cdot b \cdot d^2 \end{cases} \tag{2}$$

where V_{Ed} and V_{Rd} – acting lateral force and the design value of the shear resistance; M_{Ed}- acting bending moment; $M_{Rd,s}$ - the design value of the moment of resistance determined by tensile reinforcement, and $M_{Rd,c}$ - the design value of the moment of resistance determined by masonry compressive strength, f_{vd}- design shear strength of masonry, b- the minimum width of the beam over the effective depth, d- the effective depth of the beam, A_s– cross-sectional area of reinforcement, f_{yd} – reinforcement strength, z – shoulders of internal forces, f_d – masonry compressive strength under compression parallel to bed joint, μ_{Edc} – the value limiting the compressive zone of the element.

A theoretical character of lintel failure can be defined while analysing the ratio of the bending moment calculated from the design value of the shear resistance ($V_{Rd} \cdot c$) and the design value of the moment of resistance (M_{Rd}):

$$\left. \frac{V_{Rd} \cdot c}{M_{Rd}} \right| \begin{matrix} <1 \\ >1 \end{matrix} \tag{3}$$

where c – distance from the support reaction to the point load (Fig. 5a). If the received value of the submitted ratio in Formula 3 is > 1, the failure of the lintel should appear in the flexural cross-section. However, if the ratio is < 1, failure takes place in the diagonal cross-section. The received ratio of the lintels described in this article and provided in Formula 3 makes < 1 in all cases, which means that failure occurs in the diagonal cross-section and which can be proved by experimental investigation, as all specimens failure in the diagonal cross-section (Fig. 12). A comparison of calculated and experimentally established shear forces is shown in table 3.

Table. 3. Results of tested lintels.

Series	Shear force [kN]		
	$V_{u,obs}$[1]	V_{cal}	$V_{m,obs}/V_{cal}$
SR1	55,3	25,0	2,21
SR2	23,5	18,5	1,27

1 – mean value

5. Conclusions

The conducted investigation demonstrates that the bearing capacity of masonry lintels can be calculated applying EN 1996-1-1 methodology for bent reinforced masonry elements. The applied methodology gives reliable results and ensures sufficient reserves of bearing load capacity. The experimental investigation shows that the lintels of a similar type exhibit high stiffness.

Fixing bricks in the bottom row of the lintel by special joints hanging them next to the longitudinal reinforcement of bed joints is a reliable procedure.

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