THE EFFECT OF HORIZONTAL CHASES ON THE LOADBEARING CAPACITY OF MASONRY

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ABSTRACT

The concealed laying of electric lines (or comparable installations such as heating or plumbing) requires the arrangement of chases and recesses in masonry. Recently, an investigation on the effect of horizontal chases on the load bearing capacity of masonry is carried out at the chair of structural design at TU Dresden. By means of the results it should be determined whether an additional structural analysis for chases close to the support of the reinforced concrete slab is necessary or whether, as before, a limitation of the geometry and the position of the chase are sufficient to ensure structural safety.

Based on the analysis of the current state of the art, the influence of horizontal chases on the structural behaviour of masonry was investigated experimentally by means of suitable specimens. Therefore, the bearing capacity of specimens with horizontal chases under centric and eccentric loads was determined and compared to the results of reference tests on specimens without chase. The structural behaviour was investigated with regards to masonry units with vertical cavities.

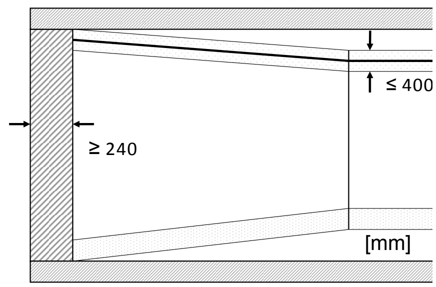
The results of experimental studies and additional analytical considerations will be finally supplemented and underpinned by means of a numerical parameter study, carried out with the help of common FE Software.

KEYWORDS: masonry, chase, load bearing capacity, eccentric load application

INTRODUCTION

The in-wall laying of electric lines requires the arrangement of chases in masonry. The German standard [1] provides information concerning the chase geometry and the distances between the chases. If those values are complied with, no separate structural analysis is required, see Table 1. However, the code does not provide any information on how the sectional weakening has to be considered if the listed values are exceeded. In most cases, the masonry is modified in this way that it is conform to the requirements in [1]. Therefore, the validation of the standard guidelines is eminently important.

Table 1: Allowable horizontal chases according to DIN 1053-1 [1]

Wall thickness	Chase length		Allowed arrangement for horizontal chases
	unlimited	≤ 1,25 m	
	Chase depth[1]	Chase depth	
(mm)	(mm)	(mm)	
≥ 115	-	-	
≥ 175	0	≤ 10	
≥ 240	≤ 15	≤ 25	
≥ 300	≤ 20	≤ 30	
≥ 365	≤ 20	≤ 30	

[1] Depth can be increased by 10 mm when using special machines

Based on the results and conclusions from a research project carried out in the 1980s [2] it is generally assumed that the reduction in vertical load bearing capacity resulting from horizontal chases is proportional to the weakening of the cross section. According to [3] and [4], the magnitude of the reduction of the load bearing capacity can be determined by means of the ratio of the weakened cross section (net cross section) and the unweakened cross section (total cross section). Resulting from this approach, the weakening of the cross section for admissible chases according to [1] amounts up to 10.4% (e. g. wall thickness t = 240 mm, chase depth t_{ch} = 25 mm, 25/240 = 0.104). The resultant reduction of the vertical loading is accepted. Thus, a verification of the normative standards appears to be of great importance.

According to [1], horizontal chases may be positioned in an area of 400 mm below or above the floor slab without structural analysis, but no minimum distance to the slab is specified (cf. picture in Table 1).

Due to the arrangement of a chase close to the position of load application (eccentric, in the case of partially supported slabs or because of large slab deflections) the distribution of stresses in the masonry can be influenced considerably. Extensive stress concentrations may occur close to the chase. The occurring splitting forces have to be covered by the tensile strength of the unit and can probably exceed it.

This behaviour is investigated with regards to masonry units with vertical cavities. In the case of hollow blocks or bricks, the webs are disproportionately high involved into the load transfer. Since the vertical loads are mainly transferred by the longitudinal webs, a weakening of the cross section the more affects the load bearing capacity.

Based on an analysis of the current state of the art, the effects of horizontal chases close to the support of the slab on the structural behaviour of masonry are experimentally investigated by means of appropriate specimens. The results are backed up and supplemented by a numerical parameter study using conventional FE-Software.

On the basis of the results it should be determined whether an additional verification of slotted masonry is necessary or if the limitation of the position and the geometry of the chases are sufficient to ensure structural safety.

MATERIAL, TEST PROGRAMME AND TEST SET-UP

A total of 26 tests on masonry specimens with and without chases have been carried out. The elements were fabricated by a mason and had a length of 2 or 3 masonry units and a height of 3 or 4 masonry units. The overlapping length was equal to half of the unit length. The thickness of the bed joints differed between 3 mm for thin layer mortar and 12 mm for masonry with general purpose mortar, while the perpend joints remained unfilled. Fourteen days after preparation, the horizontal chases were cut into the respective specimens. Depending on the wall thickness, the depth of the chase was 25 mm or 30 mm, the height was 30 mm. According to the recommendations in [5] the chases were arranged in a distance of 15 cm below the top of the specimen (recommended range is 15-45 cm below the slab).

In Table 2, the properties of the used materials are summarized. Here, *CSC* is the Compressive Strength Class of the unit given by the producer (corresponds to the lowest allowable single value of the compressive strength of the unit $f_{b,min}$), f_{bd} is the normative specified average minimum value of the compressive strength corresponding to the declared compressive strength class (25% higher than the lowest single value), f_b is the experimentally determined compressive strength of the unit, f_{md} is the mean compressive strength of the used mortar (corresponds to mortar class), f_m is the experimentally determined compressive strength of the mortar and f_k is the characteristic value of the compressive strength of masonry built from the listed units in connection with the listed mortar (according to the code or the technical approval).

Due to the deviation of experimental values f_m and f_b from the theoretical (normative specified) values f_{md} and f_{bd}, for the subsequent comparison of theoretically and experimentally determined compressive strength a reduction of the experimentally determined masonry compressive strength (see Table 4) by the factor K_{Red} can be necessary following DIN EN 1052-1 [6].

Finally, f_{ma} in Table 2 is the mean value of the masonry compressive strength of the considered material combinations calculated from the product of the characteristic value f_k and the factor 1.2 according to [6].

Table 2: Properties of used materials and specimens

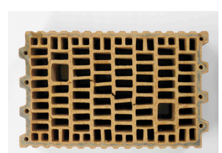
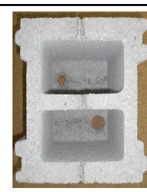
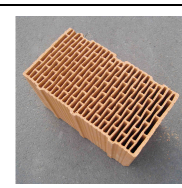
Series	K	Z	H	X
Shape				
Name / Type	sand-lime hollow block	vertical coring brick	standard conrete hollow block	vertical coring lightweight brick
Size of unit $(l_u/t_u/h_u)$	248/240/238 mm	373/240/238 mm	247/300/238 mm	200/365/249 mm
Size of specimen $(l/t/h)$	500/240/750 mm	750/240/750 mm	750/300/750 mm	600/365/1000 mm
CSC $(f_{b,min})$	12 MPa	12 MPa	12 MPa	10 MPa
f_{bd}	15 MPa	15 MPa	15 MPa	12.5 MPa
f_b	14.8 MPa	11.3 MPa	12.1 MPa	10.4 MPa
used mortar	general purpose	general purpose	general purpose	thin layer mortar
mortar class / f_{md}	M5 / 5 MPa	M5 / 5 MPa	M5 / 5 MPa	M10 / 10 MPa
f_m	11.3 MPa	10.1 MPa	11.0 MPa	12.9 MPa
$K_{Red} = (f_{bd}/f_b)^{0,65} \cdot (f_{md}/f_m)^{0,25} \leq 1.0$	0.82	1.00	0.94	1.00
f_k	5 MPa	5 MPa	5 MPa	3.2 MPa
$f_{ma} = f_k \cdot 1{,}2$	6.00 MPa	6.00 MPa	6.38 MPa	3.84 MPa

Figure 1 illustrates the experimental arrangement. With regard to the test set-up, the loadings at the top and the bottom of the wall were defined as surface loads. Concerning the tests with centric load application (test set-up A and B), the loaded area was equal to the complete cross section, at which the load axis (*1*) of the testing machine corresponded to the half of the wall thickness (*2*). In contrast, with regard to the eccentrically loaded specimens (test set-up C and D), the load was applied only at a part (t_{load}) of the cross section (between half or 1/3 of wall thickness). At this, the load axis of the testing machine ran with distance *e* to the middle of the wall thickness.

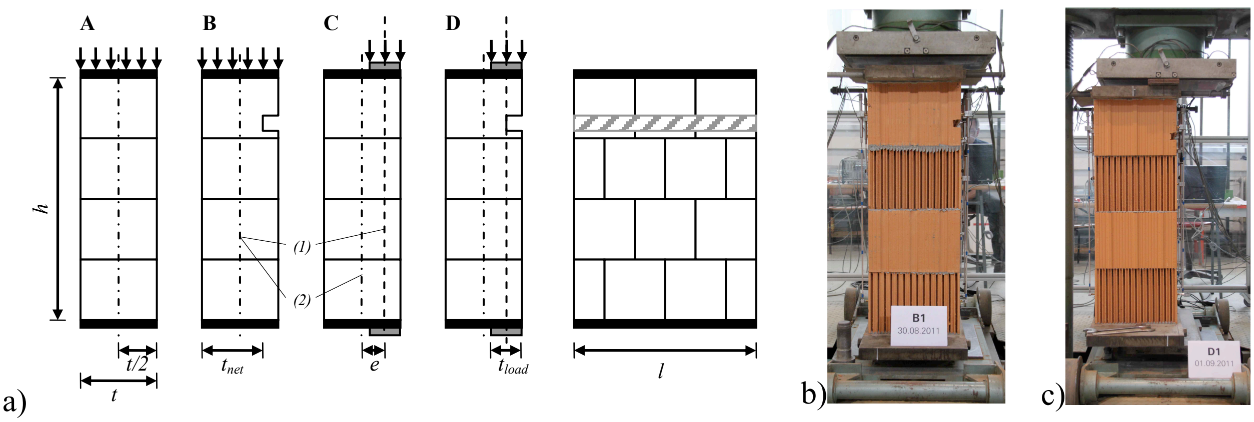


Figure 1: Experimental arrangement: a) Schema, front and side view; b) Sample for centrically loaded specimen; c) Sample for eccentrically loaded specimen

After placing the specimen into the testing machine, the loading was increased in a force-controlled manner up to failure. In addition to the ultimate load, the vertical deformation of the specimen was measured using inductive displacement transducers. Table 3 gives an overview of the test programme.

Table 3: Designation of specimens

Series	Eccentricity of load application $e = 0$		Eccentricity of load application $e > 0$	
	Without chase	With chase	Without chase	With chase
	A	B	C	D
K-	K-A-1	K-B-1, K-B-2	K-C-1	K-D-1, K-D-2
Z-	Z-A-1	Z-B-1, Z-B-2	Z-C-1	Z-D-1, Z-D-2
H-	H-A-1	H-B-1, H-B-2	H-C-1	H-D-1, H-D-2
X-	X-A-1, X-A-2	X-B-1, X-B-2	X-C-1, X-C-2	X-D-1, X-D-2

TEST RESULTS

Table 4 contains the test results wherein e/t represents the eccentricity of the load application, A_{net}/A_{tot} is the ratio of the weakened and the unweakened cross section and F_{max} is the failure load. In addition, the load factor Φ which describes the ratio between the failure load of the specimen with chase and the failure load of the specimen without chase (for reference test $\Phi = 1$) and the experimental determined masonry compressive strength values f_{exp} are shown. Furthermore, f_{tot} is the compressive strength related to the full (total) cross section area, f_{net} is the compressive strength related to the net cross section (t_{net}, remaining cross section after chasing) and f_{load} is the compressive strength related to the loaded cross section (t_{load}, compare Figure 1). As mentioned above, a reduction of the experimentally determined masonry compressive strength can be necessary for comparison with the theoretical values. In Table 4, the values in parentheses ($f_{exp,red}$) show the reduced compressive strength, calculated by means of the factor K_{Red} (cf. Table 2; $f_{exp,red} = f_{exp} \cdot K_{Red}$).

Table 4: Test results

Specimen	Chase	e/t	A_{net} / A_{tot}	F_{max}	Φ_a	Φ_b	f_{exp} ($f_{exp,red}$)		
							f_{tot}	f_{net}	f_{load}
			(-)	(kN)			(MPa)	(MPa)	(MPa)
K-A-1	-	0	1.00	859.1	1.00	-	7.16 *(5.87)*	7.16 *(5.87)*	-
K-B-1	x	0	0.89	719.9	0.82	-	6.00 *(4.92)*	6.70 *(5.49)*	-
K-B-2	x	0	0.89	707.0	0.80	-	5.89 *(4.83)*	6.58 *(5.39)*	-
K-C-1	-	0.25	1.00	549.8	0.64	1.00	4.58 *(3.76)*	-	9.16 *(7.51)*
K-D-1	x	0.25	0.89	461.4	0.52	0.84	3.85 *(3.15)*	-	7.69 *(6.31)*
K-D-2	x	0.25	0.89	392.7	0.45	0.71	3.27 *(2.68)*	-	6.54 *(5.37)*
Z-A-1	-	0	1.00	1323.6	1.00	-	7.35 *(7.35)*	7.35 *(7.35)*	-
Z-B-1	x	0	0.89	1213.3	0.92	-	6.74 *(6.74)*	7.52 *(7.52)*	-
Z-B-2	x	0	0.89	1080.4	0.82	-	6.00 *(6.00)*	6.70 *(6.70)*	-
Z-C-1	-	0.25	1.00	883.7	0.67	1.00	4.91 *(4.91)*	-	9.82 *(9.82)*
Z-D-1	x	0.25	0.89	586.7	0.44	0.66	3.26 *(3.26)*	-	6.52 *(9.82)*
Z-D-2	x	0.25	0.89	620.8	0.47	0.70	3.45 *(3.45)*	-	6.90 *(6.90)*
H-A-1	-	0	1.00	953.9	1.00	-	6.36 *(5.98)*	6.36 *(5.98)*	-
H-B-1	x	0	0.90	889.0	0.93	-	5.93 *(5.57)*	6.59 *(6.19)*	-
H-B-2	x	0	0.90	719.9	0.75	-	4.80 *(4.51)*	5.33 *(5.01)*	-
H-C-1	-	0.30	1.00	626.6	0.66	1.00	4.18 *(3.93)*	-	10.44 *(9.82)*
H-D-1	x	0.30	0.90	512.4	0.54	0.82	3.42 *(3.21)*	-	8.54 *(8.03)*
H-D-2	x	0.30	0.90	524.9	0.55	0.84	3.50 *(3.29)*	-	8.75 *(8.22)*
X-A-1	-	0	1.00	1270.8	1.00	-	5.80 *(5.80)*	5.80 *(5.80)*	-
X-A-2	-	0	1.00	1201.1		-	5.48 *(5.48)*	5.48 *(5.48)*	-
X-B-1	x	0	0.92	1069.9	0.87	-	4.89 *(4.89)*	5.32 *(5.32)*	-
X-B-2	x	0	0.92	1035.2	0.84	-	4.73 *(4.73)*	5.15 *(5.15)*	-
X-C-1	-	0.33	1.00	628.3	0.51	1.00	2.87 *(2.87)*	-	8.73 *(8.73)*
X-C-2	-	0.33	1.00	563.9	0.46		2.57 *(2.57)*	-	7.83 *(7.83)*
X-D-1	x	0.33	0.92	301.8	0.25	0.51	1.38 *(1.38)*	-	4.19 *(4.19)*
X-D-2	x	0.33	0.92	439.0	0.36	0.74	2.00 *(2.00)*	-	6.10 *(6.10)*

The observed failure mode of the centrically loaded specimens was characteristic for masonry failing in compression and was caused by the exceeding of the transversal tensile strength perpendicular to the direction of load application, see Figure 2 a) and b).

Specimens loaded eccentrically show somewhat different failure patterns, see Figure 2 c) and d). First, a vertical crack develops starting from the lower edge of the chase. Immediately before failure, the unloaded section below the chase is sheared off and partially buckling of the specimen occurs.

The failure of all specimens was brittle. Figure 2 shows the failure patterns of different specimens.

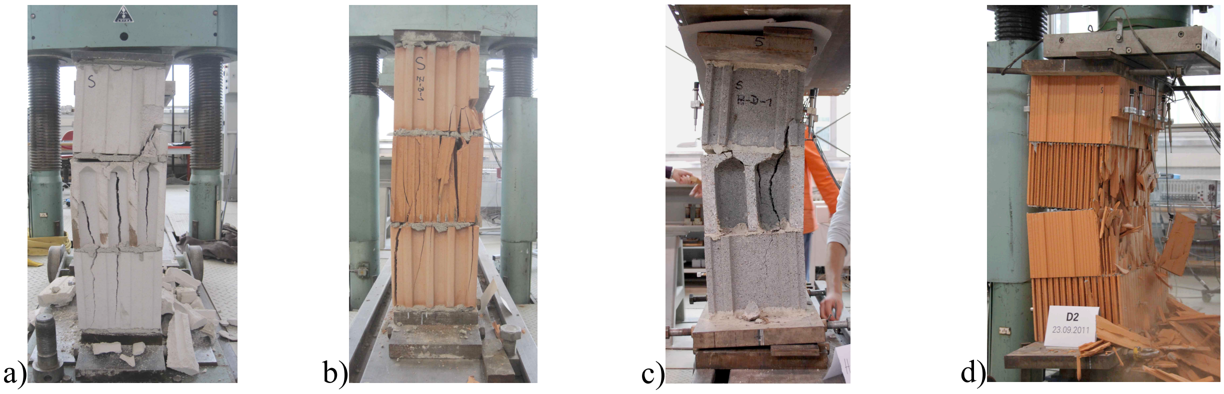


Figure 2: Failure patterns of centrically and eccentrically loaded masonry with chases; a) K-B-1; b) Z-B-1; c) H-D-1; d) X-D-2

ANALYSIS

As stated in literature and also follows from the test results subsumed in Table 4, cutting of chases in masonry leads to a reduction of the load bearing capacity. Comparing the experimentally determined compressive strength $f_{exp,red}$ (e=0, f_{exp}=f_{net}; e>0, f_{exp}=f_{load}) to the mean compressive strength of masonry f_{ma} (Table 2) shows, that in the majority of cases the experimental values exceed the theoretically determined mean value of the compressive strength f_{ma} (cf. Table 2), as can be seen in Figure 3.

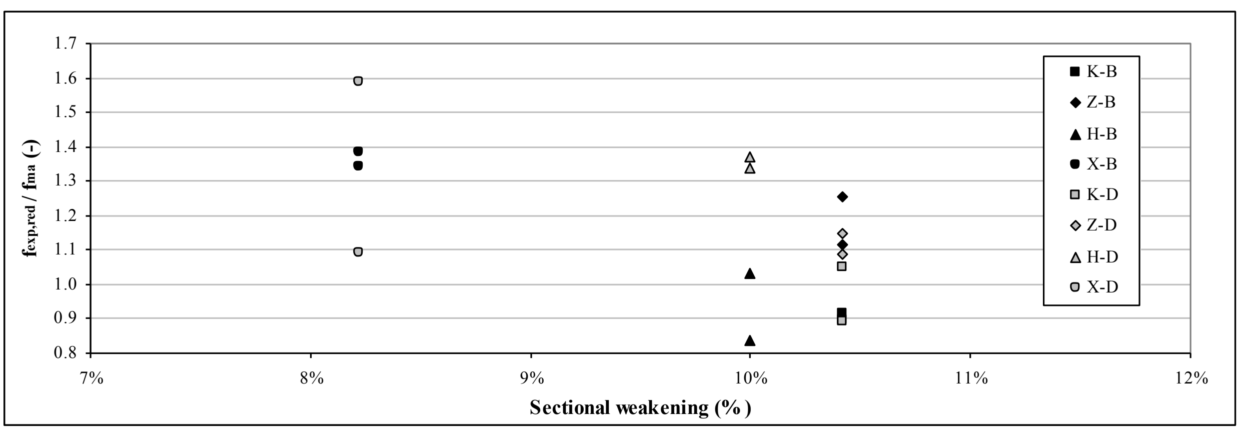


Figure 3: Ratio of experimental and theoretical compressive strength depending on the sectional weakening of the cross section

Assuming a rectangular stress distribution, the bulk of the experimentally identified failure loads exceed the theoretical load bearing capacity, calculated with the help of f_{ma}. Within the limits of the tests at hand, the influence of the horizontal chases on the load bearing capacity can mostly be covered by the load reserves of the masonry.

So far, the weakening of the cross section due to a horizontal chase was calculated in relation to the complete cross section of the wall ($A_{tot} = t \cdot l$). The remaining cross section is determined according to Equation (1).

$$A_{net} = A_{tot} - A_{chase} \quad with \quad A_{chase} = t_{ch} \cdot l_{ch} \tag{1}$$

In this case, the sectional weakening results from the ratio of chase depth t_{ch} and wall thickness t, since the chase length l_{ch} is equal to the wall length. Based on the allowable chase depth of t_{ch}=25-30 mm (depending on wall thickness) according to [1], the weakening of the cross section amounts to between 10% (t=240mm) and 8% (t=365mm), see Table 5.
Since, today, the percentage of voids of masonry units can be above 50%, it was checked, to which extent the different cross sections are effectively weakened. The calculations of the effective cross section (web surface = A_{eff}) and the remaining web surface after cutting the chase ($A_{eff,ch}$), cf. Figure 4, were carried out by means of a common CAD-program.

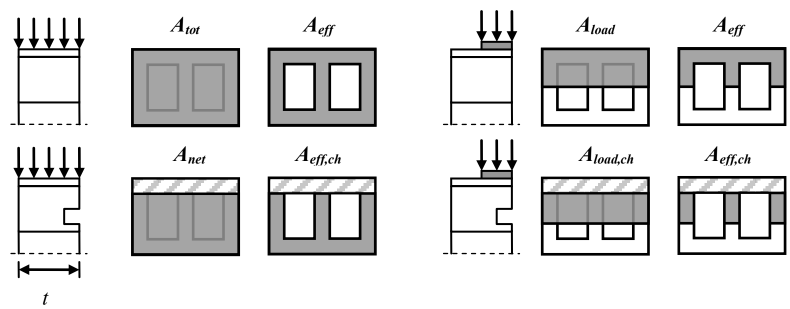
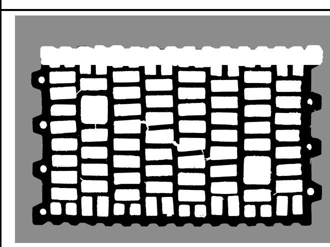


Figure 4: Definition of utilized cross section denotations using the example of a hollow block

Comparing sectional weakening determined according to Eq. (1) to the sectional weakening related to the effective cross section shows, that the effective loss of cross section (based on the web surface) is higher for all masonry units, see Table 5. The largest discrepancy can be found for the concrete hollow block with a ratio of 2. The shape in Table 5 exemplifies the remaining web surface (remaining effective cross section) after chasing a vertical coring brick.

Table 5: Comparison of different approaches to determine the sectional weakening

Series	t	t_{ch}	Sectional weakening related to		Δ	Shape
			Total cross section	Effective cross section		
	(mm)	(mm)	(%)	(%)	(-)	
Z	240	25	10.4	13.8	1.32	
H	240	25	10.0	20.3	2.03	
K	240	25	10.4	16.0	1.54	
X	365	25	8.2	9.7	1.18	

As can be seen in Table 4, the load reduction Φ_a for centrically loaded specimens with chases amounts to between 7% and 25%. According to the previous approach for calculating the weakening related to the total cross section, the percentaged load reduction is higher than the percentaged loss of cross section, see Figure 5 a).
In contrast, Figure 5 b) shows the relation between the load reduction and the loss of the effective cross section. As to be seen, the loss of effective cross section shows a good correlation to the loss of load bearing capacity. Taking into account the expected scatter of the experimental results, nearly a proportional correlation is found (proportionality factor is 1).

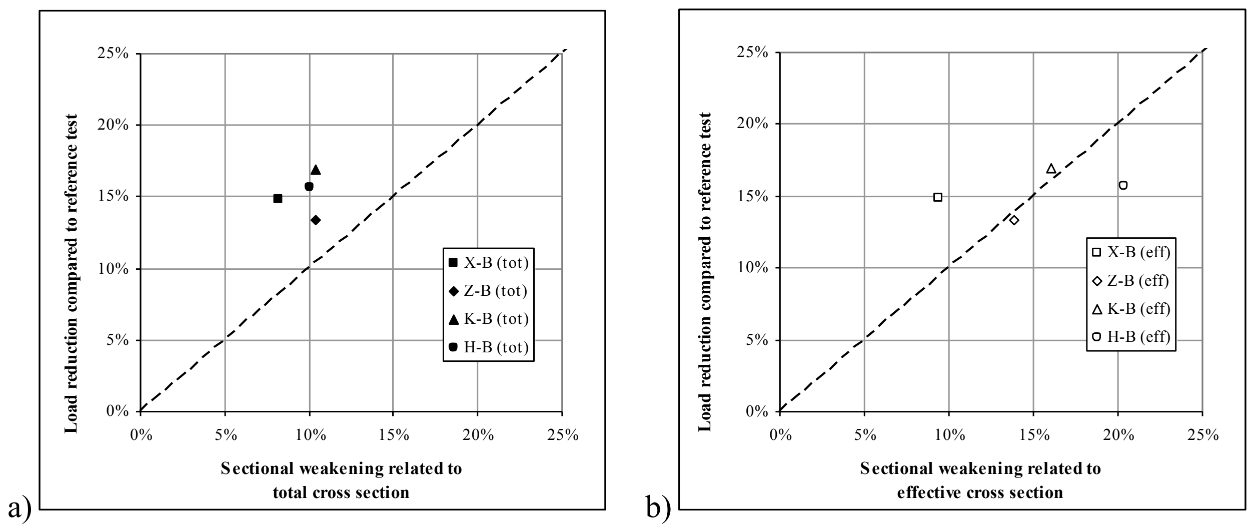


Figure 5: Load reduction depending on sectional weakening related to a) total cross section and b) effective cross section (mean values, e=0)

Due to the eccentric load application, the loss of load bearing capacity for the specimens without chases (test arrangement C, see Figure 1) was up to 50% and for slotted specimens up to 75% compared to the centrically loaded specimens without chases (Φ_a, cf. Table 4). Comparing the load bearing capacities of eccentrically loaded specimens with and without chase leads to a loss of 16-49% (Φ_b, cf. Table 4).
According to the previously described procedure, for specimens under eccentric load application the reduction of the effective load area caused by a chase was calculated. For the used masonry units, the weakening of the effective load area was between 28% and 50%. Figure 6 shows the load reduction of eccentrically loaded specimens with chases compared to the load reduction of specimens without chases.

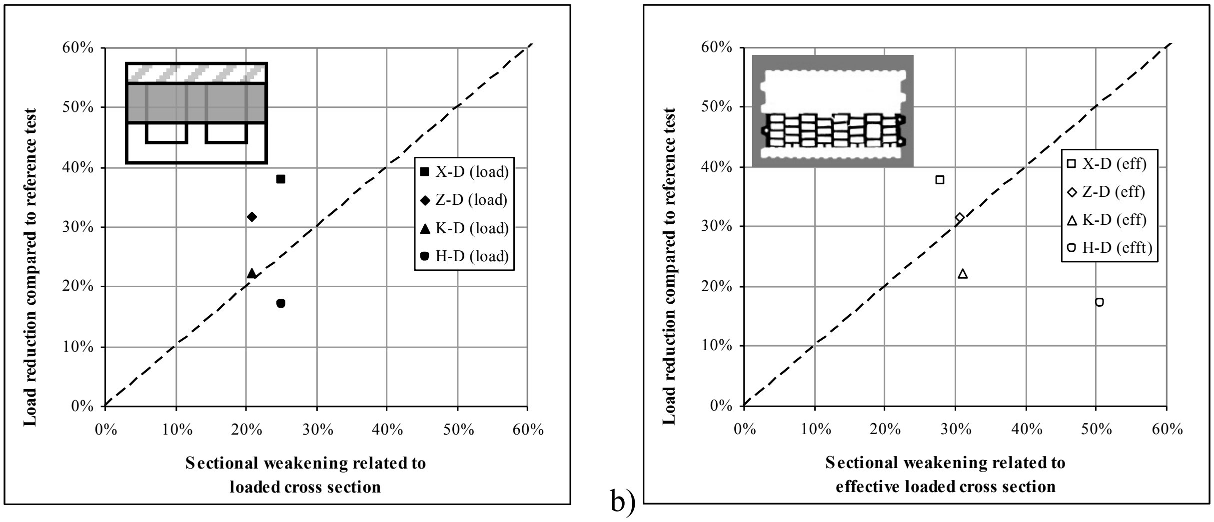
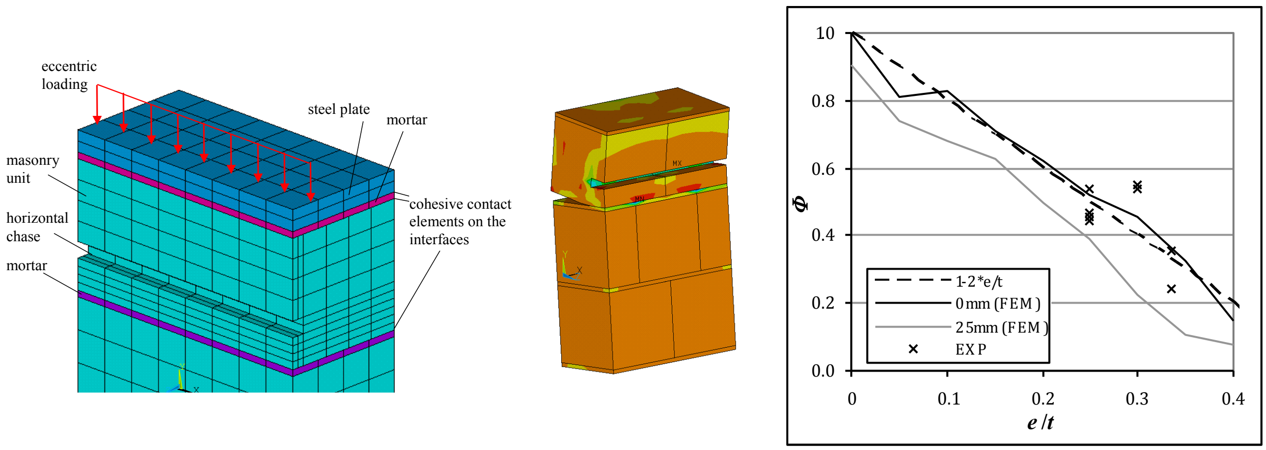


Figure 6: Load reduction depending on sectional weakening related to a) loaded cross section and b) effective loaded cross section (mean values, e>0)

Based on the presented results it can be concluded, that for centrically loaded masonry the influence of a horizontal chase on the load bearing capacity can be determined as a good approximation by the reduction of the effective cross section.
Taking into account the scatter of the test results, for masonry specimens under eccentrically applied loads, the influence of horizontal chases can be determined by the reduction of the effective loaded area.

NUMERICAL ANALYSIS

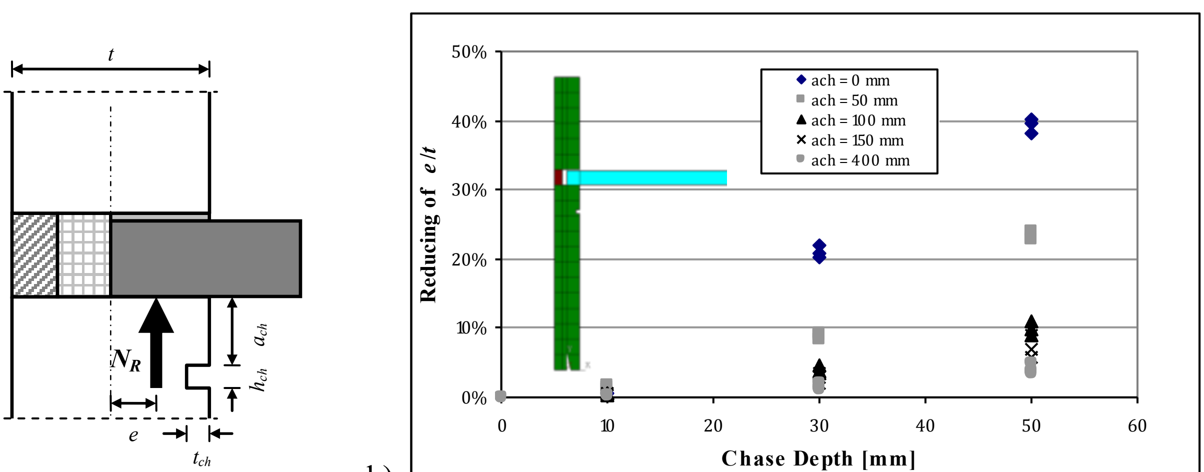
Currently, numerical analyses according to the subject matter are under progress. Therefore three-dimensional micro finite element models were created. Here, the carried out FE studies have two main objectives. First, the re-creation of the results of the experimental investigations using 3D-modelling is aimed for to analyze other combinations of chase depth, eccentricity of load application, supporting conditions etc. In the finite element model, masonry units and mortar were meshed individually and a cohesive contact element was inserted on the unit-mortar interfaces so that the model is capable to capture the separation on the interfaces (see Figure 7 a). An elasto-plastic material model based on the Willam-Warnke yield criterion has been used for units and mortar.
Figure 7 b), as an example, shows a plot of an eccentrically loaded specimen with hinged support at the top and the bottom of the wall, failing due to loss of stability. As a preliminary result of the FE-studies, the load factor as function of chase depth (t_{ch} = 0 mm and 25 mm) and eccentricity of load application (e/t) is presented in the diagram in Figure 7 c). Therein, the dashed line represents the capacity reduction factor ($\Phi_o = 1\text{-}2 \cdot e/t$) based on a rectangular stress block and allowing for the effects of slenderness and eccentricity of load application (for calculating the vertical resistance of single leaf walls without chases) according to [7]. As can be seen, differences exist between FEM and experimental results (*EXP*), which necessitates a deeper investigation of the load bearing behaviour.



a) b) c)

Figure 7: a) 3D FE-Model; b) Example, plot of eccentrically loaded specimen; c) Load factor as a function of chase depth and eccentricity of load application

Second, an extensive two-dimensional numerical parameter study is under progress. The model consists of a slab in the intermediate story which is supported on the external wall. To capture the effect of the adjacent walls, in addition, a floor below and half a floor above the analyzed wall-slab-connection are included. It should be analysed how the geometry and the position of the horizontal chases affect the eccentricity (e) of the resulting normal force (N_R) on the top of the wall. Preliminary results indicate an approximately linear correlation between the chase depth resp. the weakening of the cross section and the reduction of the eccentricity of N_R.
Figure 8 shows a part of the 2D-Model and the reduction of e/t depending on chase depth and distance a_{ch} to the support of the slab.



a) b)

Figure 8: a) Part of the 2D-model; b) Reduction of eccentricity depending on the chase depth and the distance to the support of the slab (and used 2D-FE-model)

The numerical investigations are still in progress. Further research is necessary. It is foreseen to extend the numerical investigations with respect to walls with vertical chases and recesses.

SUMMARY AND CONCLUSIONS

An investigation on the effect of horizontal chases on the load bearing capacity of masonry is carried out at the Chair of Structural Design at TU Dresden. The results obtained until now were analysed and can be summarized as follows:

- In general, chases can considerably reduce the load bearing capacity of masonry specimens.
- Depending on the reference basis, the experimental determined compressive strength (f_{net}, f_{load}) mostly exceeds the theoretical mean value of masonry compressive strength f_{ma}.
- In the tests at hand, the influence of the horizontal chases on the load bearing capacity can be covered by the load reserves of the masonry in the majority of cases.
- The weakening of the cross section due to a horizontal chase should be calculated in relation to the effective cross section (web surface).
- Then the influence of horizontal chases on the load bearing capacity of centrically (resp. eccentrically) loaded masonry can be determined by means of the sectional weakening related to the effective cross section (for e>0 related to the effective loaded cross section).
- In order to complete the research project, some further experimental tests and an analytical investigation will be carried out. Additionally, the numerical studies are extended.

ACKNOWLEDGEMENTS

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