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„Development of a new model for efficient design of non-load-bearing inner and outer masonry walls“

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- Abridged report -

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1 RESEARCH TARGET

Presently, the design of non-load-bearing walls is based on the German code for masonry design, which does not allow taking into account the tensile strength perpendicular to the bed joint. Hence, a corresponding axial force is required to resist the bending moment. The small vertical loads due to the self-weight of the wall, do not allow the design of non-load-bearing walls. Up to now, the design of such walls therefore happens by help of tables, which have been developed on experimental basis in the 1980s. These tables do not cover all boundary conditions of modern masonry as e.g. the influence of ungrouted head joints. Additionally the new wind loads of DIN 1055-4 must be covered. Other design methods for the structural analysis of such walls are not provided in the literature.

Current research shows that masonry is able to transfer small tensile stresses perpendicular to the bed joint. The existent flexural tensile strength is the basis for the development of a new efficient design method of non-load-bearing walls. The target of the research is to analyse the material and structural behaviour of the masonry. Based on the described load-bearing behaviour, a new model for the non-linear analysis and a new consistent design concept for masonry walls has been developed.

The load bearing capacity depends on the loads and the material properties of the masonry units and mortar. The new design model must take into account the great variety of different combinations of unit und mortar to ensure a more efficienct and more flexible design of residential buildings.

2 RESEARCH PROCEDURE

The fundamental idea is based on the yield line method. The cracks are summarized in lines, which are used to describe the rotation between the panels or fixed supports, respectively. The yield line method was transferred from the reinforced concrete slab to the masonry panel assuming the same fracture pattern. The basic thought of this theory is the occurance of plastic material behaviour after reaching the bearing capacity of the cross section. The material behaviour of masonry is less plastic compared to reinforced concrete. Therefore, the major task is to find a realistic analytical model for the material behaviour. The analysis of masonry has to differentiate between the directions parallel and perpendicular to the bed joint with respect to the orthotropic material behaviour. The lateral loading of the wall leads to bending and twisting moments. The influence on the material behaviour with regard to the strong interaction has to be considered.

After a short introduction, various established analytical models for the structural analysis of non-load-bearing walls have been collected and evaluated on the basis of standardised parameters. The theoretical background of the methods is based on the yield line theory.

Therefore a short description of a plastic structural analysis is given and the use in masonry is discussed. The calculation methods represent only a part of the provided models in the literature. The other methods differ in the determination of the capacity of the system due to different applications of material properties or modified side conditions. Here, the flexural tensile strength, the load bearing capacity and the modification of the supports are significant parameters.

In the following chapter the material behaviour of masonry subjected to flexure perpendicular to the bed joint has been analysed using the moment-curvature relationship of masonry. The new analytical model consists of a combination of beams in flexure and springs. The nonlinear material behaviour in the cracked section is described by the stiffness of the spring. The required angle of rotation has been determined by integration of the curvature over the crack expansion.

In the next step, the load bearing behaviour parallel to the bed joint has been investigated. Due to the different stiffness of the wall in horizontal and vertial direction, the assumption of isotropic behaviour is not justified. The material and structural inhomogenities, e. g. due to unfilled head joints, have to be considered by an analytical model for the ratio of stiffness in the decisive cross section. For masonry with unfilled head joints, analytical equations are provided in the literature. Additional FE-investigations, carried out for filled head joints, showed that only compressive stresses were transferred. A significant influence on the ratio of stiffness could not be confirmed for small size units.

Basically, a differentiation in terms of the two failure modes is required. On the one hand, the units can fail due to the flexural tensile stresses in the unit and on the other hand failure can occur due to the shear stresses in the bed joint. An analytical model for the ultimate load-bearing capacity and for the description of the subsequent plastic material behaviour has been developed. The transition from the ultimate to the residual moment capacity was modeled by an exponential function using fracture energy. The model for the identification of the brittle failure is based on the criterion of principal stresses. The maximum tensile stresses in the unit could be determined by a factor, which depends on the geometry of the unit.

In case of two-way spanning masonry walls the structural and material behaviour show strong interaction for the two directions parallel and perpendicular to the bed joint. Therefore, new failure criteria for two-way flexure of the cross section have been developed. In addition to the new material model for the load-bearing capacity, analytical equations for the residual load-bearing capacity and the reduction of stiffness have been provided, too.

A new model for the non-linear analysis of the load-bearing capacity of masonry walls is presented in the next chapter. Based on the finite-element-method, the bar-spring-model with the failure criteria has been implemented in a computer-aided tool. Becauce of the non-linear moment–rotation relationship of the springs, the load-bearing capacity of the masonry wall has to be calculated by an iterative process. Therefore, the Newton-Raphson-method has been used as iterative calculation method in accordance with a successive approximation of the ultimate load. Subsequently, the calculation program was verified with test data. The comparison of the calculations and the tests, e. g. according to Jäger (2007), showed a very good fitting to the predicted load-bearing capacity. However, the experimental loads of Anstötz (1990) compared to the numeric calculation were underestimated. Due to large lateral wall deformations, the test set-up was detected as the significant influence.

In terms of a practical application, analytical design equations for the load bearing capacity have been developed in such a way that a complex numeric calculation can be avoided. Using the normalized ultimate load factor Y_W the design of a non-load-bearing wall is given with equation 1 as verification of the action and the resistance..

$$q_{Ed} \leq q_{Rd} \tag{1}$$

with $$q_{Rd} = \frac{t^2}{A_w} \cdot \frac{f_{tk2}}{\gamma_M} \cdot \Upsilon_w \tag{2}$$

The factor Y_W represents the normalized load-bearing capacity of the masonry wall considering the non-linear material behaviour, the slenderness of the wall and the support conditions. A design diagram for a distributed load of a simply supported wall is provided. Additionally tables for non-load-bearing inner walls have been evaluated to give the maximum span of the wall according to the tables of Kirtschig & Anstötz (1984).

3 SUMMARY

The primary objective of the research project was the development of an analytical model for the predicttion of the load-bearing capacity of inner and outer non-load bearing walls. Based on the new material models, a non-linear computer-aided tool has been developed. This has been verified by test data given in the literature. Aiming at a simplified design, a new consistent design concept is presented using a normalized capacity factor Y_w. Figure 1 shows the capacity factor for a distributed lateral load for some ratios of flexural tensile strengths against the wall slenderness.

In case of inner walls, there are only two load combinations, so that further research was necessary. For a simply supported wall with unfilled head joints, Table 1 shows the maximum span for to two values of the flexural tensile strength perpendicular to the bed joint. The safety factor for the line load q_H is γ_Q = 1.5 according to the German standard DIN 1055-100 (2001) for imposed loads.

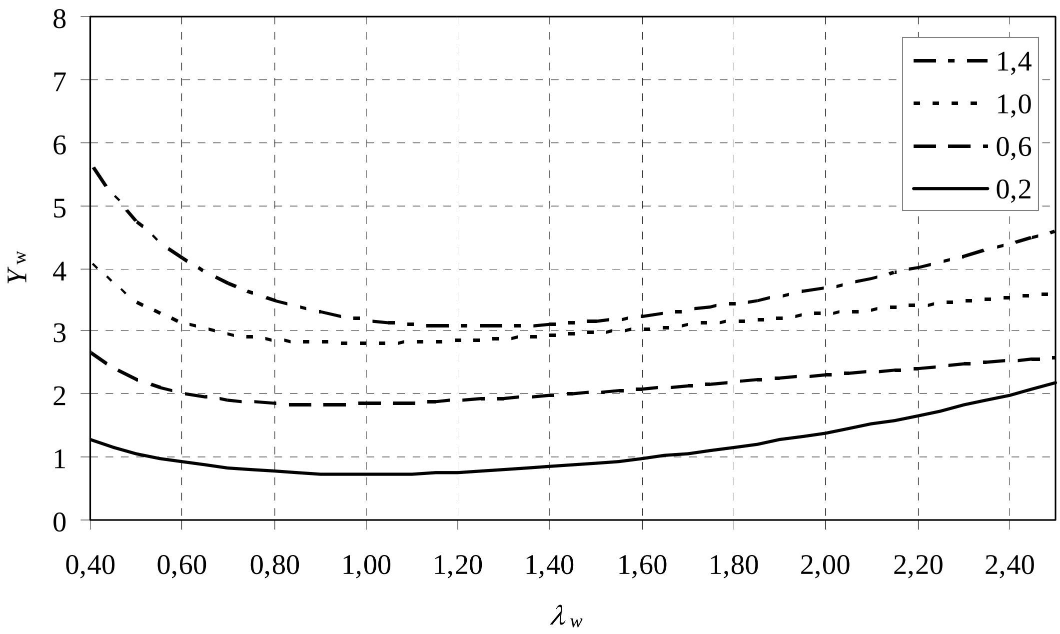

Figure 1 *Normalized capacity factor for different values of the ratio of the flexural tensile strength μ_t for a simple supported masonry wall with unfilled heat joints*

Table 1 *Maximum span of simply supported walls with $\mu_t \leq 1{,}0$*

Classifica-tion	*H* [m]	f_{tk1} [N/mm²]	Thickness of wall [cm] 11,5	17,5	24
1	2,50	0,10	3,2	∞ (12)	∞ (12)
		0,25	∞ (12)		
	3,50	0,10	5,9		
		0,25	∞ (12)		
	4,50	0,10	∞ (12)		
		0,25	∞ (12)		
2	2,50	0,10	-	5,2	
		0,25	∞ (12)	∞ (12)	
	3,50	0,10	-	10,0	
		0,25	∞ (12)	∞ (12)	
	4,50	0,10	-	∞ (12)	
		0,25	∞ (12)	∞ (12)	

The realistic assumptions of the material behaviour and simplified approximation equations and diagrams can be used for practical wall design of non-load bearing inner and outer masonry walls without a time-consuming non-linear structural analysis.