Abridged report on the research project:

Probabilistic Analysis of Reserves in Load Bearing Capacity of Masonry Structures to Achieve a More Efficient Design of Compression and Flexural Members Subjected to Self-Weight

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The new German masonry design code, DIN 1053-100 (2006), introduces the semi-probabilistic safety concept in masonry design. Now, the safety factors have to be applied on the loads as well as on the resistance. In massive construction, the required partial safety factor on dead loads plays a special role due to the fact that the percentage of the self-weight on the total load is large and so significantly influences the design and the reliability of massive members.

In this project, the influence of the self-weight on the reliability of unreinforced masonry subjected to compression was supposed to be analyzed and the possibly existent reserves in the partial safety factor γ_G on the self-weight (unfavourable action of self-weight) had to be quantified. The analysis had to be carried out using probabilistic methods, so the required stochastic properties of the self-weight had to be analyzed first. Within the scope of this research project, only structures with reinforced concrete structural slabs were investigated, because this represents the typical construction method in masonry construction. The subsequent analysis of the partial safety factor γ_G was carried out for the most unfavourable case of the member only subjected to self-weight. For the sake of completeness, the consequences of a combined loading case of live load and self-weight was analysed, too.

The analysis of the required value of the partial safety factor γ_G had to include the compliance with the target level of reliability according to DIN 1055-100 (2001). Therefore, the level of reliability of masonry structures designed according to DIN 1053-100 was assessed. Here, the influence of a combined loading case of live load and self-weight regarding practice conditions was analysed as well. Thus, the possibly available reserves in the partial safety factor γ_G should be uncovered and it had to be examined whether these are already or can be used to equalize existent shortcomings of the partial safety factor on the material γ_M. This reliability analysis on cross-sectional level included centrically acting loads as well as eccentrically acting loads. Shear stresses were not part of the research project.

In the first step, the models for the stochastic modelling of the self-weight were derived. Then, the self-weight of a panel was modelled differing between all components (unit, mortar, finish etc.). All components were modelled separately. To assess the large variety of units and materials, the influence of different coefficients of variation of the units on the deviation of the self-weight of the panel was examined. A special focus was set on the regard of the model uncertainties. Another important influence on the deviation of the self-weight of the panel is the deviation of the self-weight of the structural slabs; this was also included in the model. It was found, that the total variation of the self-weight of the structure including model uncertainties can be assumed to equal $V_{G,tot} = 8\%$. In case of a large scatter of the weight of the units, the total variation can increase up to $V_{G,tot} = 10\%$, see Table 1.

Table 1 V_{Gtot} depending on $V_{G,panel}$ and *c*

Coefficient of Variation of self-weight of the structure $V_{G,tot}$ [2)3)]							
	Coefficient of variation of self-weight of the panel $V_{G,Wand}$						
c[1)]	0,050	0,075	0,100	0,125	0,150	0,175	0,200
0,0	0,07	0,09	0,11	0,14	0,16	0,18	0,21
0,1	0,07	0,08	0,10	0,12	0,14	0,17	0,19
0,2	0,07	0,08	0,10	0,11	0,13	0,15	0,17
0,3	0,06	0,08	0,09	0,10	0,12	0,13	0,15
0,4	0,06	0,07	0,08	0,09	0,11	0,12	0,13
0,5	0,06	0,07	0,08	0,09	0,10	0,11	0,12
0,6	0,07	0,07	0,07	0,08	0,09	0,09	0,10
0,7	0,07	0,07	0,07	0,08	0,08	0,08	0,09
0,8	0,07	0,07	0,07	0,07	0,08	0,08	0,08
0,9	0,07	0,07	0,07	0,08	0,08	0,08	0,08
1,0	0,08	0,08	0,08	0,08	0,08	0,08	0,08
$c = G_{ceiling}/(G+G_{Decke})$ $V_{DG,Decke}$ beträgt 6 % Inkl. $V_{Modellunsicherheit}$ = 5 %							

In the following step, the deviation of the resistance of masonry under compression was analysed because the stochastic properties of both, the actions and the resistance, were required for the reliability assessment. The first parameter that had to be analysed was the compressive strength of masonry. It consists of the compressive strength of the units and the compressive strength of the mortar. Large databases of test results are available for both (see Jäger et al. (2007)). The stochastic moments of the compressive strength of masonry could be determined directly from these databases. The model uncertainty of the resistance was assumed on basis of JCSS (2003) to be the same as for concrete structures. Then, the analysis of the required partial safety factor on the self-weight γ_g in the design of centrically loaded masonry was carried out. Partial safety factors on the self-weight were determined on basis of assumed sensitivity values for resistance and loads. This allowed the determination of the required partial safety factor without an extensive reliability analysis. The assumption of available reserves in the partial safety factor γ_g was confirmed. But it was found that these reserves equalize shortcomings of the partial safety factor on the material γ_M. To be able to comprehensively assess the reliability of masonry cross sections, practice conditions (eccentric loading) had to be analysed as well. A significant dependence between eccentricity and reliability was found. Figure 1 und Figure 2 show the level of reliability depending on the eccentricity. Additionally, it could be shown that a reduction of the partial safety factor γ_g from $\gamma_g = 1.35$ to $\gamma_g = 1.25$ is possible in many cases without undershooting the target level of reliability ($\beta_T = 3.8$ for an observation period of 50 years). A reliability index of $\beta = 3.2$ was accepted as lower limit value following the recommendations of JCSS (2001).

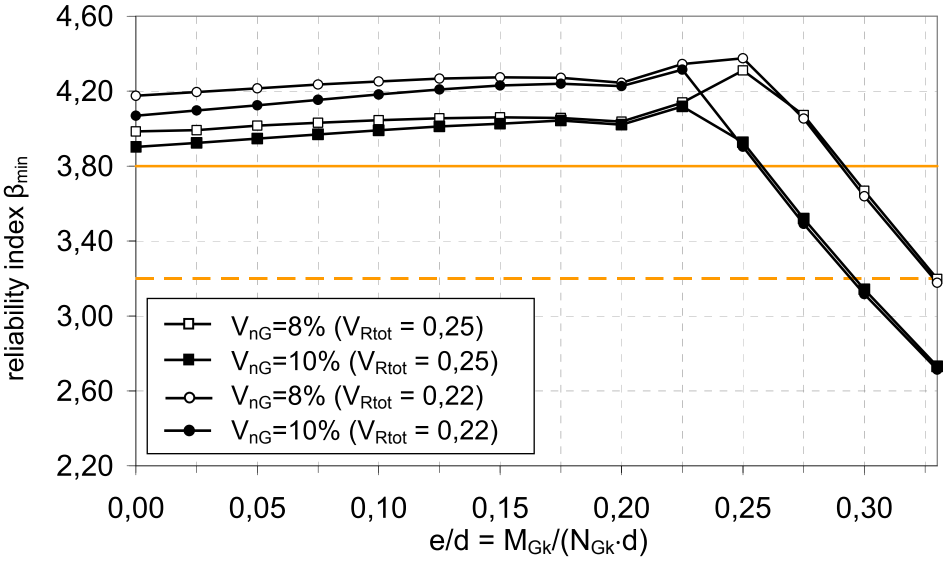

Figure 1 Bearing capacity of masonry cross sections depending on the eccentricity and corresponding reliability index β_{min} in case of $\gamma_g = 1.35$

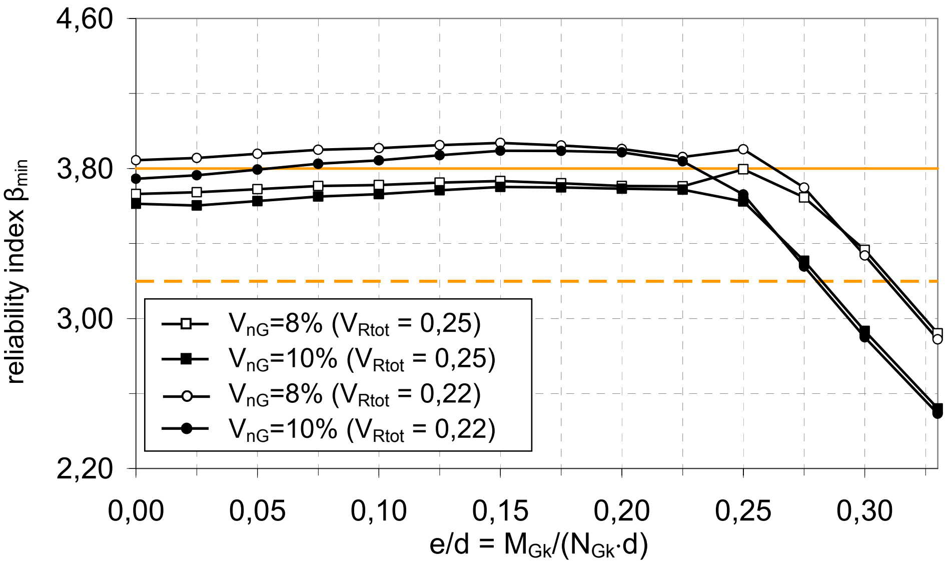

Figure 2 Bearing capacity of masonry cross sections depending on the eccentricity and corresponding reliability index β_{min} in case of $\gamma_g = 1.25$

In case of small or medium eccentricities, a significant influence of resistance and model uncertainties on the level of reliability was found. Simultaneously acting live loads lead to an increase in reliability in case of small and medium eccentricities under typical conditions in masonry construction, see Figure 3.

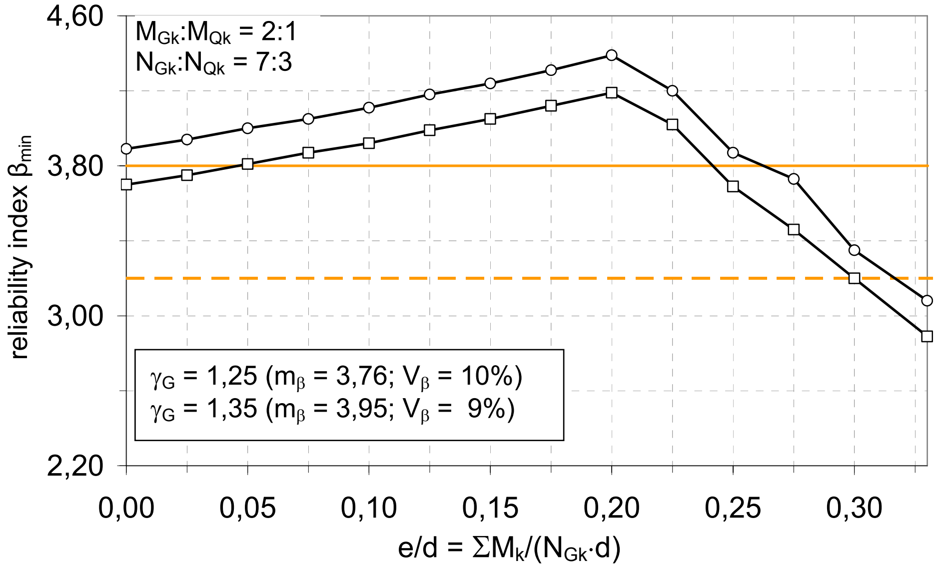

Figure 3: Bearing capacity of masonry cross sections depending on the eccentricity and corresponding reliability index β_{min} for different values of the partial safety factor γ_G in case of stress due to self-weight and live load

Oppositely to that, the failure probability is dominated by the deviation of the loads in case of large eccentricities what comes along with a relevant decrease in reliability. Firstly, all analyses were conducted for independent stress resultants (bending moments and axial force), what is approximately equal to the situation at the lower end of the wall. A correlation between axial force and bending moment - as it is often the case in practice - leads to a significant increase in reliability in case of favourably acting axial force, i.e. in case of large eccentricities. However, a realistic quantification of the coefficient of correlation at hand is difficult because of the statical system (statically indeterminate frames).

Altogether, the analyses showed that the target level of reliability defined in DIN 1055-100 (2001) is met by the design of masonry structures according to DIN 1053-100 (2006). The inevitable deviations from the target level of reliability with $\beta_T = 3.80$ (for an observation period of 50 years) are in between acceptable limits that have been assumed according to JCSS (2003) and GruSiBau (1981). A reduction of the partial safety factor from $\gamma_G = 1.35$ to $\gamma_G = 1.25$ is possible in case of $V_{G,tot} \leq 8$ % and e/d < 0.25 for unfavourably acting axial force. Alternatively, the detected reserves could be used for the reduction of the partial safety factor on the material γ_M. This should be easier to implement. For a comprehensive statement about the possibilities of a reduction of the partial safety factor in masonry construction, further investigations, taking into account the slenderness and shear stresses, are required.

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