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Summary

Title: **Constructive measures to ensure the earthquake safety of masonry structures**

Verification of constructive measures to ensure a sufficient earthquake safety of common masonry buildings in seismic areas of Germany by reality near calculation models

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1 Introduction

Until now, earthquake verification is not mandatory for masonry buildings, as long as they comply with the constructive conditions described in DIN 4149-1: 1981 or [1]. Because of the increased earthquake influence according to DIN 4149-1:2004, ENV 1998-1-3 and prEN 1998, the construction rules for such masonry buildings became more restrictive. A number of quantitative restrictions regarding the number of storeys, the geometry of the building and the total area of the shear walls are provided. These rules are considerably more sever and more detailed in comparison with the formulation in DIN 4149-1:1981. Thus, these rules can be a barrier for common masonry constructions in Germany.

In addition, the construction rules such as the number of full storeys, the maximum storey height and the minimum requirements for the shear wall area for so called "simple masonry buildings" (for such buildings an explicit safety verification under earthquake action is not mandatory) according to the current codes of practice DIN 4149 or EC 8 are fixed empirically, unfoundedly and unsatisfactorily. The empirical rules are independent of stone-mortar-combinations, the relation between storey height and minimum requirements of the shear walls was neglected and the effect of present ring anchors as well as additional reinforcement in shear walls are not taken into account.

The main purpose of this research project is to determine the constructive conditions for some typical masonry buildings in earthquake areas of Germany with the help of realistic calculation models, so that the earthquake verification for such buildings can be omitted.

2 Realistic analysis of masonry under earthquake action

For a realistic analysis of masonry under earthquake action, the time history method is only suitable calculation method. For this method, the acceleration time function of the ground acceleration and the realistic description of the nonlinear material behaviour under cyclic loading are required.

Beside existent acceleration time functions in various earthquake libraries, artificially generated acceleration time functions can be used.

An artificially generated horizontal-acceleration time function for earthquake zone 1 (a_g = 0.4 m/s²) and ground type CT (according to DIN 4149-1: 2004) is presented in Figure 1. The elastic response spectrum is shown in Figure 2.

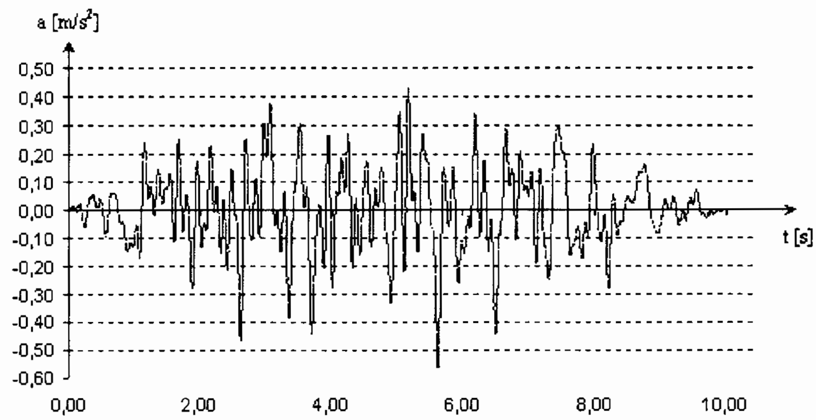
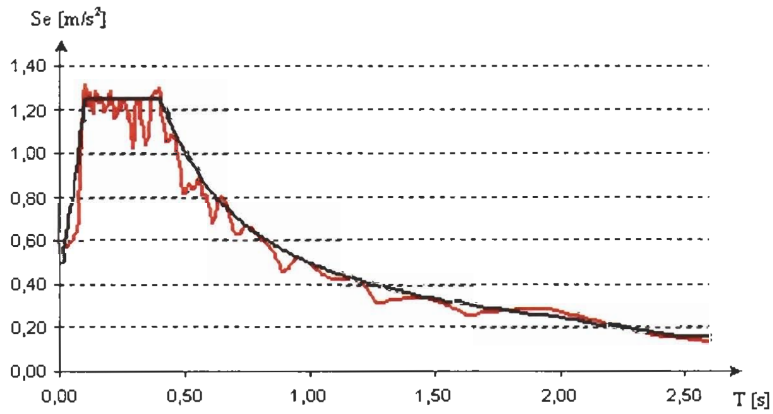


Figure 1 Horizontal ground acceleration time function ZV1 for the earthquake zone 1 (a_g = 0,4 m/s²) and the ground type CT (E DIN 4149 2004-05)

In order to describe the nonlinear material behaviour of masonry, in the context of this work a simple and robust material law on the macro level, based on the elasto-plastic theory was developed. With this material law, the elasto-plastic behaviour of masonry under cyclic loading can be described realistically. At every cross-section point, the material behaviour in the inelastic zone and the progressive material damage (eg. softening effects) can be included.

Due to the variety of possible failure mechanisms of masonry, the yield surfaces are derived from the failure criteria. The failure criteria under combined shear and compression stresses are taken from the failure model of Mann/Müller (see Figure 3). The first failure mode, the adhesive tensile failure, is taken to occur if the vertical stress is a tensile stress and exceeds the adhesive tensile strength between unit and mortar. The second failure mode gets substantial when the principal tensile stress exceeds the shear strength between unit and mortar. The third failure mode describes the compressive failure. An advantage of this model is the low number of the initial parameters which can be extracted from DIN 1053. Since the stresses in direction parallel to the bed joints are low and considerably smaller than the experimentally determined strength of masonry, no failure criteria or yield rules are set to capture a possible failure in this direction. The stresses are in the elastic range and the strains follow HOOKE's law.

Figure 2 Elastic horizontal spectrum for the earthquake zone 1 (a_g = 0.4 m/s²) with the ground type CT and the response spectrum of the ground acceleration time function ZV1 in Figure 1



1. $\tau_{R,1} = (\beta_{HZ} + \sigma) \cdot \frac{ü}{h}$

2. $\tau_{R,2} = (\beta_{HS} + \mu \cdot \sigma) \cdot \frac{1}{1 + \mu \cdot \frac{h}{ü}}$

3. $\tau_{R,3} = 0{,}45 \cdot \beta_{RZ} \cdot \sqrt{1 + \frac{\sigma}{\beta_{RZ}}}$

4. $\tau_{R,4} = (\beta_R - \gamma \cdot \sigma) \cdot \frac{ü}{h}$

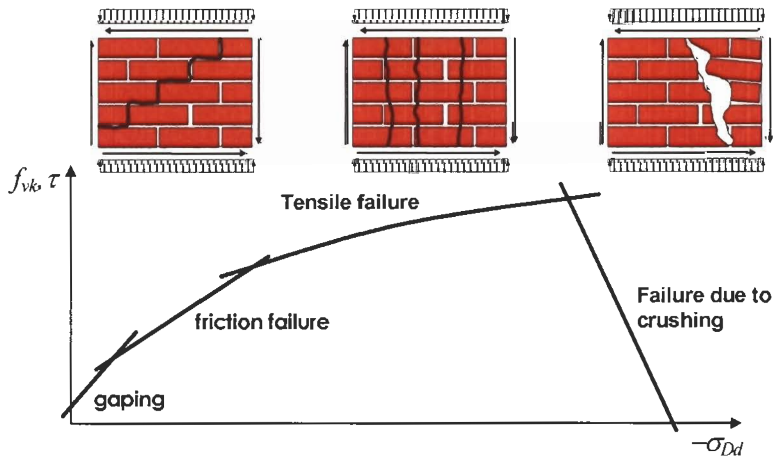


Figure 3 Failure Criteria by Mann/Müller

3 Numerical investigations

In the project some typical masonry buildings (standard terraced middle house, multi- and one-family houses) are examined to determine the minimum values of cross-sectional areas for the horizontal shear wall (in percent of the storey ground plan area) in dependence of the stone-mortar-combination and storey height. The minimum lengths of the inside walls or the minimum values of cross-sectional area for the horizontal shear wall, have been determined for two different damage conditions with the help of a numerical parameter study.

In order to realistically describe the response of masonry structures under earthquake action, a three dimensional model with volume - element is used (see Figure 4). The nonlinear behaviour of the stone-mortar-combinations is taken into account with the help of the implemented material law by Mann/Müller. The nonlinear behavior of ring anchors and reinforced concrete ceilings is neglected and modelled with elastic volume elements.

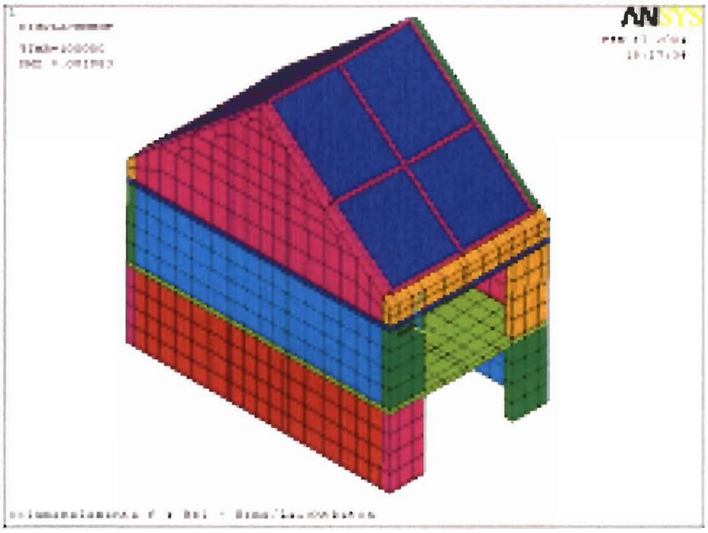


Figure 4 FE model of the row house

4 Conclusion

In this research project, on the basis of realistic numerical models the requirements for shear walls were determined in dependence of stone-mortar-combinations, storey height and the number of full storeys for some typical reference masonry buildings.

The numerical investigation of a 2½-story standard terraced middle house with a wooden roof construction has shown that the results for the stone-mortar-combinations KS20/DM, HLz6/LM21 - HLz12/IIa, V6/LM21 - V12IIa are almost identical with the requirements according to DIN 4149-1: 2004 and more favourable than the requirements for shear walls according to prEN 1998-1. The requirements for shear walls with the stone-mortar-combination PP2/DM - PP4/DM are much more favourable than the requirements according to DIN 4149-1 (up to 26.7% less shear wall cross-sectional area). The installation of a ring anchor leads to a further reduction of the required shear wall cross-sectional area, but not as much (approx. 10%). A reason for this is the diaphragm effect of the reinforced concrete ceiling which already covers the function of a ring anchor. With an additional ring anchor the flexural stiffness is, however, increased and the height of the shear walls on the other hand is reduced. The required shear wall cross-sectional areas are strongly dependent on the storey height and the stone-mortar-combination. The required cross-sectional area of shear walls for PP2/DM -- PP4/DM is approx. 50% larger than the one for KS20/DM.

The numerical study of a multi-family house has shown that the cross-sectional area of shear walls strongly depends on the number of full storeys. For single and two-storey multi-family houses, the earthquake verification is readily fulfilled at a maximum window opening and minimum length of the shear walls. For three and four-storey multi-family house the requirements are considerably lower than these for shear walls according to DIN 4149-1: 2004. For the material combination PP2/DM - PP4/DM the minimum value is lower in comparison with the cross-sectional area of shear walls for the three-storey multi-family house by up to 50% according to DIN 4149-1: 2004. In particular, it was pointed out by the numerical study that the material combination PP2/DM -- PP4/DM can also be used for four-storey multi-family houses, although this material combination is not allowed according to DIN 4149-1: 2004. The calculated minimum values of shear wall cross-sectional areas for the material combinations KS20/DM, HLz6/LM21-HLz12/IIa and V6/LM21-V12IIa for four-storey buildings are lower than the requirements fixed in prEN 1998-1 and almost identically with the requirements according to DIN 4149-1: 2004.

For single-family houses the needed cross-sectional area of shear walls is not strongly dependent on the stone-mortar-combination and the storey height but strongly dependent on the location of the shear centre.

In future, the effects of further additional constructive measures on the required shear wall cross-sectional areas have to be investigated, e.g. the effects of confined masonry, reinforced masonry and "corner-gap" elements.

To be able to assess the influence of reinforcement, in this work some variants of the multi-family house have already been investigated with and without reinforcement under static loads. The first result has pointed out that the horizontal load-capacity for gas concrete stones could be increased at least 14% in comparison with unreinforced masonry. A first simulation run for confined masonry yielded an additional increase of the horizontal load-capacity of the building as well.

5 References

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