Behaviour of Unreinforced Masonry under Seismic Action

1. Introduction - Aims

When applying the new European Standard ENV 1998 ([6] ÷ [10]) the resulting horizontal loads in German Earthquake zones turn out to be higher by 6.1-times compared to the actual code DIN 4149-1 [3]. Taking into consideration the 11% lower safety-level when designing masonry constructions with ENV 1996 ([4] ÷ [5]) compared to DIN 1053-1 [1], the factor reduces to 1.6 ÷ 5.5. Including the low behaviour factor of unreinforced masonry of q=1.5 in ENV 1998, many construction types, like terrace houses, can't be verified numerically. As masonry construction performed generally well in past earthquakes in Germany, a numerical investigation has been carried out at *Technische Universität München* supported by the *Bundesamt für Bauwesen und Raumordnung* (Reference number: Z 6 – 5.4.00-06 / II 13-80 01 00 -06).

2. Evaluating Tests on Masonry Specimen

Apart from conventional static-cyclic tests on unreinforced masonry walls given in the literature, pseudodynamic test results form earlier experiments at TU München [14], [15], [16] were equally taken into account. In this type of experiment the dynamic performance and load-bearing capacity of whole constructions is investigated under realistic conditions, considering the coupling of dynamic impact and reaction of the structure.

The investigation and evaluation of the tests showed a loss of stiffness up to 80% - independently of the failure mode. More important was the fact, that the stiffness determination according to DIN 1053-1 led to values 1.5-times higher on average compared to uncracked test specimen described in the literature.

3. Material Model

Basing on the above described test, a nonlinear material model based on theory of plasticity has been developed. The flow rules were generated from the appearing failure modes according the theory of Mann/Müller ([11] ÷ [12]), since unreinforced masonry cannot be described by just one simple flow rule. For combined shear and normal stress, four different failure modes have to be considered: *Tension failure in the bed joint*, *friction failure in the bed joints*, *diagonal tension failure in the bricks* and *compression failure*. The main advantage of the model is the low number of necessary parameters, mainly determined by standard tests according DIN 1053-1.

Plastic strain in case of *friction failure in bed joints* was generally not limited, because almost ideal plastic behaviour occurred in tests. Parameters of the linear softening were determined from the crack energy (Mode II). The plastic strain in failure mode *tension in the brick* has to be transformed to the corresponding shear-deformation. The parameters for linear-softening can be equally derived from the crack energy (Mode I).

The work-hardening rule under loading perpendicularly to the bed joints was taken from standard compression tests and simplified by a combination of a linear and parabolic curve. The unloading runs parallelly to the primary loading curve in the origin.

The verification was carried out on well documented tests. The accordance of maximum loads, occurred failure mode and qualitative load-displacement curves was good.

4. Parametric Study

Using the developed material model, a parametric study was carried out afterwards. Herein the material parameters, the geometric shape of the wall-specimen (l_{wall}, h_{wall}) and the earthquake-load were permanently varied. The spacial coaction of the walls and slabs was considered by an elastic spring $c_{\varphi,cap}$ at the top of the wall coupling cap rotation and cap moment [15].
The tests were performed dynamically on a simplified SDOF-system.

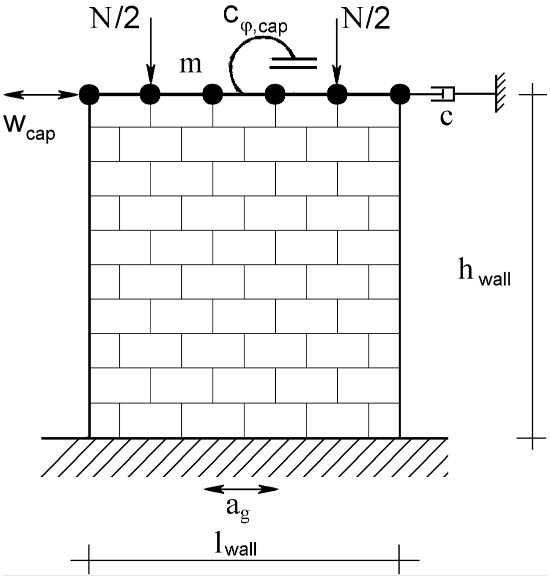

Figure 1: Simplified SDOF-system for the parametric studies

The dynamic parameters *m* and *c* were determined such as to lead to a first eigenperiod of T=0,3s and a damping rate of 5%. The ground acceleration a_g(t) was artificially generated according to the horizontal, elastic response spectra of E DIN 4149 (Oct. 2002) [2] considering several soil-subsoil-conditions.
The test results were compared to the loads resulting form a linear-elastic calculation according to earthquake standard E DIN 4149 (Oct. 2002).
The determination of the load-reduction combined with the nonlinear behaviour of the system led to of behaviour factor values in a range of q=1.4 ÷ 2.0.

It was found that the behaviour of masonry constructions under seismic loadings and the level of *q* are affected mainly by the following factors:

- failure mode (friction in bed-joints, tension in bricks)
- geometric shape of the wall
- ground acceleration time history, i.e. soil-subsoil conditions and shape of the elastic response spectra
- boundary conditions in the structure

Therefore several further parameters, which are deciding for the seismic design, have to be investigated in order to achieve a better description of the behaviour of unreinforced masonry under seismic loadings, e.g.:

- stiffness determination for masonry generally
- stiffness reduction after exceeding crack load
- coupling of impact and reaction under seismic action

5. Literature

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