



ESECMaSE – Enhanced Safety and Efficient Construction of Masonry Structures in Europe

Periodic Activity Report / Publishable Executive Summary

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Within the third period of the ESECMaSE research project, static cyclic and pseudo-dynamic tests on masonry walls were carried out. Furthermore, shaking table tests and pseudo-dynamic full scale tests have been performed to study the behaviour of masonry buildings under seismic loading as well as to identify realistic behaviour factors for masonry buildings. For different kinds of masonry walls and for different boundary conditions, a new design model for the shear resistance could be developed and verified by the tests. Finally, a proposal for a new design procedure for the coming European code has been developed including a proposal for realistic behaviour factors for masonry structures.

This report addresses the third phase of the project. This phase is mainly devoted to the static-cyclic and pseudodynamic wall tests (WP 7) as well as shaking table tests and full scale tests (WP 8).

Based on a survey of existing models and a parametric study using a nonlinear finite element modelling approach, a new design model for the shear resistance was developed within work package 4 (Design Model for the Resistance of Shear Loaded Masonry Structures). For the finite element modelling, a micro-model with a reduced level of detailing was chosen, for which the mortar in the joints had been represented by interface-elements with appropriate constitutive models (Mohr-Coulomb criterion with tension cut off).

Figure 2 shows the results of the FEcalculations in excerpts. The different types of failure were identified by analysis of the stress- and crack patterns. They are labelled as follows:

- Bd: Bending (flexural failure)
- KI: Gaping of the single units in the bed joints
- S: (Diagonal) tensile failure of the units



figure 1: crack pattern of the finite-element-model



figure 2: results of the FE-calculations



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The developed proposal for the calculation of the shear resistance of wall panels has been compared with the maximum horizontal load determined from experimental data including the ESECMaSE tests on storey high masonry panels (WP7). It could be shown that the new integral approach reduced the scatter of the predictions considerably. After calibration of the unit tensile strength specific to the different masonry types, a quite uniform safety level could be reached. Thus, the model could be validated also for the different combinations of loading parameters and geometry as used in the ESECMaSE tests.

It should be mentioned that the model works without consideration of the uncertain parameters tensile strength perpendicular to the bed joints and initial shear strength (cohesion). The investigations have also shown, that some of the developed equations are valid for all types of units (bending and gaping), whereas others (friction and tensile) should be modified in terms of the types of units to achieve better results.

In WP 7 static-cyclic tests were carried out at Kassel University, Pavia University and at the Technical University of Munich. Furthermore, pseudo-dynamic wall tests were arranged at Kassel University and at the Technical University of Munich.

For the static-cyclic tests, three slightly differing test set-ups at the three laboratories were established according to WP 6. However, comparative wall tests with the different setups have proven good congruency of the results.

In total, 47 static-cyclic tests on different kinds of masonry were carried out to analyse the influence of different boundary conditions on the shear strength and the deformation capacity of masonry walls. The influence of the optimisation of the masonry units on the load bearing



figure 3: test set-up of Pavia University



figure 4: ground plan and view of the JRC specimen



figure 5: simplification for the pseudo-dynamic tests in Kassel



capacity of the wall as determined by the wall tests is rather low. For clay units, however, a higher deformation capacity of the walls built with optimised clay could be found in comparison to walls built with conventional clay units.

Eight pseudo-dynamic wall tests were carried out at Kassel University using the same test setup as for the static cyclic tests (see deliverable D 7.1.a). The test specimen with a height of 2.5 m represents one of the main walls in the ground floor of a two storey terraced house as tested in full scale at JRC Ispra (see figure 4). In order to approximately simulate the behavior of a masonry wall in such a building, the pseudo dynamic tests were performed as single degree of freedom tests assuming the distribution of inertia forces from the first vibration mode of the two stories building (see figure 5).

At the Technical University of Munich, 12 pseudo-dynamic wall tests were carried out on a 2- resp. 3-storey structure-system where the relevant shear wall in the 1st storey was investigated experimentally while the rest of the structure was modelled numerically using a finite-element-programme. Figure 6 shows the numerical model of the tests.

To validate the results of the staticcyclic and pseudo-dynamic wall tests under fully dynamic loading conditions, shaking table tests have been performed at NTU Athens. Therefore seven specimens built of clay bricks, calcium silicate units and lightweight aggregate concrete (LAC) units, as shown in figure 7, were tested.

Pseudo-dynamic tests on two full scale two-storey high terraced houses have been carried out at the Joint Research Center (JRC) of the European Union in Ispra (Italy). The houses were constructed with clay unit masonry and





figure 6: FE-model of the pseudo-dynamic tests in Munich



figure 7: view of a dynamic test in Athens



figure 8: view of the full scale test at JRC Ispra



calcium silicate unit masonry respectively. Figure 8 gives an overview of the test arrangement. Both houses withstood the maximum design accelerations in central Europe of

 $a_g = 0.8 \text{ m/s}^2 = 0.08 \text{ g in Germany, and}$ $a_g = 1.3 \text{ m/s}^2 = 0.13 \text{ g in Switzerland}$ without major damage.

Figure 9 shows the load / interstoreydrift relationship of the clay masonry building for a ground acceleration of 0.14 g. The horizontal load bearing capacity of the buildings is even higher than expected based on the pertinent wall tests in Pavia. The increase of resistance can be explained by the combined action of longitudinal and transversal walls as Tsection and the increase of normal force due to uplift movement coinciding with the horizontal deformation.

In WP 9 a text proposal for the revision of the EC 6 is given after a brief reflection of the safety concept. The proposal was thereupon compared with the existing experimental results. It could be established, that within the terms of the tested range, an acceptable safety margin can be guaranteed.

Herewith presented proposals give simplified approaches of calculation for masonry constructions under seismic loads, which should be implemented in the existing Eurocode EN 1998-1. Furthermore behaviour factors derived from the pseudo-dynamic tests and by use of the ductility of the static-cyclic wall tests, as shown in figure 10.

In conclusion, the project has shown the complex behaviour of masonry walls under in plane loading. The new approach for a design model could be validated by the great number of tests in this research project. Furthermore behaviour factors were extracted from all the tests. ESECMaSE ELSA [Clay Brick] (62: PsD Model Derived) m17: 0.14g EARTHQUAKE. 13/03/2008

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figure9: load –interstorey drift - relationship



figure 10: relation of the ductility and vertical load