Full scale testing of modern unreinforced thermal insulation clay block masonry houses

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SUMMARY:
Aim of this project is testing of the most common construction method in Europe and the world, namely structures constructed with fired clay brick masonry. Although some tests are already existing, main focus in the past was on cyclic shear tests, but no real scale 3-D shaking table tests were performed on the nowadays used, modern thermal insulation hollow clay brick masonry. Therefore, two real scale models will be tested on a 3-D shaking table at Laboratório Nacional de Engenharia Civil (LNEC), where all three directions of areal seismic event (two horizontal and one vertical) can be simulated in order to reflect the real nature of earthquakes. In particular, the dynamic response behaviour, behaviour factors (q-values) damping values and also maximum drift values will be elaborated out of the tests and used for further analysis.
This project is an absolutely novelty on this field which will close the gap between classical masonry research (material side) and earthquake engineering (excitation side) as a consequent continuation of past European research projects (eg. FP 6 ESECMASE) on high thermal insulation bricks.

Keywords: Modern masonry, Full scale testing, Shaking table

1. INTRODUCTION AND AIM OF THE PROJECT

Nowadays, requirements on fired clay blocks are not only due to mechanical resistance but have also fulfil thermal insulation tasks in order to save heating/cooling energy within the house and furthermore protect the rare environmental resources. Therefore, new modern fired hollow clay blocks are developed to fulfil these needed properties. Knowledge and research in dynamical and seismic behaviour of such modern masonry structures are still rare compared to structures made of other building materials like reinforced concrete or steel. Furthermore, most of these research works are focusing on existing masonry structures, particularly on means of vulnerability assessment and mitigation for ordinary and historical structure. On the contrary, few things are yet available for modern masonry in the perspective of a direct efficient seismic design of modern structures.

Compared to other structural materials, knowledge about masonry is still limited, not only in the domain of experimental studies but also software and educative programmes at all levels, having in mind the fact that most of the European and World population still lives in masonry structures.

In the context of modern masonry, available test results are dealing with the cyclic shear behaviour of wallets in order to get out the hysteretic behaviour of single structural members [Magenes and Calvi 1997, Tomazevic 1999, Tomazevic and Lutman 1988, Magenes 2006, Tomazevic and Klemenc 1986], but less have been performed on full-scale models including the global structural behaviour.

Some first shaking table tests have been recently performed on stone masonry as well as cavity walls structures at ISMES (Italy), LNEC (Portugal), ISPRA (Italy), NTU Athens (Greece) within FP6 LESSLOSS, FP6 ESECMASE and FP5 ECOLEADER. This makes however quite a limited number of data available. In particular very few have been done regarding clay block structures (for example Ecoleader tests at LNEC were dealing with natural stone and with concrete blocks). Moreover, absolutely no 3-D shaking table tests (i.e. with combination of both horizontal components and vertical component seismic excitation) have ever been performed on modern, thermal insulating clay block structures (reminding that clay blocks is the main focus of the present proposal).

It is also of prime importance to notice that very strong discussions are currently occurring in normative committee (i.e. for drafting national annexes to Eurocode 8) regarding unreinforced masonry under seismic action, in particular in those countries where the usual way of building masonry structures is actually unreinforced and where the seismic risk is existing but limited (for example Germany, Belgium, Austria Switzerland, Hungary, Czech Republic, Slovakia).

These discussions are dealing with two main aspects: (i) the resistance of structural elements (for which some test and analyses results are now available) (ii) the global structural behaviour and in particular the appropriate value of the behaviour factor to be considered. On this particular point, very different approaches are proposed, starting from very conservative approaches ($q = 1.5 – 2.0$ in any cases) to more modulated values according to the structural type (regular, irregular…).

Also of interest is the behaviour of floors and connections. It is indeed requested in seismic zones that floors are acting as efficient diaphragms and that wall and floors are efficiently connected. Very few are however said on the practical way to achieve these two objectives.

The aim of this study is helping clarifying all the previously exposed aspects for modern clay blocks unreinforced masonry, including constructive details associated with the insulation devices. In order to fill the gap and achieve knowledge of the structural behaviour of clay masonry structures with modern thermal insulation blocks the focus of this study is laid on large scale shaking table tests. 2 models are intended to be considered. These models will be 2 storey structures designed to use the experimental equipment to its maximum payload. The main difference between the two models will be the regularity in plan: the first one will be regular while the second will include significant irregularities.

Time histories will be chosen based on both, artificial time histories matching the EC8 spectra and real time histories from past earthquakes selected from the European strong motion database.
Instrumentation set-up will be prepared in such a way as much as possible data to be collected that will be relevant for describing overall tri-directional behaviour of the model structures. Further, by the processing and advanced analysis of the recorded data, type and development of failure mechanism will be defined, as well as bearing, deformation and energy dissipation capacity of the plain masonry tested structures.

Both specimens will be designed on the base of theoretical and numerical modelling developed preliminary to the testing phase. To this purpose, specimens will be defined on the one hand on the base of table capacities and on the other hand on usual way of building masonry structure. Preliminary analyses will be realized according to available standards (EC6 + EC8) and refined on the base of numerical models developed by University of Liège. The objective is to come out with testing models for which the expected failure modes are correctly estimates previous to testing, in order to focus on the phenomena for which the knowledge is known to be the most questionable.

2. EXPERIMENTAL SETUP

2.1. Shaking table

The tests will be performed at the shaking table of LNEC (see Figure 1). LNEC has a vast experience in performing shaking table tests to assess the seismic behaviour of masonry building structures [Degée and Plumier 2006, Candeias et al. 2006]. The large 3D shaking table is able to impose motions in two horizontal directions simultaneously. This is a vital condition according to the proposed testing setup to induce the dynamic in plane and out of plane response of the walls. The capacity of the LNEC 3D shaking table [www.ext.lnec.pt] is perfectly adequate to both the mass of the model and the range of input motions foreseen for the tests in terms of stroke, velocity, acceleration and frequency content.

The testing procedure used at LNEC is fine-tuned according to the performance of the models [Coelho et al. 2000]. The input motions are compared between the target and the achieved in order to assess the quality of each test. LNEC high speed data acquisition system allows the simultaneous measurement of a dense array of sensors which is fundamental to detect local modes and evaluate the seismic response of the walls. This way it is possible to assess the full seismic behaviour of masonry buildings up to near collapse of the structure. Moreover, coherence functions between input and output motions are computed giving a measure of the testing errors by the corresponding signal-to-noise-ratio. This is done through software tools for processing input and output signals that are being developed in LNEC.

Figure 1. 3-D shaking table at LNEC

2.2 Masonry models

Two different models will be tested. These models will be 2 storey structures with the main difference of the regularity in plan: the first one will be regular (model I) while the second will include significant irregularities (model II). This is necessary to study the overall behaviour of this common type of buildings, were until now no research in this direction has been performed. The total weight will be approximately 290 kN for model I and approximately 360 kN for model II. Sketches of both models are given in Figures 2 to 5.

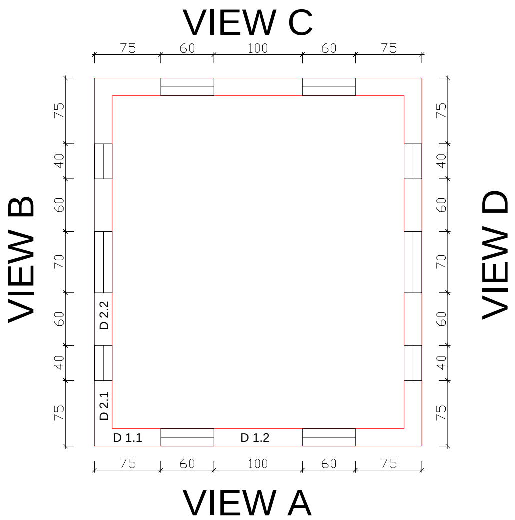

Figure 2. Ground floor and 3-D view of model 1

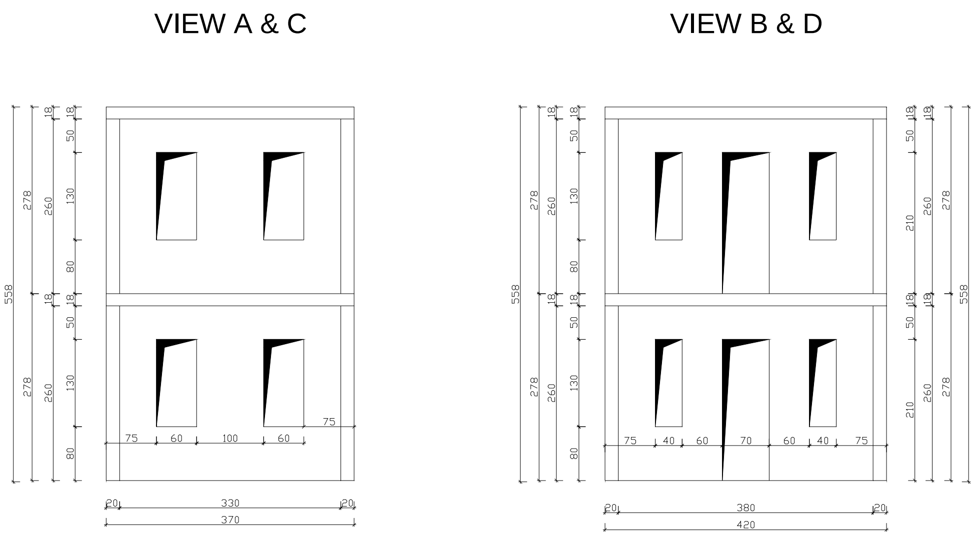

Figure 3. Side views of model 1

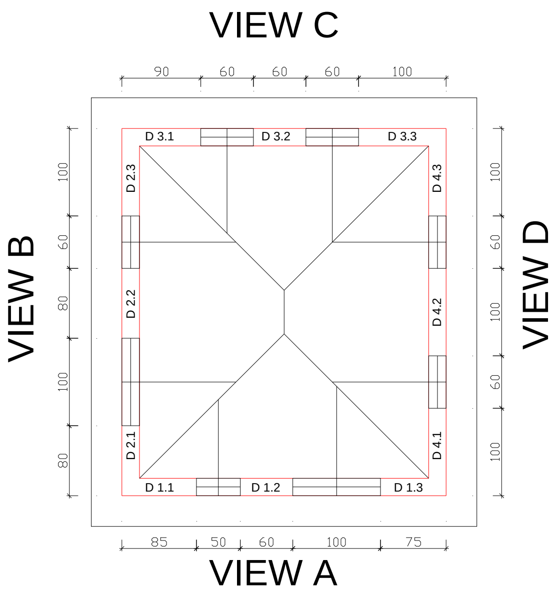

Figure 4. Ground floor and 3-D view of model 2

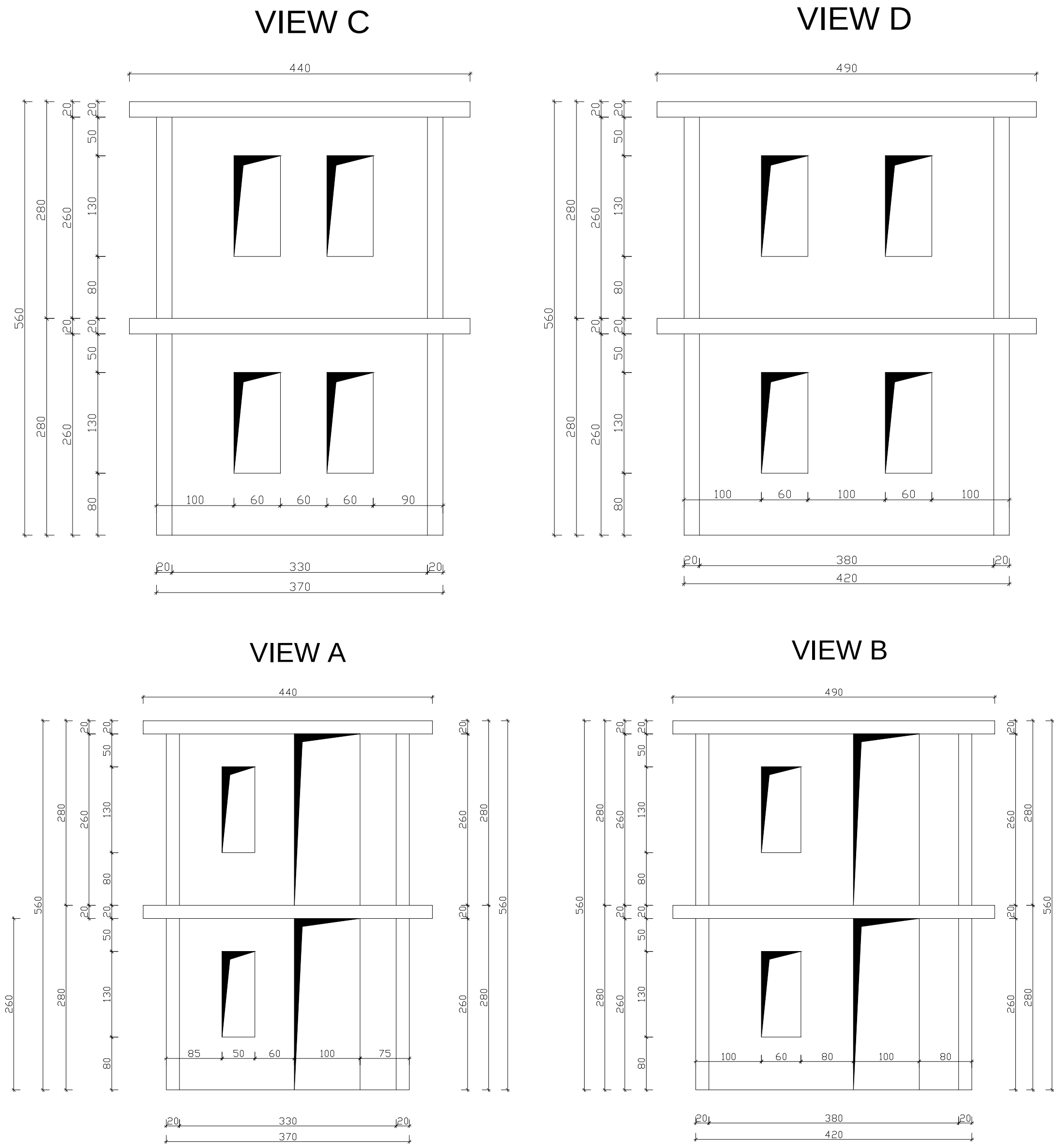

Figure 5. Side views of model 2

2.3 Instrumentation setup

For the foreseen shaking table testing of two masonry physical models the instrumentation set-up will be composed in such a way to collect as much possible data relevant for assessment of the overall, as well local behaviour of the tested models.

In general, several types of transducers will be used, such as accelerometers, LVDTs (Linear variable Differential Transducer), linear potentiometers, clip gages. For measuring the floor accelerations, 6 accelerometers will be placed on at every floor level, two at the corners and one in the middle in both orthogonal directions. Also 6 accelerometers will be placed at art two levels along the height of each wall, on two perpendicular sides of the model. This means that total 36 acidometers are foreseen to be used.

Linear potentiometers will be used for recording absolute displacements of the model in respect to the reference point outside of the shaking table. Total 12 Linear potentiometers will be used, 6 for each floor in both orthogonal directions (one at the midpoint of the plate and two at the corners LVDTs will be used for measuring the displacement in the plane of the wall, due shear deformation and cracking.

The total number LVDTs will be depended on the agreed location. In general, major diagonals should be covered as well as diagonals above each opening.

In addition to this, clip gauges could be used for measuring the crack openings in the walls. LVDTs and/or clip gages could be used for measuring the uplifting and sliding of the model in respect to the foundation. However, the total number of channels – transducers will be very much depended on the capacity of the current data acquisition system at LNEC laboratory.

3. NUMERICAL ANALYSIS

For estimation of mechanical performance special software for the seismic design of masonry buildings, AmQuake, is used. This software is based on pushover analysis and equivalent frame method. In this method, each wall is modelled as a vertical beam element. The parapets, lintels and reinforced concrete ring are modelled by horizontal beam element that is connected to the vertical elements by special rigid links. The rigid links are treated as generalized displacement constraints in the underlying finite element solution. The nonlinear behaviour of masonry and reinforced concrete elements is treated on the sectional level. This means that the internal forces such as moments, normal and shear forces in the critical sections are evaluated and compared with the standard Eurocode 6 or 2 formulas. When the sectional forces reach the ultimate section capacity, plastic hinges are introduced and nonlinear iterative solution based on arc-length method is used. Following this approach, the full pushover curve is calculated for various orientations and shapes of the horizontal force. The displacement capacity and target displacements are evaluated following the Eurocode 8 guidelines.

For bother models push over curves are computed using the following input parameters: soil category A, spectrum type 1, damping ratio 5.0, ultimate acceleration 3.0 m/s², soil factor (S) 1.0, period B 0.15 s, period C 0.4 s, period D 2.0 s. The life load was set to 2 kN/m² and a dead load of 5 kN/m² was applied. Analyses were performed in both principal directions applying uniform and triangular displacement distribution. Unreinforced masonry was used in the analysis with the strength of masonry units set to 15 N/mm² and normal mortar with a compressive strength of 15 N/mm².
In Figure 6 a typical push over curve is depicted showing numerical results (green line) and the linearized pushover curve (blue line). Additionally the target limit states according to Eurocode 8 with deformation limit state (orange line) and ultimate limit state (red line) are given.

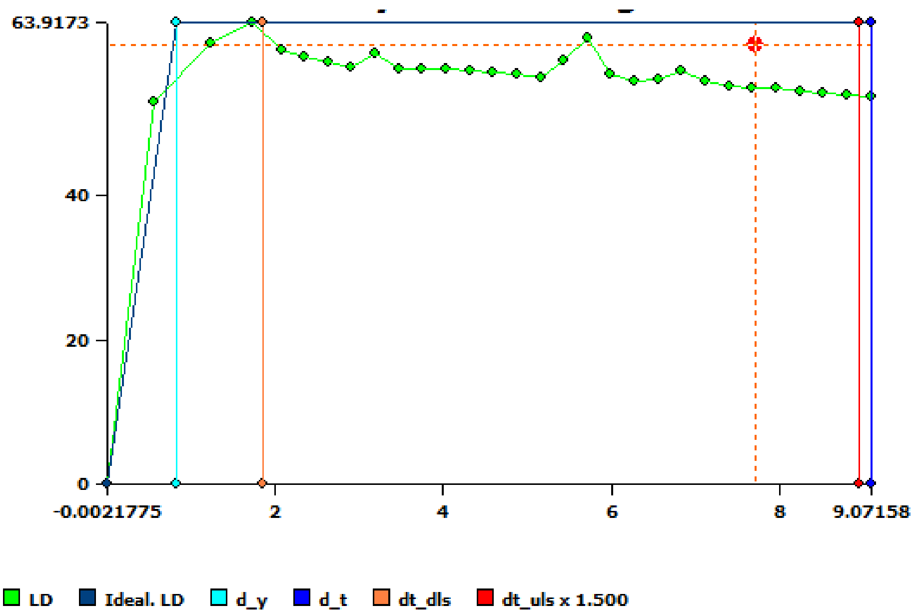

Figure 6. Typical pushover curve showing numerical results (green line), linearized pushover curve (blue line), and target limit states according to Eurocode 8 with deformation limit state (orange line) and ultimate limit state (red solid line)

In Figures 7 and 8 the linearized pushover curves for model I and model II are given together with a 3D plot of the model. For model I, which is regular in plane, the scatter in maximum load is smaller compared to model II with a higher irregularity. The deformation capacity in x- and y-direction is quite similar for model I whereby one can see a difference in model II. In model II, the displacement capacity is higher in x direction.

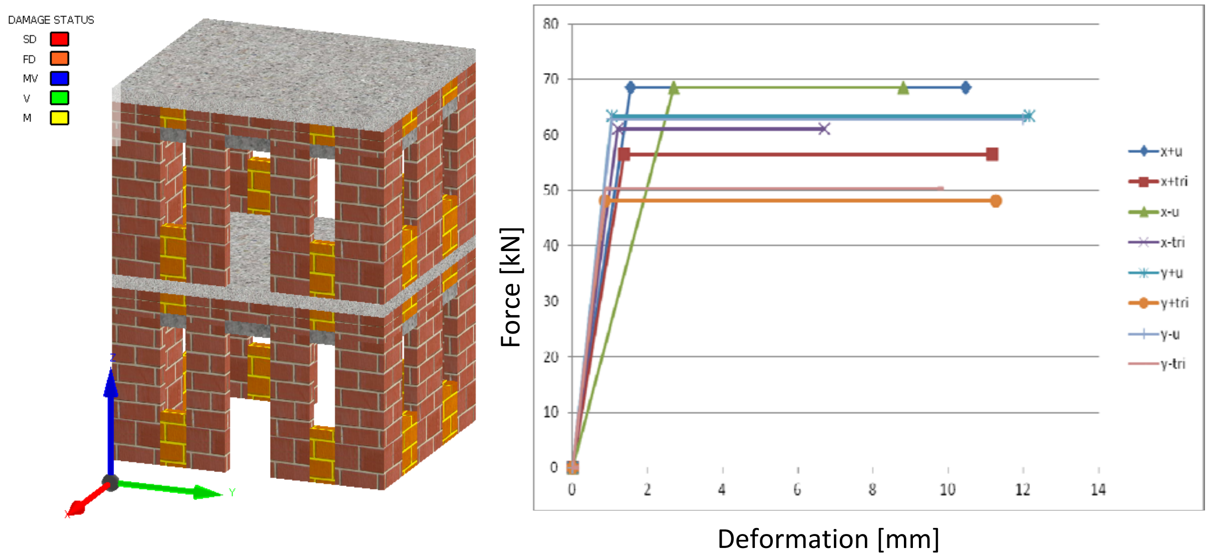

Figure 7. Numerical modelling results of model I: 3-D sketch model and linearized pushover curves for deformations in positive/negative x/y-direction using uniform or triangular displacement

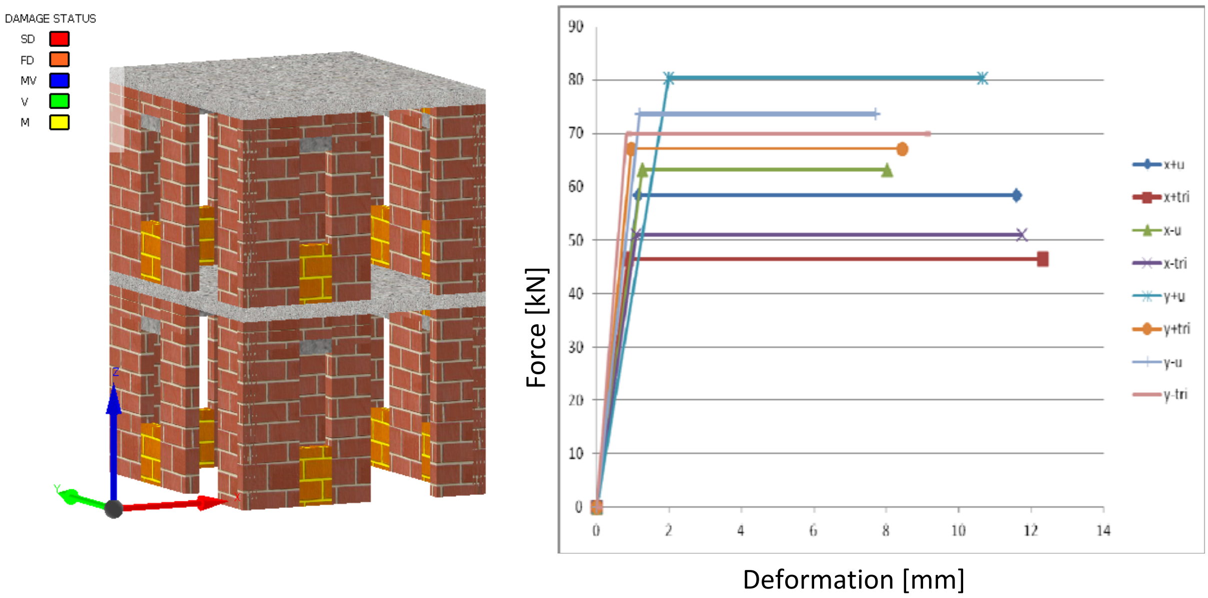

Figure 8. Numerical modelling results of model II: 3-D sketch model and linearized pushover curves for deformations in positive/negative x/y-direction using uniform or triangular displacement

4. SUMMARY AND OUTLOOK

In the course of this project, the seismic behaviour of modern masonry buildings will be studied in detail. For this purpose, real scale 3-D shaking table tests on two models will be performed. One of the models is regular in plane and the other one irregular. The instrumentation set-up will be composed in such a way to collect as much possible data relevant for assessment of the overall, as well local behaviour of the tested models. Measurements will focus on the dynamic response and on the degradation of natural frequencies according to the level of seismic action. Moreover, the models will be instrumented in order to measure precisely the displacements and accelerations during the earthquake shake in order to assess the load distribution between the different shear walls as well as the reduction of inertial forces as function of the progressive dissipative effect due to masonry cracking. In parallel to the tests, both models will be analysed analytically and numerically.

The outcome of the project will be used directly to assess q-factors and to define simple practical designer friendly statements for the approximation of cracked stiffness to be used in a linear calculation.

Wall to slab and wall to wall joints will also be analysed carefully in particular to evaluate the demand on forces at the connection and see to what extent this distribution can be influence by wall cracking. One other outcome will be the assessment of "weak points" of the structure (i.e. where cracks mainly develop) to know already in the pre-design stage of a structure, which parts and structural members have to designed with specific care, as well as locations where strengthening possibilities should be required in existing buildings.

The results will also be used for improvement of existing and development of new computer programmes for analysis and design of masonry structures. Also, considering that important knowledge will be gained regarding occurrence of the first cracks and development of the failure mechanism under excitation in two horizontal directions and vertical direction, this knowledge will also be used in seismic performance, evaluation of seismic stability and seismic upgrading of existing plain masonry structures.

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