SEISMIC HAZARD ASSESSMENT OF HISTORIC RESIDENTIAL BUILDINGS BASED ON EXPERIMENTAL INVESTIGATIONS

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ABSTRACT:

In this paper current developments within the Austrian research project SESIMID are presented. The scope of SEISMID is to evaluate the seismic hazard of the Viennese basin. In a particular work package, which is subject of this paper, a simple and economically competitive methodology for the seismic assessment of historic buildings is under development. The approach combines experimental in-situ measurements and numerical analyses. Achievements and further steps of the conducted research are described.

KEYWORDS: In-Situ Measurements, Masonry Buildings, Material Testing, SEISMID

1. INTRODUCTION

A substantial amount of residential buildings in the urban areas of Central Europe are older than 90 years. In particular in the city centre of the Austrian capital Vienna approximately 32.000 houses were erected between 1850 and 1918, which is about one third of the present-day stock of buildings. Mostly, these structures have been retained unchanged without considerable structural improvement since decades. Those buildings are generally made of unreinforced masonry material, which makes them very vulnerable against horizontal loading. A particular problem is the reconstruction of historic residential buildings. Many of these objects are landmarked, and since space is limited for the construction of new houses, in the last twenty years unused attics of those buildings were converted into new apartments in order to recreate additional living space. The reconstruction and development of attics in historic buildings is regulated in national standards.

Before the responsible authorities permit the reconstruction of an attic, the seismic resistance of the complete building structure must be verified according to the actual standards. Recent investigations have revealed that in the past in Central Europe the earthquake hazard was underestimated considerably. Thus, in the related standards the effective seismic load was increased, see [Eurocode 8, 2005]. In Austria the new regulations come into effective in 2009. As a consequence for the majority of existing buildings the seismic resistance according to these standards cannot be verified when custom numerical methods of analyses are utilized. The reason is that the actual condition of the structural system of old buildings is in general hardly known, and hence the resistance of the structure against horizontal loads can only be considered at a very low level. There is also a lack of information on parameters of construction material utilized in ancient houses.

In 2007 the Austrian research project SEISMID, funded by the Center of Innovation and Technology ZIT, was established with the intention to evaluate the seismic hazard of the Viennese basin. In one work package of SEISMID a methodology is developed in order to assess the global seismic resistance of historic buildings close to reality. This methodology is based on a combined experimental-numerical investigation, see [Achs et al., 2007a and 2007b], and its implementation is supposed to be economically and sufficiently accurate for the prediction of the actual seismic resistance. In the following, actual achievements and progress of this work are described.

2. METHODOLOGY

The described methodology consists of a step-by-step seismic classification of the investigated building. In the first step a pre-evaluation of the structural seismic vulnerability is performed, which is mainly based on visual inspection. If a further assessment is necessary, the appropriate method has to be defined using a decision matrix. The next step comprises in-situ measurements in order to gather information about the dynamic parameters of the structure. For historic buildings this can be of great importance, because the structural parameters are very often unknown and material aging effects play an important role. Employing a finite element update procedure an appropriate numerical model can be extracted. Additionally, small and medium scaled laboratory tests are to be performed. They render actual material parameters, which enter the numerical model. Subsequently, the capacity spectrum method can be applied to the updated mechanical model leading to the seismic performance of the building structure [Achs et al., 2007a and 2007b].

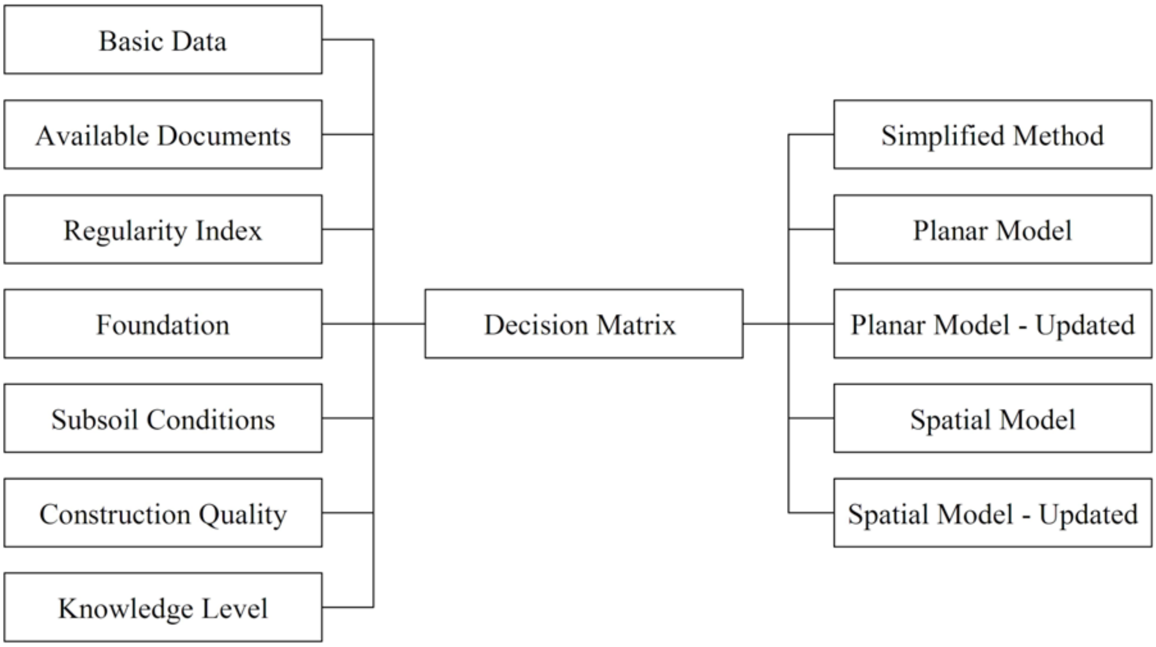

Figure 1 Principle procedure of the seismic pre-evaluation procedure

2.1. Pre-evaluation

Several procedures have been proposed to classify and categorize building structures with respect to the seismic vulnerability, see e.g. [FEMA 154, 2002], [FEMA 155, 2002], [BWG, 2005], [Rusnov, 2006]. Within the project SEISMID an electronic pre-evaluation tool has been developed in order to classify the vast number of historic residential buildings. This tool interrogates general parameters of the investigated object, which are utilized to categorize the building structure. Figure 1 shows a simple decision matrix for selection of the appropriate methodology for further investigations. The evaluation of most of the building parameters is supposed to be done on site. As an example in Figure 2 the validation of the building regularity using drop-down buttons is presented. Once the input parameters of the pre-evaluation procedure are set, the adequate method of analysis is recommended automatically. The application of this tool is simple and straight forward.

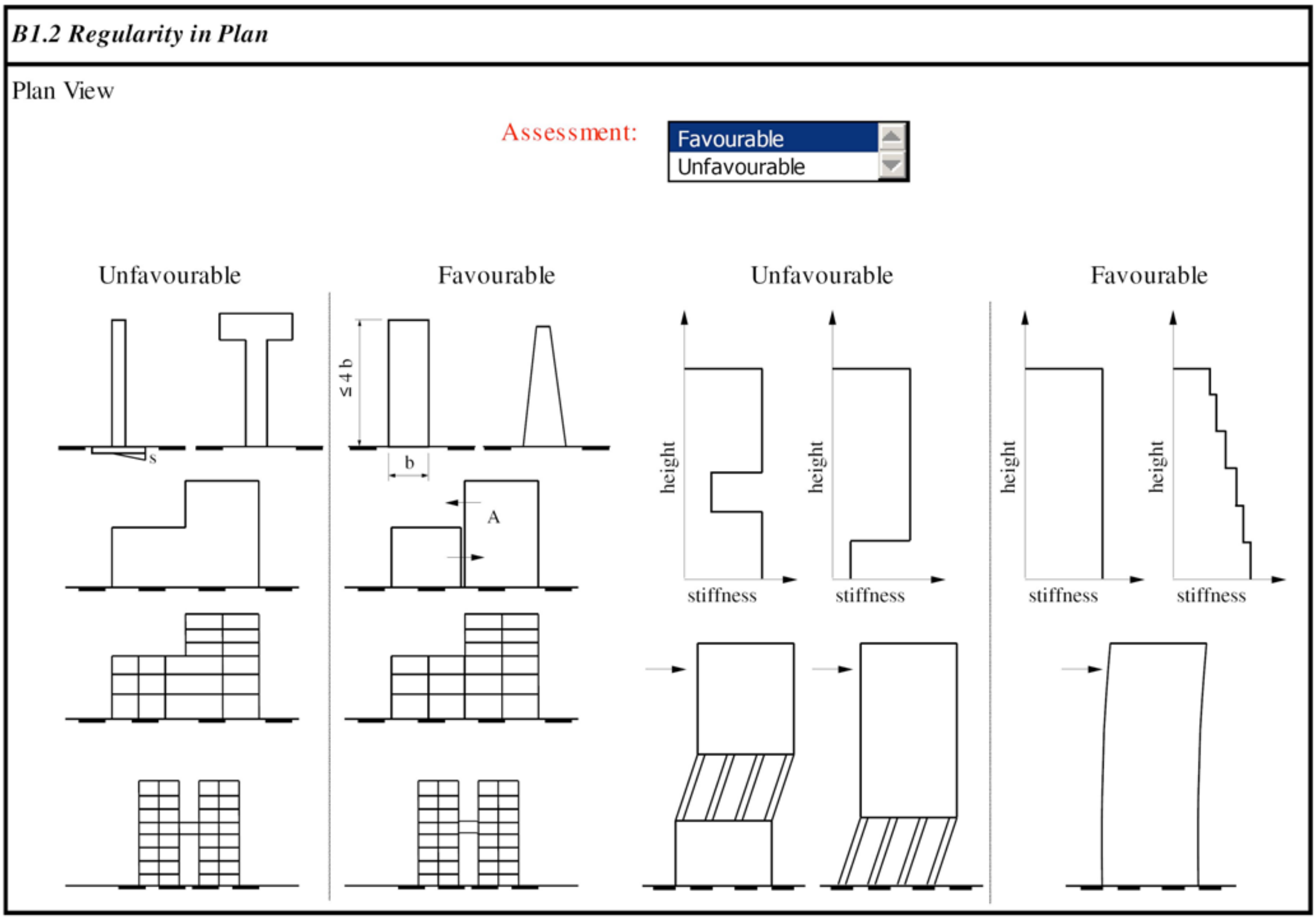

Figure 2 Pre-evaluation: subdivision of the regularity in plan.

2.2. In-situ measurements

Seismic analyses are based on basic dynamic parameters of the considered object such as natural frequencies, the corresponding mode shapes, and damping coefficients. For existing buildings these parameters are determined beneficially from data recorded by in-situ measurements, in particular when the structural system and built-in materials are unknown. Thereby, accelerometers are distributed on the story levels on top of each other. In Figure 3 the experimental test set-up utilized in a building is shown.

Depending on the type of building and the available measurement the dynamic parameters may be extracted from [Achs et al., 2007a]:

(a) the ambient vibrations response or
(b) the free vibration response following an impulse load applied with an impulse hammer.

The dynamic time history response is recorded in three directions by means of force balance accelerometers. If reasonable, the evaluation of the data is confined to one building axis, where the structure is most vulnerable, and effects of torsion or coupled bending torsional vibrations can be neglected. The natural frequencies of the building structure are determined by transforming the time-history signals of each sensor into the frequency domain by Fast-Fourier-Transformation. Depending on the recorded data the mode shapes are evaluated in the time domain or in the frequency domain.

Exemplarily, in Figure 4 the first two bending modes of a typical historic residential building are shown, which were determined from the measured dynamic response of the building.

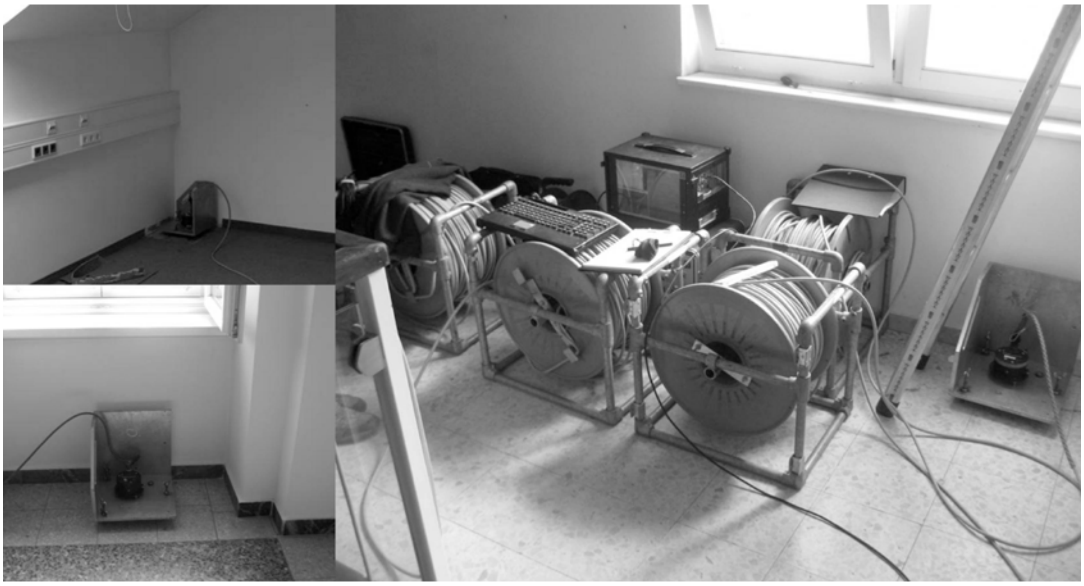

Figure 3 Test set-up for in-situ measurements

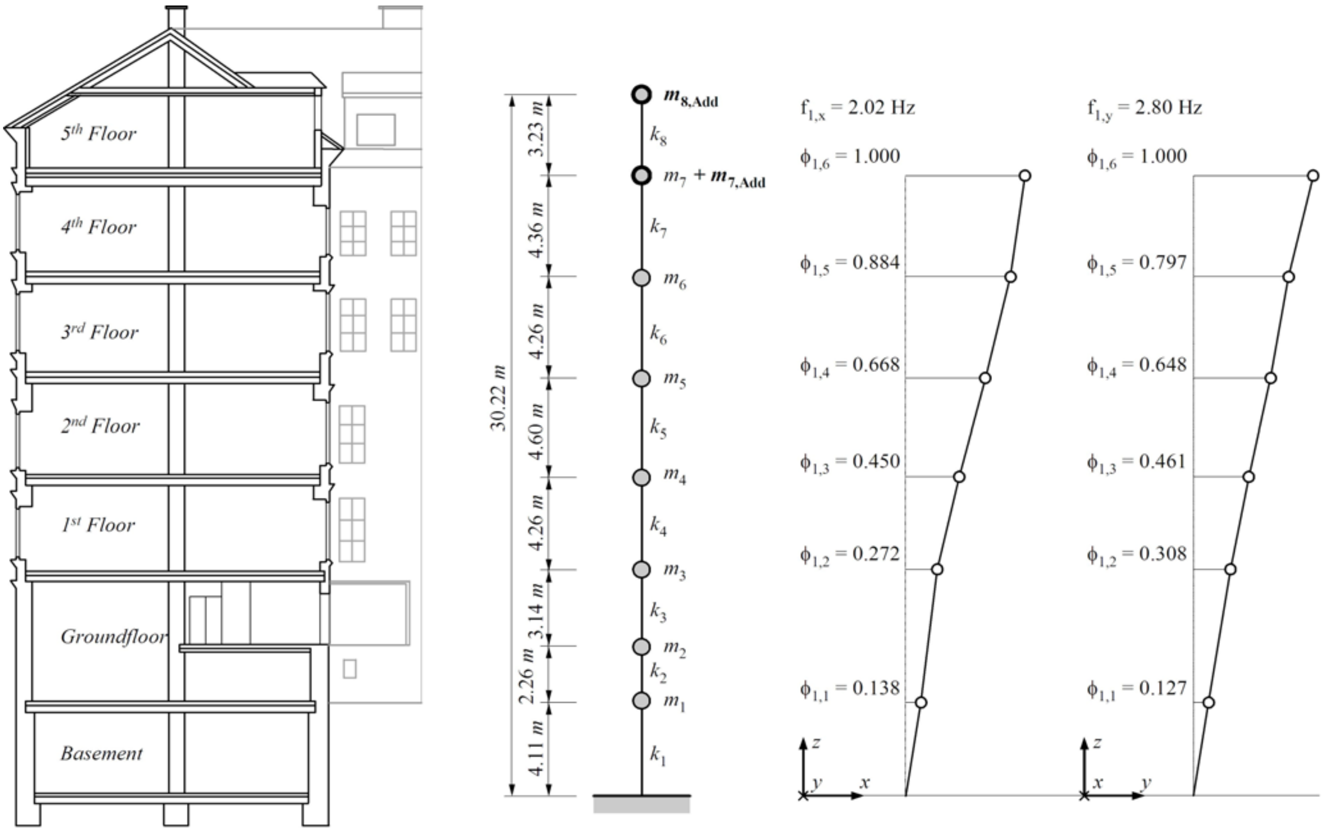

Figure 4 Natural frequencies and mode shapes of a historic residential building, extracted from the recorded dynamic response

2.3. Finite element model update

An estimation of the distributed stiffness of the investigated building can be found utilizing the equations of motion of a simplified mechanical model. Thereby, the structure is considered as a multi-degree-of-freedom (MDOF) system with lumped masses at each story level. The MDOF model is an approximation based on several assumptions and, thus there are differences to the real structure. The accuracy of the system is improved calibrating the dynamic parameters with the outcomes from in-situ measurements. For this purpose a numerical updating procedure is utilized. In general finite element model updating can be performed using direct or iterative methods [Friswell and Mottershead, 1995]. The former has the advantages that no iteration is required and measured data are reproduced exactly. However, if the measured data are inaccurate (or correspond to a highly nonlinear system) a model with no physical meaning may be obtained. In contrast, iterative methods based on non-linear penalty functions, which are minimized through subsequent linear steps, require more computational time.

For the procedure proposed in this project, a sensitivity-based iterative method is utilized [Mordini et al., 2008]. The computational technique is carried out by VCUPDATE, an iterative updating algorithm implemented in Scilab [Scilab], which is interfaced with the finite element code OpenSees [OpenSees].

2.4. Material testing

In general there is a lack of information about the actual condition of the material built-in in historic buildings. Thus, there is a need to determine experimentally these material parameters. The walls of most of the historic buildings in Central Europe are made of masonry consisting of bricks and mortar.

2.4.1. Small scale tests

Within the SEISMID project a scheme for small-scale experimental tests is developed in collaboration with the laboratory of the University of Innsbruck. For bricks taken from historic objects the following parameters are to be determined experimentally:

- Comprehensive stress
- Tensile strength
- Flexural tensile strength
- Static Young’s modulus
- Dynamic Young’s modulus
- Fracture Energy
- Poisson’s ratio

For example, in Figure 5 small brick cubes are shown, which were tested in the laboratory of the University of Innsbruck. The bricks of this test series were taken from historic residential buildings in Vienna.

Furthermore, the chemical configuration, comprehensive strength and shear strength of historic mortar need to be identified.

Additionally, it is planned to test simple composite brick-mortar specimens to identify their shear strength.

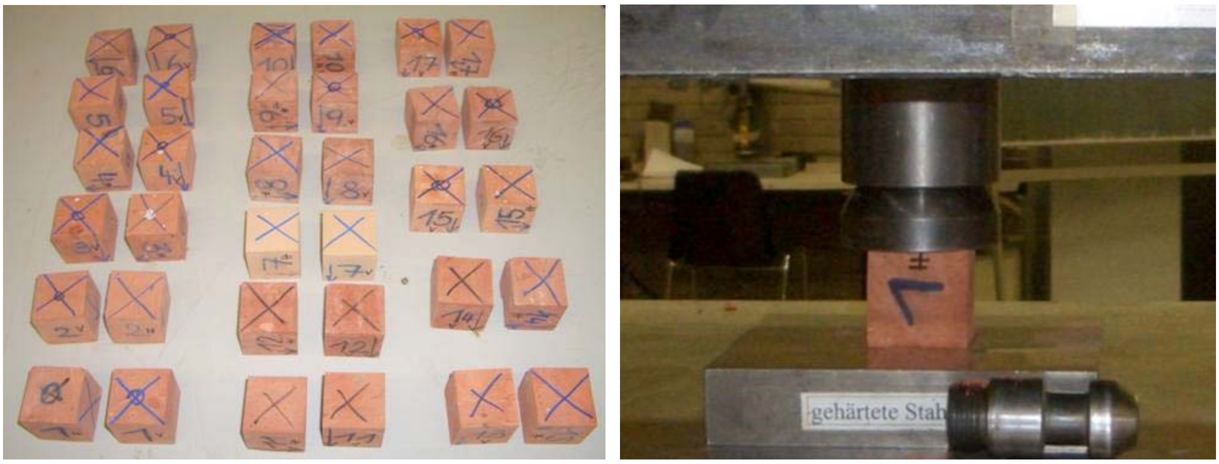

Figure 5 Laboratory testing of brick specimens in laboratory of the University of Innsbruck

2.4.2. Medium scale tests

In the next step dynamics tests on medium-scale test specimens will be performed. A series of shear walls composed of historic bricks and reproduced mortar, whose mixture is based on outcomes of the first test series, are manufactured and subsequently tested under cyclic loading. This test set up has been developed by the SEISMID project partner University of Natural Resources and Applied Life Sciences in Vienna (Strauss, 2008). A scetch of the test set-up of a masonry specimen is depicted in Figure 6 (Strauss, 2008). These experiments will be conducted at the University of Natural Resources and Applied Life Sciences.

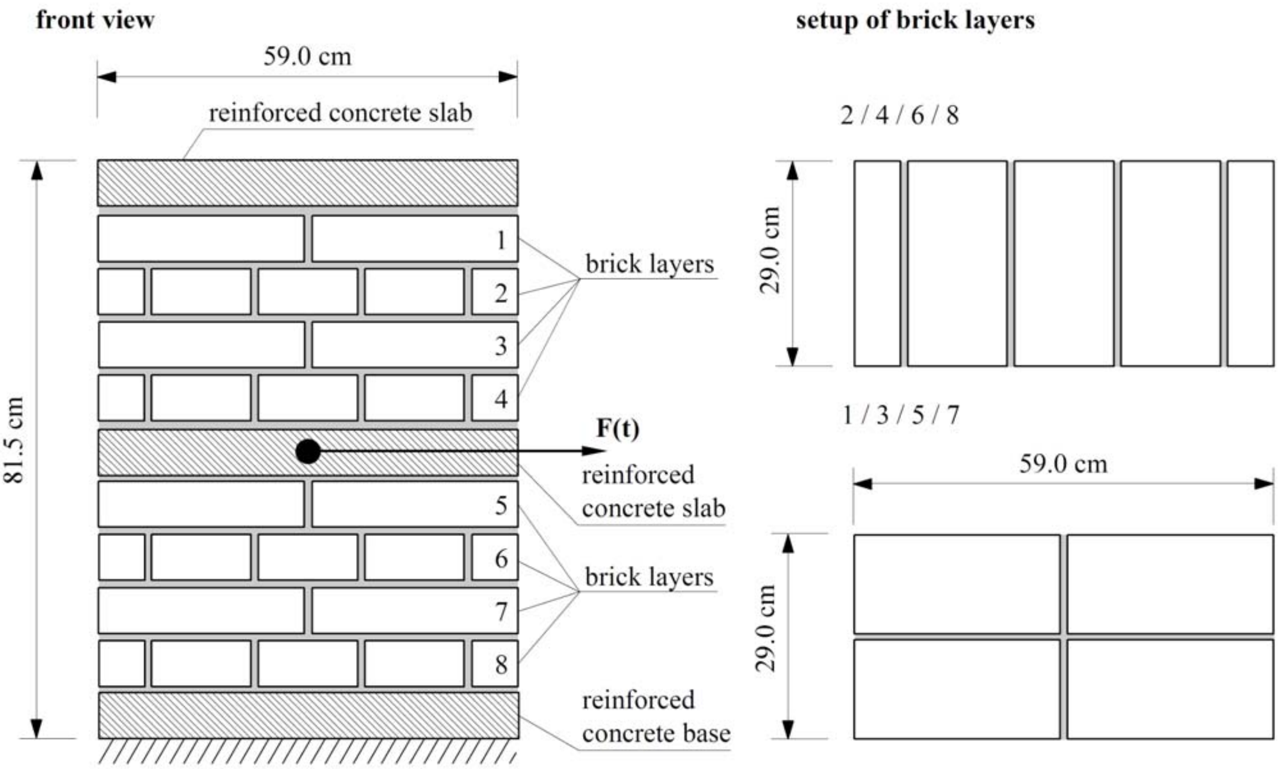

Figure 6 Medium scaled masonry specimens for dynamic tests with a horizontal cyclic load F(t), two different set-ups of brick layers

2.5. Capacity curve

The performance of the historic residential buildings under seismic loading will be estimated by means of the capacity spectrum method [ATC-40, 1996]. The simplified mechanical model obtained from the experimental analysis and the finite element update procedure is subjected to a pushover analysis, which yields the capacity curve of the structure. The pushover analysis facilitates the consideration of material nonlinearities of the structure. Using an appropriate demand spectrum, the superposition with the capacity curve renders the initial value of the performance point of the building subjected to a given seismic input.

3. CONCLUSIONS AND OUTLOOK

In recent years the realistic seismic hazard assessment of buildings has become much more important, mainly induced by tightened requirements of modern codes and guidelines. In particular the reconstruction of historic residential buildings is strongly affected, whereby the economic loss caused by the decline of renovated houses is substantially high in the city centre of Vienna. Thus, the Austrian research project SESIMID has been initiated to assess the seismic hazard of the Viennese basin.

A combined numerical - experimental seismic analysis is proposed, which is based on in-situ measurements of the building structure. The assessment of the dynamic parameters such as natural frequencies and mode shapes is done by the evaluation of the recorded vibration response. The stiffness of the structure is estimated utilizing a finite element model update procedure. Subsequently, the seismic vulnerability of the building will be verified utilizing capacity curves. Therefore, it is necessary to evaluate the material parameters of those buildings within extensive laboratory tests.

Finally an economic and proper methodology must be developed in order to assess the huge stock of residential buildings in the historic city centre of Vienna.

4. ACKNOWLEDGEMENTS

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