

SEISMIC MICROZONATION IN THE VIENNA BASIN

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ABSTRACT

The reassessment of the seismic risk in countries north of the Alps has brought considerable changes in civil engineering. Until 1998 wind loads guided the design regarding horizontal resistance. International standards and national regulations have made the seismic load case guiding the process now. A strict application of the code means that the vast number of structures in the Vienna basin does not conform to the design guidelines. The proposed methodology consists of two different tools which are used to reach a realistic assessment of seismic loads on existing structures. First of all the proposed and well-known microzonation study of urban areas leads to adapted soil amplification factors which have been given very generally by the code up to now. In a second step the actual resistance of a building is verified, which in most of the cases is considerably higher than the design resistance.

These two methodologies were combined for residential buildings and are currently applied in a major national project. A microzonation study is done using a grid of 200 by 200 m over the whole city of Vienna to make the existing risk map more precise. In addition a methodology for vibration measurement of existing buildings has been developed, which allows the calibration of numerical models and is able to verify structural changes due to aging of buildings.

Keywords: Residential Buildings, System Identification, Microzonation, In-Situ Measurements

INTRODUCTION

Various projects in the field of research and development of seismic hazard analysis led to a very careful handling of seismic demand in the last few decades. A noticeable amount of them was concentrated on the field of seismology resulting in the fact that many existing urban areas are situated in previously “quiet” zones.

In Austria earthquake hazard prediction has dramatically changed in the last few years. Due to several investigations of scientists of the University of Vienna [Hinsch and Decker, 2003] different seismic slip rates of various sectors of the Vienna Basin Transform Fault (VBTF) indicate locked fault elements. According to their estimation they predict a strong-motion earthquake of a magnitude of at least $M = 6.1$ to normalize the slip rate of the slowest sector of the VBTF to the rate of the fastest sector.

To evaluate the structural parameters for a seismic hazard analysis as precisely as possible it is necessary to combine numerical methods with experimental examination. Due to the changes in international regulations the seismic resistance of existing residential building structures has to be evaluated. Particular in the stage of reconstruction of these buildings a comprehensive analysis has to be carried out. Typically numerical simulations do not consider the changes of the dynamic behaviour with elapsed time. The reasons for these changes are the aging of material and the

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structural discrepancies with the initial state. To determine these fundamental effects, periodical measurements of the dynamic parameters can implicate major advantages.

To meet the above mentioned requirements for an advanced assessment of seismic vulnerability of residential buildings, the proposed method consisting of a semi-empirical approach was developed and verified.

ECONOMIC RELEVANCE

The changes of international standards and their applications in national regulations have resulted in considerable changes in seismic hazard analysis. One of the most drastic and effective parts of these regulations is controlling the assessment and strengthening of existing buildings. It is a matter of fact that seismic demand was not considered during the construction of most of the older buildings. Therefore it is proposed in Eurocode 8 that these buildings need to be reconstructed and reinforced. On the one hand this is absolutely necessary for the reliability of the structure, on the other hand this can be one of the most serious economic problems for the city of Vienna.

About 32.000 (one third of all buildings) residential buildings in Vienna were erected at the beginning of the last century. According to Eurocode 8 it would be necessary to investigate these buildings to fit the regulations.

On the other hand, according to the findings of the scientists of the University of Vienna [Hinsch and Decker, 2003], it is indispensable to enhance the safety measures for the whole region. Regarding the social and economic importance of this area (about 2.4 million inhabitants producing 45% of the Austrian GDP) it will be strongly recommended to determine possible site-effects, enforce the proposed microzonation and enhance the evaluation of actual dynamic parameters using system identification techniques.

SEISMIC MICROZONATION STUDY

Introduction

In the current national research project SEISMID, the H/V-Method according to Nakamura [Nakamura, Y., 1989] was used to identify the influence of local soil conditions. The method is very effective and economic so that a meaningful local amplification factor can be determined. According to the importance of the location and the areas with already known soil conditions a measurement grid was developed. After the determination of the amplification ratios the values are transformed into a GIS-based seismic hazard map [Wenzel, H., 2006]. Therefore the method can be used as a basic decision-support device for many purposes.

Progress of Measurements

In order to perform a well organised measurement campaign it is necessary to divide the urban area into different working-phases.

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| Phase 1: | 1 st , 2 nd and 20 th district | (including a particular consideration of historic buildings and monuments of the 1 st district) |
| Phase 2: | 3 rd - 9th district | (main residential districts with old buildings) |
| Phase 3: | 10 th - 19 th , 21 st – 23 rd district | (remaining districts) |

In principle the measurement grid consists of a 200 x 200 m grid in areas with uniform and well known subsoil whereas the grid was reduced to 50 x 50 m in areas with inhomogeneous subsoil conditions. It is also necessary to reduce the grid around important objects (historic monuments,

bridges, industrial buildings etc.). The measurement procedure of the microzonation study in Vienna can be seen in figure 1.

Determination of H/V-Ratio

The amplification factor is evaluated using the H/V-Ratio according to Nakamura [Nakamura, Y., 1989]. The method was successfully accomplished in countries with moderate seismicity where no strong motion data was available and is therefore convenient for almost every region in Europe. In general the input for the H/V-Computation can also consist of transient or even ambient excited signals.

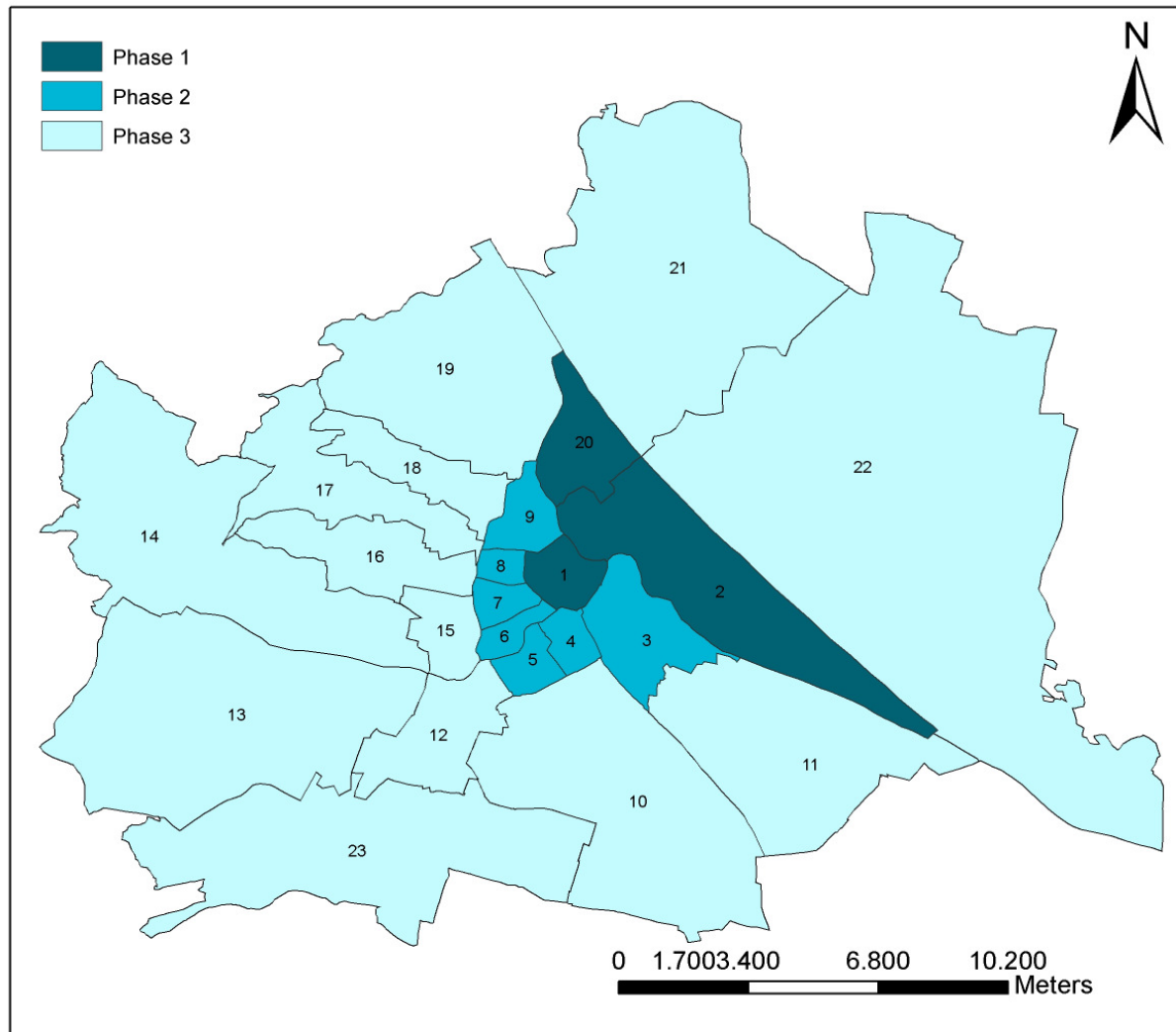


Figure 1. Measurement procedure for the microzonation-study in Vienna.

In case of the proposed measurements of the amplification factor it is more beneficial to use ambient excitation because the large number of samples which are needed for statistical evaluation would, in case of transient excitation, lead to unacceptable disruption for occupants. During the SEISMID project an ambient vibration technology for seismic microzonation was applied, which was also used in former projects, see e.g. the SESAME-project [SESAME European research project, 2004]. The evaluation of the measured acceleration signals in the time domain is performed using the following algorithm:

- 3-dimensional input (North-South, East-West and vertical components)

- Windowing of the signal
The acceleration signals in the time domain are divided into several windows with a defined overlap. In this case transient parts of the signals are not used for the H/V determination.
- Offset-removal
- Main Data-Processing:
The different windows of the signal are considered separately (n-steps of main data-processing according to the numbers of separated windows).
 - Filtering of the signal using a Butterworth bandpass-filter
 - Transformation in the frequency domain using Fast Fourier Transformation (FFT)
 - Smoothing of the three spectral amplitudes
 - Computation of the resulting horizontal component as the quadratic average of the North-South and East-West component
 - Evaluation of the H/V-Value as the logarithmized ratio of the resulting horizontal component and the vertical component
- Average of the H/V-spectra over the predefined number of windows.
- Statistical evaluation

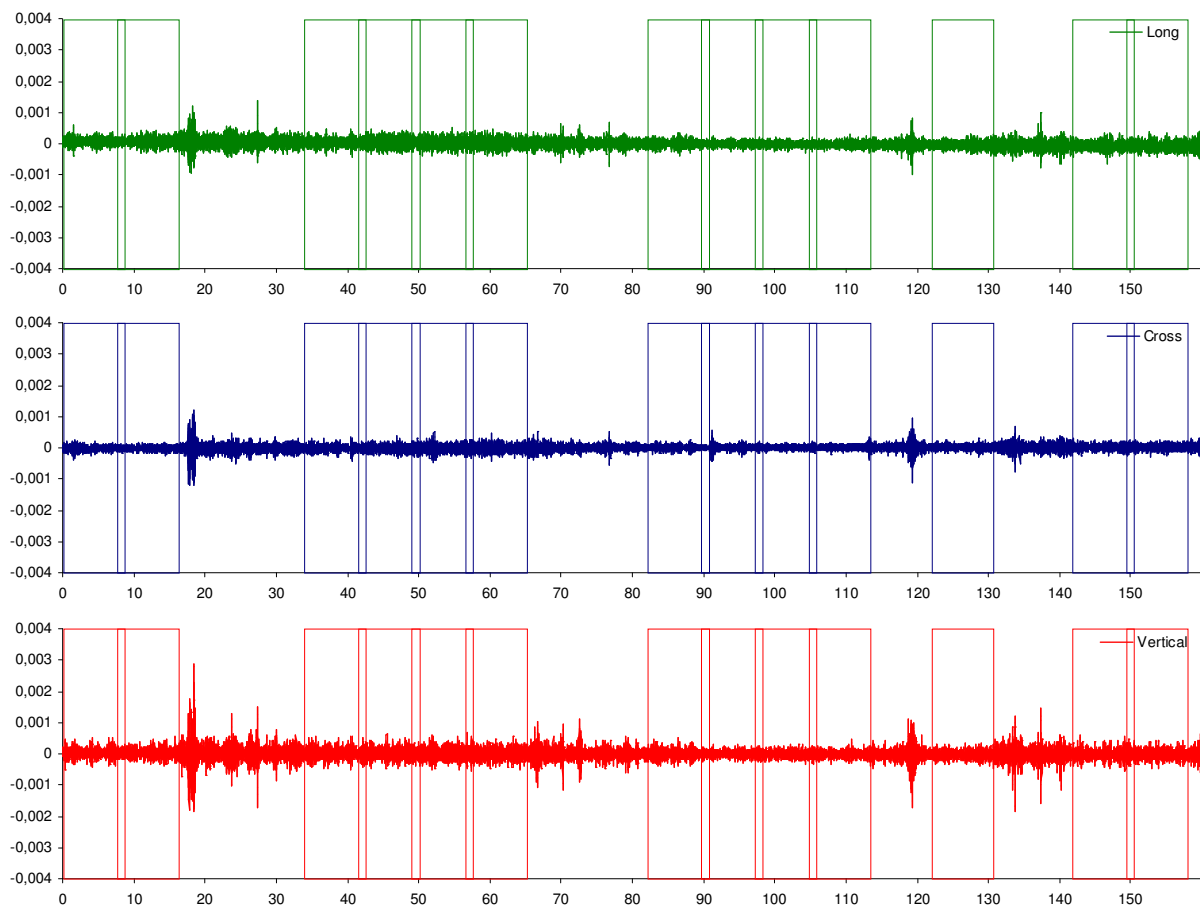


Figure 2. Windowing of the three different components of the recorded acceleration signal.

Seismic Hazard Map

The main intended purpose of the microzonation study in Vienna is the implementation of the results in the existing catastrophe management. To identify the most vulnerable parts of an urban area it is indispensable to use a seismic hazard map. This is primarily useful to organize the rescue teams in case of a tremendous earthquake event. In addition the identification of the most vulnerable seismic zones within the city can have a direct influence on urban planning. In case of existing public utilities and infrastructure in very vulnerable areas it may have an influence on the ongoing safety precautions. Therefore the main utilizations of a seismic hazard map can be listed as:

- Additional tool for the catastrophe management
- Implementation on urban and regional planning
- Attachment for national building regulations
- Decision support for insurance companies

The following figure shows the implementation of the measurement results of the H/V-amplification ratio into a seismic hazard map using a Geographic Information System GIS.

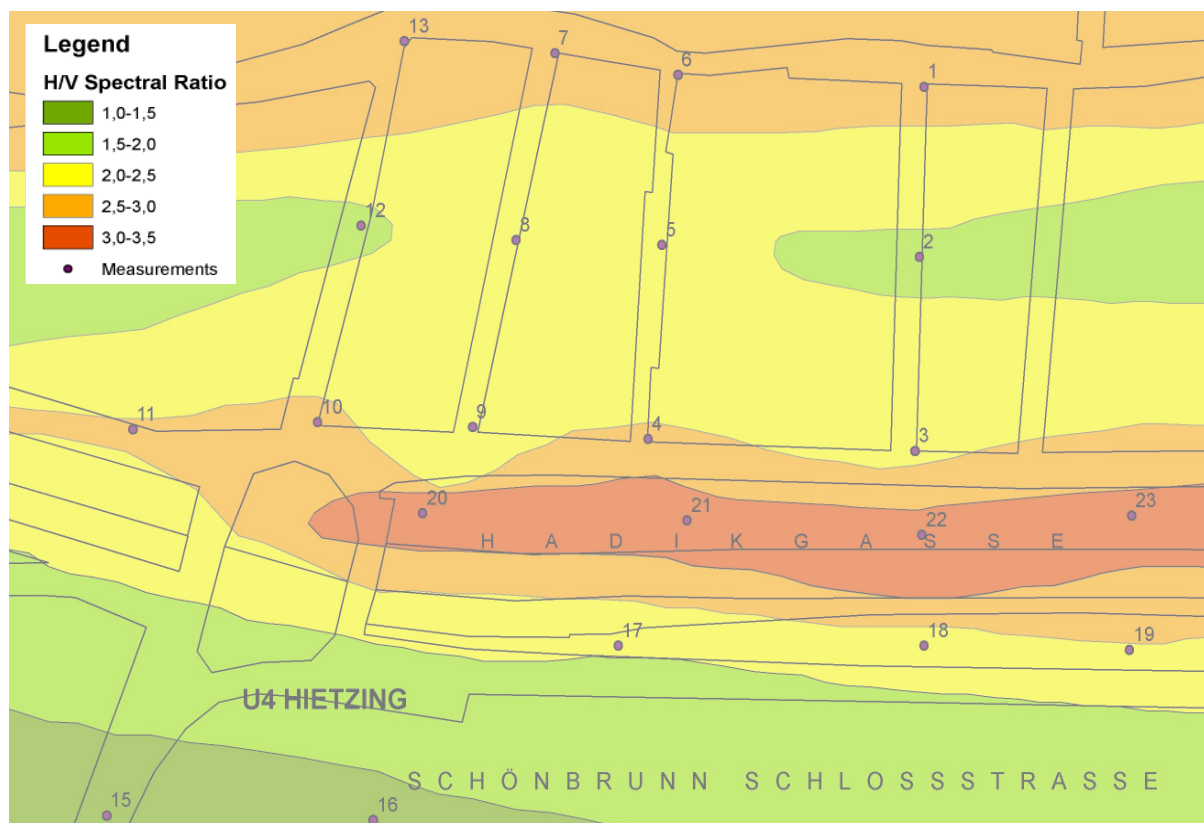


Figure 3. Seismic hazard map - part of the 14th district of Vienna.

Future prospects

The successful application of the proposed method in Vienna should be applied to other regions in Austria with a similar potential of underestimated earthquake events. In general, apart from the Vienna basin area, the western and southern part of Austria (Tyrol, Carinthia and Styria) is the most endangered zone. In the following the number of threatened inhabitants is listed, considering the whole provinces:

- Tyrol: 694 000 inhabitants
- Carinthia: 560 000 inhabitants
- Styria: 1 200 000 inhabitants

SYSTEM IDENTIFICATION OF RESIDENTIAL BUILDINGS

Introduction

As mentioned before the changes in the international standards (Eurocode 8) and their application to national regulations have brought considerable changes in the assessment of residential buildings. The most meaningful fact is that changes in the structural parts of an existing building (e.g. reconstruction of the attic) will cause the need of an overall seismic hazard analysis of the whole building. It is therefore necessary to offer an accurate but economic analysis to verify the structural safety in case of seismic demand.

The developed method will combine the numerical model with in-situ measurements so that the reliability of the analysis increases.

Progress of Measurements

The in situ tests were conducted as both ambient and transient excited vibration measurements. The distribution of the accelerometers inside the building is shown in figure 4.

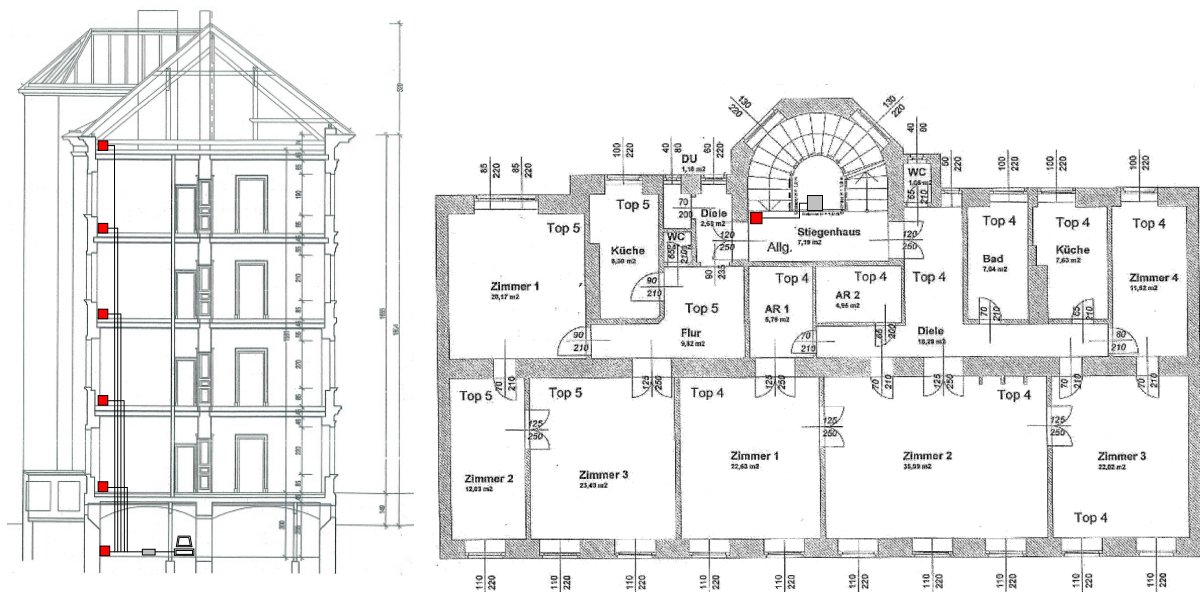


Figure 4. Cross section and outline of a typical residential building in Vienna; test set up (accelerometers) for dynamic measurements.

To identify the most vulnerable direction of the building structure in the horizontal plane it is on the one hand necessary to identify the weak direction (which is obvious for regular outlines) of the structure itself and on the other hand it is very important to have extensive knowledge about the regional seismology. As this is often not definitely known in advance, the measurements were conducted with three-dimensional accelerometers.

Measurement results

As most of the investigated building structures have a regular outline with a cross-section ratio of width to depth of at least 2:1 the primary results were evaluated for the weaker direction. This assumption is also supported by the fact that the residential buildings in Vienna were built very close to each another.

To supply the numerical model as well as possible, the following dynamic parameters should be determined by the measurements:

- Natural frequencies
- Corresponding mode shapes
- Damping coefficients

In addition to the dynamic measurements it is necessary to identify the structural mass of the system. A typical spectrum of a residential building in its weak horizontal direction is shown in figure 5.

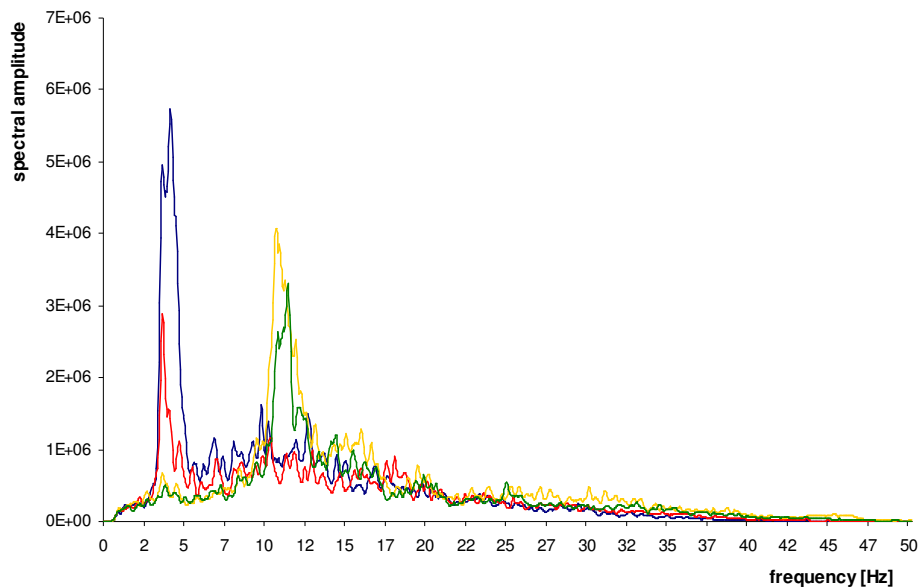


Figure 5. Natural Frequencies of the investigated structure in the weak horizontal direction.

Numerical model

Before the numerical model of the investigated building structure can be evaluated, the distributed stiffness of the building has to be evaluated. Therefore it is necessary to run an adopted Finite-Element-Update code [Mordini, A., 2006] whereby the natural frequencies and mode shapes are used as input values.

After the determination of the distributed stiffness the numerical model can be evaluated. As shown in figure 6, the storey masses are lumped to the frame nodes. According to the construction of the residential buildings the following assumptions have to be made:

- Due to the very stiff basement, the dynamic model is fixed at the ceiling of the basement.
- The wooden ceilings of the residential buildings are only supported in vertical direction and therefore considered as flexibly connected to the structural walls.

The transformed model of the residential building can be seen in figure 6.

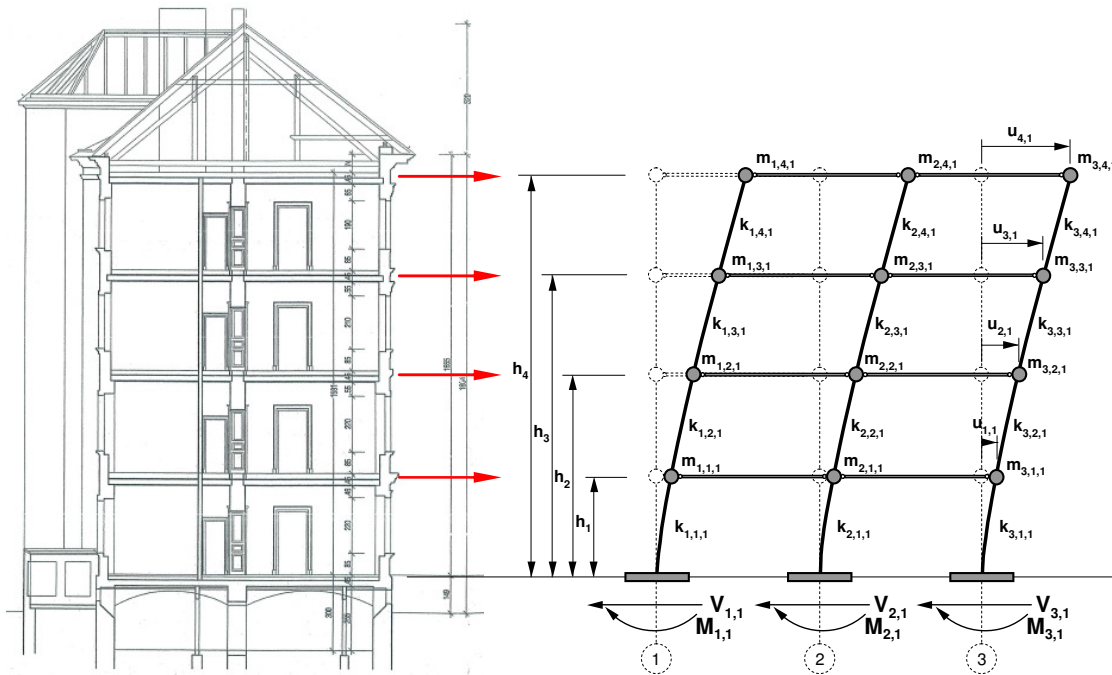


Figure 6. Transformation of existing structure into the numerical model.

In many cases, the reconstruction of residential buildings concerns the unused attics. After the implementation of several flats it is obvious that the structural mass in the last storey is increasing tremendously. The consequence of this additional mass is a change of all dynamic parameters. If the structure itself remains unchanged the reconstruction can be easily modelled, illustrated in figure 7:

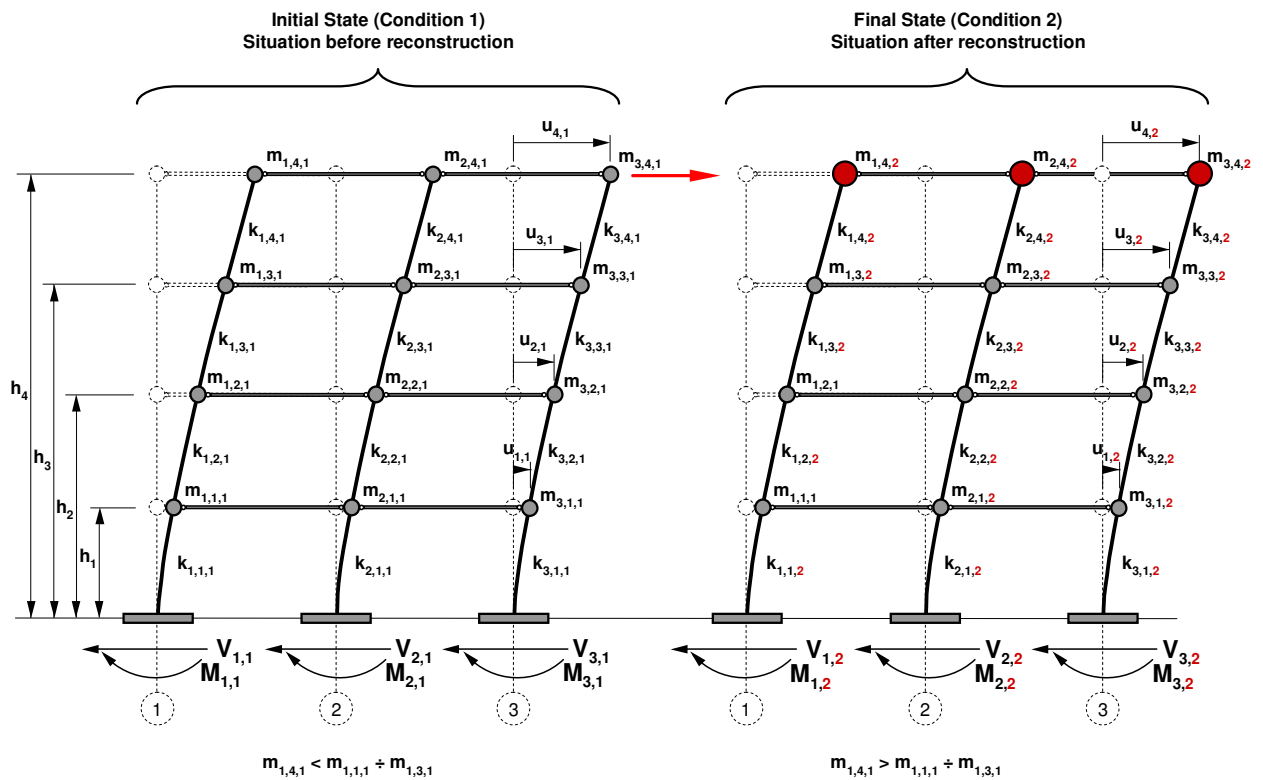


Figure 7. Consideration of reconstruction measures in the numerical model.

To determine the actual bearing capacity, the capacity spectrum method is used. In the following figure the methodology of the determination of capacity curves for residential buildings is described.

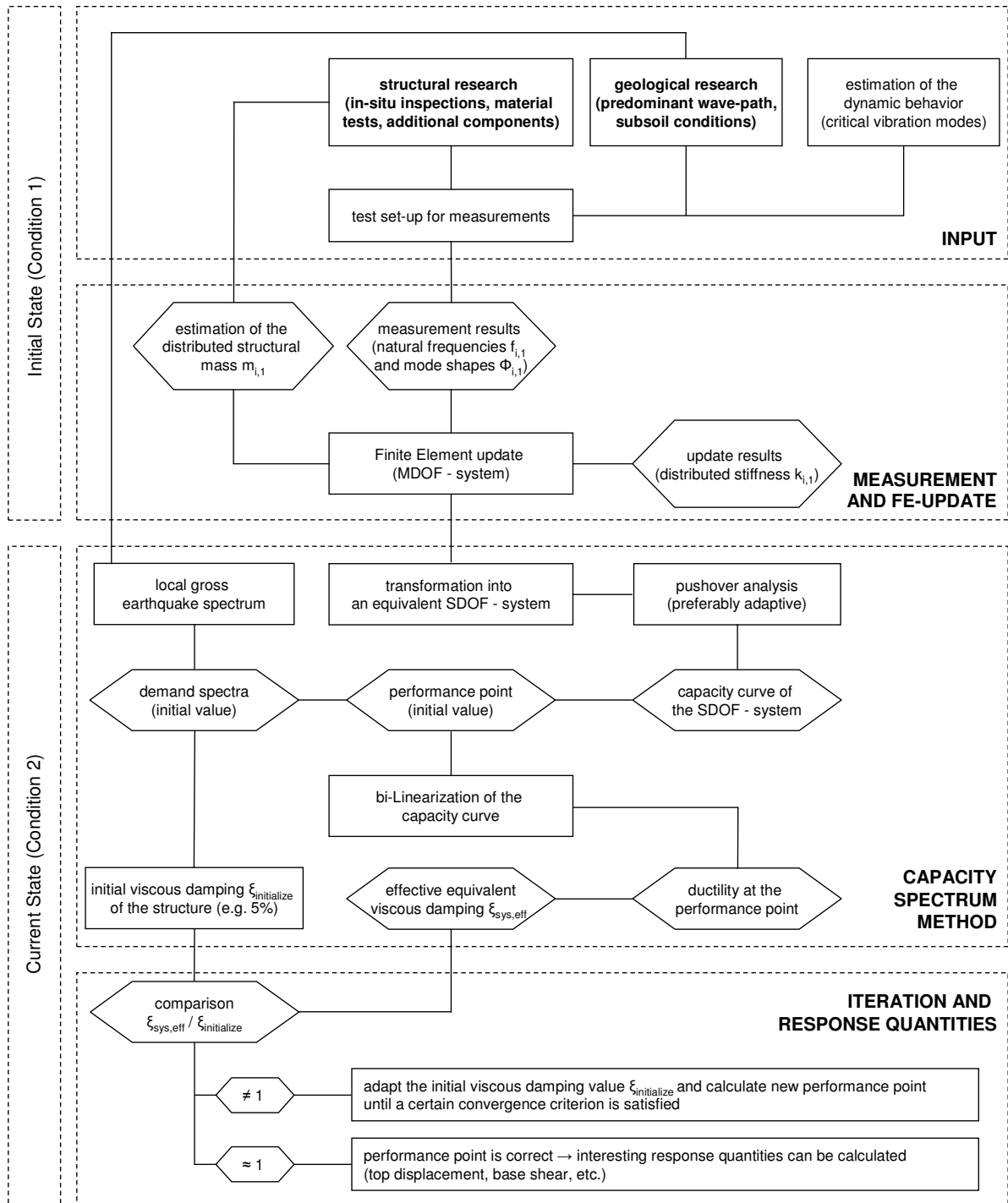


Figure 8. Flow chart - determination of the actual bearing capacity using the capacity spectrum method.

Capacity Spectrum Method

To determine the dynamic response of the reconstructed residential building in comparison to the initial state, it is common to use the capacity spectrum method. Therefore the MDOF-system of both states (initial and reconstructed) is subjected to a static pushover analysis, which is preferably performed using the displacement-based adaptive pushover technique [Pinho, R., 2006]. The basic

assumption of this technique is that the response of the system is controlled by the fundamental mode shape which is not changing with structure yields and plastic hinges. The innovative adaptive pushover analysis computes the shape of the load vector in each analysis step and therefore can account for problems arising from the disadvantages of conventional methodologies. After the pushover analysis is performed, in a first step it is necessary to transform the MDOF-System into an equivalent SDOF-System in order to determine the capacity curve. Subsequently the capacity curve of the equivalent SDOF-System can be plotted. The computation of the performance point requires the calculation of the demand spectrum of the investigated building structure. To calculate a realistic seismic demand the following considerations have to be taken into account.

- Source considerations (active and capable faults)
- Size characterization (maximum magnitude, duration)
- Recurrence rate
- Attenuation relationships
- Site effects (soil amplification, consideration of soil-structure interaction effects)

If the seismic demand curve is calculated with respect to all of these terms, it can be plotted against the capacity curve of the equivalent SDOF-System whereas an initial viscous damping value has to be estimated. After the bi-linearization of the computed capacity curve the ductility of the equivalent SDOF-system can be calculated and the effective viscous damping of the system can be computed. Afterwards it has to be compared with the initial viscous damping value. If the values do not correspond a new initial viscous damping value has to be chosen and the iteration has to be repeated until a certain convergence criterion is satisfied. After all, the response quantities of interest can be computed.

OUTCOMES AND FUTURE PROSPECTS

The changes of international and national regulations have brought considerable restrictions in seismic hazard engineering. Once these codes are valid a vast number of structures in the Vienna basin is not conform to the design guidelines in advance. As the actual resistance against seismic demand is generally underestimated, it is necessary to adopt assessment of building parameters. Therefore the proposed method should ensure the determination of the real structural stiffness.

To reach a realistic assessment of seismic loads on existing structures, the SEISMID-methodology consists of two different parts. On the one hand the proposed microzonation study of urban areas leads to adapted soil amplification factors which have been given very generally by the code up to now. On the other hand the actual resistance of a building is verified, which in most of the cases is considerably higher than the design resistance.

Microzonation

The microzonation study is done using a grid of 50 by 50 m (up to 200 by 200 m in zones with well-known subsoil conditions) over the whole city of Vienna to make the existing risk map more precise. The results of the investigations should be used in the existing catastrophe management (seismic hazard maps).

In the next step the information gained by the measurements should be implemented in a virtual map and published online.

System identification of residential buildings

The investigation of existing buildings allows the calibration of numerical models and is able to verify structural changes due to the aging of buildings. The main purpose of the measurements is to identify the structural stiffness.

Furthermore several reference objects should be evaluated in order to develop an automated methodology because, considering the very exact restrictions of the international regulations, the demand for a detailed estimation of the actual structural parameters can be enormous.

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