Recent Actions Taken in Austria towards Seismic Risk Assessment and Reduction

C. Adam
Department of Civil Engineering Sciences, University of Innsbruck, Austria

SUMMARY:
In Austria a vibrant community of researchers and practitioners is involved in activities aiming at assessing and reducing the seismic risk. These activities are conducted on a larger scale within funded research projects, or they are based on individual research efforts. This paper gives an overview of the seismic network and infrastructure in Austria, historical earthquake research, research activities on the seismic assessment of historical and modern buildings, and further developments on passive and semi-active seismic control devices.

Keywords: Austria; Seismic hazard; Seismic risk assessment; Seismic risk reduction

1. INTRODUCTION

1.1. Seismic Hazard in Austria

Austria is partially located in a moderate seismic zone. The most active seismic regions are the Vienna Basin, the Mürz Valley (*Mürztal*), and the Inn Valley (*Inntal*) in Tyrol, compare with Fig. 1. The southern part of Carinthia may be subjected to moderately large earthquakes, which have their origin in Italy and Slovenia. In average, every three years an earthquake of intensity 6 according to EMS-98 (Grünthal 1998) occurs, every 15 years an earthquake of intensity 7, and every 75 years an earthquake of intensity 8. The focal depth of most earthquakes is about 7 to 8 km. Earthquakes of lower focal depth occur mainly in the eastern part of the Vienna Basin and in the Bohemian Massif (ZAMG 2012c). Fig. 1 shows the seismic zones according to the last version of the Austrian Standard ÖNORM B4015 (2002) before Eurocode 8 (EC8 2004) came into effect. According to this standard Austria is divided into five seismic zones. Zone 1 with low seismic risk exhibits an effective horizontal acceleration smaller than 0.35 m/s^2, while in zone 5 the effective acceleration is larger than 1.00 m/s^2.

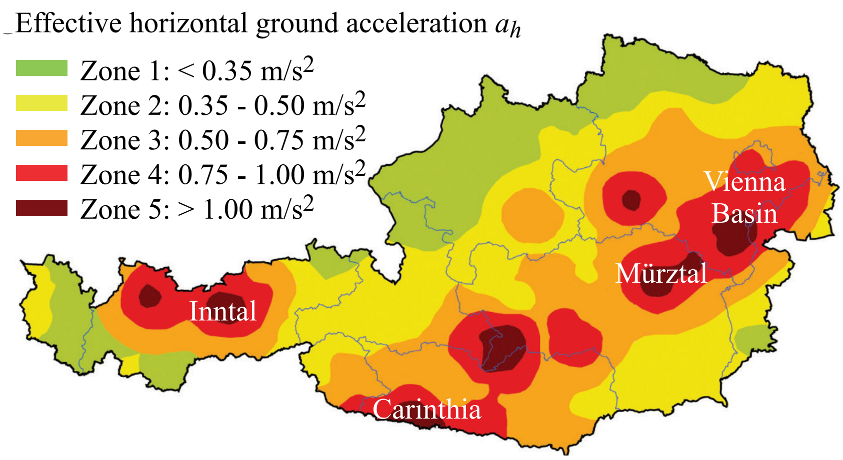

Figure 1. Seismic zones in Austria (ÖNORM B4015 2002)

The last earthquake of intensity 8 occurred on October 8, 1927 in the village of *Schwadorf*, southeast of Vienna. The earthquake caused severe damage to the property in *Schwadorf* and in the neighborhood. The latest more severe earthquake took place on April 16, 1972 in *Seebenstein*, which is located in the southern part of the Vienna Basin. The impact of this earthquake could also be felt in Vienna, where several buildings and numerous chimneys were damaged. In Fig. 2 the epicenters of historical moderately large earthquakes in the Vienna Basin are depicted. Red-colored dots mark larger seismic events and additionally, year and estimates of the magnitude are specified.

1.2. Austrian Research Institutions Involved in Seismic Risk Assessment and Reduction

Research on the seismic hazard in Austria is conducted at the University of Vienna (Department of Meteorology and Geophysics: Prof. Götz Bokelmann; Department of Geodynamics and Sedimentology: Dr. Kurt Decker), Vienna University of Technology (Institute of Geodesy and Geophysics, Research Group Geophysics: Prof. Ewald Brückl), and University of Innsbruck (Institute of Geology and Palaeontology: Prof. Bernhard Fügenschuh). The Central Institute for Meteorology and Geodynamics - ZAMG (Doz. Dr. Wolfgang Lenhardt, Dr. Christa Hammerl) is a non-academic public research facility, which maintains an advanced infrastructure for seismic monitoring throughout Austria. The seismic hazard map of Austria is essentially based on the research of ZAMG.

In the field of earthquake engineering the Vienna University of Technology (Institute of Building Construction and Technology: Prof. Christian Bucher, Prof. Rudolf Heuer, Prof. Andreas Kolbitsch, Prof. Franz Ziegler), the University of Innsbruck (Unit of Applied Mechanics: Prof. Christoph Adam), and the University of Natural Resources and Life Sciences (Institute of Structural Engineering: Prof. Alfred Strauss) contribute substantially on the academic level. The Department Mobility of the Austrian Institute of Technology - AIT Mobility (Prof. Rainer Flesch) is a partially public non-academic research facility involved in earthquake engineering research.

Several private companies and (semi-)public institutions participate in funded research projects. Most prominent, the VCE Holding GmbH (Dr. Helmut Wenzel) is actually coordinator of two research projects (IRIS, SYNER-G) funded by the European Commission (EC) within the Seventh Framework Programme (FP7). *Wienerberger*, an Austrian-based and the world's largest manufacturer of fired clay bricks and blocks, conducts, partially EC funded, research on the seismic behavior of modern brick-masonry.

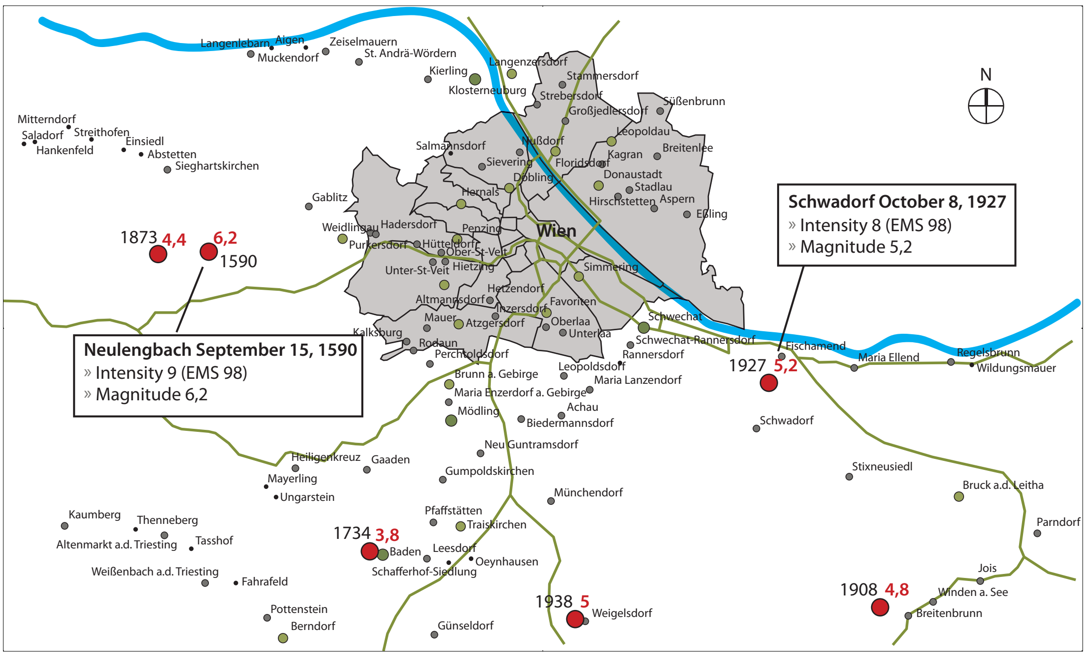

Figure 2. Earthquakes in the Vienna Basin (Achs et al. 2011)

The Austrian Association for Earthquake Engineering and Structural Dynamics - OGE (President: Prof. Andreas Kolbitsch, Secretary General: Prof. Rudolf Heuer) is a non-profit organization, which represents individual members, academic and non-academic research institutions, and companies involved in earthquake engineering and seismic hazard assessment. Seismologists are organized in the Austrian Geophysical Society - AGS (President: Doz. Dr. Wolfgang Lenhardt, Vice-President: Prof. Dr. Bruno Meurers).

1.3. Meetings and Congresses

Every second year the Austrian Association for Earthquake Engineering and Structural Dynamics (OGE), the German Association for Earthquake Engineering and Structural Dynamics (DGEB), and the Swiss Society for Earthquake Engineering and Structural Dynamics (SGEB) rotationally organize a two day meeting (*DACH Tagung*) to disseminate outcomes of research projects and problems of the engineering practice in the German speaking countries. For the international scientific community involved in seismic risk assessment and reduction the Austrian Association for Earthquake Engineering (OGE) is preparing the Vienna Congress on Recent Advances in Earthquake Engineering and Structural Dynamics (VEESD 2013), which will take place at the Vienna University of Technology from August 28 to 30, 2013 (VEESD2013 2012).

2. ACTIVITIES ON SEISMIC HAZARD

2.1. Seismic Network and Infrastructure in Austria

The Central Institute for Meteorology and Geodynamics (ZAMG) maintains the infrastructure for seismic monitoring in Austria. Ground motion monitoring constitutes one of the basic parameters for earthquake resistant design. Therefore, a number of strong motion recording stations have been installed across Austria to observe continuously seismic ground accelerations. In addition, the seismic network of Austria has further been improved by upgrading its instrumentation and extending the network. As an example, the strong motion network in Vienna was upgraded from SMACH® instruments to BASALT®, the latter being manufactured by Kinemetrics®, and three strong motion stations have been added to the seismic network in Tyrol. Today's network in and around Austria, whose data are routinely analysed, consists of more than 50 broadband and strong motion stations. Most data can be accessed via AutoDRM (an e-mail data request procedure) or from the Data Center of the Observatories and Research Facilities for European Seismology (ORFEUS 2012).

Project NERIES - Network of Research Infrastructures for European Seismology
NERIES was an Integrated Infrastructure Initiative (I3) project in the Sixth Framework Program (FP6) of the EC, aiming at linking the European seismic networks, improving access to data, allowing access to specific seismic infrastructures and pursuing targeted research developing the next generation of tools for improved service and data analysis (NERIES 2011). In Austria, in the Conrad observatory comparative measurement campaigns were conducted, and methods for investigation of the soil properties were developed and checked (ZAMG 2012b). ZAMG (Doz. Wolfgang Lenhardt) was the Austrian participant of the consortium comprising 24 members. NERIES was carried out in the period of June 1, 2006 through May 31, 2010.

2.2. Historical Seismology in Austria and Vicinity

The knowledge of past earthquakes is essential to judge the seismic hazard. In particular, in areas of low to moderate seismicity research on historical earthquakes, it is very important to improve the reliability of earthquake hazard estimation. Since in those seismic areas the number of severe earthquakes is relatively small, an extension of the observation time allows a better estimate of the return period and intensity of seismic events (Eisinger et al. 1992). A few thousand written records, which date back almost 1000 years, were analysed during the past years to gain insight into the seismic history of several provinces of Austria. As the process is very laborious, the work will certainly take a few additional years. Two important outcomes should be mentioned: Firstly, besides numerous new seismic events, which could be found, a few seismic events have been proven to be fakes and secondly, experience has shown that previous earthquake magnitudes were rather over- than underestimated. Multiple entries, due to the combination of several earthquake catalogues, had also to be clarified. The correctness of an earthquake catalogue is therefore a very important contribution for seismic risk assessment and its mitigation. In Austria, amongst others ZAMG conducts ongoing research on historical earthquakes.

As an example, Dr. Christa Hammerl headed a research project aiming at improving the assessment of seismic hazard in the province of Lower Austria (Hammerl 2006). Particularly, a focus of the study was the period between 1000 and 1589, in which no earthquakes with the epicenter located in Lower Austria were known. For the 16th to the 19th century the earthquake catalogue was completed. The most important historical earthquakes were reviewed and their interpretation revised. The local government of the province of Lower Austria financed this project between 2003 and 2010. (ZAMG 2012a)

Recently, Dr. Georg Gangl and Dr. Kurt Decker from the University of Vienna provided a compilation of strong Austrian earthquakes with intensities higher than 7 (Gangl and Decker 2011).

Interreg IVA Project HAREIA - Historical And Recent Earthquakes in Italy and Austria
Within the Interreg IVA project HAREIA, funded by the EC, six regions in the border area of Italy and Austria investigated in a collaborative effort historical earthquakes in this area. Numerous earthquakes in the area of Tyrol, Friuli, but also in South Tyrol and Veneto pose a threat to this economic area, as it has been shown in the 1976 Friuli earthquake and in the 2001 Meran earthquake, among other historical earthquakes. Thus, the ultimate aim of the project was the compilation of a catalogue of historical earthquakes in the regions Tyrol, South Tyrol, Friuli-Venetia Giulia, and Veneto. A further focus concerned the extension of the seismological network in this region, which was set up between 2004 and 2007 in collaboration with ZAMG within the Interreg IIIA-project Austria - Italy „FASTLINK – cross-border seismological networks in the Southeastern Alpine region". Additionally to the existing network three strong-motion stations were installed in each region. The third focus aimed at integration of the single data centers to ensure data exchange between these centers. The partners of this project, which was carried out between April 1, 2009 and March 31, 2012, were the Office of the Tyrolean Government, the Department of Civil Defense and Emergency Management (PI), the *Amt für Geologie und Baustoffprüfung* - Autonomous Province Bolzano-South Tyrol, the *Protezione Civile di Palmanova* - Autonomous Region Friuli-Venetia Giulia, and *ARPAV – Dipartimento Provinciale di Belluno.* (tirol.gv.at 2012)

3. ACTIVITIES IN EARTHQUAKE ENGINEERING

3.1 Seismic Assessment of Historical Viennese Brick-Masonry Buildings

The City Center of Vienna is dominated by historical residential brick-masonry buildings, which were built during a major urban expansion in the period of 1848 through 1918 referred to as *Gründerzeit*. At present, one third of the complete building stock in the urban area of Vienna, that is 32,000 objects, consists of these Viennese brick-masonry buildings. They shape the urban image of Vienna, and thus, make the city attractive for visitors. Recently, the behavior of Viennese brick-masonry buildings under seismic loads has become of significant interest, because the European Standard on Earthquake Engineering Eurocode 8 (2004) imposes additional seismic demands to these structures compared to the previous standards. As a consequence, their seismic resistance cannot be verified anymore with traditional methods of analysis available to the design engineer in practice. This has led to a drastic decline of rehabilitation and remodeling of this building type, and consequently to huge economical losses.

Research Project SEISMID - Seismic System Identification

In 2006 the Austrian national research project SEISMID has been launched aiming at assessing the seismic resistance of Viennese brick-masonry buildings more realistically (Achs et al. 2011). The most important elements of this investigation are summarized in the following.

- Development of a simple Rapid-Visual-Screening spreadsheet for potential seismic hazards of Viennese brick-masonry buildings (Achs and Adam 2011). The property owner may determine, whether his object is vulnerable to earthquakes.
- Proposal of an engineered building check for Viennese brick-masonry buildings with respect to their earthquake resistance.
- Identification of the actual constitutive behavior through tests on original bricks extracted from buildings and mortar (Furtmüller et al. 2012).
- Medium-scale experiments on brick-masonry elements in an effort to reveal the actual load-bearing capacity (Zimmermann and Strauss 2010; Furtmüller et al. 2012).
- Large-scale experiments on Viennese brick-masonry buildings to be demolished to determine the actual stiffness. Elements such as partition walls, timber ceilings and the roof structure were removed step-by-step and simultaneously the dynamic response was measured (Achs and Adam 2012; Kopf et al. 2012a).
- Investigation of the soil-structure interaction by means of dynamic measurements on an anti-aircraft tower located in the park *Augarten*. Thereby, the specific behavior of the subsoil in the Vienna Basin was revealed (Kopf et al. 2012b).
- Recommendation of methods of structural analyses, such as pushover analysis, which are not used by engineers in practice (Furtmüller and Adam 2011; Adam et al. 2012).
- Compilation of a hazard map for the Vienna Basin based on interpretation of areal photographs, radar, and ambient vibration measurements.

Research for SEISMID was carried out between January 1, 2007 and December 31, 2010. The partners were the VCE Holding GmbH (business partner, PI), the Aplica Advanced Solutions GmbH (business partner), Brusatti GmbH (business partner), the University of Natural Resources and Life Sciences (scientific partner), the University of Innsbruck (scientific partner), the AIT Mobility (sub-contractor), and the BAGF Birkenweg (sub-contractor). Funding agency was the ZIT Center for Innovation and Technology.

3.2. Seismic Behavior of Modern Clay Brick-Masonry

The increase of earthquake safety of buildings built with fired clay bricks and blocks is an important research topic of the Austrian based brick manufacturer *Wienerberger* (Lu and Kasa 2011). Amongst others, *Wienerberger* is currently involved in the following projects to reduce the earthquake risk of modern brick-masonry.

3.2.1. AmQuake

Eurocode 8 permits nonlinear static analysis based on the pushover methods for a more realistic assessment of the earthquake risk. As conventional software packages do not include this type of analysis, *Wienerberger* developed the software AmQuake (2012) in collaboration with the company Cervenka Consulting. This software facilitates the seismic analysis of fired clay brick-masonry buildings with simple measures. Thereby, dissipative properties of brick-masonry can be considered in a realistic manner.

3.2.2. Research Project SERIES - Full scale testing of modern unreinforced thermal insulation clay block masonry houses

In modern residential buildings the requirements on thermal insulation are very demanding. Thus, the clay brick industry has developed high thermal-insulating fired hollow clay blocks to consider the tightened demands. The mechanical behavior of these products subjected to earthquakes has already been tested in cyclic shear test. However, experiments on real full-scale structures have not been conducted before. Within the project SERIES (funded by the EC) two three-dimensional shaking table tests on real structures will be conducted at the facility LNEC in Portugal. Two two-story model buildings will be excited in three directions with recorded earthquake accelerograms. The dynamic building behavior, the seismic behavior factor q, damping coefficients and maximum drift values will be evaluated. This project will directly entail synergies in markets, and its outcomes will enter next generations of codes and product development. Experts from five different countries are participating in this project. (SERIES 2012)

3.3. Further Developments of the Tuned Liquid Column Damper

In many cases it suffices to add passive damping to reduce the vulnerability of low damped C.E. structures in seismic active zones. The main goal of research conducted under the guidance of Prof. Franz Ziegler at the Vienna University of Technology has been the improvement of the Tuned Liquid Column Damper (TLCD) by sealing the U- or V-shaped piping system and thus adding the resulting gas-spring effect. By means of assigning a proper static equilibrium gas pressure, the novel parameter for optimizing the absorber frequency makes this Tuned Liquid Column Gas Damper (TLCGD) ideally suited to substitute the classical Tuned Mass Damper (TMD) of the spring-mass-dashpot type for dominating horizontal vibrations. The extension to account for coupled translational-rotational vibrations as observed in multi-purpose asymmetric buildings and towers is extensively discussed in Fu and Ziegler (2010). For base isolated buildings a new type of base isolation elements has been developed providing high vertical and low lateral stiffness and virtually no damping. The abrasive processes in classical dry friction dampers are avoided, and the concept of a functionally separated modular base isolation system is adapted in Khalid and Ziegler (2010) by providing the required energy dissipation for excessive horizontal vibrations of the isolation modes by TLCGD installed in the basement (Ziegler and Khalid 2011). The three main elements are the novel pendulum pre-stressed coil-steel-spring base isolation element acting in shear, an innovative sliding element to resist minor dynamic loads, and a TLCGD to dissipate vibrational energy during the strong motion phase of an earthquake. A special design to reduce vertical vibrations by a VTLCGD (the horizontal pipe section is minimized) and the limiting condition of the maximum allowed relative fluid speed to keep the fluid-gas interface intact during vibrations is discussed in Ziegler (2008). Damping of large arch-dams by TLCGD has been considered in Azar Razzaghi and Ziegler (2011).

3.4. Assessment of the Seismic Performance of Tuned Mass Dampers

At the University of Innsbruck the seismic performance of TMDs based on sets of recorded ground motions has been assessed (Tributsch and Adam 2012). For the simplest configuration of a structure-TMD assembly, in a comprehensive study characteristic response quantities have been derived and statistically evaluated. The effect of detuning on the maximum spring displacement of the TMD and on the structural response is assessed and quantified. Analytical relations for quantifying the effect of a TMD have been derived and subsequently evaluated. These relations allow the engineer in practice a fast and yet accurate assessment of the TMD performance in an earthquake environment. In a further study based on the random set theory the vulnerability of earthquake excited TMD-structure configurations has been considered (Schmelzer et al. 2010).

3.5. Seismic Collapse Capacity of Frame Structures Vulnerable to the P-Delta Effect

A topic of ongoing research at the University of Innsbruck is the prediction of the global collapse capacity of earthquake excited frame structures with simplified but yet reliable measures (Adam and Jäger 2012b). The addressed flexible planar frame structures with non-deteriorating inelastic component behavior are supposed to be vulnerable to the destabilizing effect of gravity loads. The proposed collapse capacity spectrum methodology is based on pushover analyses, equivalent single-degree-of-freedom systems, and a collapse capacity spectrum (Adam and Jäger 2012a; Jäger and Adam 2012). The results lead to the conclusion that in the initial design process the collapse capacity spectrum methodology is an appropriate tool to assess reliably median and dispersion of the collapse capacity of P-delta sensitive regular moment-resisting frame structures subjected to severe earthquake excitation. This work is partially supported by the Tyrolean Science Fund (*Tiroler Wissenschaftsfond*).

3.6. Field Testing for Seismic Vulnerability Assessment

An ongoing research activity of AIT Mobility concerns the seismic assessment of important existing buildings such as hospitals. In order to assess an existing building by an elaborated structural model, a methodology was developed, where dynamic in-situ measurements on the structure and its subsoil are combined with finite element calculations. The application of a mobile vibration generator for forced vibration testing offers the possibility to identify accurate boundary conditions in the initial linear elastic range of deformation. These data enter the numerical model, and thus, an improved seismic vulnerability assessment is provided. Since the updated model is based on measured results, it represents in a realistic manner the structural behaviour during the initial phase of a seismic event. Vulnerable building members can be identified with more accuracy, and targeted structural retrofitting is possible. Based on this seismic assessment methodology, three pilot studies were carried out. Two industrial RC buildings with secondary risk to the environment and one hospital were assessed (Friedl et al. 2010; Ralbovsky et al. 2010; Friedl et al. 2011). A further research topic aims at improving emerging methods of seismic fragility assessment by field monitoring data.

4. OUTLOOK

In Austria various academic and non-academic research institutions as well as private and semi-public companies are involved in activities towards seismic risk assessment and reduction. These activities are embedded in both internationally and nationally funded research projects, or they are carried out on an individual basis. In recent years there was a particular focus on the seismic assessment of historical brick-masonry buildings located in Vienna. The Austrian seismic network and infrastructure is continually improving. Other research activities comprise the seismic assessment of modern buildings, further developments on passive and semi-active damping devices to mitigate earthquake induced vibrations, and historical earthquake research, amongst others. At Austrian universities, more recently several Professors involved in the fields of earthquake engineering, structural dynamics, and seismology have been appointed, thus intensified research efforts are to be expected in these fields.

ACKNOWLEDGEMENTS AND REMARKS
The author is grateful for the input of the following individuals, who provided substantial contributions: Prof. Franz Ziegler from TU Vienna, Dr. Günther Achs and Doz. Dr. Fritz Kopf from VCE Holding GmbH, Doz. Dr. Wolfgang Lenhardt from ZAMG, Dr. Andreas Jäger and Dr. Suikai Lu from Wienerberger AG, and Herbert Friedl from AIT Mobility. In preparation of this paper the author has conducted a thorough research completed by an Internet search. Additionally, the Secretary General of the Austrian Association for Earthquake Engineering and Structural Engineering, Prof. Rudolf Heuer, asked all members of this association to inform the author about their activities in the fields of seismic risk assessment and reduction. In several of the described activities (such as in the research project SEISMID) the author is involved himself. However, this paper raises no claim to completeness to summarize all Austrian actions taken in these fields recently.

REFERENCES

Achs, G. et al. (2011). *Erdbeben im Wiener Becken. Beurteilung – Gefährdung – Standortrisiko* (in German). VCE Holding GmbH (ed.).

Achs, G. and Adam, C. (2011). Risk assessment of historic residential brick-masonry buildings in Vienna by Rapid-Visual-Screening. Proc. of the *III ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering* (*COMPDYN 2011*), Corfu, Greece (Papadrakakis M., Fragiadakis, M., Plevris, V., eds), paper no. 419, 14 pp.

Achs, G. and Adam, C. (2012). Assessment of the global dynamic behavior of a historic residential brick-masonry building in Vienna. Proc. of the *Third International Symposium on Life-Cycle Civil Engineering* (IALCCE 2012), October 3 - 6, 2012, Vienna, Austria (accepted for publication).

Adam, C. and Jäger, C. (2012a). Seismic collapse capacity of basic inelastic structures vulnerable to the P-delta effect. *Earthquake Engineering & Structural Dynamics*: **41**, 775-793.

Adam, C. and Jäger, C. (2012b). Collapse capacity assessment of earthquake excited regular frame structures vulnerable to P-delta. *Engineering Structures* (accepted for publication).

Adam, C., Furtmüller, T. and Achs, G. (2012). Seismic assessment of historical brick-masonry buildings in Vienna. Proc. of the *15th World Conference on Earthquake Engineering* (15 WCEE), September 24 - 28, 2012, Lisbon, Portugal (accepted for publication).

AmQuake (2012). www.amquake.eu (March 15, 2012).

Azar Razzaghi, N. and Ziegler, F. (2011). Passive control of vibrations of seismically activated arch dams with tuned liquid column gas dampers: Part 1 Theory. *Proc. 6th International Conference on Seismology and Earthquake Engineering* (SEE6), May 2011, Tehran, Iran.

EC8 (2004). Eurocode 8: *Design of structures for earthquake resistance*.

Eisinger, U., Gutdeutsch R. and Hammerl, C. (1992) Historical earthquake research - an example of interdisciplinary cooperation between geophysicists and historians. *Historical Earthquakes in Central Europe*. Vol. I. (Gutdeutsch, R., Grünthal, G. and Musson, R., eds), pp. 33-50. Book Series: *Abh. Geologische Bundesanstalt*, Vol. 48.

Friedl, H., Kwapisz, M. and Flesch, R. (2010). Improvement of numerical simulation due to dynamic in-situ investigations. Assessment of industrial structures with potential risk. Proc. of the *14th European Conference on Earthquake Engineering* (14. ECEE), August 30 - September 3, 2010, Ohrid, Macedonia.

Friedl, H., Kwapisz, M., Lechner, A. and Flesch, R. (2011). Seismic assessment of concrete tanks considering fluid structure interaction and nonlinear time history analysis. Proc. of the *Third ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering* (COMPDYN 2011), May 25 - 28, 2011, Corfu, Greece.

Fu, C. and Ziegler, F. (2010). Vibration prone multi-purpose buildings and towers effectively damped by tuned liquid column-gas dampers. *Asian Journal of Civil Engineering* **10**: 21-56.

Furtmüller, T. and Adam, C. (2011). Numerical modeling of the in-plane behavior of historical brick masonry walls. *Acta Mechanica*: **221**, 65-77.

Furtmüller, T., Adam, C. and Niederegger, C. (2012). Seismic capacity of old masonry buildings in Vienna: Laboratory testing on bricks, mortar, and small-scale brick masonry. Proc. of the *Third International Symposium on Life-Cycle Civil Engineering* (IALCCE 2012), October 3 - 6, 2012, Vienna, Austria (accepted for publication).

Gangl, G. and Decker, K. (2011). Compilation of strong Austrian earthquakes with intensities higher than 7 (in German). *Österr. Ingenieur- und Architektenzeitschrift* (ÖIAZ): **156**, 229-237.

Grünthal, G. (ed.) (1998). European Macroseismic Scale 1998 (EMS-98). Cahiers du Centre Européen de Géodynamique et de Séismologie 15, Centre Européen de Géodynamique et de Séismologie, Luxembourg, 99 pp.

Hammerl, C. (2006). Historical earthquakes in Lower Austria - source investigation. *Proc. of the First European Conference on Earthquake Engineering and Seismology*. September 3 - 8, 2006, Geneva, Switzerland.

Jäger, C. and Adam, C. (2012). Influence coefficients for collapse capacity spectra. *Journal of Earthquake Engineering* (accepted for publication).

Khalid, B. and Ziegler, F. (2010). A novel base isolation system for asymmetric buildings effectively damped by tuned liquid column-gas dampers. Proc. of the *14th European Conference on Earthquake Engineering* (14. ECEE), August 30 - September 3, 2010, Ohrid, Macedonia.

Kopf, F., Schäfer, D. and Pietsch, M. (2012a). System identification of Wilhelminian style buildings in the Vienna Basin. Proc. of the *Third International Symposium on Life-Cycle Civil Engineering* (IALCCE 2012), October 3 - 6, 2012, Vienna, Austria (accepted for publication).

Kopf, F., Bekö, A., Schäfer, D., Pietsch, M. and Rossbacher, L. (2012b). The assessment of soil-structure-interaction by measurements. Proc. of the *Third International Symposium on Life-Cycle Civil Engineering* (IALCCE 2012), October 3 - 6, 2012, Vienna, Austria (accepted for publication).

Lu, S. and Kasa, M. (2011). Seismic behaviour of precision ground fired hollow clay blocks with Polyurethane glue. Proc. of the *14th European Conference on Earthquake Engineering* (14. ECEE), August 30 - September 3, 2010, Ohrid, Macedonia.

NERIES (2011). http://www.neries-eu.org// (March 11, 2012).

ÖNORM B4015 (2002). Design loads in building - Accidental actions - Seismic actions - General principles and methods of calculation. Austrian Standards.

ORFEUS (2012). http://www.orfeus-eu.org (March 14, 2012)

Ralbovsky, M., Flesch, R. and Friedl, H. (2010). Coupling of buildings by viscous dampers and nonlinear response estimation. Proc. of the *14th European Conference on Earthquake Engineering* (14. ECEE), August 30 - September 3, 2010, Ohrid, Macedonia.

Schmelzer, B., Oberguggenberger, M. and Adam, C. (2010). Efficiency of Tuned Mass Dampers with uncertain parameters under stochastic excitation. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability*: **224**, 297-308.

SERIES (2012). http://www.series.upatras.gr/urm_buildings (March 15, 2012)
tirol.gv.at (2012). http://www.tirol.gv.at/themen/sicherheit/katziv/lwz/hareia/hareiade/ (March 11, 2012).
Tributsch, A. and Adam, C. (2012). Evaluation and analytical approximation of Tuned Mass Damper performance in an earthquake environment. *Smart Structures and Materials* (under review).
VEESD2013 (2012). http://veesd2013.conf.tuwien.ac.at/ (March 26, 2012).
ZAMG (2012a). http://www.zamg.ac.at/forschung/geophysik/erdbebenforschung/noe/ (March 11, 2012).
ZAMG (2012b). http://www.zamg.ac.at/forschung/geophysik/eu-projekte/NERIES/ (March 11, 2012).
ZAMG (2012c). http://www.zamg.ac.at/lexikon/Erdbeben.php (March 11, 2012).
Ziegler, F. (2008). Special design of tuned liquid column-gas dampers for the control of spatial structural vibrations. *Acta Mechanica*: **201**, 249-267.
Ziegler, F. and Khalid, B. (2011). A novel base isolation system for asymmetric buildings in seismic active zones: damping supplied by tuned liquid column-gas dampers. *Advanced Dynamics and Model Based Control of Structures and Machines*. (Belyaev, A.K., Irschik, H., Krommer, M. eds). Springer Vienna, pp. 225-234.
Zimmermann, T. and Strauss, A. (2010). Old masonry under seismic loads - Comparison of normative guidelines and measured results (in German). *Bautechnik*: **87**, 532-540.