A Rapid-Visual-Screening Methodology for the Seismic Vulnerability Assessment of Historic Brick-Masonry Buildings in Vienna

G. Achs
VCE Holding GmbH, Austria

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

15 WCEE
LISBOA 2012

SUMMARY:
This paper addresses seismic vulnerability assessment of historic brick-masonry buildings located in the city of Vienna based on Rapid-Visual-Screening (RVS). The RVS methodology has been adopted for this specific type of buildings considering their consistent typology and consequently, enhancing the validity and quality of the seismic assessment. In this connection two parameters of the inspected object are evaluated, i.e. the damage relevance and an overall structural parameter. Based on the derived score of these parameters the building is classified into one of four vulnerability classes. In a large-scale in-situ investigation a set of 375 buildings within the 20th district of Vienna has been seismically assessed. The resulting vulnerability map gives useful information for emergency and evacuation planning as well as for identification of critical objects vulnerable to seismic loading.

Keywords: Historic brick-masonry buildings; Rapid-Visual-Screening; Seismic vulnerability

1. INTRODUCTION

Historic brick-masonry buildings, which were mainly built in the period between 1850 and 1918, represent a substantial amount of the existing building stock in the city of Vienna, the capital of the Republic of Austria. Most of these objects have been maintained unchanged without considerable structural improvement for decades, but nevertheless they are typically still used as residential buildings. In particular, the reliability of these buildings against earthquake-induced collapse is a major issue of a comprehensive areal seismic assessment. In such an assessment the objects of a larger area are classified with respect to their seismic vulnerability. Based on this classification into categories critical objects are identified and further, more detailed investigations can be performed.

In the last few years several different methodologies for the assessment and classification of existing buildings have been developed (Calvi et al. 2006). Many of them, so called Rapid-Visual-Screening (RVS) methodologies, are based on visual inspection of the buildings using predefined forms. Their main advantage is the fast and elementary implementation, which allows the user to evaluate a large amount of buildings in a relatively short period of time. Particularly in areas with high seismicity the application of RVS techniques is widespread. In this paper a recently developed RVS methodology (Achs 2011, Achs and Adam 2011) specified for the comprehensive seismic evaluation of Viennese brick-masonry buildings is presented, which aims at realistically estimating the vulnerability of these historic objects under seismic loading.

One of the basic documents, developed and used in the United States of America, is the RVS methodology described in the FEMA 154 (2002) handbook for seismic evaluation of existing buildings. This method has already been used for years and is an important basis for various international techniques. In particular the method is based on a scoring system, in which different building parameters are classified and benchmarked. Apart from the RVS procedures in the United States of America several other techniques have been developed in different countries. The Japanese technique (JBDPA 2001) is based on the so-called Seismic Index (IS), which describes the resisting earthquake capacity of a storey and is estimated from the strength and ductility of the building, the regularity of the building and a certain time index. In contrast, the RVS procedure applied in Canada (NRCC 1993) accounts for structural parameters, such as the stiffness and the regularity of the building, as well as for non-structural parameters, the foundation of the building, building occupancy, importance of the building, and falling hazards. Compared to other countries, India has a very large amount of existing buildings of different types, which led to the development of several RVS procedures in the last few years (Jain et al. 2010, Gogoi 2010). Most of the European RVS procedures were developed in Greece (OASP 2000, Demartinos 2006) and in Turkey (Sen 2010, Hassan and Sozen 1997, Ozdemir and Taskin 2006), with the investigated masonry buildings of the high seismicity area of Istanbul (Vatan and Arun 2010, Erberik 2010) being of primary interest for the proposed RVS procedure developed for Viennese brick-masonry buildings. The Swiss Standard SIA 2018 (2004) applies a three-stage concept for evaluating the seismic risk. In the first stage, based on the building plan and visual inspection, the most important elements of the building and the seismic risk are roughly assessed. In the second stage the seismic risk of some selected objects is studied in more detail. In the third stage strengthening measures are developed for a limited number of vulnerable buildings.

Some fundamentals of the methodology described in this paper were developed for historic masonry buildings in Italy (D’Ayala and Speranza 2002) and Portugal (Ferreira et al. 2010). The assessment of brick-masonry facades can be directly applied by quantifying the building geometries (D’Ayala and Speranza 2002). Among the numerous other RVS procedures, methods developed in Germany (Meskouris 2001, Sadegh-Azar 2002) are of particular interest for the proposed RVS methodology in Vienna, as they were applied on similar historic buildings located in areas with comparable seismicity.

2. RAPID-VISUAL-SCREENING OF VIENNESE BRICK-MASONRY BUILDINGS

2.1. Fundamentals

As most of the international RVS methodologies are focused on buildings with a consistent topology, an adopted method with specific parameters for the historic residential buildings in Vienna had to be developed. The proposed methodology for Viennese brick-masonry buildings considers the results of a detailed study of historic documents such as Viennese building codes from the 19th century (Building Code for Vienna 1859, Building Code for Vienna 1869, Building Code for Vienna 1883, Municipality of Vienna 1892). Furthermore, findings of more recent investigations (Flesch et al. 2005, ÖIBI 2009, Rusnov 2006) on this specific building type entered this RVS methodology appropriate for Viennese brick-masonry objects. Particularly, several approaches from a guideline (ÖIBI 2009) for the in-situ assessment of the state of preservation of the structural system of existing Viennese buildings were adjusted.

2.2. Elementary Parameters

The proposed RVS methodology is based on two parameters (SIA 2004), i.e.

- the Structural Parameter *SP* of the inspected building, and
- its Damage Relevance *DR*.

The Structural Parameter *SP* consists of nine single indicators to evaluate the impact of certain structural parts on the seismic vulnerability of the building. In Table 2.1 all individual parameters of *SP*, denoted as S_{01}, S_{02}, … S_{09}, are specified. Parameter S_{08}, which evaluates the foundation, and parameter S_{09}, which refers to the state of preservation, are described in more detail in Tables 2.2 and 2.3, respectively. Depending on the actual situation and condition, each of the individual parameters are benchmarked, compare with Table 2.1.

Table 2.1. Set of individual parameters describing the Structural Parameter *SP*

Parameter	Description	Benchmark
S_{01} Seismicity	Seismic zone according to ÖN EN 1998-1 (2006) - Vienna, southwest of the river Danube $S_{01} = 1.0$ - Vienna, northeast of the river Danube $S_{01} = 2.0$	$S_{01} = 1.0 - 2.0$
S_{02} Regularity in plan	Classification of the regularity in plan according to ÖN EN 1998-1 (2005) - Regular plan, length to width ratio in plan < 4 $S_{02} = 1.0$ - Regular plan, length to width ratio in plan > 4 $S_{02} = 5.0$ - Irregular plan, length to width ratio in plan < 4 $S_{02} = 5.0$ - Irregular plan, length to width ratio in plan > 4 $S_{02} = 10.0$	$S_{02} = 1.0 - 10.0$
S_{03} Regularity in elevation	Vertical irregularities with particular attention to soft storeys - All partition walls and shear elements preserved $S_{03} = 1.0$ - Some partition walls removed / shear elements preserved $S_{03} = 20.0$ - All partition walls removed / shear elements preserved $S_{03} = 50.0$ - All partition walls and shear elements replaced by columns $S_{03} = 100.0$	$S_{03} = 1.0 - 100.0$
S_{04} Horizontal stiffening	Evaluation of the ceiling-wall connection - Connection of timber ceilings and walls with steel ties Existing and in good condition $S_{04,1} = 1.0$ Non-existent, not identified, or in bad condition $S_{04,1} = 5.0$ - Brick faults above the basement Existing and in good condition $S_{04,2} = 1.0$ Non-existent, not identified, or in bad condition $S_{04,2} = 5.0$ $S_{04} = S_{04,1} \times S_{04,2}$	$S_{04} = 1.0 - 25.0$
S_{05} Local failure	Potential local failure mechanism of the façades (Achs 2011) according to the load factor λ_0 (D'Ayala and Speranza 2002) $\lambda_0 < 0.25$ $S_{05} = 1.0$ $0.25 \leq \lambda_0 < 0.50$ $S_{05} = 5.0$ $0.50 \leq \lambda_0 < 0.70$ $S_{05} = 10.0$ $\lambda_0 \geq 0.70$ $S_{05} = 20.0$	$S_{05} = 1.0 - 20.0$
S_{06} Secondary structures	Exposed secondary structures such as chimneys, sculptures and statues of the façade, cornices, etc. Number Exposure to the public 0 $S_{06} = 0.0$ < 3 low / high $S_{06} = 1.0/5.0$ 3 – 6 low / high $S_{06} = 5.0/10.0$ > 6 low / high $S_{06} = 10.0/20.0$	$S_{06} = 0.0 - 20.0$
S_{07} Soil condition	Local soil conditions classified according to ÖN EN 1998-1 (2005) Soil class A $S_{07} = 1.0$ Soil class B $S_{07} = 2.5$ Soil class C $S_{07} = 5.0$ Soil class D $S_{07} = 7.5$ Soil class E $S_{07} = 10.0$	$S_{07} = 1.0 - 10.0$
S_{08} Foundation	Score depending on the location of the building and type of foundation. For details see Table 2.2	$S_{08} = 1.0 - 10.0$
S_{09} State of preservation	State of preservation of the structure (ceilings, columns, brick-masonry, etc.). For details see Table 2.3	$S_{09} = 0.0 - 30.0$
	Structural Parameter (total score)	$SP = \sum_{i=1}^{9} S_{0i}$

Table 2.2. Foundation: Parameter S_{08}

Foundation type	1^{st}, 3^{rd} - 19^{th}, 23^{rd} district of Vienna	20^{th}-22^{nd} district of Vienna; Building located in the area of historic waters
Shallow foundation, embedding depth $\geq$ 0.65 m	$S_{08} = 1.0$	$S_{08} = 2.5$
Shallow foundation, embedding depth < 0.65 m	$S_{08} = 2.5$	$S_{08} = 5.0$
Wood pile foundation	$S_{08} = 5.0$	$S_{08} = 10.0$
Unknown	$S_{08} = 2.5$	$S_{08} = 10.0$

Table 2.3. State of preservation: Parameter S_{09}

Extent of damage	Very high	High	Moderate	Low	Very low	No damage
Basic score BS_{09}	15.0	10.0	7.5	5.0	2.5	0

Structural element	Factor FS_{09}
Roof structure (Ingress of water, damaged connections)	1.00
Cornice (cracks, deposits on cornice, condition of the eaves purlin)	1.25
Top ceiling (moisture, other damage)	1.75
Standard storeys: ingress of water	1.75
Standard storeys: Cracks	1.25
Staircase (damage at the support of the stairs, joint between the stairs, condition of the supports of the stair head)	1.25
First floor (damage of load-bearing elements)	2.00
Basement	1.75
Building equipment and appliances (connections, condition)	1.50

$$S_{09} = \max\left(FS_{09} \times FS_{09}\right)$$

A high score implies a large impact on the seismic vulnerability of the considered building. Thus, as it can be read from Table 2.1, the most important individual parameters, which can be directly related to earthquake-induced damage, are the regularity of the building in elevation and the state of preservation. The sum of the scores of the individual parameters S_{01} to S_{09} yields the Structural Parameter *SP* of the inspected building.

The Damage Relevance *DR* is composed of five individual parameters, denoted as D_{01}, D_{02} …. D_{05}, to evaluate the social and economic influence of earthquake-induced damage on the inspected building. An overview on the content of the Damage Relevance, and the description and quantification of the individual parameters are outlined in Table 2.4. One of the main parameters of the Damage Relevance is the number of exposed persons within the inspected object.

2.3. Classification

The categorization and prioritization of Viennese brick-masonry buildings is based on the combination of the Damage Relevance *DR* and the Structural Parameter *SP*. To this end four vulnerability classes have been adopted (Achs 2011), depending on the benchmark of *SP* and *DR* as specified subsequently.

Table 2.4. Set of parameters describing the Damage Relevance *DR*

Parameter	Description	Benchmark
D_{01} Human exposure	Number of endangered individuals within the inspected object (estimation accepted in case of limited accessibility of the inspected object).	D_{01} = no of individuals
D_{02} Building importance	Importance of the inspected object according to ÖN EN 1998-1 (2005) ranging from importance class II to IV. - II: Ordinary residential buildings $D_{02} = 1.0$ - III: Schools, assembly rooms, etc. $D_{02} = 10.0$ - IV: Hospitals, etc. $D_{02} = 50.0$	$D_{02} = 1.0 - 50.0$
D_{03} Economic importance	Useable living area (ULA) multiplied by the potential price per m², and consideration of the remaining life time (RLT) of the inspected object.	$D_{03} = \frac{ULA \cdot Price}{100000} \cdot \frac{RLT}{25}$
D_{04} = Material assets	Real assets at risk (building content) - Low risk: residential buildings $D_{04} = 1.0$ - Medium risk: archives and libraries $D_{04} = 5.0$ - High risk: museums, etc. $D_{04} = 10.0$	$D_{04} = 1.0 - 10.0$
D_{05} Effects on the environment	Effects of building collapse or partial collapse on the environment of the building - Low exposure $D_{05} = 1.0$ - Medium exposure: exposure of pedestrians $D_{05} = 5.0$ - High exposure: exposure of important infrastructure $D_{05} = 10.0$	$D_{05} = 1.0 - 10.0$
	Damage Relevance (total score)	$DR = \sum_{i=1}^{5} D_i$

– Vulnerability Class I: $SP < 50$ and $DR < 50$

– Vulnerability Class II: $80 > SP \geq 50$ and $DR < 100$
or
$100 > DR \geq 50$ and $SP < 80$

– Vulnerability Class III: $140 > SP \geq 80$ and $DR < 150$
or
$150 > DR \geq 100$ and $SP < 140$

– Vulnerability Class IV: $SP \geq 140$
or
$DR \geq 150$

If a building is categorized in Vulnerability Class I, its damage potential under seismic loading is low. In contrast, the seismic risk of a building in Vulnerability Class IV must be assessed in more detail because it is very likely vulnerable to earthquake excitation. Fig. 2.1 visualizes the separation of the individual Vulnerability classes as a function of the Damage Relevance *DR* and the Structural Parameter *SP*.

The limits of the individual vulnerability classes are based on a calibration of the outcomes of an initial application of this RVS methodology on a set of 18 Viennese brick-masonry buildings. In this connection the state of preservation, structural system, dynamic behaviour, and socio-economic parameters of those buildings were known in advance from detailed in-situ investigations, experimental tests and computations. The buildings distributed across the historic city centre of Vienna should represent a wide range of evaluation parameter possibilities. A comprehensive description of those buildings, results of the application of the RVS methodology and outcome of the calibration is given in Achs (2011).

2.4. Inspection Form

A standardized inspection form has been prepared to simplify the on-site visual screening of Viennese brick-masonry buildings. The form guides the surveyor through the screening procedure step-by-step, and it supports the inspection. After digitalization of the data the Structural Parameter *SP*, the Damage Relevance *DR* and the classification of the inspected building into a particular vulnerability class is evaluated automatically. For details refer to Achs (2011).

3. APPLICATION

3.1. Test Area

The proposed RVS methodology was applied in a large-scale experimental investigation. Therefore, an adequate test area was chosen in the 20th district of Vienna including a set of 375 historic brick-masonry buildings. A site plan of the test area is shown in Fig. 3.1 with the inspected objects highlighted in red. It can be seen that the historic brick-masonry buildings are the predominant object type within the test area. In particular, whole blocks of buildings have remained homogenous since their construction in the 19th century. The inspection of the buildings was performed continuously within a time period of three months.

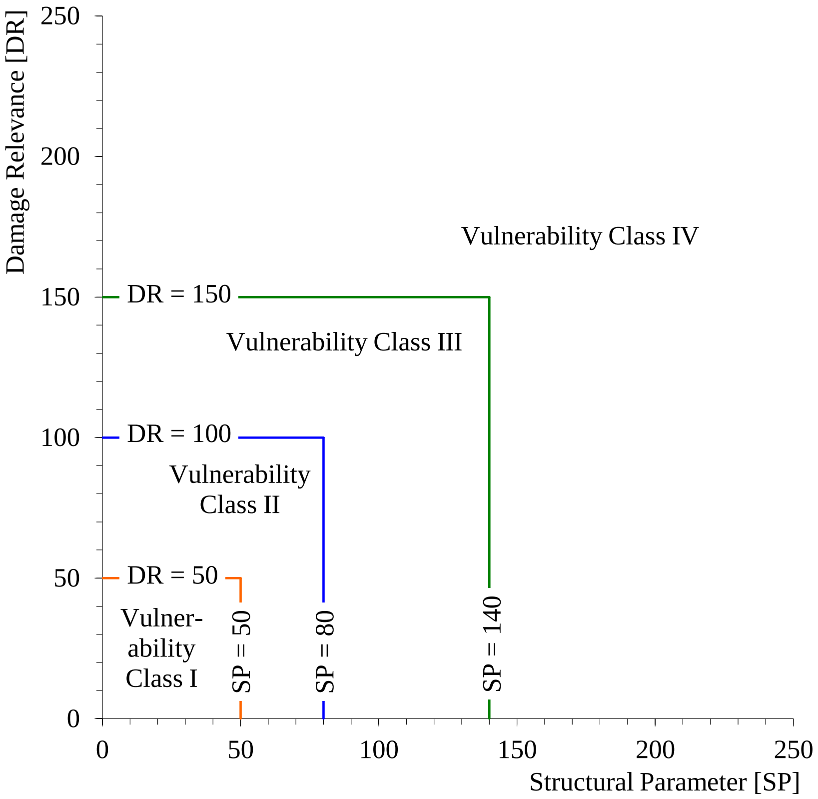

Figure 2.1. Vulnerability classes presented as a function of the Structural Parameter *SP* and the Damage Relevance *DR*

Figure 3.1. Map of the test area in the 20th district of Vienna. Inspected historic residential buildings (highlighted in red)

3.2. Results

In Fig. 3.2 the Damage Relevance *DR* is plotted against the Structural Parameter *SP* for each inspected building of this large-scale application. This figure reveals that the outcomes of the experiment show a precise separation of Vulnerability Classes III and IV either in terms of the Damage Relevance *DR* or the Structural Parameter *SP*. Hence, inspected objects classified in Vulnerability Class IV either have a comparatively high Damage Relevance *DR*, predominantly caused by the high number of exposed persons within the building, or have a very high Structural Parameter *SP*, which can be only generated by an irregularity in elevation. According to Fig. 3.2 most of the inspected objects were classified in Vulnerability Classes II or III, without any precise separation between those classes. The main reason for that is the relatively large number of different individual parameters, which enter *DR* and *SP*, and hence, the benchmarks of a single parameter at a specific building may vary significantly. The comprehensive results of each inspected building and any evaluated parameter can be found in Achs (2011).

4. CONCLUSIONS

The Rapid-Visual-Screening (RVS) methodology is a fast and widespread method for seismic assessment of existing buildings. Recently, a RVS technique for historic brick-masonry buildings in Vienna was adopted, due to the fact that those buildings represent the predominant type of constructions in the city centre of Vienna, and so far there was no information about their vulnerability under seismic actions. The developed methodology consists of a visual inspection form and the subsequent evaluation of several parameters to capture the effects of possible damages on the environment and to describe and classify the structural behaviour of the building under earthquake loading. Subsequently, the buildings are classified into four vulnerability classes to prioritize the building stock by using the evaluated parameters. In a large-scale investigation a set of 375 historic brick-masonry buildings was evaluated by the proposed RVS methodology. The results of these tests were integrated into a local seismic building vulnerability map. The evaluated vulnerability maps give useful information for emergency and evacuation planning as well as for identification of critical objects and further investigations.

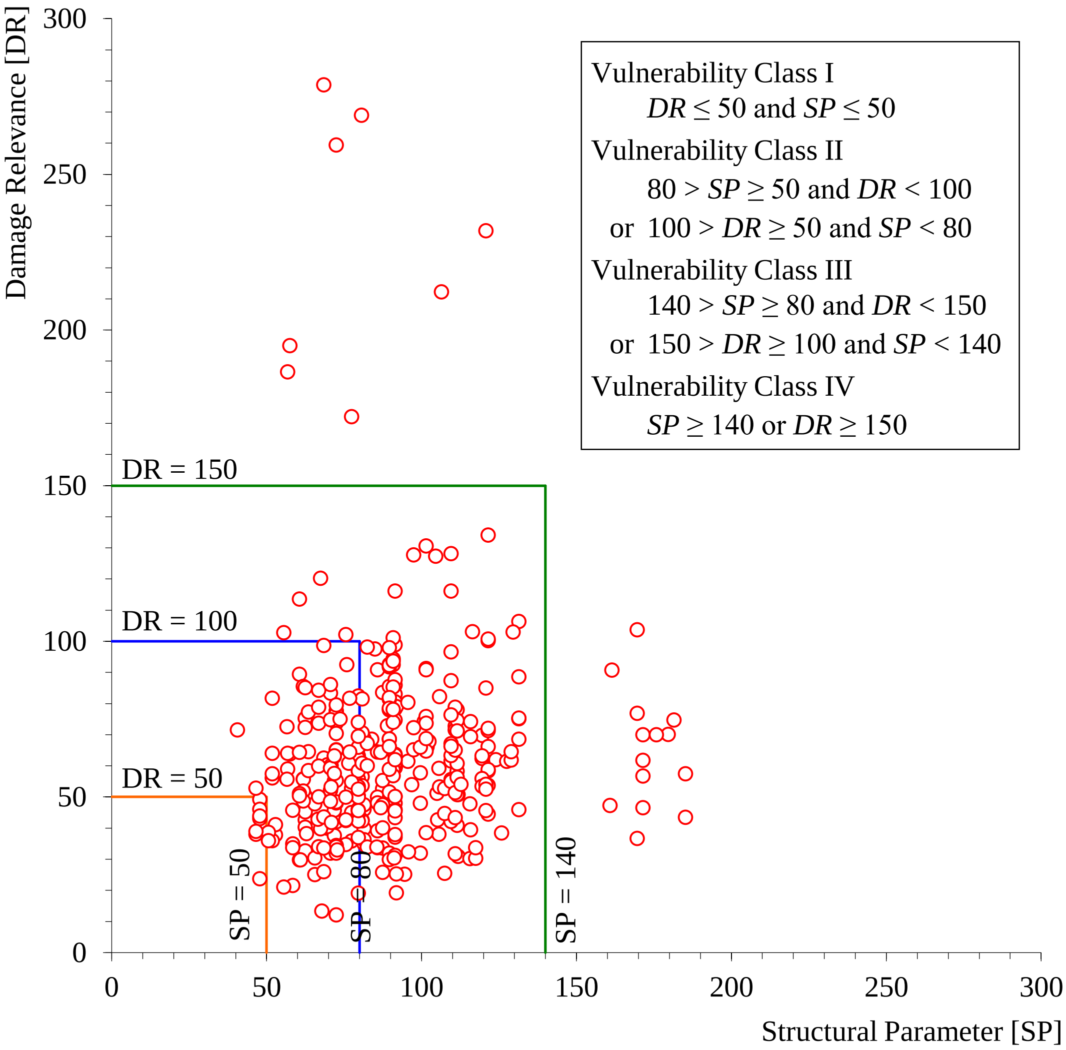

Figure 3.2. Damage Relevance *DR* of various buildings plotted against the corresponding Structural Parameter *SP*. Test area in the 20th district of Vienna

ACKNOWLEDGEMENT

The investigations described were performed within the Austrian research project SEISMID (Achs et al. 2011), which aimed, among others, at the development of a methodology to assess the actual seismic load-bearing capacity of historic buildings located in Vienna. SEISMID was funded by the ZIT Centre for Innovation and Technology, which is a subsidiary of the Vienna Business Agency (WWFF). This support is gratefully acknowledged.

REFERENCES

Achs, G. (2011). Seismic hazard of historic residential buildings. Evaluation, classification, and experimental investigations (Erdbebengefährdung von Gründerzeithäusern. Beurteilung, Klassifizierung und experimentelle Untersuchungen). Doctoral Thesis (in German), Vienna University of Technology.

Achs, G. and Adam, C. (2011). Risk assessment of historic residential brick-masonry buildings in Vienna by Rapid-Visual-Screening. *III ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2011)*, May 25-28, 2011, Corfu, Greece (Papadrakakis M., Fragiadakis, M., Plevris, V., eds), CD-ROM paper, paper no. 419.

Achs, G. et al. (2011). Earthquakes in the Viennese Basin. Evaluation – Hazard – Site Risk (in German). (*Erdbeben im Wiener Becken. Beurteilung – Gefährdung – Standortrisiko*) VCE Holding GmbH (ed.).

Building Code for Vienna (1859). Regulation of the Ministry of the Interior, September 23, 1859, to enact a building code for the imperial capital and residence city of Vienna, Journal of the provincial government of the Archduchy Austria below the river of Enns, Volume 1859, first division, part 52. Released and dispatched on October 15, 1859, Imperial-royal national press, Vienna (in German). (Bauordnung Wien, 1859. Verordnung des Ministeriums des Innern vom 23. September 1859, womit eine Bauordnung für die k.k. Reichshaupt- und Residenzstadt Wien erlassen wird, Landes-Regierungsblatt für das Erzherzogthum Oesterreich unter der Enns, Jahrgang 1859. Erste Abtheilung. LII. Stück. Ausgegeben und versendet am 15. Oktober 1859. Wien: Kaiserlich-Königliche Hof und Staatsdruckerei.)

Building Code for Vienna (1869). Regulation of the Ministry of the Interior, December 2, 1868, to enact a building code for the imperial capital and residence city of Vienna, Journal of the provincial government of the Archduchy Austria below the river of Enns, Imperial-royal national press, Vienna (in German). (Bauordnung Wien, 1868. Landesgesetz vom 2. Dezember 1868, womit eine Bauordnung für die k.k. Reichshaupt- und Residenzstadt Wien erlassen wird. Landes-Gesetz- und Verordnungsblatt für das Erzherzogthum Oesterreich unter der Enns. Wien: Kaiserlich-Königliche Hof und Staatsdruckerei.)

Building Code for Vienna (1883). Regulation of the Ministry of the Interior, January 17, 1883, to enact a building code for the imperial capital and residence city of Vienna, Journal of the provincial government of the Archduchy Austria below the river of Enns, Part 12, Regulation 35, Imperial-royal national press, Vienna (in German). (Bauordnung Wien, 1883. Bauordnung für die k.k. Reichshaupt- und Residenzstadt Wien. Gesetz vom 17. Jänner 1883, Nr. 35. Landes-Gesetz- und Verordnungsblatt für das Erzherzogthum Oesterreich unter der Enns, XII. Stück. 35. Gesetz. Wien: Kaiserlich-Königliche Hof und Staatsdruckerei.)

Calvi, G.M., Pinho, R., Magenes, G., Bommer, J.J., Restrepo-Vélez, L.F. and Crowley, H. (2006). Development of seismic vulnerability assessment methodologies over the past 30 years. *ISET Journal of Earthquake Technology* **43**, 75-104.

D'Ayala, D. and Speranza, E. (2002). An integrated procedure for the assessment of seismic vulnerability of historic buildings. *12th European Conference on Earthquake Engineering (12th ECEE)*. London, England.

Demartinos, K. and Dristos, S. (2006). First-level pre-earthquake assessment of buildings using fuzzy logic. *Earthquake Spectra* **22**, 865-885.

Erberik, M.A. (2010). Seismic risk assessment of masonry buildings in Istanbul for effective risk mitigation. *Earthquake Spectra* **26**, 967-982.

FEMA 154 (2002). Rapid visual screening of buildings for potential seismic hazards: a handbook. 2nd ed. The Federal Emergency Management Agency, Washington D.C.

Ferreira, T., Vicente, R. and Varum, H. (2010). Seismic vulnerability assessment of masonry facade walls. *14th European Conference on Earthquake Engineering (14th ECEE)*, Ohrid, Macedonia.

Flesch, R., Lenhardt, W. and Geier, R. (2005). Earthquake induced damages in Austria - assessment of existing buildings (in German). *Bautechnik* **82**, 533-538.

Gogoi, I. (2010). Rapid Visual Screening of buildings in Assam. *14th European Conference on Earthquake Engineering (14th ECEE)*, Ohrid, Macedonia.

Hassan, A.F. and Sozen, M.A. (1997). Seismic vulnerability assessment of low-rise buildings in regions with infrequent earthquakes. *ACI Structural Journal* **94**, 31-39.

Jain, S.K., Mitra, K., Kumar, M. and Shah, M. (2010). A proposed Rapid Visual Screening procedure for seismic evaluation of RC-frame buildings in India. *Earthquake Spectra* **26**, 709-729.

JBDPA (2001). Seismic evaluation and retrofit. Japan Building Disaster Prevention Association, Tokyo, Japan.

Meskouris, K.H., Sadegh-Azar, H., Bérézowsky, H. and Dümling, R. (2001). Rapid assessment of seismic hazard of buildings (in German). *Der Bauingenieur* **76**, 370-376.

Municipality of Vienna (1892). Building code for the imperial capital and residence city of Vienna, January 17, 1883, Journal of the provincial government of the Archduchy Austria below the river of Enns, Regulation 35, and Regulation of December 26, 1890, Journal of the provincial government of the Archduchy Austria below the river of Enns, Regulation 48, including instructions for officials of the urban building authority for the execution of the technical building code for Vienna, released on January 17, 1883. Private publishing venture, Vienna (in German). (Magistrat Wien, 1892: Bau-Ordnung für die k.k. Reichshaupt- und Residenzstadt Wien; Gesetz vom 17. Jänner 1883, L.-G.-Bl. Nr. 35 und Gesetz vom 26. December 1890, L.-G. u. V.-Bl. Nr. 48; inkl. Instructionen für die Beamten des Stadtbauamtes bei Handhabung des Baugesetzes für Wien vom 17. Jänner 1883. Im Verlage des Magistrates, Druck von Johann R. Bernah der Stadt Wien.)

NRCC (1993). Manual for screening of buildings for sesimic investigation. Institute for Research in Construction, National Research Council of Canada, Ottawa.

OASP (2000). Provisions for pre-earthquake vulnerability assessment of public buildings (Part A). Greek Earthquake Planning and Protection Organization, Athens, Greece.

Ozdemir, R. and Taskin, B. (2006). Seismic safety screening method for Istanbul Metropolitan City. *10th East Asia Pacific Conference on Structural Engineering and Construction (EASEC 10)*, Bangkok, Thailand.

ÖIBI (2009). ÖIBI, Special seminar “Structural assessment for building renovations” (in German) (Spezialseminar “Ingenieurbefund”). Course Material, Vienna University of Technology.

ÖN EN 1998-1 (2005). European Committee for Standardization - Eurocode 8, Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings (in German), Austrian Standards Institute.

ÖN EN 1998-1 (2006). European Committee for Standardization - Eurocode 8, Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings. National specifications concerning ÖNORM EN 1998-1 and national comments (in German), Austrian Standards Institute.

Rusnov, B. (2006). Analysis of buildings vulnerable to earthquakes with emphasis on old and historic buildings (in German). Doctoral Thesis, Vienna University of Technology.

Sadegh-Azar, H. (2002). Rapid assessment of seismic hazard of buildings (in German). Doctoral Thesis, RWTH Aachen University.

Sen, Z. (2010). Rapid visual earthquake hazard evaluation of existing buildings by fuzzy logic modeling. *Expert Systems with Applications* **37**, 5653-5660.

SIA 2018 (2004). Assessment of existing buildings with respect to earthquakes (in German). Technical Note 2018, Swiss Society of Civil Engineers and Architects, Zurich, Switzerland.

Vatan, M. and Arun, G. (2010). A method for assessing the risk level of monumental historical structures by visual inspections. *14th European Conference on Earthquake Engineering (14th ECEE)*, Ohrid, Macedonia.