Assessment and retrofitting of façade elements of 19th century buildings

A. **Kolbitsch**
Vienna University of Technology

SUMMARY:
In Vienna as in the most cities of Central Europe more than 25% of existing buildings are older than 100 years. A survey of seismic caused damages of these buildings during the last 50 years has shown that most collateral damages were caused by the collapse of parts of the facade elements.
Within the last years several buildings of this construction phase have been investigated in the context of preservation of the built heritage.
In the course of these research projects basic concepts of limit state verification of the seismic resistance of these parts have been developed. The main topics of these investigations were concerned with the mechanical properties of the existing structures, limit state verification of seismic resistance and methods for assessment and retrofitting of these elements.

Keywords: Assessment, Built Heritage, Façade Elements

1. INTRODUCTION

In Vienna and other Central Europe cities, a considerable high percentage of existing building stock was constructed before 1918. Figure 1 shows the actual age pattern of Viennese residential buildings.

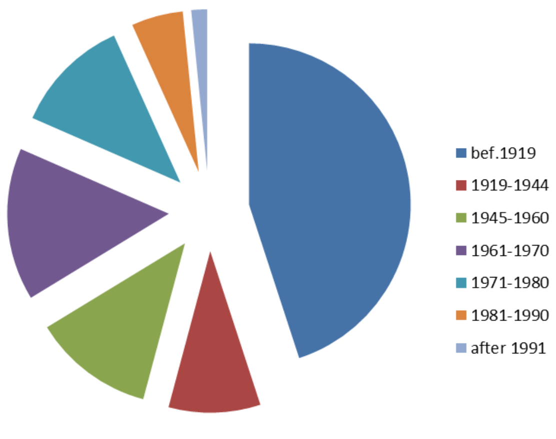

Figure 1. Age distribution of Viennese residential buildings

More than 25% of the building stock is elder than 100 years. Many of these buildings were constructed during the second half of the 19th century during the so called period of promoterism and have elaborate façade elements.

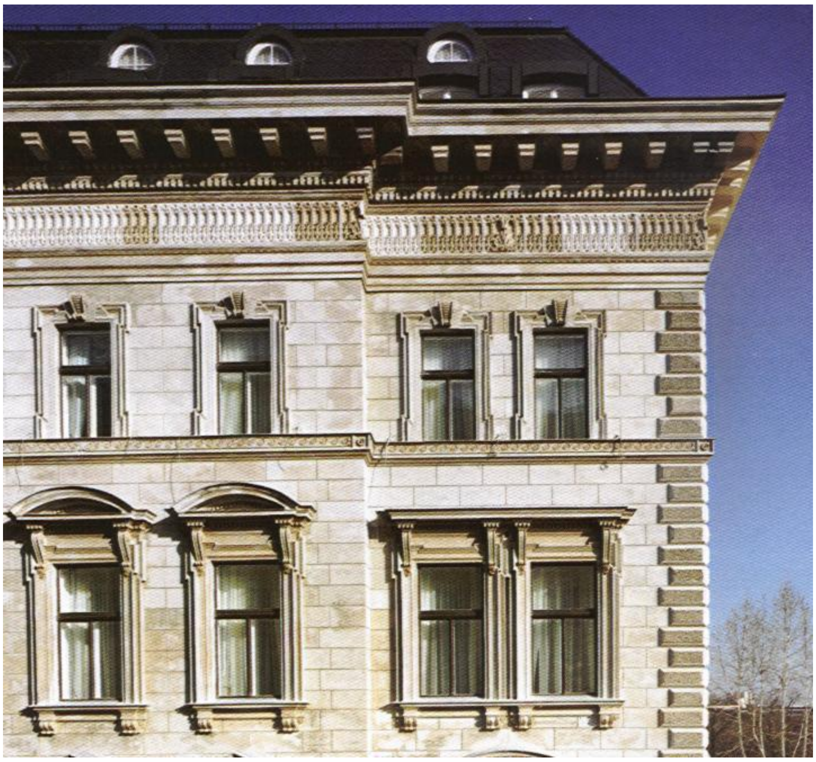

Figure 2. Palais Leitenberger, 1871/1872 with typical façade elements.

1.1. Recent investigations

In the course of investigations within the scope of the Institute for Building Construction and Technology, Vienna University of Technology over more than 20 years it turned out, that evaluation and retrofitting of façade elements is often neglected.

The analysis of several earthquakes in the area of Vienna has proved that the data for ground acceleration, recorded in EC 8 and ÖNORM B 1998 can be reached. In 1972 the so called "Seebenstein" earthquake caused ground accelerations in that range. More than 800 damages were reported, most of them affected to façade elements and masonry chimneys.

Similar observations were recorded during several other earthquakes e.g. in Alaska 1964. In most cases cornice and parapet damages are activated by an overturning moment under rapid horizontal displacements. Unless the façade elements are adequately anchored severe damages can be caused.

Since more than 20 years 19^{th} century constructions have been investigated in several research programs under the scope of Viennese University of Technology e.g. presented in Kolbitsch (2010). For the Viennese region the research project SEISMID, depicted in Achs et al. (1911) was focused on the seismic behavior of old masonry constructions. Aspects of general building assessment were discussed in Kaindl & Kolbitsch (2009).

1.1. Main topics

The main topics of the presented investigations dealt with the following topics:

- Mechanical properties of existing façade structures
- Limit state verification of seismic resistance
- Assessment and retrofitting of balustrades, cornices, chimneys and similar parts.

2. TYPICAL CONSTRUCTIONS

In the course of the investigations typical constructions were categorised and typical earthquake-caused damages were identified. In most cases cornice-structures were affected.

2.1. Cornice constructions

Cantilever cornice constructions consist of stone and iron (not steel) elements. A typical 19th century construction is depicted in Figure 3.

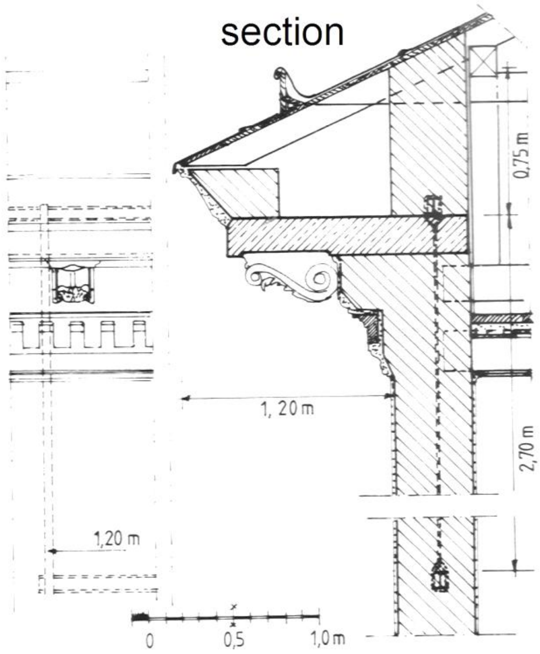

Figure 3. Typical natural-stone cornice construction.

Investigations of damaged natural-stone cornice constructions evidenced, that damages of the loadbearing masonry and corrosion of stone and iron elements in most cases were the cause of the structural collapse.

Figure 4. Partly collapsed cornice construction

Iron Cornice constructions often showed premature corrosion damages as depicted in figure 4.

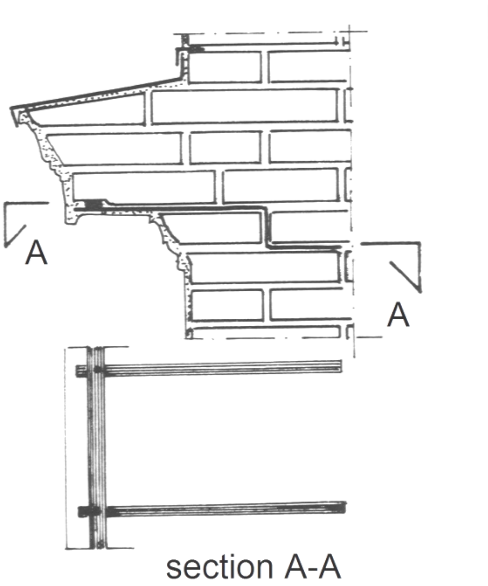

Figure 5. Typical masonry cornice (about 1870)

Figure 5 shows a typical masonry cornice often found in masonry buildings erected before 1880.

2.2. Free parapet elements and chimneys

Prestigious buildings in the so called "Ringstrassenzone" often have free parapet elements that are not adequately anchored or have severe corroded anchor elements.

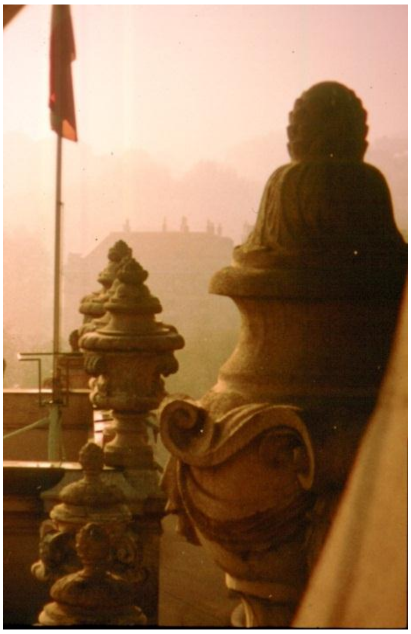

Figure 6. Free parapet elements

Figure 6 shows some of the assessed natural stone constructions. The anchoring of these constructions is often corroded, in case of an earthquake severe damage by crashing elements could result.

Chimney constructions in older buildings are simple masonry elements. Methods for examining, evaluating and strengthening of these masonry constructions have been investigated in various research projects under the scope of the Institute for Building Construction and Technology since 1990. Experimental research in seismic behavior of old masonry structures has been carried through since 30 years; an overall review of these investigations is given in Tomaževič (1999). It turned out, that in most cases damages are affected to the mechanical properties of the historic lime-mortar.

3. EXAMINATIONS

Experimental research in seismic behaviour of old façade structures has been carried through since 1986; overall reviews of these investigations are given in Kolbitsch (1989 and 2010).

Further dynamic tests on old masonry were carried through during the last years by the Institute for Building Construction and Technology, presented e.g. in Seltenhammer & Heuer (2009). It turned out, that elder results could be verified. Tests of stone constructions yielded the following results:

If the stone pit location can be detected the mechanical properties of the material can be narrowed down in a close range. Critical parts of the constructions in most cases were the mortar joints, some constructions showed severe corrosion damages of the anchor-elements.

The examination of mechanical properties of mortar joint turned out to be of significant importance, therefore in situ impact test methods for the examination of these joint have been developed and proved in practice within the last ten years.

3.1. Material properties

Verification of seismic resistance depends on knowledge about the material properties of the investigated materials, many tests and evaluations have been carried through, some of the results are presented in the following tables.

Table 3.1. Typical compressive strength for 19th century bricks, collected in several research programs

Type of bricks	Compressive Strength f_b [MPa]
Average bricks (19th cent.)	6- 12
Handmade bricks	14 – 25
Industrial manufactured bricks	20.5 – 23
Clinker bricks	30 - 90

Historical lime mortar has a compressive strength between 0,5 and 2,5 MPa. In most cases only 1,0 MPa could be detected.

The typical mechanical properties of natural stone construction elements depend on stone pit location and corrosion effects. Some typical properties are listed in Table 2.2.

Table 3.2. Typical mechanical properties of natural stone construction used in Vienna.

Type of stone	Apparent density [kg/dm³]	Compressive strength [MPa]		
		Minima	Mean Values	Maxima
Limestone	2,34 – 2,57	10 - 60	80 -120	60-210
Sandstone	1,68 – 2,50	-	49 -80	-
Granite	2,60 – 2,65	130	160	230

3.1. Limit state verifications

During an earthquake façade elements generally will be affected by motions different to those of the ground floor. The buildings acceleration will change with the height of the building, for stiff masonry buildings generally becoming greater in amplitude and frequency content.

Several Codes as Eurocode 8 give simple formulae to find the horizontal seismic force occurring the overturning moment of free parapet elements and chimneys. Similar practical codes are discussed e.g. in ATC-69 State-of-the-Art and Practice Report (2008).

The formula in Eurocode 8 is:

$$F_a = (S_a \cdot W_a \cdot \gamma_a)/q_a \tag{3.1}$$

F_a is the horizontal seismic force acting at the center of mass of the façade element and W_a is the weight of the element. For the discussed elements the importance factor of the element γ_a and the behavior factor q_a are equal to 1. The so called "seismic coefficient" describes the ratio of peak acceleration on ground to that of the façade element. It is calculated as follows:

$$S_a = \alpha \cdot \mathrm{S}[3\,(1 + z/H)/(1 - T_a/T_1)^2 - 0{,}5] \text{ or } S_a = \alpha \cdot \mathrm{S} \text{ (if greater)} \tag{3.2}$$

S is the soil factor and ranges from 1 up to 1.8; α is the ratio of the design ground acceleration a_g on hard ground to the acceleration of gravity. Ta is the fundamental vibration period of the façade element and T1 is the fundamental vibration period of the building in the considered direction. z is the height of the façade element and H is the building height above the level of application of the seismic action. This is either the foundation or the top of a rigid basement.

Other methods for verification are discussed in ATC-69 report and in Booth&Key (2006).

In general it turned out that in nearly all cases the acceleration of the Façade element is greater than ground acceleration. For cornice constructions also the vertical seismic force has to be calculated in a similar way as in formulae (3.1) and 3.2). For the area of Vienna wind caused forces on façade elements in any examined case were lower than the calculated seismic forces.

4. ASSESSMENT AND RETROFITTING

Some methods for refurbishment of the discussed elements were developed and tested under practice.

3.1. Assessment of cornice constructions

The main effort is to fix the clamped abutment of the construction by means of prestressed anchor bars.

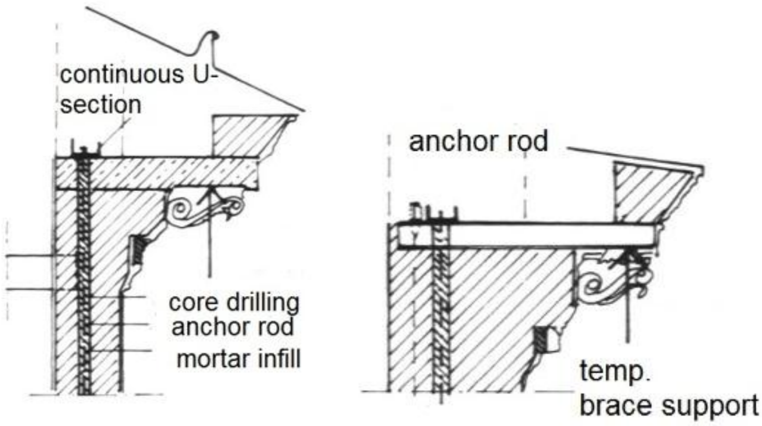

Figure 7. Assessment of a natural stone and metal cornice construction

The depth of the drilling core in Figure 7 depends on the weight of the Masonry construction that is activated as a balance weight.

3.1. Retrofitting single elements

Figure 8 shows the assessment of a cracked cantilever construction in a baroque façade. The stone construction was prestressed by a single anchor rod and afterwards injected with resin grout.

Figure 7. Assessment of a natural stone and metal cornice construction, before and after restoration

4. CONCLUSION

The results of the investigation of façade elements in 19th century end elder buildings revealed that in most cases it is possible to find a method to assess or retrofit the constructions. In any case it was necessary to carry through a detailed analysis including material tests and to execute a limit state verification.

REFERENCES

Achs, G. et al. (2011). Erdbeben im Wiener Becken. VCE, Vienna. (In German).
ATC (ed.) (2008). ATC-69 Reducing the Risks of Nonstructural Earthquake DamageState-of-the-Art and Practice Report. ATC, Washington D.C.
Bachmann, H. (2003) Seismic Conceptual Design of Buildings – Basic principles for engineers, architects, building owners, and authorities. BWG Biel.
Booth, E., Key, D. (2006) Earthquake design practice for buildings. Second edition. London: T. Telford
Committee on the Alaska Earthquake oft he Division of Earth Sciences – National Research Council (ed). (1973). The Great Alaska Earthquake of 1964. Washington D.C.: National Academy of Sciences.
Duma, G. (1988). Seismische Mikrozonierung des Stadtgebietes von Wien. ZAMG, Wien. (In German).

Fierro, E.A., Miranda, E., Perry, C.L.(2011). Behaviour of Nonconstructural Components in Recent Earthquakes. *Proceedings of the 2011 AEI Conference,* ASCE, 2011 361-377.
Furtmüller, T., Adam, C. (2011). Numerical modeling of the in-plane behavior of historical brick masonry walls. *Acta. Mech.* **221** 65-77.
Kaindl, M. and Kolbitsch, A. (2010). Die Bestandsaufnahme als Teil des Risikomanagements im Baubestand. *Journal für Facility Management, Wissenschaft trifft Praxis*, **1/2009**: 32-45. (In German)
Kirchmayer, W., Popp, R. and Kolbitsch, A. (2011). Dachgeschoßausbau in Wien. Verlag Österreich, Wien. (In German).
Kolbitsch, A. (1988). Altbaukonstruktionen, Charakteristika, Rechenwerte, Sanierungsansätze. Springer, Wien, New York. (In German).
Kolbitsch, A. (2010). Möglichkeiten zur Ertüchtigung von Hochbauten der Gründerzeit. *ÖIAZ* **1-3/2010** and **4-6/2010 155.Jg.** 85-91. (In German)
Korjenic, S. and Kolbitsch, A. (2010). Ausziehversuche an Aramidstäben im Ziegelmauerwerk. *Mauerwerk* **2010, 6**, 357-359. (In German)
Pauser, A. et al. (1995). Bestimmung der Festigkeit von Mauermörtel mittels Schlagversuchen – Grundlagenversuche zur Entwicklung eines in-situ Prüfverfahrens. TU Wien, Institut für Hochbau und Industriebau. (In German)
Seltenhammer, A., Heuer, R. (2009). Kalibrierung von Mauerwerkparametern mittels verfeinerter mechanischer Modellierung. Erdbeben und Mauerwerk 11. *DACH Tagung, 2009. Zürich*: 107-112.
Tomaževič, M. (1999). Earthquake-Resistant Design of Masonry Buildings. Imperial College Press, London.