DAMAGE SCENARIOS FOR CENTRAL EUROPE – HISTORICAL EARTHQUAKES AS BASIS FOR CALIBRATING PROGNOSIS TOOLS

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Intensity-based risk assessment procedure- Basic elements of EDAC model

For the study area of Central Europe, an intensity-oriented damage and loss prediction model is developed and adapted to regional seismic risk studies in Germany (Schwarz *et al.*, 2008), Austria (Schwarz *et al.*, 2007), Greece (Langhammer *et al.*, 2006), and Switzerland (Schwarz *et al.*, 2008a). The procedures implemented in the model are structured in a modular system, and accordingly in a transparent way. Case studies for Central Europe are performed, not at least, to calibrate the damage and loss model to the existing particularities of regional predominant building types (expressed by a regionalisation factor [Ri]). The presented scenarios refer to historical earthquakes in different Federal States of Germany (BW, NW, TH) as well as in Austria (A) and Switzerland (CH).

Within the Geographical Information System (GIS)-based earthquake damage and loss prediction tools, the different data layers represent essential steps of the whole approach. Figure 1 illustrates the basic elements (modules) of the EDAC intensity-based earthquake model assuming an epicentral intensity of I_0 = 8.0 and a source close to the epicentral coordinates near the 1601 Nidwalden (Switzerland) earthquake (cf. Figure 3, scenario CH2).

(1) Shaking effects (intensities) describe the regional or local hazard [I_s]: The intensity correction factors [ΔI_s] accounts for the effect of local site conditions (subsoil, topography, deep geology; see Figure 2). Intensity correction factors (ΔIs) are derived from different approaches, including site response studies as well as the statistical studies on the repeatedly observed shaking effects in differently sized raster elements.(Note: The impact of soil conditions is considered, i.e., an intensity correction is applied in Figure 1(1) – Map of shaking effects.)
(2) Mean Damage Grades D_m [D_m] are derived from local intensities using specifically elaborated damage functions and reflect regional differences in the building substance. [A regionalisation factor [R_i] - as the key element for the damage prognosis - reflects the vulnerability of building types and leads to a modification of vulnerability functions.]
(3) Using correlations between the Mean Damage Grades [D_m] and the Mean Damage Ratio [MDR] the loss [€] (4) can be predicted for any value basis. The assets are taken from data provided by Bureaus for Statistics or authorized annual reports of economical development.
According to the scheme Vulnerability (VF) and Damage Functions (DF) have to be distinguished:

Vulnerability Function (VF) of Type ① correlates the intensity with the Mean Damage Grade Dm; Vulnerability is related to the level earthquake resistance of the building or the building stock under consideration.
Damage Function (DF) of type ② tries to correlate the damage grade to building(s) and loss. An example is given by Schwarz *et al.* (2004) for the case study of North Rhine Westphalia (NRW) as an outcome of a comprehensive risk project (Deutsches Forschungsnetz Natur-katastrophen DFNK, Schwarz *et al.*, 2006a).
Damage Function of type ③ represents the insurance standard approach. Functions of this type are used in the past and have been elaborated within different application projects.

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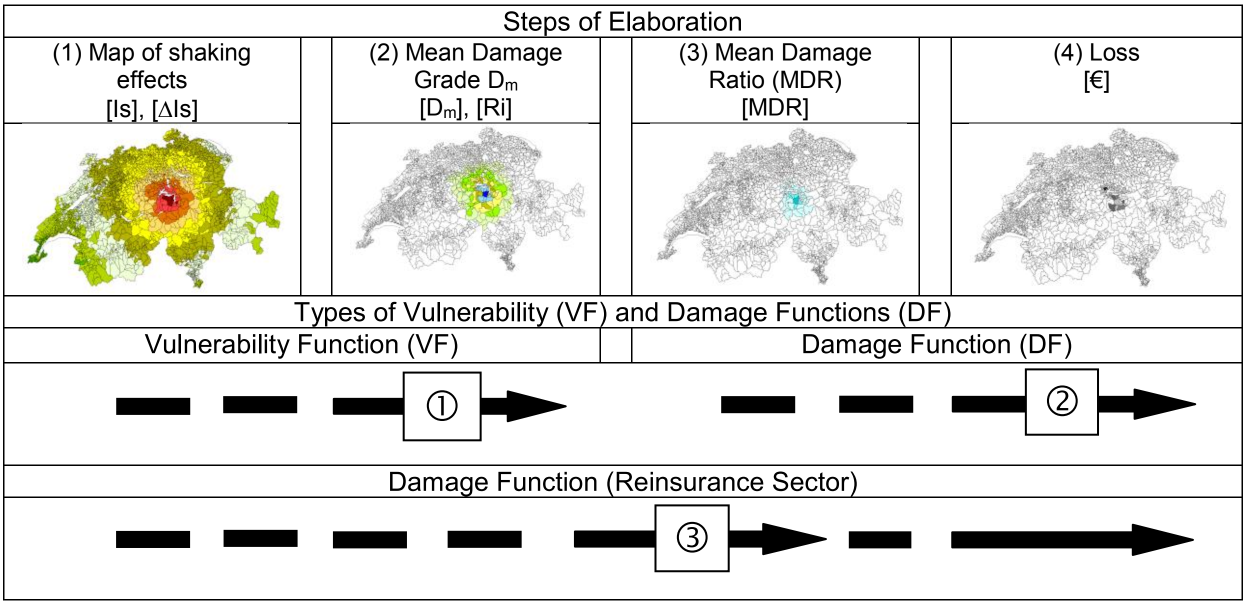
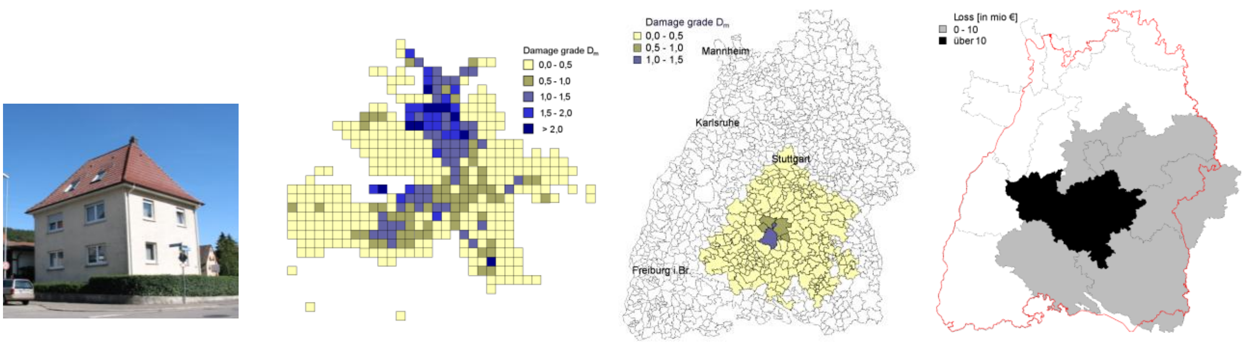


Figure 1: *Basic steps and data layers of EDAC damage and loss assessment model (following the scheme of the EDAC model and pilot studies for Baden-Wuerttemberg* (Schwarz *et al.,* 2006) and Switzerland (Schwarz *et al.*, 2008a).

Levels of Elaboration

From an engineering point of view and with respect to damage prognosis, four levels of elaboration and data processing are distinguished (from address-oriented macro scale) and implemented into the damage and loss prediction tools of Earthquake Damage Analysis Center (EDAC). Based on address-orientated level, damage and loss description are related to individual buildings (or damage cases). Any prognosis requires a nonlinear analysis as well as the prediction of the capacity curve of the main structural system. Results can be used for geo-statistical extrapolation and reliability check between analytical and empirical approaches.

Micro-scale studies are related to Damage Grades D_i according to EMS-98 (Grünthal *et al.*, 1998) which can be transformed into Mean Damage Grades D_m for a mesh of small sized grid elements overlaying the area under consideration. Damage scenarios are presented for the epicentres of major historical events. The loss is determined on the basis of the Mean Damage Grades D_m derived for administrative units (district elements) following the steps illustrated in Figure 1.



(a) Address-oriented

(b) Micro-scale. Mean Damage Grades D_m in small raster elements

(c) Meso-scale. Mean Damage Grades D_m in district elements

(d) Macro-scale Loss estimation in 2-ZIP code area elements

Figure 2: *Processing levels and parameters for damage and loss assessment* (Schwarz *et al.*, 2006, 2008b)

Scenarios for Central Europe

Case studies for Central Europe are performed, not at least, to calibrate the damage and loss model to the existing particularities of regional predominant building types (expressed by a regionalisation factor [Ri]). The presented scenarios refer to historical earthquakes in Federal States of Germany (BW, NW, TH), Austria (A) and Switzerland (CH); see Figure 3, and Table 1.

For some of these events, the remarkable refinement of the available intensity maps support supplementing studies on the effect of site conditions (Schwarz *et al.*, 2008a,b). The paper considers the impact of site conditions and the discrepancies between the hypothetically predicted and the observed shaking effects.

It can be concluded that an intensity correction is required to account for the effect of local site amplification phenomena to receive realistic results. The significant impact of local intensity "anomalies" can be elaborated while comparing the results of radial uniform intensity attenuation ("Is, radial") with those being derived from the maps of observed shaking effects ("Is,obs"), i.e. intensity maps are overlapped with the now existing building stock. Results are scaled to the losses predicted for the variants "Is,obs". Different maps of site intensity correction factors ("Is ± ΔIs") are implemented in the damage model.

Losses derived by the EDAC model will be compared with those from other scenarios and attempts summarizing the results of (rather limited) published damage scenarios or models for Central Europe.

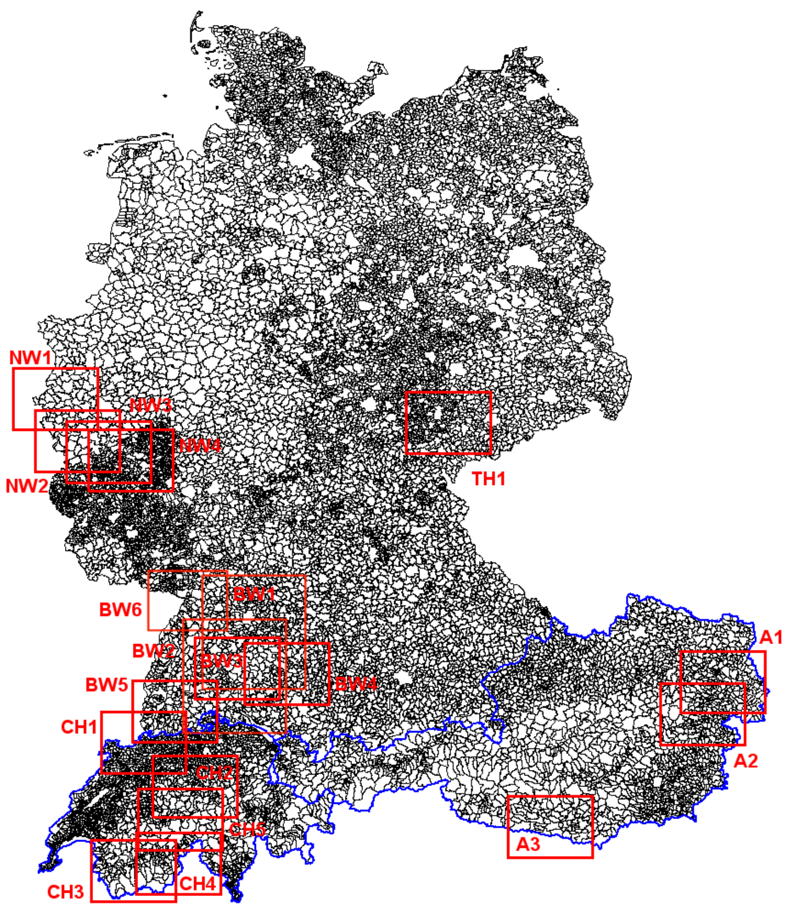


Figure 3: *Map of D-A-CH states indicating the administrative units and scenario Earthquakes derived from historical events* (Schwarz *et al.*, 2008b)

Table 1: *Overview of historical and recent earthquakes used as scenarios events*

Scenario ID	Location	Year	I_0	Scenario ID	Location	Year	I_0
			Germany (D)				Austria (A)
BW1	Albstat-Ebingen	1911	VIII	A1	Ebreichsdorf	2000	VI
BW2	Tübingen	1755	VII	A2	Seebenstein	1972	VII
BW3	Albstadt	1978	VII-VIII	A3	Villach	1690	VIII-IX
BW4	Saulgau	1935	VII-VIII				
BW5	Waldkirch	2004	VI				
BW6	Mahlberg	1728	VII-VIII				Switzerland (CH)
NW1	Roermond	1992	VII	CH1	Basel	1356	IX
NW2	Düren	1756	VIII	CH2	Niedwalden	1601	VIII
NW3	Euskirchen	1951	VII-VIII	CH3	Sierre	1946	VIII
NW4	Tollhausen	1848	VIII	CH4	Visp	1855	VIII
TH1	Posterstein	1872	VII	CH5	Sarnen	1964	VII

Results and consequences of intensity-calibrated loss prediction

To compare the results, for the coordinates of the scenario, earthquakes epicentral intensities I_0 = VII and I_0 = VIII and a uniform source depth of 10 km are assumed. Within the first test series, losses are calculated on the basis of shaking effects predicted from a radial (uniform) intensity attenuation, i.e. no intensity correction due to site conditions is applied. Results are scaled to the Central European Earthquake from November 16, 1911. The losses are predicted for the recent building situation, values (assets) are calibrated to the statistics from 2000. For the same level of ground shaking (intensity) losses differ by a factor 2 and even more. There are areas with the tendency of lower, and areas with the evidence of substantially higher damage (Schwarz *et al.*, 2008b).

The critical scenario for Germany (and for North Rhine-Westphalia NRW) might be generated by the simple repetition of the 1756 Düren earthquake (NW2), if the epicentral coordinates of historical earthquakes are considered in their repetition.
As the critical scenario for Southern Germany, an earthquake with the epicentre near Tübingen (BW1) could be identified (Schwarz *et al.,* 2006b). This can be explained by the vicinity to Stuttgart and the extent of affected areas with high population density and assets concentration. Remarkable loss could be expected by stronger earthquakes in Eastern Thuringia (TH1); the extent of damage again has to be explained by the vicinity to larger urban areas and city centres (Schwarz *et al.*, 2002, 2004).

The significant impact of local intensity “anomalies” can be elaborated by comparing the results of radial uniform intensity attenuation (“I_S,radial”) with those being derived from the maps of observed shaking effects (“I_S,obs”). Referring to the particularities of earthquakes in North Western Europe the scenarios of this study demonstrate the tendency of an increase of losses due the high building density and concentration of assets in vicinity of probable epicentres. Realistic prognoses might be obtained by considering the subsoil-related amplification phenomena of thick sedimentary layer, in more detail. It becomes evident that for the earthquakes in North Western Germany (scenarios NW1, 2 and 4) commonly used models tend to overestimate the loss.

Recent and further developments

Recent and further developments will be touched, finally:
(1) For recent central European Earthquakes the outcome of ShakeMap procedures can be discussed with respect to the available ground motion database for the Waldkirch 2004 (scenario BW 5) earthquake (Beinersdorf & Schwarz, 2014).

(2) A higher level of refinement could be reached by a new procedure which correlates the statistical data and the results of the field surveys. It seems to be possible to develop an extrapolation and simulation tool to transform the available data (age, number of stories) into the probable composition of the building types within the administrative unit (provided with statistical information). The basic idea will be illustrated for the study area of Sarnen (CH5). where the results of (a) a rapid screening (by Random Urbanization Method, RUM) and (b) the detailed survey on the basis of about 1220 Data points (buildings) will be compared with respect to the composition of buildings types.

(3) Finally, an intensity-based tool will be presented using EQ libraries obtained by PSHA and Monte-Carlo simulation techniques For the case study of Albstadt earthquake (scenario BW 3) it will be illustrated how instrumental site investigations and search routines can be implemented to generate site-specific ground motion prediction equations for reconstructing the observed shaking effects (Kaufmann & Schwarz, 2014). This developed approach offers several advantages by considering uncertainties from the hazard, ground motion and vulnerability assessment in a consistent and quantifiable way.

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