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MODULAR SYSTEM FOR SEISMIC RISK ANALYSIS CONSIDERING UNCERTAINTIES OF BASIC INPUT PARAMETERS

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ABSTRACT

For the study area of Central Europe, an intensity-oriented damage and loss prediction model is developed and being adapted to regional seismic risk. The procedures implemented in the model are structured in a modular system, and therefore in a transparent way. The paper refers to the modification of the tools of risk analysis to account for the uncertainties and the scatter of basic input parameters. Results are presented for the strongest earthquake in Central Europe over the last 50 years, the September 03, 1978 Albstadt (Germany) earthquake (M_L = 5.7; I_{EMS} = 7.5). The evaluation of the existing building stock and its vulnerability is considered in more detail. The identification of the predominant building types, the assignment of their most likely or probable vulnerability classes and the formulation of correlations between these classes and the distribution of damage grades are regarded as the innovative key elements of the whole intensity-based procedure. Damage scenarios are related to the recent earthquake comparing the hypothetically predicted and the observed shaking effect. Damage is given in terms of fractiles replacing the commonly used mean damage grade.

KEYWORDS: risk, intensity, vulnerability, damage and loss assessment, uncertainty

1. BASIC ELEMENTS AND MODULES OF THE INTENSITY-BASED RISK ASSESSMENT

Within the Geographical Information System (GIS)-based earthquake damage and loss prediction tools, the different data layers represent essential steps of the whole approach. In the meanwhile, the developed – mainly deterministic - procedure was successfully applied in a series of case studies within the main seismic zones of Germany, e.g. for a city in Eastern Thuringia [Schwarz *et al.*, 2006], for Cologne (Lower Rhine Embayment [Schwarz *et al.*, 2004, 2006] and for Albstadt (Swabian Alb) [Schwarz *et al.*, 2005]. In collaboration with Greek institutions, the building stock of Aigion (Greece) was surveyed to reconstruct the building damage after the June 1995 Earthquake [Langhammer *et al.*, 2006]. Recently, damage and loss scenarios for Central Europe and adjacent areas (Germany, Austria and Switzerland) are compared on the basis of historical earthquakes and the reinterpretation of observed shaking effects [Schwarz *et al.*, 2008a]. Basic elements (modules) of the EDAC intensity-based earthquake model are subsequently applied to the case study of Albstadt-Tailfingen (Baden-Württemberg; Germany).

2. TRETAMENT OF UNCERTAINTIES WITHIN THE MODULAR RISK ASSESSMENT TOOLS

The implementation of seismic risk analysis requires the appropriation of characteristic input parameters and data levels which are usually afflicted by uncertainties. At the moment, within the model 10 levels of data processing and refinement are distinguished. Comparisons between the results of these levels enable the quantification of the scatter and the impact of the basic input parameters [Schwarz *et al.*, 2004, 2005, 2006]. Nevertheless, it is still not sufficiently and systematically studied how and in which extent the uncertainties of the individual input parameters affect the results, which are of engineering interest, i.e. the level and local distribution of damage, and their probability of being exceeded due to model uncertainties

The scatter of results is in a so far not adequately quantified. Therefore, the existing modular system is modified and extended by new elements, correlations and definitions that allow a multi-directional treatment of uncertainties. The system is based on the following principles [Kaufmann, 2008]:

- Separate treatment of uncertainties in each module,
- Maintaining scatter of interim results within the input for the subsequent or interacting modules and
- Quantification of influence on the scatter arising from the individual modules as well as module changes for the interim and the final results.

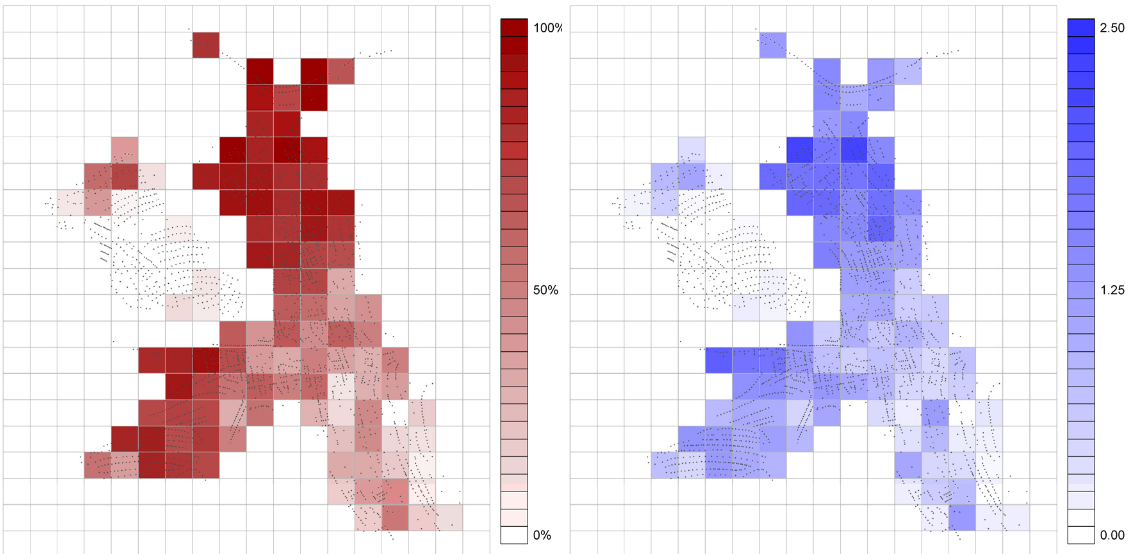
In general preference is given to describe the uncertainty of models, correlations or functions in distributions of parameter probability or density.

3. CASE STUDY: ALBSTADT-TAILFINGEN

3.1 Reinterpretation of the September 3, 1978 Albstadt (Germany) earthquake

The application is illustrated exemplary for the September 03, 1978 Albstadt (Swabian Alb, Germany) earthquake (M_L = 5.7). The occurred (reported) structural and monetary building damage could be reinterpreted on the basis of well-documented questionnaires from the local administration offices (see Schwarz *et al.,* 2005). About 1.300 damage cases could be recently revaluated by the EDAC staff. The calculated scenarios can be compared with real occurred loss or observed damage. A mesh of raster elements with slightly adaptable size is introduced to enable the link between different previous studies and to calibrate the model to the building stock and to the damage situation at time of and after the earthquake, respectively. The quality of the elaborated damage situation can be proven on the basis of the Damage Rate D_r (indicating the percentage of damaged building within single raster elements) and the Mean Damage Grade D_m (see Figure 1). It can be shown that the reinterpretation fits the situation caused by the earthquake (see Schwarz *et al*., 2005).

In recently up-dated earthquake catalogues, the macroseismic (epicentral) intensity of the earthquake is still given with I_{EMS} = 7.5. Due to close distance to the fault line (intersecting the city) this intensity can be taken for the scenario (see also Figure 2). From the reassessed damage and calculated loss, Schwarz *et al.,* 2005 concluded that the reference intensity of the earthquake should be in a range between 7.0 and 7.5. Subsequently, a calculational intensity I_{EMS} = 7.25 is taken.



a) Damage Rate D_r b) Mean Damage Grade D_m

Figure 1 - Indicators of observed damage, averaged within (125 m x 125 m) raster elements

3.2 Hazard

Probabilistic Seismic Hazard Analysis is performed using the program PSSAEL [Rosenhauer, 1999]. For each zoning element of the applied seismicity model by Ahorner and Rosenhauer (in its recent version given by Ahorner *et al*., 2006), the magnitude-exceedance rates are calculated on the basis of Extreme-Value statistics and GUMBEL-Parameter (m, τ, σ, M_{max}). The intensity exceedance rates for the study area of Albstadt are given by Figure 2. For practical reasons, damaging intensities are of interest, only. Shaking effects (intensities) describe the regional or local hazard. Following the descriptions of EMS-98 slight to moderate structural damage has to be expected by shaking effects between intensity I_{EMS} = 6 and 8. A mean return period of about 100 years can be assigned to the intensity of the September 03, 1978 Albstadt Earthquake (I_{EMS} = 7.25). The PSSAEL tools enable the Monte-Carlo simulation of earthquake libraries. For each intensity level a list of about 2000 successful trials (from several millions generated ones) seems to be representative for the hazard level under consideration. Each data point (earthquake) is described by a magnitude-distance pair (and its epicentral coordinates, see Figure 4c). The cumulative distribution of magnitudes and distance parameter are illustrated for mean return periods between 20 and 2500 years (Figures 4a, b). Due to the high seismicity of the study area, the differences in the hazard are mainly related to the magnitude M_L. The median and 84% fractiles of distance (d_{50} and d_{84}) remain nearly unchanged in a range form 5 to 8 km, while the magnitude is increasing steadily, i.e. damage and loss scenarios have to consider near-field events, only.

The earthquake libraries deliver the condensed information about the uncertainties of the site-dependent hazard estimate. The parameters of the simulated earthquakes can be related to ground motion models (attenuation functions), directly. They have to be regarded as one key element of the procedure pre-determining the scatter within spectral amplitudes on the action side (cf. Figure 5) and damage grades in case of analytical investigations of individual building of the predominant structural system (see Figure 6). Their impact is less important within the empirical intensity-based approach where the damage is related to the building type and/or vulnerability assignments (see Table 3.1).

In general, existing and recently developed damage models indicate the tendency to ignore deterministic approaches and to overestimate the role of probabilistic seismic hazard assessment (PSHA). Within the recently developed procedures and within the module HAZARD deterministic hazard assessment is qualified and extended by semi-probabilistic principles enabling the validation of PSHA results by deterministically derived design earthquakes (see Schwarz *et al*., 2007a).

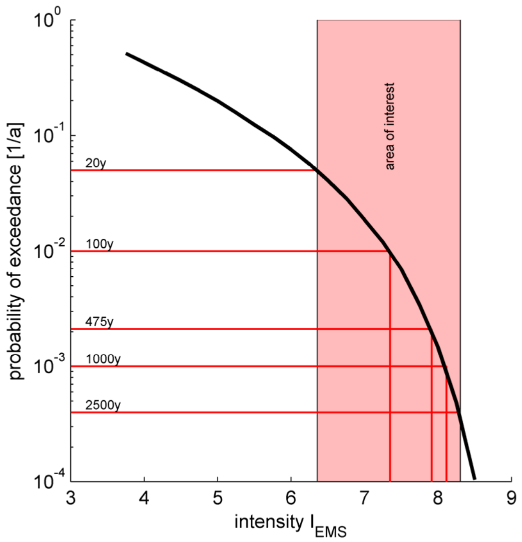


Figure 2 - Probabilistic Seismic Hazard Assessment (Module HAZARD): Intensity exceedance rates

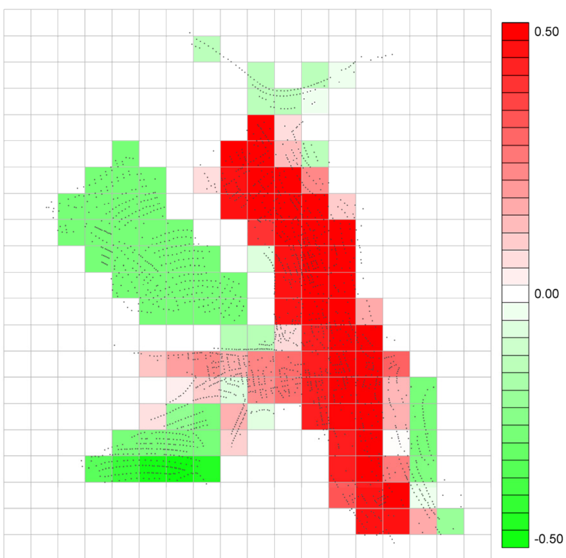
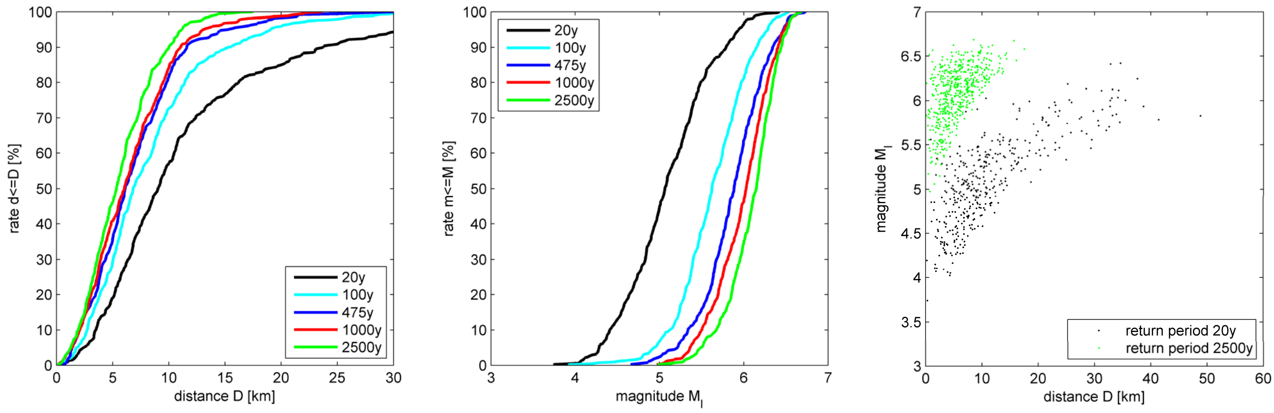


Figure 3 - Incremental site intensity correction [ΔI_S]; taken from Schwarz *et al*., 2007c



a) Cumulative distribution of distance D

b) Cumulative distribution of magnitude M_L

c) Magnitude – distance relation for return periods 20y and 2500y

Figure 4 - Disaggregation of seismic hazard for intensities of different mean return periods; cf. Figure 2

3.3 Soil and Site-dependent Seismic Action

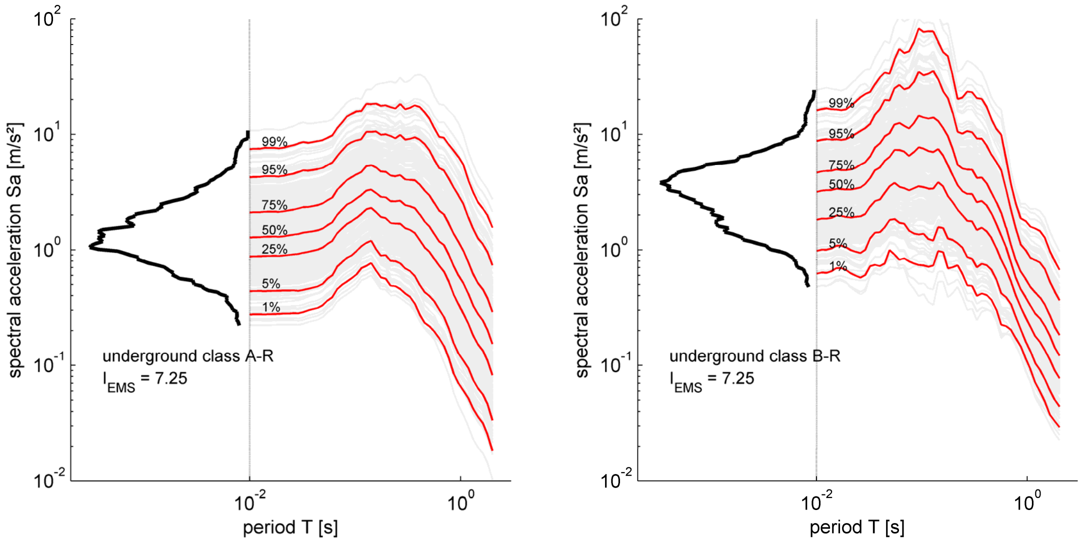
The module SOIL allows the integration of site-dependent ground effects including the associated uncertainties of soil profile and layer properties. In addition, the local intensity increments (site correction factors) are derived. The significant impact of local intensity “anomalies” can be elaborated while comparing the results of radial uniform intensity attenuation with those being derived from the observed shaking effects, leading to a modification (correction) of the local site intensity. The intensity correction factors [ΔI_S] accounts for the effect of local site conditions (subsoil, topography, deep geology; see Figure 3).

Within the microscale level of Albstadt-Tailfingen, the intensity correction increments [ΔI_S] are derived from different approaches including statistical studies on the repeatedly observed shaking effects in differently sized raster elements, site response studies as well as site response analysis in combination with instrumental site classification.

The module SEISMIC ACTION allows defining and manipulating the site-dependent type attenuation function. It is shown by [Kaufmann, 2008], to which extent the standard error (σ term) can be minimized by choosing the appropriate type of attenuation function.

For analytical site and building response studies peak ground motion and spectral acceleration have to be provided. In this context, a remarkable progress is reached with the development of classification scheme for the results of instrumental studies with the concept of geology and subsoil-dependent spectra [Lang, Schwarz., 2006], being implemented within the German Seismic Code DIN 4149:2005. Subsoil classes (A, B, C – rock, stiff, soft) are combined with geological features (R, T, S - rock, transition, basin); i.e. the resultant underground classes (A-R, A-T, A-S, …, C-S) are indicators for the whole deep profile. The situation in the study area of Albstadt-Tailfingen can be characterized as follows: Underground class B-R (stiff soil over bedrock) is predominant for the whole inner city area corresponding to an increase of site intensities; a soil factor $S = 1.25$ is given for their types in DIN 4149:2005. Approaching the middle of the river valley the thickness of sediments is increasing; here higher periods ground motions have to be expected (partially explaining the concentration of damage to industrial chimneys caused by the earthquake in 1978). In the mountainous area underground class A-R tends to a slight intensity reduction (minor or negligible site effects).

For the case study of Albstadt-Tailfingen, benefit is taken from the recently elaborated attenuation functions being directly related to the underground classes of DIN 4149 (see Schwarz *et al.*, 2007b). Figure 5 is illustrating how the results of module HAZARD is linked with the module SOIL and module SEISMIC ACTION. Using the simulated earthquake library for the intensity I_{EMS} = 7.25, different fractiles of spectral accelerations can be determined for the predominant site conditions (at a particular building site or for a small sized raster element).

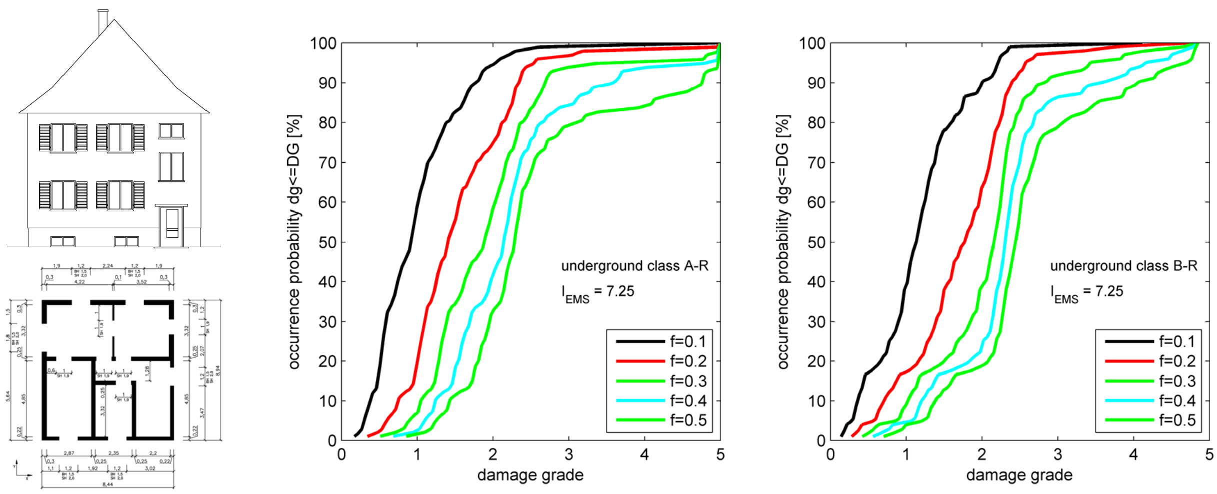


a) Underground class A-R (rock)   b) Underground class B-R (thin layer of stiff soil over rock)

Figure 5 - Simulated spectra for PSSAEL result and simulated earthquake library for I_{EMS} = 7.25; subsoil- and ground class related attenuation function (Schwarz *et al.*, 2007b)

3.4 Vulnerability Classes (VC) and damage probability distributions

Results of the risk analysis for a typical masonry building with wooden floors are given by Figure 6. Uncertainties of seismic HAZARD (expressed by the earthquake libraries, Figure 4c), SOIL amplification (Figure 5) and SEISMIC ACTION (error term σ from the attenuation models) are combined in the hazard-consistent, site-dependent ground motions applied to the structural system. By quasi-static nonlinear pushover-analysis and further evaluation criteria of the BLM-Tool (EDAC, 2002) the damage grade is predicted for about 1000 simulated scenarios. Results for underground classes are illustrated by the damage probability curves in Figure 6b and c. The variants for f = 0.1 to 0.5 are related to the effective level of ground motion in case of unreinforced masonry structures. It account for the observed discrepancy between the outcome of analytical studies and the occurred damage grades at Albstadt September 1978 earthquake statistically investigated by [Schwarz *et al.*, 2008b]. For the example building (class B-R site) a damage grade 3 was reported.



a) Example building   b) Underground class A-R   c) Underground class B-R

Figure 6 - Distribution of damage grades due to subsoil conditions (single building: masonry with wooden floors)

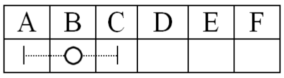
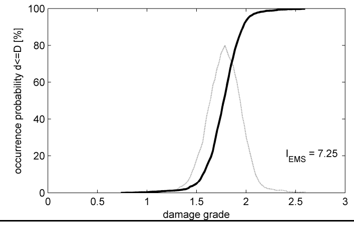
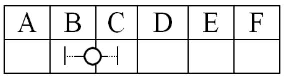
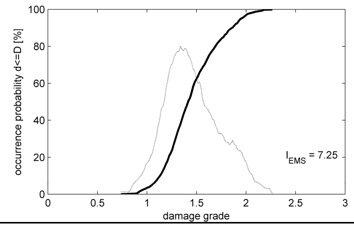
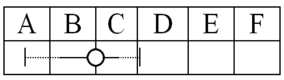
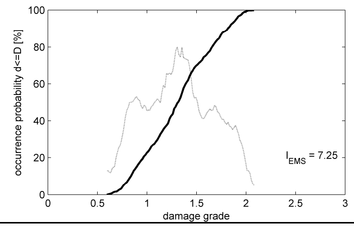
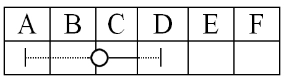
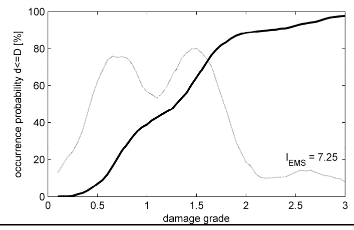
Another procedure is required if the risk for the whole building stock has to be quantified. For this case, the module VULNERABILITY includes the conversion of typical building types into (ranges of) vulnerability classes. In general and to cover larger areas as well as the regional variations of the building stock geo-statistical methods are applied. By transforming the empirical vulnerability classes of *European Macroseismic Scale* EMS-98 into damage distribution functions the influence of the uncertain knowledge about the composition of a building stock and its vulnerability on the analysis results can be investigated. In Table 3.1 four approaches are presented; they are related to quite different levels of data pre-processing:

EMS (No.1): Basic approach; the ranges of Vulnerability Classes (VC) according to EMS-98 are taken; the descriptive elements (“most likely”, “probable range” and “less probable exceptional cases”) are “translated” into damage occurrence rates.

RUM (No 2), Field Survey (No 3): The building types and appropriate Vulnerability Classes (VC) are elaborated by rapid screening or more refined field surveys. Geo-statistical extrapolations may limit the effort [Schwarz *et al.,* 2005]. The building by building Field Survey (No 3) provides the data entry to calculate damage probability distributions, i.e. therefore to quantify uncertainties on the basis of the existing building type.

As an outcome from comprehensive field surveys, each building in Albstadt was evaluated, enabling more precise assignments of existing Vulnerability Class distributions for the same building type. The whole procedure is explained by the Table 3.1. The innovative approach is related to the transformation of the indicated ranges of VC into intensity-dependent probability distributions of the corresponding damage grades.

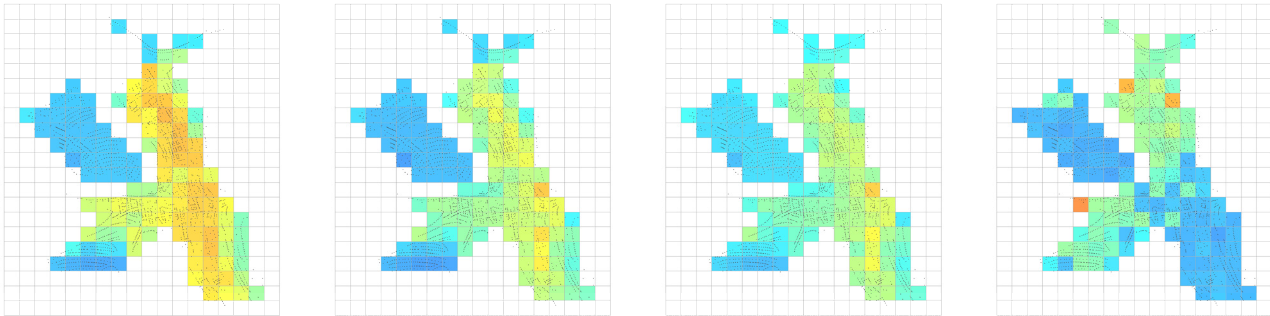
Table 3.1 - Vulnerability classes (Example: masonry type buildings with wooden floors)

Approach		Ranges of VC	Damage probability distribution(s)		Remarks
No	Basis		Path	Scheme used for risk analysis	
1	EMS - 98		➔		Empirical, on the basis of European as well as world-wide earthquakes (1988-1998)
2	Regional adaption of EMS – 98 by rapid screening (**R**andom **U**rban **M**onitoring)		➔		Empirical, on the basis of field survey in Albstadt (2003-2004)
3	Local refinement through building by building Field Survey		🡐		Calculated, on the basis of data obtained from complete field survey
4	Observed damage for the same building type		🡐		about 1300 damage cases (reinterpretation of Albstadt 1978 earthquake)

O most likely; —— probable range; ········ less probable, exceptional cases

4. RESULTS AND OUTLOOK

Results of the four approaches in Table 3.1 are compared for the intensity I_{EMS} = 7.25 in Figure 7. The subsequently introduced definition D_{fx} has to be read as follows: D_{f15} is describing the damage grade which couldn't be exceeded by 15% of the buildings and being exceeded by 85% of the buildings. D_{f50}, median damage grade is covering 50% of all cases (being exceeded by 50% of the buildings) being comparable to the mean damage grade D_m. On the basis of approach No. 3, it can be tested which scenario in terms of intensity and fractile, D_{fx} (fractile, I_S) can be taken as best estimate of the observed damage D_{f50} given by Figure 7d. The rectangular element is indicating that this scenario will is obtained for intensity in between 7.0 and 7.25 and Damage Grade in between D_{f25} and D_{f50}. It is the advantage of the procedure that statements about the damage can easily be given in upper and lower limits, thus providing a more refined for the use of the results (code requirements, strengthening measures, insurance rates etc).

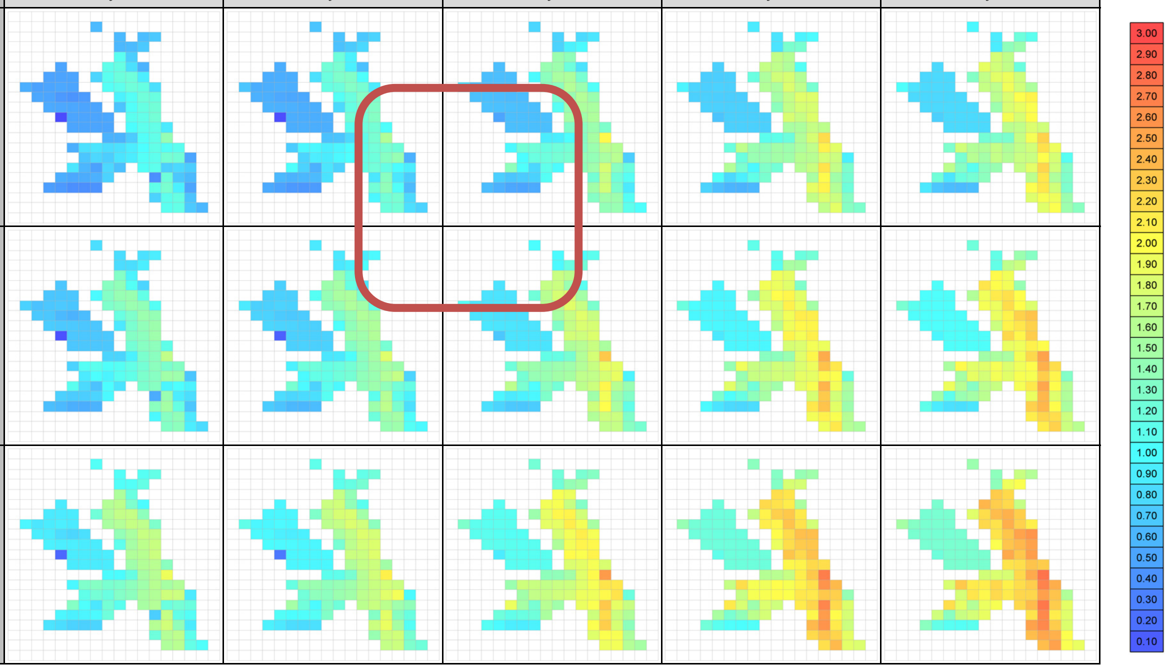


a) EMS (No 1). b) RUM (No.2) c) Field Survey (No. 3) d) Observed (No.4)

Figure 7 - Damage Grade D_{f50} considering intensity correction increments [ΔI_S] for I_{EMS} = 7.25; see legend in Tab. 4.1

Table 4.1 - Calculated Damage scenarios according to approach No.3 in Table 3.1 with intensity correction [ΔI_S]

I_S	Damage distribution in dependence on fractile				
	D_{f15}	D_{f25}	D_{f50}	D_{f75}	D_{f85}
7.0					
7.25					
7.5					



As it can be shown from the outcome of simulations in the module HAZARD (to account for the effect of uncertainty) a serious reduction of the efforts can be reached by a simple factorization for the fractiles, i.e. the interim scatter is maintained and taken as input for the subsequent or interacting modules [Kaufmann, 2008]. Therefore, it is recommended to concentrate the progress and activities in the refinement of the data base for the damage-relevant module of VULNERABILTY. While introducing, the new approaches, uncertainties in seismic risk assessment and thus the scatter of the result can be quantified and reduced to a remarkable extent.

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