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# Seismic Risk Analysis for Germany: Methodology and Preliminary Results

**Rutger Wahlström[1,2], Sergey Tyagunov[1], Gottfried Grünthal[2], Lothar Stempniewski[1], Jochen Zschau[2] and Matthias Müller[1]**
*[1] CEDIM, University of Karlsruhe (TH), D-76128 Karlsruhe, Germany;*
*[2] GeoForschungsZentrum Potsdam (GFZ), Telegrafenberg F454, D-14473 Potsdam, Germany*

**Abstract**

The main objective of the earthquake risk sub-project of CEDIM is assessment and mapping of seismic risk for Germany. There are several earthquake prone areas in the country, producing ground shaking intensity up to grade VIII (EMS-98). The seismicity is highest in parts of the Federal States of Baden-Württemberg, Rhineland-Palatinate, North Rhine-Westphalia, Saxony and Thuringia, which all are densely populated, industrialized and have a high concentration of developed infrastructure. This implies a challenge for future disaster preparedness and risk mitigation activities. The seismic risk in Germany represents typical features with a low earthquake occurrence probability, yet potentially high consequences. Therefore, the results of seismic risk analysis are indispensable for planners and decision-makers for preventing possible future seismic disasters. The paper describes a methodology of seismic risk analysis, including hazard, vulnerability and assets, and presents preliminary results.

## 1 Introduction

Germany has several seismic prone zones, where earthquakes can produce shaking intensity up to grade VIII. The seismic prone zones are in part densely populated, industrialized and have a high concentration of developed infrastructure, which implies a challenge for future disaster preparedness and risk mitigation activity.

Seismic risk consists of the components seismic hazard, seismic vulnerability and value of elements at risk (both in human and economic terms). The proper approach to the problem of risk assessment and risk management should include consideration of all the contributing components. Countries of low and moderate seismicity can still have high risk values. The seismic risk assessment in Germany represents a typical problem with a low earthquake occurrence probability but potentially high damaging consequences.

The Center for Disaster Management and Risk Reduction Technology (CEDIM), established as a joint initiative of the GeoForschungsZentrum Potsdam and the University of Karlsruhe (TH) conducts an interdisciplinary study aimed at assessment and mapping of different kinds of risks for the territory of Germany, including the earthquake risk. The Potsdam team is concentrated on the hazard aspects and the Karlsruhe team on the vulnerability aspects The GIS technique is utilized in combining different layers of information. The paper presents current results of the earthquake risk subproject of CEDIM.

The used technique to carry out these steps is preliminary. Other techniques will be considered in the continued work.

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## 2 Seismic Risk Analysis at Various Scales

There is a general agreement that the term "earthquake risk" refers to the expected losses of a given element at risk over a specified time period. The seismic risk can be specified for different types of elements at risk: economic loss, loss of human lives, physical damage to property, etc., where appropriate measures of damage are available. The risk may be expressed as the average expected loss or damage or in a probabilistic manner and should include proper consideration of hazard, vulnerability and exposed values.

The approach to risk analysis depends on the geographical scale. For individual existing buildings or construction sites, the analysis can be conducted in detailed manner, taking into account geotechnical information about the site, location of probable hazard sources and estimated seismic influence, using advanced numerical or simplified methods of structural analysis and considering all relevant elements at risk. Obviously, this is a finance- and time-consuming procedure and it is applicable only for individual sites, in particular for critical buildings and facilities. At the next level for local, often urban areas, microzonation maps and building stock inventory are used. The inventory is often implemented using visual screening procedures and selecting representative buildings. In the same manner, the distribution of the exposure at risk can be estimated. Yet one level up, at a regional or national scale, another set of input data and more generalized methods of analysis are used. This is the final level aimed at in the CEDIM project and the developed and applied GIS-based procedure is described more in detail below.

## 3 Seismic Hazard

At the first stage of the study we use the German part of the so-called D-A-CH map (Grünthal et al., 1998), a seismic hazard map for Germany, Austria and Switzerland expressed in intensity for a non-exceedence probability of 90% in 50 years. The seismic intensities of the D-A-CH map are interpolated from a grid of points over the territory of Germany. The intensity is now assigned for the centre of each community. The corresponding GIS layer is shown in Figure 1. Some of the most densely populated areas, in particular the Lower Rhine Embayment and parts in the south-west of the country (Baden-Württemberg), coincide with earthquake prone zones.

In the framework of CEDIM, a new national hazard map will be calculated based on a new earthquake catalogue (Grünthal and Wahlström, 2003), a seismotectonically better founded source zonation model, a revised technique for calculation of the maximum magnitude, and consideration of the aleatory and epistemic uncertainties in the input models and parameters. This will give uncertainties in the hazard output and subsequently in the risk values.

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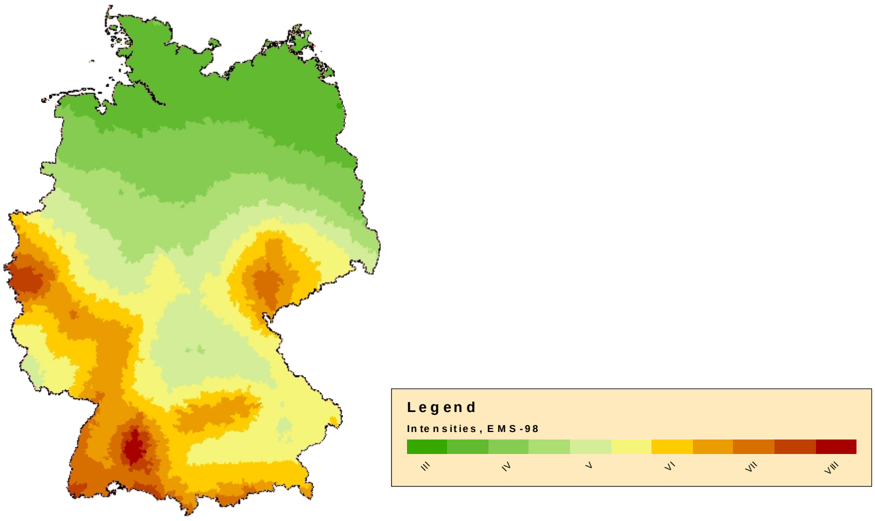


Figure 1: Seismic hazard distribution for non-exceedence probability of 90 % in 50 years; after Grünthal et al. (1998) with intensity contours modified according to community borders.

## 4 Seismic Vulnerability of the Building Stock

The seismic vulnerability implies the expected degree of damage to a given element at risk resulting from a given level of seismic hazard. There are two principal approaches to vulnerability assessment - observed and predicted vulnerability. Observed vulnerability refers to assessment based on statistics of past earthquake damage. Predicted vulnerability refers to assessment of expected performance of buildings based on engineering computation/judgement and design specifications. Obviously the second way is more suitable for areas of low and moderate seismicity, where, as a rule, there are few or no data of observed earthquake damage. In Germany, despite the damaging Albstadt (1978) and Roermond (1992) earthquakes, there are not sufficient data about the seismic performance of the existing building stock. On the other hand, there is growing interest in the national engineering community to address the problem of vulnerability assessment of the building stock (e.g., Sadegh-Azar, 2002, Schwarz et al., 2002a and Meskouris and Hinzen, 2003).

Analysis of seismic vulnerability in our study is conducted using the classification of buildings in terms of the European Macroseimic Scale (EMS-98; Grünthal, 1998), where six vulnerability classes were introduced and for different types of structures a most probable class and a probable range of classes are given. For Germany, the classes A-D apply.

Taking into account the national scale of the task, the communities of Germany are taken as units at risk. The approximately 14,000 communities are classified in five population size classes: P1 (less than 2,000 inhabitants), P2 (2,000 – 20,000), P3 (20,000 – 200,000), P4 (200,000 – 800,000) and P5 (more than 800,000). In our simplified study, the building stock is considered similar in each community belonging to a certain population class. As prototypes we took into consideration the communities listed in Table 1. All these communities are located within seismic prone zones and we assume that they are representative for the five population classes given above.

For some of the prototype communities, existing information was used; in particular for Cologne and Schmölln, where study cases of the recent DFNK (Deutsches Forschungsnetz Naturkatastrophen - German Research Network Natural Disasters) project with detailed vulnerability analyses were conducted for the building stock (Schwarz et al., 2002a,b, 2004). Also information from Stricker (2003) was used for Cologne. For the other communities, information about the building stock was collected using simpli-

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fied visual screening procedures and other available data. Generally, the most probable vulnerability class of the EMS-98 schedule was assigned.

| Community | Population / class |
|---|---|
| Cologne | 1 020 000 (P5) |
| Schmölln | 13 000 (P2) |
| Albstadt | 48 000 (P3) |
| Lörrach | 47 000 (P3) |
| Karlsruhe<br>Stupferich (Karlsruhe) | 283 000 (P4)<br>3 000 (P2) |
| Ettlingen<br>Schluttenbach (Ettlingen)<br>Schöllbronn (Ettlingen)<br>Spessart (Ettlingen) | 39 000 (P3)<br>(P1)<br>(P2)<br>(P2) |

Table 1: Considered prototype communities

Based on available information and using engineering judgement, vulnerability composition models for the building stock of German communities corresponding to different population classes were constructed (Table 2). Table 2 gives the vulnerability composition models as percentage of buildings of different vulnerability classes. Probable ranges are given, not only to depict the uncertainty but also to emphasize that the composition of the building stock of individual communities in the same population class is different. The contents of Table 2 are illustrated in Figure 2.

| Population classes (number of inhabitants) | Percentage of buildings of different vulnerability classes (EMS-98) | | | |
|---|---|---|---|---|
| | A | B | C | D |
| P1 (< 2,000 inhabitants) | Few | Most | Few | Very few |
| P2 (2,000 – 20,000) | Few | Most | Many | Very few |
| P3 (20,000 – 200,000) | Very few | Many | Very many | Very few |
| P4 (200,000 – 800,000) | Very few | Many | Most | Few |
| P5 (> 800,000) | Very few | Many | Most | Few |
| Very few - (0-5%); Few - (5-20%); Many - (20-40%); Very many - (40-65%); Most - (65-100%) | | | | |

Table 2: Vulnerability composition models of the building stock of communities

Damage probability matrices (DPM) were constructed following the ideas of the European Macroseismic Scale (EMS-98), where the description of damage distribution in terms of “few”, “many”, “most” is given in the definition of the highest damage grades. Supplementing with results of other studies, e.g., ATC-13 (1987) and Nazarov and Shebalin (1975), the descriptions are here extended also to lower damage grades.

Vulnerability functions were constructed for each of the considered vulnerability classes (from A to D) in terms of the mean damage ratio (MDR) versus intensity of ground shaking (Table 3). For computation of the MDR, which is considered as the cost of repair over the cost of replacement, the damage ratio range was assigned to the damage grades classified in the EMS-98 based on many earlier studies. The resulting vulnerability functions for the vulnerability classes A-D and for the considered interval of seismic intensities from V to IX (EMS-98) are shown in Figure 3.

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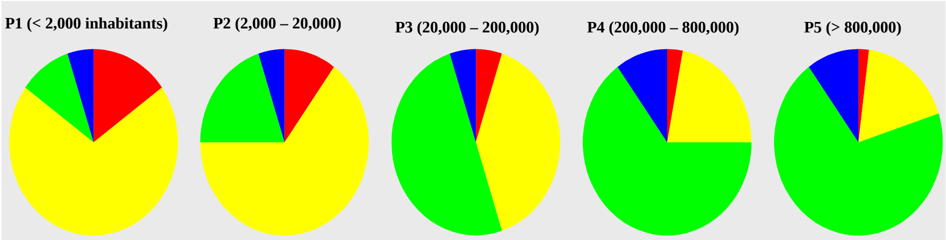


Figure 2: Building stock vulnerability models for different communities; composition of the vulnerability classes A, B, C and D

| Classification of damage; after Grünthal (1998) | MDR % | Mean value % |
|---|---|---|
| Grade 0: No damage | 0 | 0 |
| Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage) | 0-1 | 0.5 |
| Grade 2: Moderate damage (slight structural damage, moderate non-structural damage) | 1-20 | 10 |
| Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage) | 20-60 | 40 |
| Grade 4: Very heavy damage (heavy structural damage, | 60-100 | 80 (100) |
| Grade 5: Destruction (very heavy structural damage) | 100 | 100 |

Table 3: Classification of damage and damage ratio

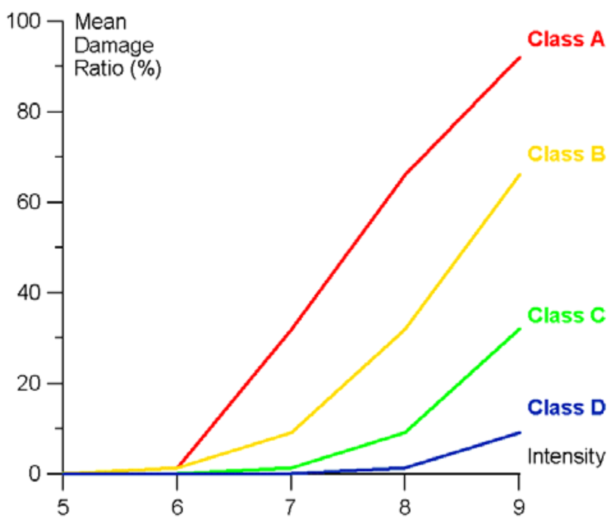


Figure 3: Vulnerability functions for the different vulnerability classes according to EMS-98

Combining the vulnerability curves (Figure 3) with the building stock vulnerability models (Figure 2), the expected damage can be plotted versus seismic intensity for the different population classes (Figure 4). From the curves in Figure 4 and the hazard map of Figure 1, we can make rough judgements of the earthquake damage potential of different German communities.

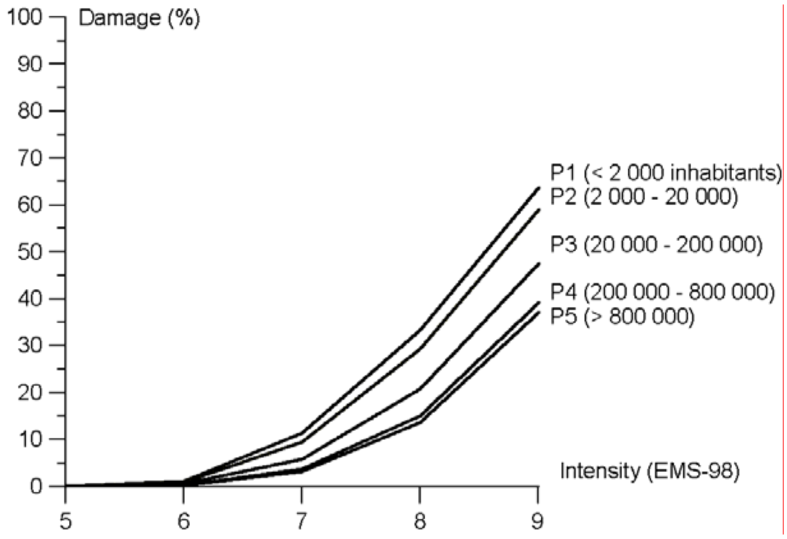


Figure 4: Vulnerability functions for the building stock of different population classes

## 5 Damage and Risk Estimations

Combining the seismic hazard (Figure 1), the distribution of communities of different population classes and the vulnerability models for these classes (Figure 4), the distribution over German communities of the specific damage of buildings is obtained as a GIS layer and shown in Figure 5. The resulting range of estimated damage values is from 0 to about 37% for the assumed probability of non-exceedence of 90% in 50 years. The map is constructed without consideration to the exposed values. Therefore, Figure 5 is not proportional to a seismic risk map.

At the present, time the CEDIM team is engaged in collecting data about the distribution of values at risk (assets) in the country, which are necessary for seismic risk analysis and will be used for assessment of other kinds of risks as well. Awaiting this information for the final risk assessments, a preliminary concept, “seismic risk potential”, is defined and calculated as the product the specific damage (Figure 5) and the number of inhabitants in the communities. The outcome is shown in Figure 6. This map provides a first indication of seismic risk distribution over Germany, although its provisional and rudimentary character must be pointed out.

## 6 Conclusions and future tasks

The principal emphasis of the first stage of the CEDIM study from the earthquake group was to work through the methodology of seismic risk assessment at the national scale. A new hazard assessment based on modern data and techniques (see Chapter 4), more diversified vulnerability data and future access of asset data will improve the yet in several respects simplistic approach and its preliminary results.

It is interesting to compare the maps of seismic hazard (Figure 1), specific damage (Figure 5) and risk potential (Figure 6). Although the distributions of specific damage and risk potential generally follow that of the hazard, there are also clear distinctions. The estimated specific damage to the building stock, which is a combination of hazard and vulnerability and shows the percentage of damaged buildings, does not consider the number of buildings and other values at risk in the community. Therefore, the picture is rather smooth and provides no idea about potential losses in the area. On the other hand does the map of the risk potential, where the distribution of exposed values is taken into consideration in a rough manner, give at least a hint of the main features in a future risk map.

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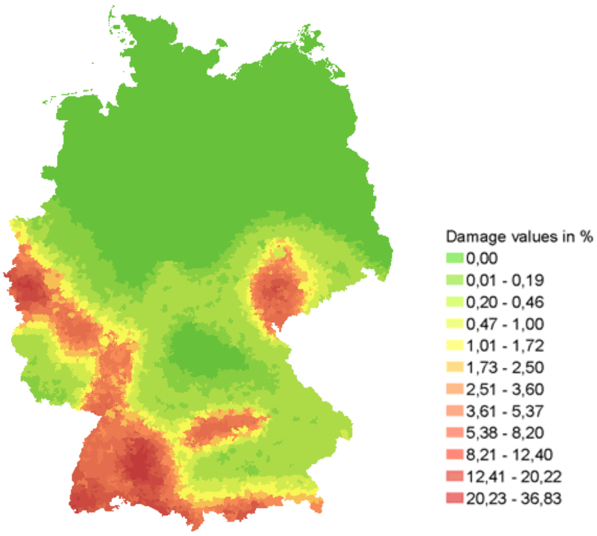


Figure 5: Distribution of the estimated specific damage (percentage of damaged buildings) based on a non-exceedence probability of 90% in 50 years

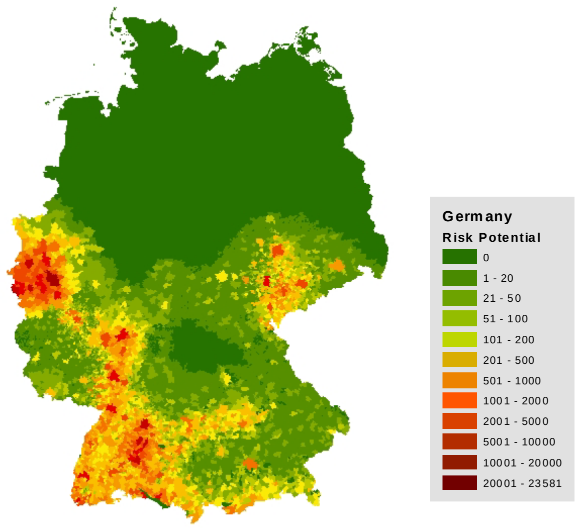


Figure 6: Distribution of the estimated “seismic risk potential” (relative scale; see text for explanations) based on a non-exceedence probability of 90% in 50 years

The obtained results show that, on the one hand, the smaller communities are characterized by more vulnerable composition of their building stock and, therefore, a higher percentage of damaged buildings can be expected there than in more populated communities in the case of a damaging earthquake. On the other hand, the larger communities located in earthquake prone areas, even with more favourable building stock composition and smaller estimated damage percentage, can have a higher level of risk due to the higher concentration of exposed values.

The future steps of the seismic risk program of CEDIM include:

- Improvement of the seismic hazard input data as outlined in Chapter 4.
- Improvement of the vulnerability input data, meaning improvement of the used generalized vulnerability models and development and application of vulnerability analysis on the basis of available GIS data of the building stock distribution in the communities.

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- Collection and analysis of data on values at risk. This will be done in conjunction with the other working groups of CEDIM.
- Testing other techniques for risk calculation for possible use.

All these activities are directed towards the main goal of the project – assessment and mapping of seismic risk for Germany.

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