Building-Code Related Seismic Hazard Analyses of Germany and their Relation to SHARE

Gottfried Grünthal[1], Christian Bosse[1], Dietrich Stromeyer[1]

[1] Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences
Telegrafenberg, 14473 Potsdam, Germany
ggrue@gfz-potsdam.de

ABSTRACT

The seismicity level of Germany requires the usage of seismic regulations. Respective seismic hazard assessments as basis of national seismic zoning maps are discussed and compared with results of the EU-FP7 project SHARE as the so far latest harmonized European seismic hazard approach and with seismic zoning maps of neighbouring countries. Some of the improvements of the new generation of national seismic hazard assessment with respect to SHARE are highlighted.

Keywords: Seismic hazard maps, seismic zonation, European seismic hazard harmonization, SHARE, Germany

1 Introduction

The seismicity of Germany is, in a global context, very low, but not such low that earthquake resistant design provisions can be neglected. The first building-code related seismic zoning was introduced in Germany in 1955 as a deterministic map of maximum observed intensities in the entire country, according to contributions by Sponheuer (Jena), Hiller (Stuttgart) and Schwarzbach (Köln) [1], which are based mostly on data collections by Sieberg, largely used by him earlier for earthquake cataloguing, e.g. [2]. This first seismic zoning was used for the draft of the German earthquake resistant regulation DIN 4149 from March 1955 [3], which was approved in July 1957 [4]. DIN stands for the Deutsches Institut für Normung (German Institute for Standardization). The follow-up version of the code DIN 4149 from April 1981 [5] again made use of a map of maximum observed intensities for the Federal Republic of Germany. The new map was mainly based on a study on damaging earthquakes of the country [6]. In the other German state, the GDR, a seismic zoning according to a probabilistic seismic hazard analysis (PSHA) [7] was introduced by the state construction supervision agency in July 1988, recommended to be used immediately. It became formally binding in July 1989 [8]. After the re-unification of Germany the seismic zoning map of DIN 4149 in the version of 1981 was extended to the new Länder in 1991 by the first author and introduced as DIN 4149, version December 1992 [9].

This contribution represents the invited reporting on the state of the art of the German building-code related seismic hazard analyses in the frame of a joint workshop[1] of DGEB, OGE and SGEB. The contribution gives (1) a brief overview on the seismicity of the country and its surroundings and provides (2) several features of the currently still used seismic zoning approach for the National Application Document of the Eurocode 8 from the mid-1990s. Further on, (3) the probabilistic assessment of seismic loads for the current code for hydraulic structures is characterized and (4) harmonized European seismic hazard assessments are summarized. Furthermore, (5) previous seismic hazard maps are compared with the recently published results of the SHARE project and seismic zoning maps of neighbouring countries. Finally, (6) some innovations within the frame of the project on the new generation of a national probabilistic seismic hazard assessment are highlighted.

2 Seismicity of Germany and surroundings

The seismicity of a study area is the fundamental basis for respective seismic hazard analyses. The seismicity of Germany; i.e., the area-related frequency and magnitudes of tectonic earthquakes, can be regarded, in an European context, as medium to low. Fig. 1 shows the catalogued seismicity of Germany and its wider surroundings according to the database of the European-Mediterranean earthquake catalogue EMEC [10], which is the first long-term pan-European catalogue harmonized in moment magnitudes M_w. A wider zone around Germany as target region needs to be considered for PSHA, since seismic hazard assessments require an area of 200 to 300 km beyond the study area itself. In the presented map section the seismicity is largest in the northernmost Apennines, in the Friuli area and the adjacent Dinarides. It is fairly large as well in the western and central Alps. The remarkable seismicity of the Mur-Mürz-Zilina shear zone in eastern Austria and adjacent parts of Slovakia marks the tectonically active prolongation of the Alpine chain towards the Carpathians.

North of the Alpine chain the seismicity is largest along the river Rhine and at the eastern and western flanks of the southern Upper Rhine Graben. The most prominent seismic source area since 1911 in Germany is that of the Hohenzollernalb, where a

[1] Workshop „Presentation and Discussion of the Collaborative European Project SHARE "Seismic Harmonization in Europe", Frankfurt/Main Airport, May 27, 2014.

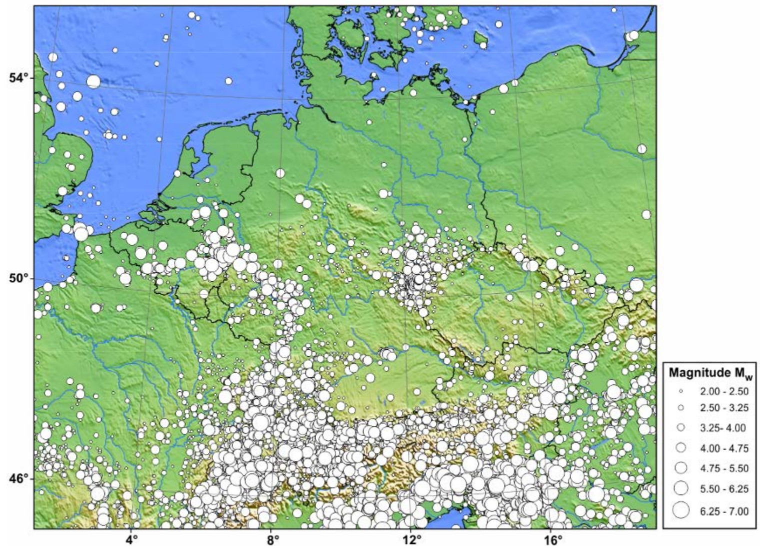


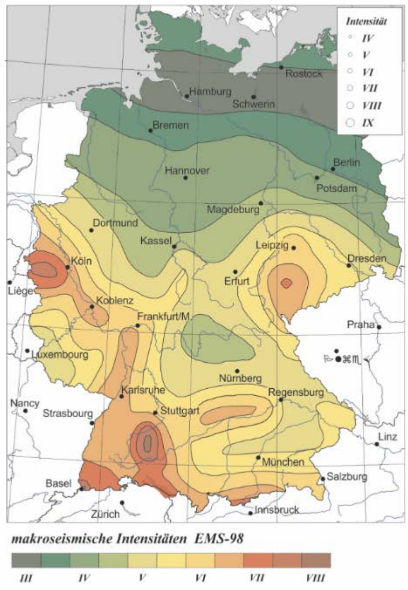
Figure 1. Catalogued natural tectonic seismicity of Germany and its wider surroundings according to the database of the European-Mediterranean earthquake catalogue EMEC [10].

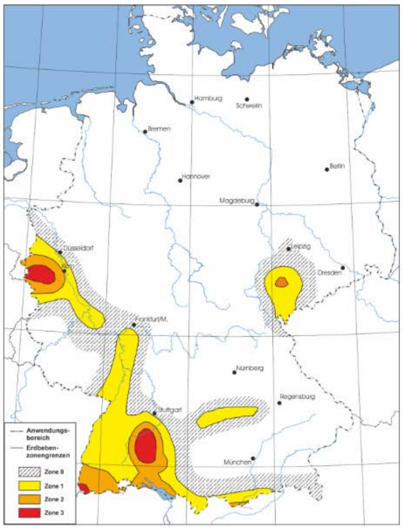
still ongoing seismic sequence started with an M_w 5.7 earthquake on November 16, 1911. Other seismic epicentres concentrate on the region between the rivers Altmühl and Donau, as well as in a zone covering Western Thuringia, eastern Saxony and the adjacent areas of Bohemia and Bavaria. In this Saxothuringian seismotectonic province damaging earthquakes with macroseismic intensities larger than 7 of the EMS-98 [11] (or M_w = 5) are lacking in historical times.

M_w 6 earthquakes occurred in the immediate surroundings of Germany in 1692 (M_w 6.1), in eastern Belgium and in 1356 (M_w 6.6) immediately south of Basel, Switzerland. According to [12, 13] an M_w 6.4 earthquake occurred in 1117 directly SSE of the focal zone of the above mentioned Hohenzollernalb. An earthquake with this magnitude would be even stronger than the disastrous northeast Italian Friuli earthquake on May 6, 1976 with M_w 6.3, which was felt, e.g. in northerly direction, as far as the Baltic Sea. Generally, no area of Germany can be regarded as aseismic; i.e. where no earthquakes can be expected.

3 Seismic zoning map of the current German building code DIN 4149, respectively DIN EN 1998-1/NA

The introduction of a PSHA-based seismic zoning map became overdue in the early 1990s. A respective research proposal for the calculation of a PSHA map in terms of peak ground acceleration (PGA) was submitted by the first author in 1992. In 1993





Zone		int. calc.	a_g [m/s²]
1		6.5-6.9	0.4
2		7-7.4	0.6
3		7.5-8.1	0.8

Figure 2. Intensity based seismic hazard map [14] for a 10% exceedence probability within 50 years (left) and the corresponding seismic zoning map of the DIN 4149, resp. DIN EN 1998-1 with the seismic zones 0 and 1-3.

a respective research project for an intensity-based PSHA was approved. It was completed in July 1995[2]. The results were delivered to the related national committee of standards. After a verification procedure, the hazard map was accepted by the committee of standards and the respective report [14] was released.

For the intensity-based PSHA a procedure was developed which fully made use of intensity based steps of the processing. The prerequisite for this procedure is a seismicity data base which is harmonized in terms of macroseismic intensity, where the European Macroseismic Scale EMS-92 [15], i.e. the test version of the EMS-98 [11], has served very well.

The delineation of seismic source zones was conducted with feedback by L. Ahorner (Bensberg) and G. Schneider (Stuttgart). The seismic source zones of the focal areas in the Alpine region south of Germany were defined together with D. Mayer-Rosa (Switzerland) [16]; later also with W. Lenhardt (Austria), published as an extension of the German map for the D-A-CH countries Germany, Austria and Switzerland

[2] A respective seismic hazard map according to this PSHA project was first published on July 25, 1995 in the Frankfurter Allgemeine Zeitung, followed by a number of other newspapers.

[17]. It also served as the test case for the European part of the project GSHAP (cf. chapter 5).

For each source zone the parameters of cumulative frequency intensity rates were determined. The upper bound earthquakes have been defined in terms of intensities as well. The intensity-based ground motion prediction relation by Sponheuer [18] was applied; i.e. all steps of the procedure are based on the same parameter without the need to apply empirical conversions between earthquake strength parameters. The validation of the resulting seismic hazard map was carried out according to historically observed macroseismic intensities. Admittedly, an intensity based PSHA map implies that it is old-fashioned from today's perspective, but at least for validation purposes it still has its justification.

The definition of seismic zones was introduced by the committee of standards, where the recommendation of the authors of the hazard map [14] was adopted. Fig. 2 shows the hazard map and the corresponding zoning map [19, 20].

The difficulty in the applied approach concerns the assignment of acceleration based parameter from intensity; i.e. the effective acceleration a_g, as required at that time by the respective version of the Eurocode 8 (EC8) [21] for the National Application Document (NAD) and the respective design spectra. This part of the procedure towards the definition of seismic loads for the seismic zones was not part of the PSHA project, but was provided with respect to the design spectra in the frame of independent research projects [22, 23].

Effective accelerations a_g of 0.4 m/s^2, 0.6 m/s^2 and 0.8 m/s^2 (cf. [24, 25]) were associated to the seismic zone 1, 2 and 3. A comparison of the values of a_g for the calculated intensity ranges of the three seismic zones with empirical relations between intensities and PGA [26-28] are given in Table 1, both for mean PGA and their standard deviations ±1σ. The PGA ranges for the calculated intensities are, according to Table 1, not unexpectedly, higher than the values of a_g.

Table 1. Relation between intensity, effective acceleration a_g and peak ground acceleration PGA in m/s^2

Seismic zones: DIN 4149, DIN EN 1998-1/NA			Faenza & Michelini [28]		Faccioli & Cauzzi [27]		Wald et al. [26]	
Zone	Intensity, calculated	a_g m/s^2	PGA mean for 6.5-6.9 etc.	PGA ±1σ	PGA mean	PGA ±1σ	PGA mean	PGA ±1σ
1	6.5-6.9	0.4	0.74-1.06	0.54-1.44	0.95-1.53	0.34-4.34	1.69-2.18	0.86-4.30
2	7-7.4	0.6	1.15-1.65	0.84-2.25	1.72-2.75	0.60-7.81	2.32-2.99	1.18-5.90
3	7.5-8.1	0.8	1.80-3.09	1.39-4.21	3.09-6.25	1.09-17.78	3.18-4.64	1.61-9.16

A respective web-service provides the association of any settlement in Germany; i.e. towns and villages, to a corresponding seismic zone [Web-1]. This performance uses the calculated shapes of seismic zones. It operates since 04/2005 and has numerous users daily since its implementation.

4 The seismic hazard results for the use of the safety regulations of hydraulic structures DIN 19700

A much more advanced PSHA approach in relation to the described intensity-based procedure is the acceleration based 2006 version [29]. On behalf of the Ministry of the Environment Baden-Württemberg the 2006 earthquake model was applied for the needs of the safety regulation of hydraulic structures DIN 19700 [30]. Hazard results in terms of maps and uniform hazard response spectra (UHS) were derived for the mean return periods T = 100, 500, 1000 and 2500 years [31]. Related UHS

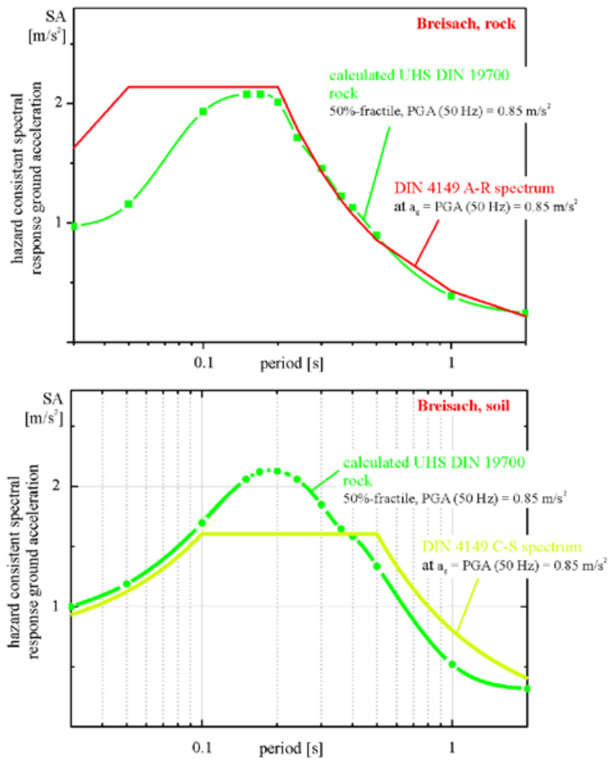


Figure 3. Illustration of the good coincidence of the calculated uniform hazard spectra (UHS) according to [Web-2] with the related design spectra of DIN 4149 (resp. DIN EN 1998-1), when the a_g-value of the respective design spectrum is calibrated to the calculated PGA value (at 50 Hz) of the UHS. On the one hand rock conditions are assumed for the site and on the other hand, for better comparison, soil conditions.

for rock or soil are provided via the respective web-service [Web-2] for any location not only in Baden-Württemberg but, as agreed, for any site in entire Germany as well. This web-service is in operation since 11/2007 and frequently used not only for the purpose of dam construction.

The approach extensively considers both aleatory and epistemic uncertainties of input parameters and models used in the procedure. The resulting UHS coincide surprisingly well with the DIN 4149 design spectra for different subsoil conditions when calibrated to the same PGA, which is exemplarily illustrated in Fig. 3 for the location Breisach. For details see the respective report [31]. Further below; i.e. in chapter 6, the PGA hazard map (mean value, for the underground conditions of rock) and UHS are compared with other hazard maps as subject of this paper.

5 Harmonized European seismic hazard models and hazard maps

An essential requirement of a Europe-wide PSHA is to achieve a cross-bordering harmonization in preferably all steps of the procedure. The first project to carry out such a goal was the Global Seismic Hazard Assessment Program (GSHAP) in the frame of the United Nations International Decade on Natural Disaster Reduction (IDNDR). GSHAP was implemented in the period from 1992 to 1999. In total, more than 500 experts were actively involved in this undertaking [32]. The GFZ Potsdam was selected as the European seismic hazard competence centre and Regional Centre of the GSHAP Region 3 [33]. A first version of the calculated harmonized seismic hazard map for GSHAP region 3 was already presented in 1996 [34]. In the final stage of GSHAP, the GFZ Potsdam became responsible for the Mediterranean region as well; i.e. GSHAP region 4. The map for GSHAP region 4 was basically generated by harmonizing latest versions of national maps, where available [35]. The final hazard map of both regions [33, 35] is part of Fig. 4. After finishing the project, the harmonized earthquake catalogue for GSHAP region 3; i.e. Europe north of 44°N, was published [36], which was later updated as the harmonized database CENEC [37] and checked with respect to the level of harmonization, which could be achieved [38].

The SESAME hazard map [39] as another example of a European-wide harmonized PSHA is north of 44°N; i.e. in the area of the GSHAP region 3, identical with the results by GSHAP [33], while further south the differences are in general minor except for the area of Greece and Turkey. The SESAME hazard map is shown in Fig. 4 as the upper right map.

In the frame of the EC project NERIES [Web-3] a harmonized seismic hazard map was calculated [40] as basis map for the “living European seismic hazard map” [41]

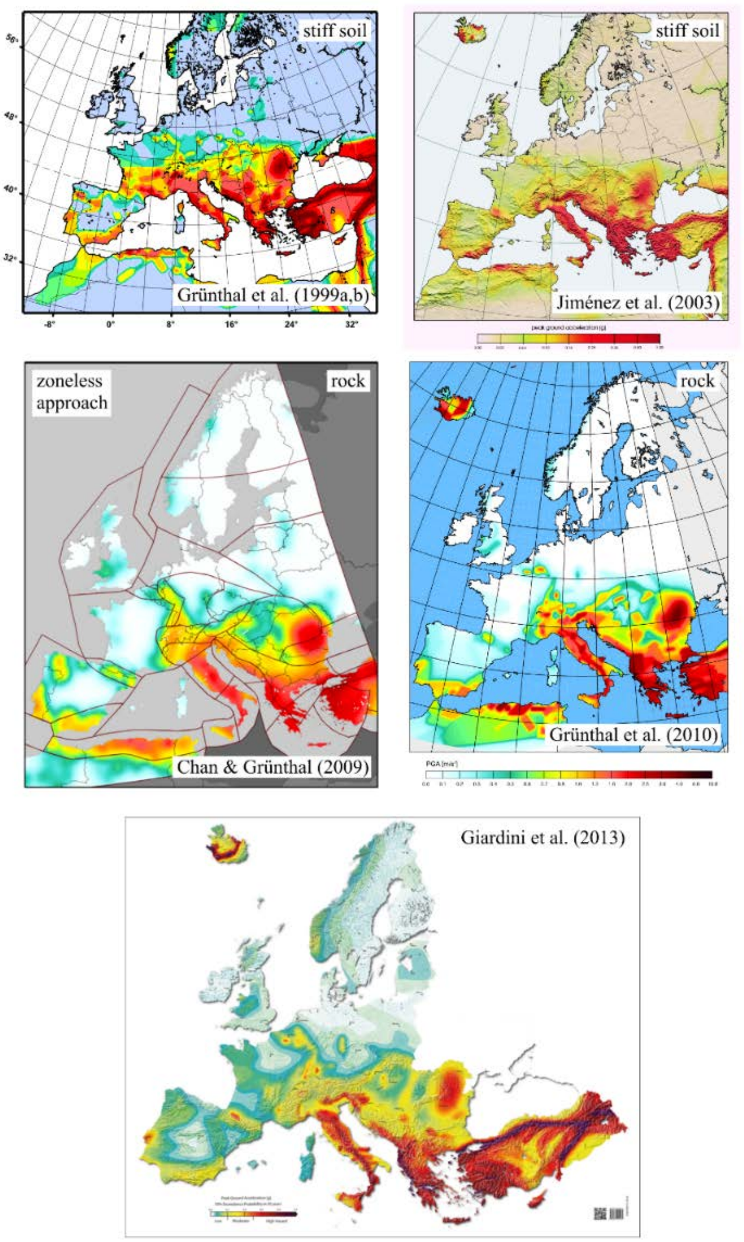


Figure 4. Harmonized European-Mediterranean PSHA maps, all in PGA for 10% exceedence probability in 50 years. Upper left: GSHAP [33-35], upper right: SESAME [39] both for stiff soil. Middle left: EC project NERIES [40]. Middle right: GEM1 [42]. Below: EC project SHARE [Web-5]. The three lower ones for rock.

to show short-term time-dependent seismic hazard modulating the basis map. The basis map (in Fig. 4 as the map in the middle on the left) was developed as an innovative hybrid zoneless approach to allow easy updates, when new seismicity pattern have occurred. The harmonized European-Mediterranean earthquake catalogue EMEC [10], in its early stage, could be applied for this project.

Another harmonized Euro-Mediterranean seismic hazard map [42], shown in the middle part of Fig. 4 on the right, was computed in the frame of the test phase of the Global Earthquake Modeling Project GEM1 [Web-4]. This PSHA approach makes use of the harmonized seismic source zone model of SESAME [39].

The so far last and most elaborated harmonized European seismic hazard map is the one produced in the frame of the EU-FP7 project SHARE "Seismic hazard harmonization in Europe" [Web-5] with many innovations and a large number of experts involved. The here discussed PGA hazard map as one of the results of SHARE is shown in Fig. 4, lower part. The final SHARE results were produced a couple of months after the cost neutral prolongation of the project until November 2012. From the engineering point of view, the most important results of SHARE are not the different hazard maps, but the UHS, similar to the German project with respect to the calculation of the seismic loads for the DIN 19700 [Web-2]. UHS for rock site conditions as result of SHARE [Web-6] are dealt with in the next chapter.

6 Comparison of seismic hazard results

The hazard results of the a_g based seismic zoning map of the DIN 4149, resp. DIN EN 1998-1/NA [19, 20] are compared with the PGA map derived in the frame of the project to develop seismic loads for the DIN 19700 [31] and with the SHARE PGA map for Germany, using the same colour code for the three maps (Fig. 5). A better quantitative interpretation of the comparison is possible with difference maps between both national maps and the SHARE map excerpted for Germany (Fig. 6). Large differences between the national maps and the SHARE map are striking, but one has to consider that the DIN 4149 zoning map shows a_g and not PGA as the other two maps.

As said before, the site specific UHS are more important than the PGA maps. A respective comparison can be made between the UHS of SHARE (solely for rock site conditions) with those derived for the usage of the DIN 19700 [31] shown in Fig. 7 exemplarily for the city of Aachen for three hazard levels in terms of mean return periods T. The SHARE response spectra show higher spectral amplitudes by a factor of about 1.8. Although the values of T are not identical according to both projects (e.g. T = 475 and T = 500 years), the corresponding differences in the respective spectra can be regarded as minor.

A comparison of hazard maps is also interesting with respect to national seismic zoning or seismic hazard maps of the neighbouring countries. Fig. 8 shows the respective parts of maps of Germany's neighbouring countries. These are the maps

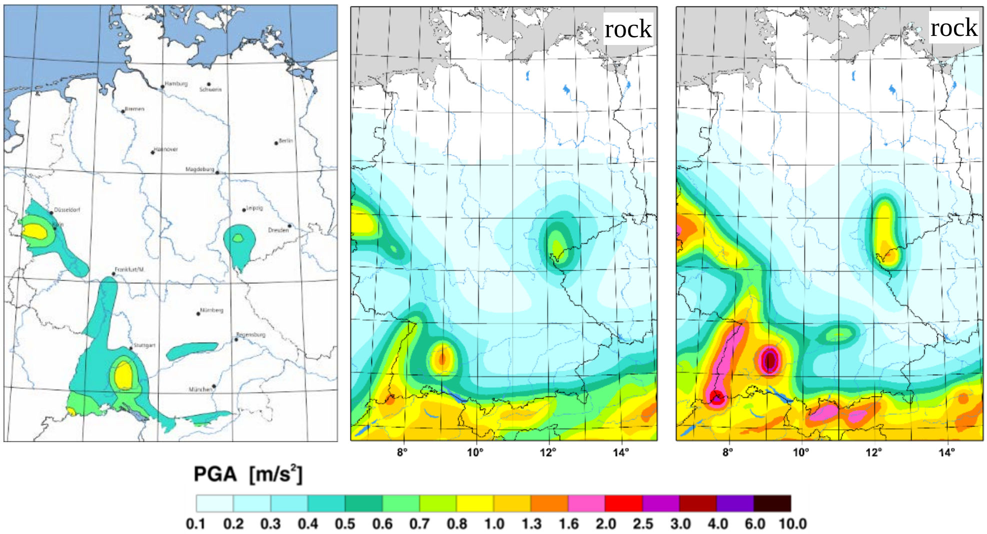


Figure 5. Comparison (from left to right) of the seismic zoning map of the DIN 4149 [19, 20] in effective acceleration a_g with the PGA seismic hazard maps of the DIN 19700 [31] and the PGA SHARE map [Web-5]. The maps are given for the standard hazard level of building codes; i.e. for 10% exceedence probability within 50 years corresponding to the mean return period T = 475 years – except the middle map of the DIN 19700 which is required for T = 500 years. All maps are in the same colour code.

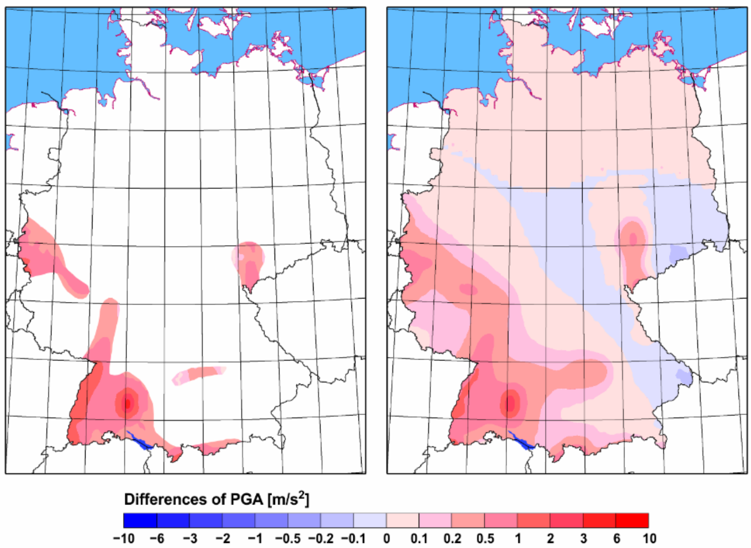


Figure 6. Differences of both national maps of Fig. 5 with the SHARE PGA for Germany. Left: SHARE PGA minus a_g of DIN 4149 seismic zoning. Right: the same as for the DIN 19700 PGA.

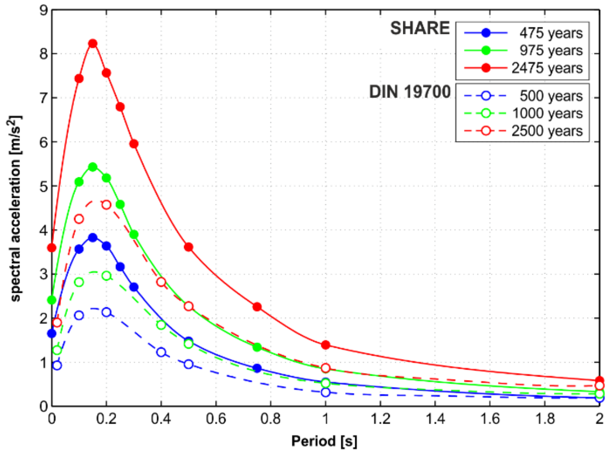


Figure 7. Comparison of uniform hazard spectra available for the usage of the DIN 19700 (www.gfz-potsdam.de/DIN19700, [Web-2]) with those according to SHARE (http://www.share-eu.org/, [Web-6]) given here as an example for the city of Aachen for rock subsoil conditions for three mean return periods.

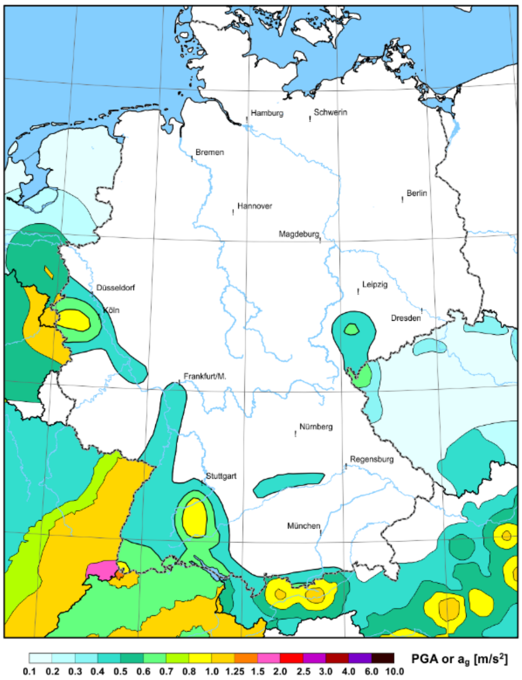


Figure 8. Comparison of the German seismic zoning map with those of the neighbouring countries. For references see text.

of the Czech Republic [43], Austria [44, 45], Switzerland [46], France [Web-7], Belgium [47] and the Netherlands [48]. For Germany itself we here use the a_g map of the DIN 4149, resp. DIN EN 1998-1/NA [19, 20]. The acceleration values of different national maps are, where needed, rounded to one decimal. In case of given ranges of PGA or a_g, particularly for Austria, the respective lower margins are used for display. The coincidence of the German a_g-values is quite good with the national values of the Czech Republic, when considering the fact that the German map omits values below 0.4 m/s^2. The general accordance with the Austrian and Swiss data is also good, except of the area of Tyrol (Austria) and the area of Basel (Switzerland) with somewhat higher values. On the other hand, the acceleration values of French and Belgian maps are distinctly higher. The Dutch map again shows a somewhat better accordance.

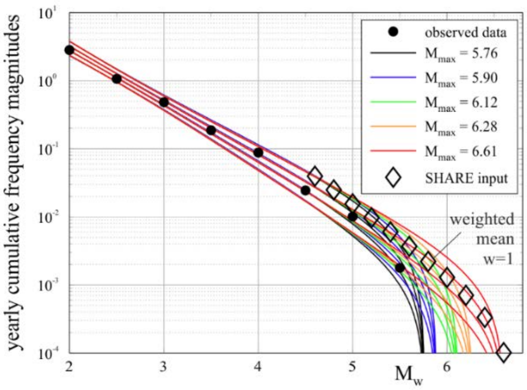


Figure 9. Seismicity rates for the seismic source zone Hohenzollernalb for the five calculated discretized M_{max} from the respective probability density of M_{max} determined for this source zone. To account for the uncertainty of the seismicity rates, four respective sets with different weights are considered for each discretized value of M_{max}, which yields altogether twenty curves of seismicity rates per source zone. A comparison is given for this source zone with the one set of rates in 0.2 magnitude bins used in SHARE. The input for the new national approach will use a minimum magnitude for the hazard calculations in the range of 4.0-4.5 and also in 0.05 magnitude bins.

7 Post-SHARE seismic hazard approaches

In a document of the SHARE-EC8 Workshop on November 28, 2013 [49] it is concluded that “All countries in Europe are thus encouraged to carry out an evaluation … of hazard results … by comparing SHARE results with those based on national source models with the SHARE GMPE[3] logic tree.” A number of respective national projects were launched in the meanwhile; e.g. in Switzerland (personal communication Stefan Wiemer, May 2012) or in Italy [50].

[3] GMPE: ground motion prediction equation

In Germany, a respective research proposal was submitted in 2011 and approved in 2013. In the frame of this approach aleatory and epistemic uncertainties are considered in a comprehensive way. The minimum moment magnitude M_w considered for the determination of e.g. seismicity rates is $M_w \geq 2$ or even smaller, while in contrary the $M_{w\ min}$ within SHARE was 3.5 in Europe north of 44°N. The higher threshold value can involve limitations in handling low seismicity areas. Among the innovations being used for this new national project is an improved way to implement seismicity rates of seismic source zones with their uncertainties, which is illustrated in Fig. 9 for a particular seismic source zone. For comparison, the respective SHARE seismicity rates are given for this source zone. An essential step of the national approach will also be to achieve a harmonization with respective activities in neighbouring countries.

8 Conclusions

In brief, the conclusions of this contribution can be summarized as follows:

- The current version of seismic zoning does not meet the needs of current code requirements.
- The 2006/2009 version of PSHA applied for requirements of DIN 19700 represents an already advanced stage of research.
- Harmonized European seismic zoning maps exists, the SHARE project being the last and most elaborated one.
- The SHARE PGA for Germany differ considerably from results of previous zoning or hazard maps in areas of highest seismicity within the country.
- Post-SHARE activities in PSHA exist in different countries, also in Germany.
- The next version of German seismic zoning will be based on distinct innovations; harmonization with neighbouring countries is aspired.

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