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# Seismic Risk Evaluation for the Upper Rhine Graben and Its Vicinity

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**Abstract.** A probabilistic large-scale seismicity model for the Upper Rhine graben and adjoining regions has been developed considering all available seismological and geological information. With this model the probability distribution of macroseismic intensities (MSK-scale) was calculated for 208 sites regularly covering the region under investigation with a grid width of 25 km. Four maps with intensity isolines are presented according to exceedance probabilities 63 %, 10 %, 1 % and 0,1 % for a period of 50 years (corresponding to annual occurrence rates $2 \cdot 10^{-2}$, $2 \cdot 10^{-3}$, $2 \cdot 10^{-4}$, and $2 \cdot 10^{-5}$). The intensities given reflect the regional seismicity level with respect to quantitative risk values, which might be modified by local particularities (soil conditions, nearby seismoactive fault lines, etc.) for a special site. The risk for an average site in the Upper Rhine graben is characterized by an annual occurrence rate of about $10^{-4}$ for intensity VIII. On a statistical basis, the exceedance of intensity IX cannot be excluded, but could only occur at a very low probability level.

**Key words:** Earthquake Risk – Upper Rhine graben – Central Europe.

## 1. Introduction

At the present state of seismological research the occurrence of major earthquakes in seismoactive regions cannot be predetermined on a deterministic basis on the one hand and cannot be excluded on the other one. The seismic risk is therefore best described by probabilities for certain earthquake effects at given sites. It is assessed in terms of exceedance probabilities for intensities, peak acceleration, or other quantities during a given period of time.

Analytical methods to determine the site dependent risk have been developed by Cornell (1968) and Esteva (1969) and applied to a great number of seismic regions all over the world. For Europe probabilistic studies have been performed, e.g., by Lilwall (1976) for Great Britain, and very recently by Sägesser et al. (1977), Sägesser et al. (1978), and Mayer-Rosa (1978) for Switzerland.

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Ahorner and Rosenhauer (1975) developed a probabilistic seismicity model using Gumbel's extreme value statistics for the Northern Rhine area. In the present paper this method is used with slight modifications to evaluate the seismic risk in the Southern Rhine area with special emphasis on the Upper Rhine graben. Instead of probability distributions of earthquake accelerations the exceedance of earthquake intensities at given sites is considered, since in Central Europe the attenuation law for macroseismic intensity is much better known than for peak acceleration.

## 2. Seismicity of the Upper Rhine Graben and Its Vicinity

The Upper Rhine graben (Fig. 1), which cuts through the earth's crust of Central Europe from Basel in the South to Frankfurt in the North, is a classical example of a continental rift valley and by this a favoured research object for geoscientists since many decades. A review of the latest results of geological, geophysical and geodetical investigations has been published in two monographs edited by Illies and Müller (1970), and Illies and Fuchs (1974).

Taphrogenesis started in the Middle Eocene, i.e., about 45 million years ago, and is continuing up to recent time. The neotectonic activity in and around the graben zone is indicated by Quaternary faults with dislocations up to several 100 m (Bartz, 1974), geodetically observed vertical crustal movements in the order of 0.5 mm/year (Mälzer, 1967; Prinz and Schwarz, 1970; Schwarz, 1974), structural damage to buildings founded immediately above the main faults (Müller and Prinz, 1966), and by a remarkable seismicity with damaging earthquakes up to moderate magnitudes (Ahorner et al., 1970).

The seismicity of the Upper Rhine graben and its vicinity has been studied in detail by Hiller et al. (1967), Schneider (1968, 1971), Ahorner (1970, 1975), Ahorner et al. (1972), Bonjer and Fuchs (1974), and others. Original data of historical events are available from earthquake catalogues of Sieberg (1940), Sponheuer (1952), Fiedler (1954), and Rothé and Schneider (1968).

The seismotectonic zone of the Upper Rhine graben and its bordering mountain ranges (Black Forest, Vosges, Odenwald, and Pfälzer Wald) forms the southern part of the Rhenish earthquake zone, which continues farther to the Northwest in the Lower Rhine graben (Ahorner and Rosenhauer, 1975). The Rhenish earthquake zone represents the most conspicuous seismological feature in the northern foreland of the Alps. Earthquakes occurring along this intraplate zone of crustal weakness have focal depths between several and 25 km as a maximum. The focal mechanisms are as well of dip-slip as of strike-slip type and are clearly controlled by the present-day stress field within the earth's crust of Central Europe (Ahorner, 1975).

The energy release diagram (Fig. 2) gives a general impression of the time distribution of seismic activity in the Upper Rhine graben region. The sum of the square roots of seismic energies, which is under simplifying assumptions proportional to the seismic strain release in the earthquake region, increases relatively uniform with time as may be expected in a highly fractured graben zone with mainly tensional tectonics. Obviously the major part of the stored

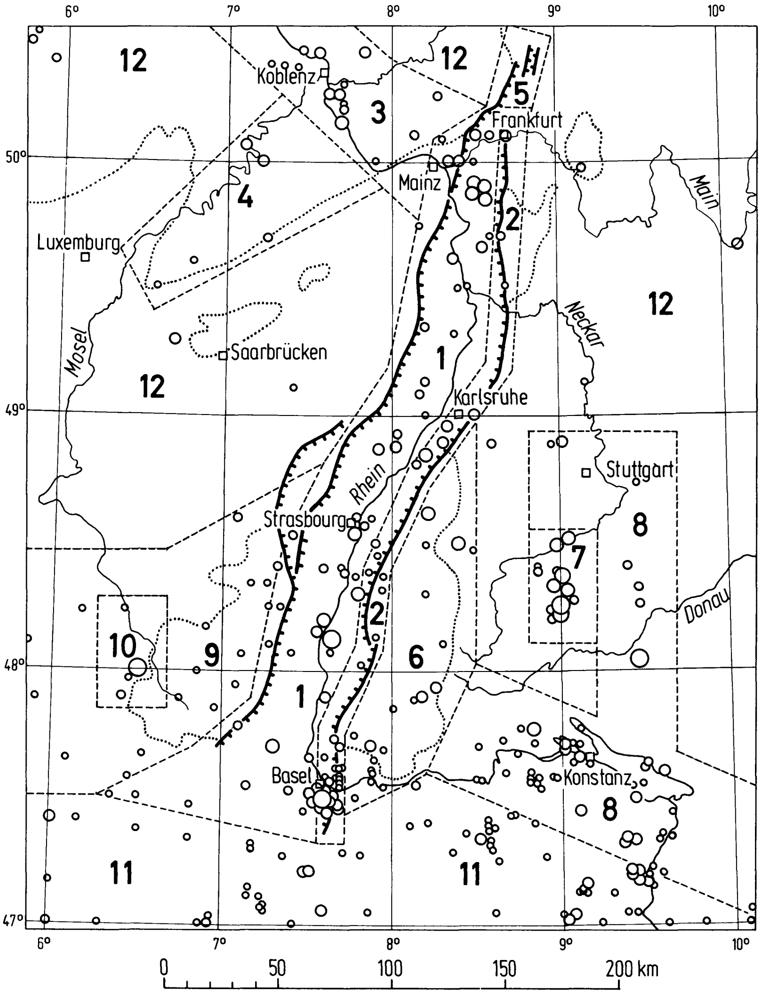

**Fig. 1.** Seismotectonic regionalization of the Upper Rhine graben region. Numbers refer to regions in Table 1. Circles denote epicenters of historical earthquakes with intensities $I \geqq V$ MSK-scale. Dotted lines give the contours of outcropping Hercynian basement rocks

stress energy is released with small and medium earthquakes, whereas stronger shocks are comparatively seldom. Damaging earthquakes with magnitudes $M_m \geqq 5$ (Richter-scale) and macroseismic intensities $I_0 \geqq \mathrm{VII}$ (MSK-scale) occur in the Rhine graben region only 2 to 3 times per century. The strongest shock observed is the famous Basel earthquake 1356, which killed 300 people (Sieberg, 1940). This event was released at the southern end of the graben and has an estimated magnitude $M_m = 6\frac{1}{4}$ and the epicentral intensity $I_0 = \mathrm{VIII–IX}$. It is the most catastrophic earthquake felt in Central Europe north of the Alps in historical time.

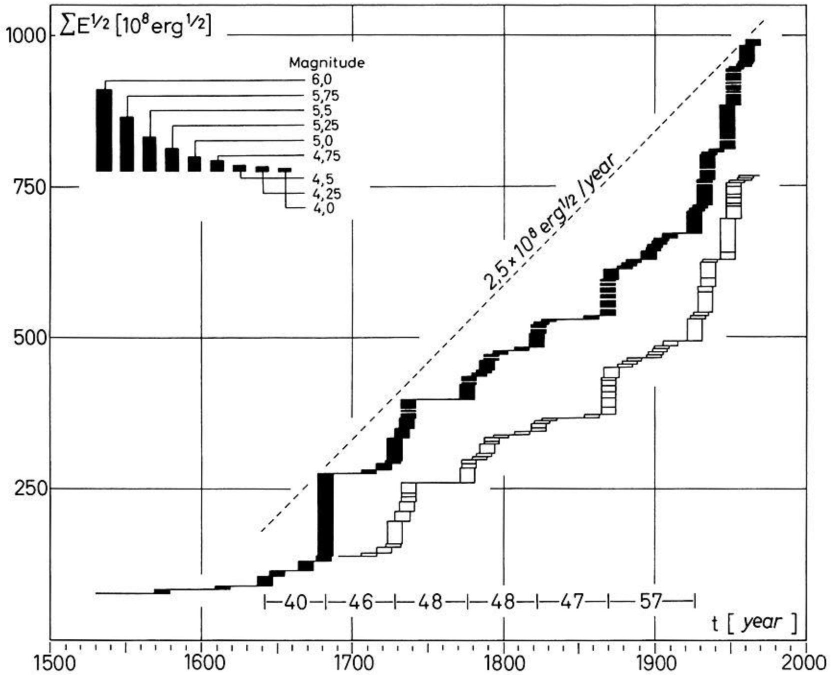

**Fig. 2.** Accumulated seismic energy release for earthquakes in the Upper Rhine graben zone during the last 300 years. The white diagram is for the graben zone alone, the black diagram for the graben zone and the bordering mountain ranges. Bursts of higher energy release occur with time intervals of 40 to 60 years. Earthquake data prior to 1600 are incomplete

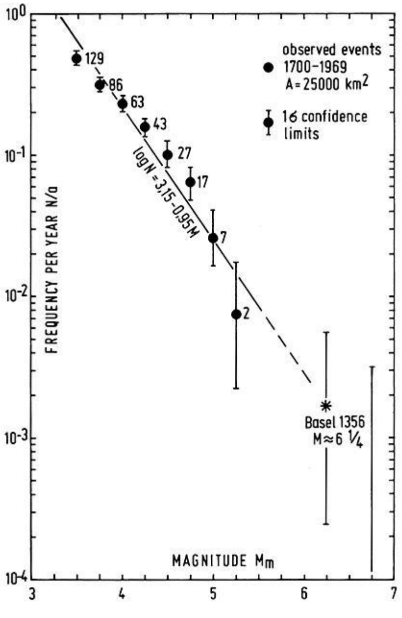

**Fig. 3.** Cumulative magnitude-frequency diagram for the Upper Rhine graben zone. The least square fit regression line gives $b = 0.95$. The uncertainty of $b$ can be judged considering the $1\sigma$ confidence limits of observed event numbers

The cumulative magnitude-frequency diagram (Fig. 3) shows how frequently earthquakes in the Upper Rhine graben region occur. The original data were taken from the earthquake catalogues mentioned above, mainly from Rothé and Schneider (1968). $M_m$ is the macroseismic magnitude determined from the epicentral intensity $I_0$ (MSK-scale) and the focal depth $h$ with the formula of Karnik (1969)

$$M_m = 0.5\, I_0 + \log_{10}(h/\mathrm{km}) + 0.35. \tag{1}$$

For shocks with unknown or uncertain intensity or focal depth the mean radius of perceptibility $R_m$ was used to get the magnitude with the empirical relationship proposed by Sponheuer (1962),

$$M_m = 0.52\, I + 1.56 \log_{10}(R_m/\mathrm{km}) + 0.7\, \alpha R_m \tag{2}$$

with the macroseismic intensity $I$ at the limit of perceptibility (usually taken as II) and the absorption coefficient $\alpha$ (normally $2.5 \cdot 10^{-3}$/km). The validity of Equation (2) for the Rhine area has been checked by us evaluating well observed earthquakes with known instrumental magnitudes.

The general trend of the observed frequencies in Figure 3 follows the linear Gutenberg-Richter (1949) relation and is closely fitted by the regression line

$$\log_{10}(N \cdot T) = a_{GR}(A, T) - b M_m = 3.15 - 0.95\, M_m \tag{3}$$

with $T = 1$ year and $A = 2.5 \cdot 10^4\ \mathrm{km}^2$. The $b$ value in Equation (3) differs only slightly from the average $b$ values for shallow earthquakes in other regions. Wohlenberg (1968) for instance found $b = 0.84$ for the East African rift zones, Karnik (1969) $b = 0.94$ for the whole European region, and Gutenberg and Richter (1949) $b = 0.90$ for the world.

It is of special interest that the regression line of Figure 3, derived from events between 1700 and 1969 in the magnitude range $3.5 \leqq M_m \leqq 5.3$, meets the isolated value of the Basel earthquake 1356. This suggests the conclusion (see Sect. 4, too), that the Basel event is not as exceptional for the seismotectonic regime of the Upper Rhine graben as is often assumed.

The linearity assumption of the magnitude – frequency relation for shocks up to $M_m \approx 6^1/_4$ seems reasonable at least in some parts of the Upper Rhine graben, bearing in mind that in other continental rift zones with comparable geological conditions similar or even higher magnitudes have been observed, e.g., $M = 6^1/_4$ for the Jordan graben (Arieh, 1967) and $M = 7.1$ for the East African graben zones (Wohlenberg, 1968).

A pessimistic seismotectonic estimate for the maximum possible earthquake along a preexisting geological fault line often used in the USA would lead to an upper bound magnitude $M_{\max} = 7$ to 8 for the Upper Rhine graben if a total length $L = 300$ km of the fracture zone is assumed and an active fault-plane length of $0.2\, L$ to $0.5\, L$ for the largest possible earthquake (Bonilla, 1970). These values, however, seem to be extremely conservative and thus cannot serve as a basis for a realistic risk assessment.

Considering all available seismological and geological information $M_{\max} = 6^1/_2$ is assumed for the eastern border faults (Fig. 1, region 2) and $M_{\max} = 5^3/_4$

**Table 1.** Seismological subdivision of the area under investigation and source specifications. Gumbel parameters $a$ and $u_0$ are normalized to $T = 10$ years and $A = 10^4$ km$^2$. Values in parenthesis are estimated or uncertain

| Region | Area $A/10^4$ km$^2$ | Gumbel parameters (normalized) | | Maximum magnitude | |
|---|---|---|---|---|---|
| | | $a$ | $u_0$ | $M$ observed | $M_{\max}$ assumed for the model |
| 1 Upper Rhine graben except eastern border zone | 1.30 | $0.51 \pm 0.12$ | $3.82 \pm 0.20$ | $5\frac{1}{4}$ | $5\frac{3}{4}$ |
| 2 Eastern border zone of the Upper Rhine graben | 0.30 | $0.51 \pm 0.12$ | $3.82 \pm 0.20$ | $6\frac{1}{4}$ | $6\frac{1}{2}$ |
| 3 Middle Rhine zone | 0.51 | $0.60 \pm 0.12$ | $3.29 \pm 0.21$ | 5 | $5\frac{3}{4}$ |
| 4 Hunsrück zone | 0.48 | (0.60) | (2.70) | $4\frac{1}{2}$ | $5\frac{3}{4}$ |
| 5 Wetterau | 0.08 | (0.60) | (2.70) | 4 | $5\frac{3}{4}$ |
| 6 Black Forest | 0.54 | $0.78 \pm 0.15$ | $3.47 \pm 0.25$ | 5 | $5\frac{3}{4}$ |
| 7 Western Swabian Alb | 0.15 | $0.58 \pm 0.15$ | $5.78 \pm 0.25$ | 6 | $6\frac{1}{2}$ |
| 8 Eastern Swabian Alb, Upper Swabia, Lake Constance, Hegau | 1.30 | $0.72 \pm 0.15$ | $3.53 \pm 0.25$ | $5\frac{1}{2}$ | $5\frac{3}{4}$ |
| 9 Vosges mountains and Eastern France | 1.13 | (0.60) | (3.00) | – | $5\frac{3}{4}$ |
| 10 Epinal-Remiremont zone | 0.15 | (0.60) | (4.00) | 6 | $6\frac{1}{2}$ |
| 11 Northern Switzerland | 2.04 | (0.60) | (3.30) | – | $5\frac{3}{4}$ |
| 12 Regions with very low seismicity (outside regions 1–11) | 6.74 | (0.48) | (1.95) | $4\frac{1}{2}$ | $5\frac{3}{4}$ |

along the western border faults and in the graben interior (Fig. 1, region 1) in our seismicity model.

Outside of the seismotectonic unit of the Upper Rhine graben several seismic source regions exist influencing the seismic risk of the graben area. The specifications of these neighbouring sources and their boundaries were determined using historical seismicity and available geological and tectonical evidence as shown in Figure 1 and Table 1.

The most important focal region southeast of the graben is the Western Swabian Alb (Fig. 1, region 7). This small-sized highly active seismotectonic unit is characterized by strike-slip shocks occurring along a $N-S$ trending crustal fracture zone (Schneider, 1968, 1971). The specific seismicity (earthquake frequency per magnitude class and unit area and time) of the Swabian Alb zone is much higher than in the Upper Rhine graben, but only for the last seven decades (Ahorner, 1975). The period of high activity starts with the major earthquake near Ebingen 1911 (epicentral intensity VIII, magnitude $M_{\mathrm{LgH}} = 6.1$; Karnik, 1969). Since that time more than 20 earthquakes with intensities equal or greater VI have been observed. Before 1911 the seismic activity of the Swabian Alb zone was of minor significance for many centuries. This non-uniform time distribution raises the difficulty whether the high activity rate of the present century or a smaller rate averaged over two or more centuries in the past should be used for the risk calculation. Conservatively the higher specifications derived from the period 1900–1974 were taken for the Swabian Alb region (see Table 1) in our seismicity model.

A seismotectonic pendant to the Swabian Alb zone is the focal region of Epinal-Remiremont (Fig. 1, region 10) on the south-western side of the Upper Rhine graben, where equally damaging earthquakes occur, too. The strongest shock observed is that of 1682 (epicentral intensity VIII–IX, magnitude $M_m \approx 6$; Sieberg, 1940).

From all other neighbouring sources only the Black Forest zone (Fig. 1, region 6) has an essential influence on the seismic risk in the graben area. The focal depths of the Black Forest earthquakes are between 8 km and 25 km, somewhat deeper than in the surrounding seismotectonic units (Ahorner et al., 1970). This implies that in spite of large areas of perceptibility the epicentral intensities are not very high. The maximum observed intensity is $I_0 =$ VI–VII (Schneider, 1968).

## 3. Attenuation Law for Macroseismic Intensity

In Ahorner and Rosenhauer (1975) a peak acceleration – distance curve has been used as transfer function between earthquake sources and site. Because sufficient acceleration data for Central European earthquakes are lacking until now, great uncertainties had to be associated with this curve, which were taken into account in the uncertainty analysis of the probability results. In the present paper, an intensity attenuation law based on local observations is derived, which is a better basis for the assessment of earthquake risk at given sites in the region under investigation.

Two well known empirical laws describe the dependence of macroseismic intensity $I$ on hypocentral distance $R$ and magnitude $M_m$. The first is from Sponheuer (1960):

$$I(R) - I(R') = 3 \log_{10}(R'/R) + 3\alpha \log_{10} e \cdot (R' - R)/\text{km}. \tag{4}$$

The absorption coefficient $\alpha$ varies for most earthquakes in the Rhine area between 0.001 and 0.005. Its uncertainty, however, is not important for hypocentral distances $R < 200$ km relevant for the calculations described in Section 4. The value $\alpha = 0.0025$ was choosen, i.e.

$$3\alpha \log_{10} e = 3.26 \cdot 10^{-3} \approx 3 \cdot 10^{-3}. \tag{5}$$

Choosing $R' = 10$ km as a reference distance one gets

$$\begin{aligned} I - I_{10\,\text{km}} &= I(R) - I(10\text{ km}) \\ &= 3 - 3 \log_{10}(R/\text{km}) - 3\alpha \log_{10} e(R/\text{km} - 10). \end{aligned} \tag{6}$$

This formula is in good agreement with observed intensity-distance curves for the Rhine area (Fig. 4).

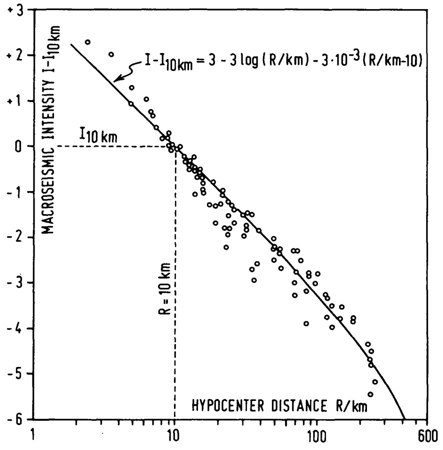

**Fig. 4.** Attenuation of macroseismic intensity $I$ (MSK-scale) with hypocentral distance $R$. Points give mean isoseismal radii for 19 earthquakes observed in the Rhine area from 1846 to 1965. The continuous variable $I_{10\,\mathrm{km}}$ (at $R=10$ km), which serves as reference intensity, has been derived from observed intensity-distance curves graphically

The second law is Equation (1) (Karnik, 1969), which gives the intensity at $R=10$ km by insertion of the focal depth $h=10$ km:

$$I_{10\,\mathrm{km}}=2M_m-2.7. \tag{7}$$

Combination of Equations (5) to (7) yields the desired intensity attenuation law valid for the Upper Rhine graben and adjacent regions:

$$\begin{aligned}&I=2M_m-3\log_{10}(R/\mathrm{km})-3\cdot\alpha\cdot\log_{10}e\cdot(R/\mathrm{km}-10)+0.3\\&3\alpha\log_{10}e\approx 3\cdot 10^{-3}.\end{aligned} \tag{8}$$

## 4. Statistical Model and Calculation Methods

The probabilistic description of earthquake occurrence and the calculation of site dependent probability distributions for intensities have been performed using the methods and computer codes presented in detail by Ahorner and Rosenhauer (1975). Therefore, only the main characteristics will be repeated here.

For each of the seismicity zones in Figure 1 Gumbel's extreme value distribution (Gumbel, 1958)

$$G(M)=\exp\left[-\exp\left(-\frac{M-u}{a}\right)\right] \tag{9}$$

is assumed to give the probability that the Richter magnitude of the largest earthquake in the zone with area $A$ in a specified time $T$ does not exceed a value $M$.

This corresponds to the linear magnitude-frequency relation Equation (3), because the following general relation between the extreme value distribution

$G(M)$ and the mean frequency $N$ holds:

$$G(M) = \exp(-N \cdot T). \tag{10}$$

Insertion of Equation (3) leads to the Gumbel distribution Equation (9) with

$$u = a_{GR}(A, T)/b, \qquad a = \log_{10} e/b \approx 1/(2.3b). \tag{11}$$

The Gumbel parameters $a$ and $u$ have been obtained from observed extremes with the INTERATOM computer code GUMBEL using unbiased evaluation methods based on order statistics. For the Upper Rhine graben examples are given in Figures 5 and 6. The evaluation of observed 50-year extremes for the

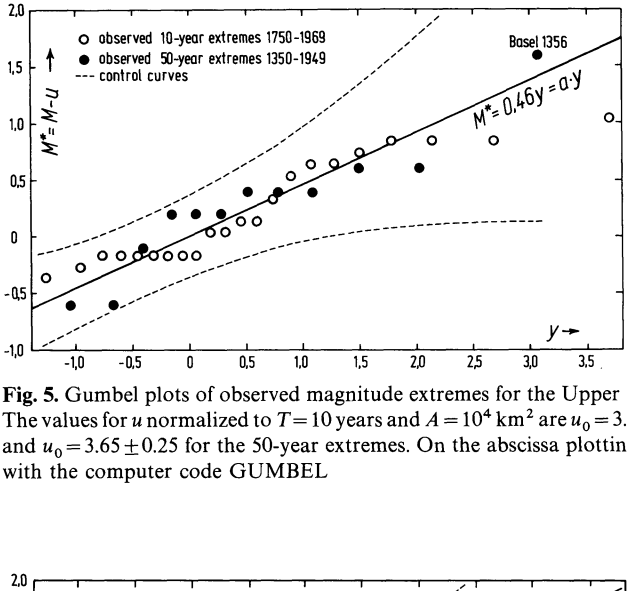

**Fig. 5.** Gumbel plots of observed magnitude extremes for the Upper Rhine graben ($A = 1.6 \cdot 10^4$ km$^2$). The values for $u$ normalized to $T = 10$ years and $A = 10^4$ km$^2$ are $u_0 = 3.99 \pm 0.20$ for the 10-year extremes and $u_0 = 3.65 \pm 0.25$ for the 50-year extremes. On the abscissa plotting positions $y$ are used calculated with the computer code GUMBEL

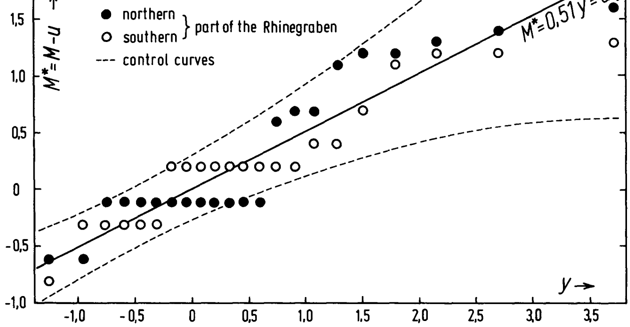

**Fig. 6.** Gumbel plots of observed magnitude extremes for the northern part ($N$ of Lat. 49°, $A = 0.9 \cdot 10^4$ km$^2$) and the southern part ($A = 0.7 \cdot 10^4$ km$^2$) of the Upper Rhine graben. Normalized values $u_0$ are very similar for both parts of the graben ($u_0 = 3.86$ and 3.82 respectively)

period 1350–1949 including the Basel earthquake of 1356 shows remarkable agreement with the values based on 10-year extremes for the period 1750–1969, indicating that the Basel event is not extraordinary for the seismic regime of the Upper Rhine graben. Similarly, no significant difference could be found between the southern and northern part of the graben.

The Gumbel parameters $a$ and $u$ can as well be determined from the Gutenberg and Richter parameters $a_{GR}(A, T)$ and $b$ using Equation (11) and the values of Figure 3,

$$u = 3.15/0.95 = 3.32 \qquad a = 1/(2.3 \cdot 0.95) = 0.46 \tag{12}$$

referring to $T=1$ year and $A=2.5 \cdot 10^4\ \text{km}^2$. Normalizing to 10 years and an area of $10^4\ \text{km}^2$ one gets (Ahorner and Rosenhauer, 1975)

$$\begin{aligned} u_0 &= u + a \cdot \ln\left(\frac{10^4\,\text{km}^2 \cdot 10\,\text{years}}{AT}\right) \\ &= 3.32 + 0.46 \cdot \ln\left(\frac{10^4\,\text{km}^2 \cdot 10\ \text{years}}{2.5 \cdot 10^4\,\text{km}^2 \cdot 1\ \text{year}}\right) = 3.96. \end{aligned} \tag{13}$$

These values for $a$ and $u_0$ agree well with $a = 0.51 \pm 0.12$ and $u_0 = 3.82 \pm 0.20$ determined by the evaluation of extremes directly (Table 1).

In order to exclude infinite values of $M$, absolute upper bounds $M_{\max}$ have again been introduced by a correction of Equation (9), which is small in the range of observed extremes:

$$\begin{aligned} &G_c(M) = G(M)/G(M_{\max}) && (M \leqq M_{\max}) \\ &G_c(M) = 1 && (M > M_{\max}). \end{aligned} \tag{14}$$

$G_c(M)$ is identical with the bounded magnitude-frequency distribution used by Knopoff and Kagan (1977). Criticism by these authors concerning the application of biased estimators for extreme value statistics to earthquake problems does not cover the methods used by us. Detailed comments defending the procedures of the theory of extremes for risk evaluations against the general objections of Knopoff and Kagan (1977) will be contained in a paper under preparation by the present authors. Methods to obtain reliable estimates for regional values of $M_{\max}$ justifying the assumptions made in our 1975 calculations and in this paper will also be published in this paper. Figure 7 shows the magnitude probability distributions $G_c(M)$ used in the Upper Rhine graben Regions 1 and 2).

For each seismicity zone a focal depth distribution $W(h)$ was used giving the probability that the focal depth of an earthquake is smaller than $h$. These distributions were found by evaluating observed data (see Ahorner and Rosenhauer, 1975).

The total region under investigation (Fig. 1) has been covered by a regular net of 208 sites with 25 km grid width. For each site, the probability distribution of the intensity has been calculated with the INTERATOM computer code WASEW. WASEW subdivides the environs of a site into elements of volume

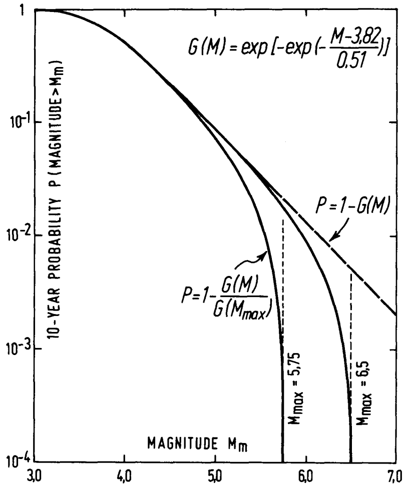

**Fig. 7.** Magnitude probability distributions used for the Upper Rhine graben model. $M_{\max}=6.5$ was assumed for the eastern border faults and $M_{\max}=5.75$ for the graben interior and the western border faults

$\Delta V$. For a fixed intensity $I$ Equation (8) gives—as a function of the distance between $\Delta V$ and the site—the magnitude that has to be exceeded in $\Delta V$ in order to get an exceedance of intensity $I$ at the site. The probability of this event is determined from the corresponding magnitude and focal depth distributions $G_c(M)$ and $W(h)$ respectively. Summing up the contributions of all $\Delta V$, the probability for exceedance of $I$ at the site is gained.

## 5. Results

Figure 8 shows as typical examples three of the 208 probability distributions calculated as described in the preceding section. The whole set of distributions was evaluated in order to draw probabilistic intensity maps. To this purpose, the intensities $I$ for each site were determined corresponding to yearly exceedance probabilities of $2 \cdot 10^{-2}$, $2 \cdot 10^{-3}$, $2 \cdot 10^{-4}$, and $2 \cdot 10^{-5}$ respectively, and drawn into maps (Figs. 9 to 12). Interpreting these values for a reasonable reference time, the maps show the intensity values and isolines with exceedance probabilities of 63 %, 10 %, 1 %, and 0.1 % within $T=50$ years.

The probabilistic intensity maps give a gross quantitative measure of the regional seismic risk level only, because local soil conditions, nearby seismoactive fault lines, and other local features contribute to the actual risk at a site. Local particularities cannot be incorporated into large scale seismicity models, which give averaging results. Because of the limited dimensions of the model the probability values are too small for sites nearer than about 50 km to the map boundaries. This influence disappears with decreasing probability level. Moreover, the far reaching contribution of the Lower Rhine area is not included in the model. Consequently, the intensities calculated for sites in the northwestern part of the maps (NW of the line Saarbrücken-Mainz) are in general too small.

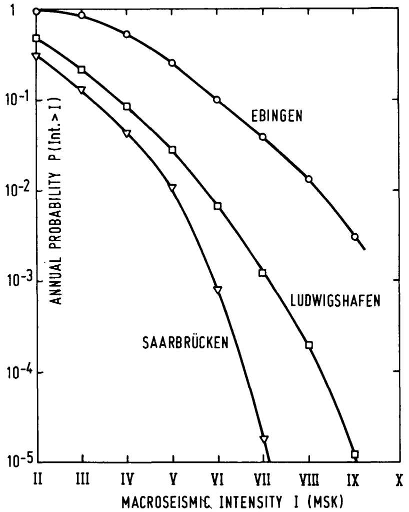

**Fig. 8.** Annual probability $P$ of exceeding an intensity $I$ at typical localities. Ludwigshafen is a representative site in the graben interior (near the confluence of the river Neckar with the Rhine). Ebingen is near the center of the Swabian Alb focal region. Saarbrücken is situated about 60 km west of the graben

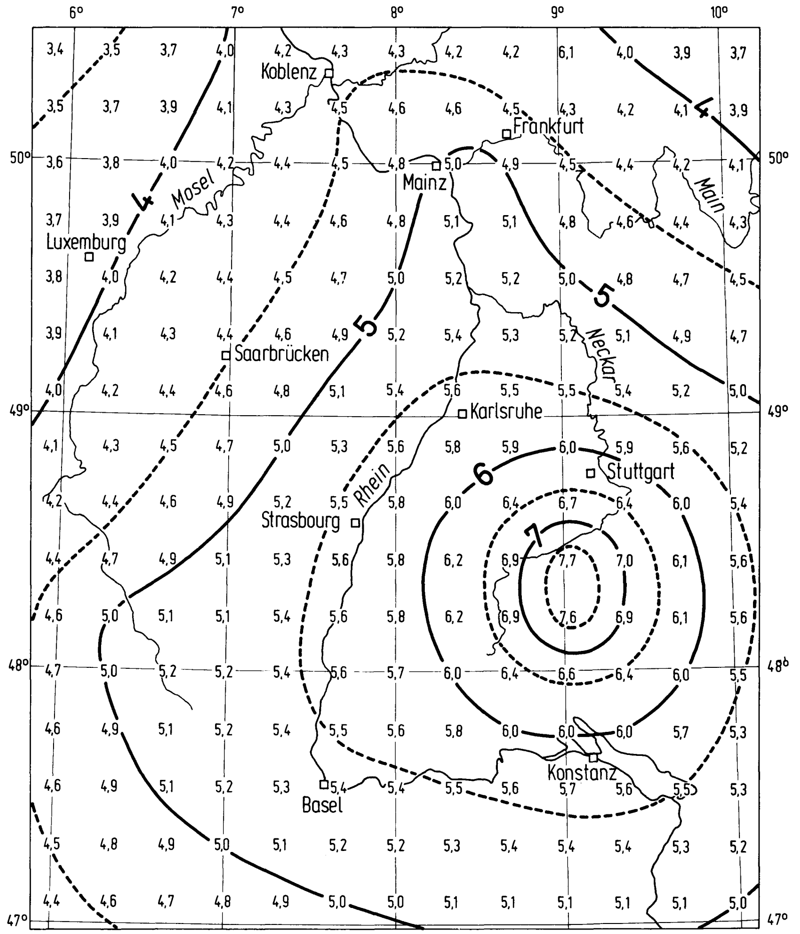

**Fig. 9.** Seismic risk map for the Upper Rhine graben region showing intensities (MSK-scale) for yearly exceedance probability $P = 2 \cdot 10^{-2}$ corresponding to $P = 63\%$ for $T = 50$ years

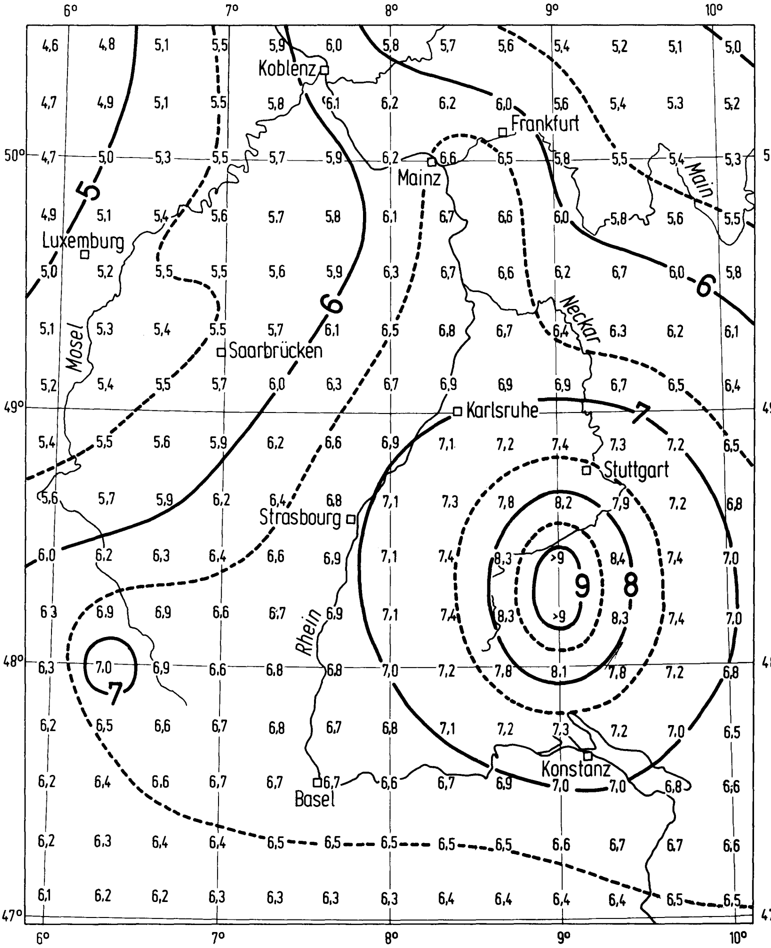

**Fig. 10.** Seismic risk map for the Upper Rhine graben region showing intensities (MSK-scale) for yearly exceedance probability $P = 2 \cdot 10^{-3}$ corresponding to $P = 10\%$ for $T = 50$ years

Both effects however are not relevant for the Upper Rhine graben itself and its direct environment.

Obviously the earthquake intensity which might be used as a basis for design purposes is strongly controlled by the site dependent occurrence frequency tolerated. For the Upper Rhine graben, for instance, a probability of 10% for exceedance within $T = 50$ years corresponds to $I \approx$ VII, whereas a value of 1% suggests $I \approx$ VIII. For sites in the Swabian Alb seismotectonic region about two units higher intensities would be requested at the same exceedance probability levels.

From the comparison of the four maps it becomes also clear that for intensities with higher occurrence rates the seismic risk in the Upper Rhine graben is influenced distinctly by the Swabian Alb focal region and that for

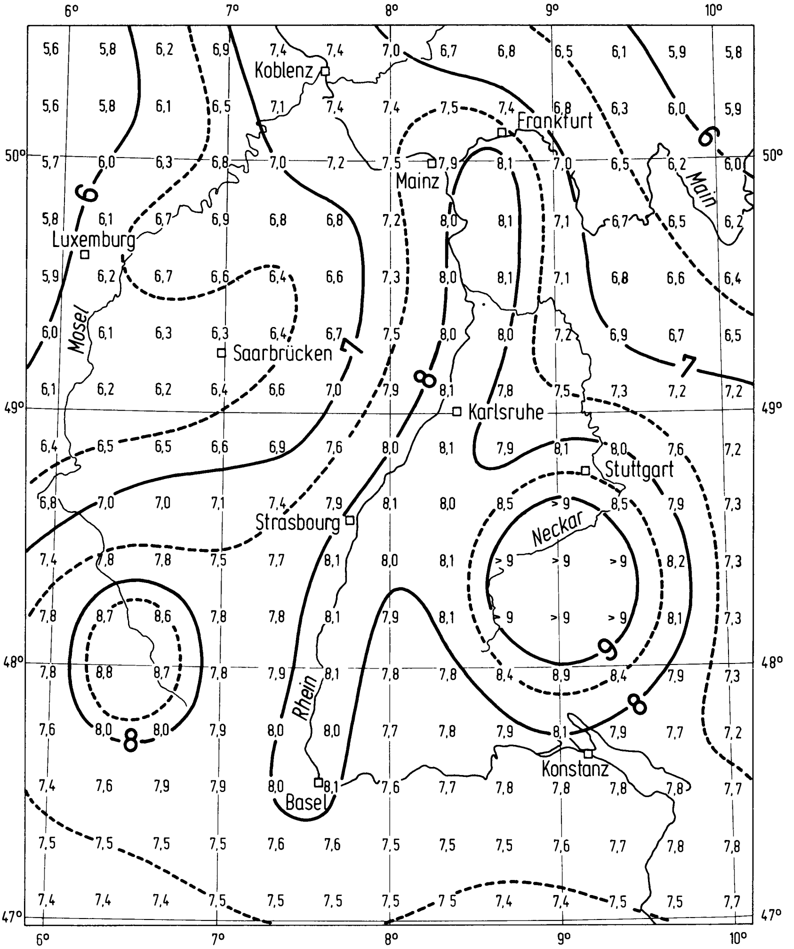

**Fig. 11.** Seismic risk map for the Upper Rhine graben region showing intensities (MSK-scale) for yearly exceedance probability $P = 2\ 10^{-4}$ corresponding to $P = 1\%$ for $T = 50$ years

lower occurrence rates events in the graben itself give the most important contributions.

The uncertainty analysis in Ahorner and Rosenhauer (1975), which has not been repeated for the Upper Rhine graben, suggests similar resulting uncertainties of the probability numbers, i.e., up to one to two orders for higher intensities, with the typical effect of smaller values for the upper, and greater values for the lower uncertainties.

Nevertheless it must be concluded that, concerning the overall seismic risk of the Upper Rhine graben, intensities up to $I = 9$ cannot be excluded on a statistical basis but might occur at very low probability levels.

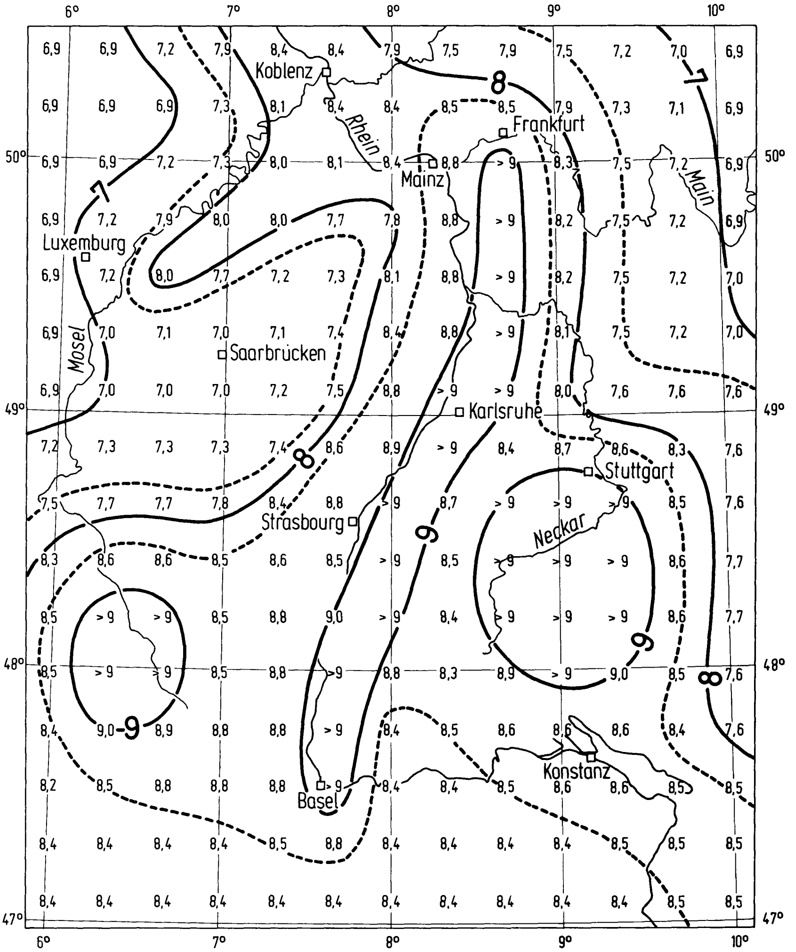

**Fig. 12.** Seismic risk map for the Upper Rhine graben region showing intensities (MSK-scale) for yearly exceedance probability $P=2\ 10^{-5}$ corresponding to $P=0.1\%$ for $T=50$ years

It is interesting to compare our results for the Upper Rhine area with those of the seismic risk maps for Switzerland recently published by the Eidgenössisches Amt für Energiewirtschaft (Sägesser et al., 1977; Mayer-Rosa, 1978). For high seismicity regions in Switzerland, e.g., the Upper Rhone valley (Valais), the Swiss maps give maximum intensities $I=9.6$ with yearly exceedance probability $10^{-4}$ comparable with our highest values for the Swabian Alb region. Though the analyses have been carried out independently and are based on different statistical models, the final results for probabilistic intensities in the Swiss-German border region (e.g., near Basel, Table 2) show – considering the uncertainties of both approaches – remarkable agreement.

**Table 2.** Comparison between probabilistic intensities for the Basel area

| Annual probability of exceedance | Intensity (MSK-scale) | |
|---|---|---|
| | Swiss risk map 1977 | Our risk analysis |
| $P=10^{-2}$ | $I=6.1$ | $I=5.8$ |
| $P=10^{-3}$ | $I=7.4$ | $I=7.0$ |
| $P=10^{-4}$ | $I=8.8$ | $I=8.5$ |

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