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Earthquake hazard for Roermond, the Netherlands

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Abstract

The frequency–intensity and the frequency–magnitude relations are calculated from the observed tectonic earthquakes in the Netherlands. The obtained mean return periods for an intensity VII and a magnitude 5.8–5.9, like the 1992 Roermond earthquake, are estimated to be 132 years and 1000 years or more respectively. The influence of the recent Roermond earthquake on the existing seismic hazard intensity maps for the Netherlands is negligible. The earthquake hazard for the town of Roermond is evaluated.

Introduction

On April 13, 1992, an earthquake occurred in the Netherlands on the Peel Boundary Fault, near Roermond, with an epicentral intensity VII (MSK-scale), a local magnitude (M_L) 5.8–5.9 and a depth in the range of 14–18 km (Ahorner 1994, Camelbeeck et al. 1994).

The mean return periods for the larger earthquakes in the Netherlands are important for earthquake engineering. Therefore, the frequency–intensity and the frequency–magnitude relations are redetermined using only the periods for which the data are complete. The Roermond earthquake occurred in the seismotectonic zone of the Roer Valley Graben. The mean return periods of this zone as a whole are determined.

Interest in a seismic hazard assessment for earthquake engineering has increased since the Roermond event. With a probabilistic method described earlier (De Crook 1993), the seismic hazard for specific sites can be calculated. In the present study the influence of the Roermond earthquake on the existing seismic hazard intensity maps for the Netherlands is investigated, and the seismic hazard for the town of Roermond determined. As site ground motion parameter the intensity is used. Although intensity is in fact a risk parameter, as it includes damage observations, it is usually accepted as a hazard parameter.

Seismicity analysis

Seismicity

Most of the earthquakes in the Netherlands have been observed in the south-eastern part of the country, in an area of 5000 km^2. Seismicity decreases to the north-west (Houtgast 1992). The largest earthquakes occurred at Uden in 1932 and at Roermond in 1992 with M_L = 5.0 and M_L = 5.8–5.9, respectively. The magnitudes of all other observed earthquakes were smaller than 4.5. The maximum observed epicentral intensity was VII (MSK scale). The focal depth estimates of the earthquakes varied between about 2 and 25 km, with an average depth of 13 km.

The major faults in the south-eastern Netherlands are the Feldbiss and the Peel Boundary Faults on either side of the Roer Valley Graben.

Frequency–intensity relation for the Netherlands

The frequency–intensity relation describes the seismic activity. The linear relation with two coefficients is:

$$\log(N) = a - bI_0 \quad (1)$$

where

N = the annual number of events with intensity equal to or larger than I_0, and

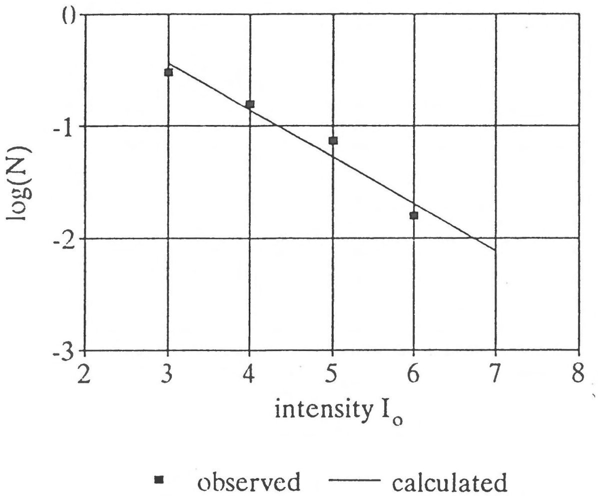

Fig. 1. Number (N) of earthquakes with observed epicentral intensities equalling or exceeding indicated I_0 in the Netherlands. The line indicates the calculated frequency–intensity relation.

Table 1. Periods for which the epicentral intensity (I_0) data are complete for the Netherlands after De Crook (1993).

Intensity I_0	Complete period
III	1975–1992
IV	1930–1992*
V	1905–1992**
VI	1875–1992
VII	1800–1992
VIII	1600–1992

* minus the world-war years 1940–1945,
** minus the world-war years 1914–1918 and 1940–1945.

I_0 = the maximum observed epicentral intensity of an earthquake.

From the observed tectonic earthquakes in the Netherlands (Houtgast 1992), excluding fore and aftershocks, this relation is calculated (Fig. 1):

$$\text{Log}(N) = (0.82 \pm 0.15) - (0.42 \pm 0.07)I_0 \quad (2)$$

N for each value of I_0, ranging from I_0 = III to I_0 = VI, is obtained from the 16 events in the complete part of Houtgast's (1992) catalogue (Table 1). The complete periods for I_0 = IV, V, VI, VII and VIII were obtained from De Crook (1993). The complete period for the magnitude class 2.5–2.9 is 1975–1992 (Table 3). According to Equation 4 this class corresponds to I_0 = III, so the complete period for intensity III is also 1975–1992. The coefficients in Equation 1 are determined by the least-squares method, resulting in $b = 0.42 \pm 0.07$. For the Roer Valley Graben $b = 0.43$ (De Crook 1993).

The mean return periods $T = 1/N$ in the Netherlands for I_0 = III to VII are determined with the frequency–intensity relation of Equation 2 and tabulated in Table 2. According to this table the Roermond earthquake with I_0 = VII was a large one for the Netherlands, but certainly not an improbable one.

Table 2. Mean return periods for epicentral intensities I_0 in the Netherlands

Intensity I_0	Mean return period T (years)
$\geq$ III	3
$\geq$ IV	7
$\geq$ V	19
$\geq$ VI	50
$\geq$ VII	132

Frequency–magnitude relation for the Netherlands

The linear frequency–magnitude relation for the Netherlands is calculated from the observed tectonic earthquakes, excluding fore and aftershocks (Fig. 2):

$$\log(N) = (1.38 \pm 0.01) - (0.68 \pm 0.01)M_L \quad (3)$$

where

N = the annual number of events with magnitude equal to or larger than M_L, and
M_L = the local magnitude.

The N for each M_L = 2.5, 3.0, 3.5, 4.0 and 4.4 is obtained from the 19 events in the complete part of the catalogue (Table 3). The complete periods are estimated from the detection capability of all seismological stations in the Netherlands since 1904 (Houtgast et al. 1987, Ritsema 1983, De Crook 1985). Before 1900 the complete periods are assumed to be the same as in De Crook (1993). The relevant magnitude classes are calculated from the intensity classes VI, VII and VIII with the magnitude–intensity relation for the Netherlands:

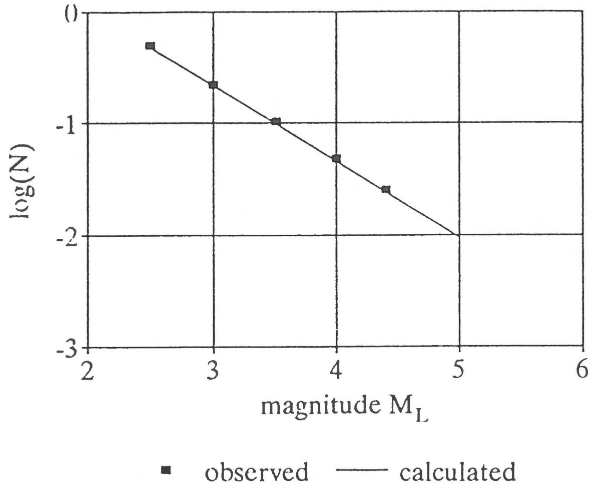

Fig. 2. Number (N) of earthquakes with observed magnitudes equalling or exceeding indicated M_L in the Netherlands. The line indicates the calculated frequency–magnitude relation.

Table 3. Periods for which the magnitude (M_L) data are complete for the Netherlands.

Magnitude M_L	Complete period
2.5–2.9	1975–1992
3.0–3.4	1950–1992
3.5–3.9	1920–1992
4.0–4.3	1905–1992
4.4–5.0	1875–1992
5.1–5.7	1800–1992
5.8–	1600–1992

$$I_0 = (-1.15 \pm 0.48) + (1.51 \pm 0.08) M_L \quad (4)$$

This relation between I_0 and M_L is determined from 42 observed tectonic earthquakes in the Netherlands and is valid for $1 < M_L < 6$. The average depth of the used earthquakes is 13 km. The coefficients a and b in Equation 3 are estimated with the least-squares method, resulting in b = 0.68 ± 0.01, which is lower than b = 0.75 as determined by Ritsema (1966, 1975) and b = 0.74 as obtained by Ahorner (1983) for the Roer Valley Graben.

The mean return periods T = 1/N for M_L = 2, 3, 4 and 5, determined with this frequency–magnitude relation, are tabulated in Table 4. For larger magnitudes the curve normally bends down and is not linear. The mean return period for magnitude 5.8–5.9, the magnitude of the Roermond earthquake, is of the order of 1000 years or more. As far as magnitude is concerned, the Roermond earthquake was a very large event and probably close to the maximum possible magnitude for the Netherlands.

Table 4. Mean return periods for magnitudes M_L in the Netherlands

Magnitude M_L	Mean return period T (years)
≥ 2	1
≥ 3	5
≥ 4	22
≥ 5	105

The mean return period for intensity VII in the Netherlands is 132 years. For a local magnitude of 5.8–5.9 the mean return period is 1000 years or more. This means that for the Roermond earthquake I_0 = VII was relatively low. Also according to Equation 4 intensity VII is low for a magnitude of 5.8–5.9. The source depth of the Roermond earthquake, in the range of 14–18 km and greater than normal, was certainly of influence, but site effects (attenuation of seismic energy by more than 1000 m of sediments) can also have contributed to the relatively low intensity.

Seismicity in the Roer Valley Graben

The cumulative linear frequency–magnitude relation for the Roer Valley Graben and the adjoining parts of the Rhenish Massif, together about 20 000 km^2, is (Ahorner 1983):

$$\log(N) = 2.44 - 0.74 M_L \text{ for } 1.5 < M_L < 5.5 \quad (5)$$

where
N = the annual number of events.

Values of T obtained from Equation 5 for M_L = 3.0, 4.0, 5.0 and 5.5 are 0.6, 3.3, 18 and 43 years, respectively. The maximum possible magnitude is about $6^1/_2$ (Ritsema 1985). For M_L = 5.8–5.9 the frequency–magnitude curve is not linear and the best estimate of T for magnitude 5.8–5.9 is about 200 years. In the last 400 years two earthquakes with $M_L \geq 5.8$ occurred.

The Roermond earthquake was a large event for the Roer Valley Graben. Its location is about 25 km northwest of the area with the highest historical seismicity, where most of the larger earthquakes occurred: Düren 1640, $M_L = 5^1/_4$; Aachen 1690, $M_L = 5$; Düren 1755, $M_L = 5^1/_2$, Düren 1756, $M_L = 6$; Düren 1762, $M_L = 5^1/_2$; Tollhausen 1878, $M_L = 5.4$; Siegburg-Zulpich 1926, $M_L = 5$; Euskirchen 1950, $M_L = 5$; and Euskirchen 1951, $M_L = 5.2$ (Van Gils & Zaczek 1978). Outside this area the larger earthquakes in or near the Roer Valley Graben were St Goar 1846, $M_L = 5.4$, Uden 1932, $M_L = 5.0$, and Roermond 1992, $M_L = 5.8$–5.9.

Hazard analysis

Seismic hazard analysis for the Netherlands

This section presents a brief description of the probabilistic McGuire method (1976) with the different steps. First the seismic zones in the region of interest are defined. Then for each zone a linear frequency–intensity relation, an upper bound of intensity and an average depth for large earthquakes are calculated from the catalogue. Also the attenuation for each zone is determined. A Poisson process is assumed for the seismicity in the region. Finally, the seismic hazard (annual probability versus intensity) is calculated for a site, adding the contribution of all seismic zones.

For the Netherlands this model was applied by modelling all relevant parameters (De Crook 1993). The seismic hazard was calculated for sites at grid points with 7 km spacing. Hazard intensity maps for the Netherlands with annual probabilities of 0.02, 0.01, 0.005, 0.001, 0.0004 and 0.0001 were obtained. The highest hazard was found in the south-east, decreasing to the north-west. The standard error was about one half of an intensity unit for all probabilities.

Influence of the Roermond earthquake

The recent Roermond earthquake, occurring within the seismic subzone 'The Lower Rhine Graben area with lower seismicity', was not included in the earlier seismic hazard analysis for the Netherlands. Including this event, the modelling parameters of the relevant subzone have now been recalculated.

The observed I_0 = VII for the Roermond earthquake does not change the expected maximum possible intensity VIII. The depth of about 14–18 km will slightly alter the used average depth of 13 km. The N for intensity VII in the frequency–intensity relation does not change significantly when we include the Roermond earthquake with a very long return period. Therefore, the coefficients of the frequency–intensity relation remain unchanged. The attenuation coefficient, calculated from the provisional isoseismal map of the Roermond earthquake with the Sponheuer formula, is about 0.001 in the north-west direction and about 0.01 in the north-east direction. Therefore, the Roermond earthquake does not motivate a change of the attenuation coefficients.

We may conclude that the modelling parameters of the relevant subzone do not change significantly and that the influence of the Roermond earthquake on the seismic hazard intensity maps of the Netherlands is negligible.

Table 5. Mean return periods (T) and annual probabilities (P) for site intensities I $\geq$ V at Roermond

Intensity	P	T (years)
$\geq$ V	0.027	37
$\geq$ VI	0.0056	179
$\geq$ VII	0.00058	1724

Seismic hazard for Roermond

The earthquake hazard for Roermond is calculated with the probabilistic method mentioned above. The results are shown in Fig. 3. The standard error is about one half of an intensity unit for all probabilities (vertical dotted lines).

The mean return periods (Table 5) for the site intensities V, VI and VII are determined with the equation:

$$T = 1/P \tag{6}$$

where
T = the mean return period in years and
P = the annual probability.

The T for site intensities IV, IV–V, V, V–VI, respectively, can also be obtained from the 17 events in the complete part of the catalogue of events that have been felt in Roermond (Table 1). These estimates for T are approximately the same as those obtained from the probabilistic hazard analysis (Fig. 3).

For intensity VII only one event has been observed in the complete part of the catalogue (the Roermond earthquake). The best direct estimate for T is 193

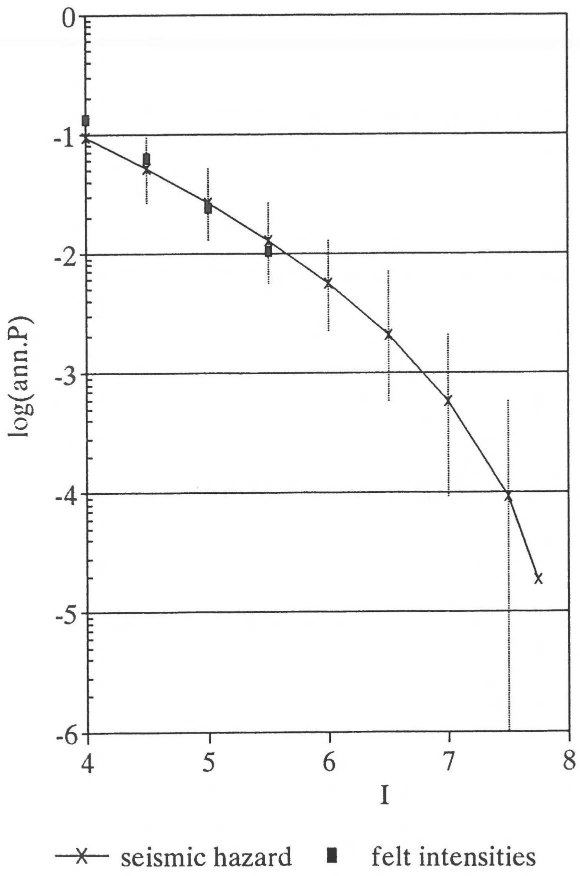

Fig. 3. Seismic hazard for Roermond, i.e. annual probability of exceeding intensity I. The vertical dotted lines are the uncertainties in the probabilistic results. The solid squares indicate the actually observed intensities.

years, which corresponds to the complete period. This is much higher than the probabilistic estimate of the mean return period of 1724 years.

Conclusions

The mean return period, T, for the maximum observed epicentral intensity I_0 = VII in the Netherlands as determined with the frequency–intensity relation (Equation 2) is 132 years (Table 2). With respect to intensity the Roermond earthquake was a large, but not improbable, event for the Netherlands.

For the local magnitude $M_L = 5.0$ in the Netherlands, T is about 105 years (Table 4), while for M_L = 5.8–5.9 it is 1000 years or more. With respect to magnitude, the Roermond earthquake was a very large event for the Netherlands and probably close to the locally maximum possible earthquake.

T for M_L = 5.8–5.9 in the Roer Valley Graben is about 200 years. For this region the Roermond earthquake was a large event. It was an exceptional event as far as its location is concerned, about 25 km northwest of the area with the highest seismicity in the Roer Valley Graben where most of the larger earthquakes occurred.

We find no significant influence of the recent Roermond earthquake on the seismic hazard intensity maps of the Netherlands and find $T \approx 1700$ years for site intensity VII in Roermond (Table 5).

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