Probabilities and Return Periods of Earthquake Intensities in Indiana

ROBERT F. BLAKELY and MADAN M. VARMA
Department of Geology
Indiana University, Bloomington, Indiana 47401

Introduction

Indiana is thought to be a seismically quiet area, however two recent tremors coupled with interest in the safety of atomic power plants have kindled interest in quantifying Indiana's seismicity. Indeed, Indiana has 36 felt earthquakes (Fig. 1) the largest of which had an intensity of VI+ and it occurred in Dubois County on April 29, 1899. Figure 1 does not show all 36 quakes because of those that occurred at the same location, only the largest was plotted. The occurrence of more than one earthquake at a location is one phenomenon that makes the determination of Midwest seismicity difficult. Another difficulty is the wide distribution of quakes in space (Fig. 1) and time. Much of the earthquake motion felt in Indiana resulted from earthquakes that occurred outside our state many years ago. Algermissen (1) established seismic zones for the U.S. but the data is not detailed enough for seismic engineering in the Midwest. Nuttli (5) and more recently Howell (3) have improved the resolution of seismic zones and offer valuable data to compare with the results of our study.

A Method for Determining Seismicity

The statistical range of the seismic activity of the midwestern U.S. in both space and time suggested a method to determine seismicity based on the statistics of extremes (c.f. Gumbel (2)). The steps used are listed below and will be described in more detail in the next section.

1. The intensity at a point due to all historical quakes is determined.
2. The resultant list of intensities is used to determine the highest intensity for each decade.
3. The cumulative probabilities of these extreme events are determined.
4. The data for the location being studied are plotted on extremal probability paper and the return period for certain intensities is determined.
5. Such a process is repeated for many points so that an area may be contoured on values of return period for a given intensity.

Details of the method

We have compiled a list of over 1200 earthquakes for the eastern U.S. in the region between 75° W to 100° W and 25° N to 50° N. The intensities at a point due to all those quakes were computed using the relation

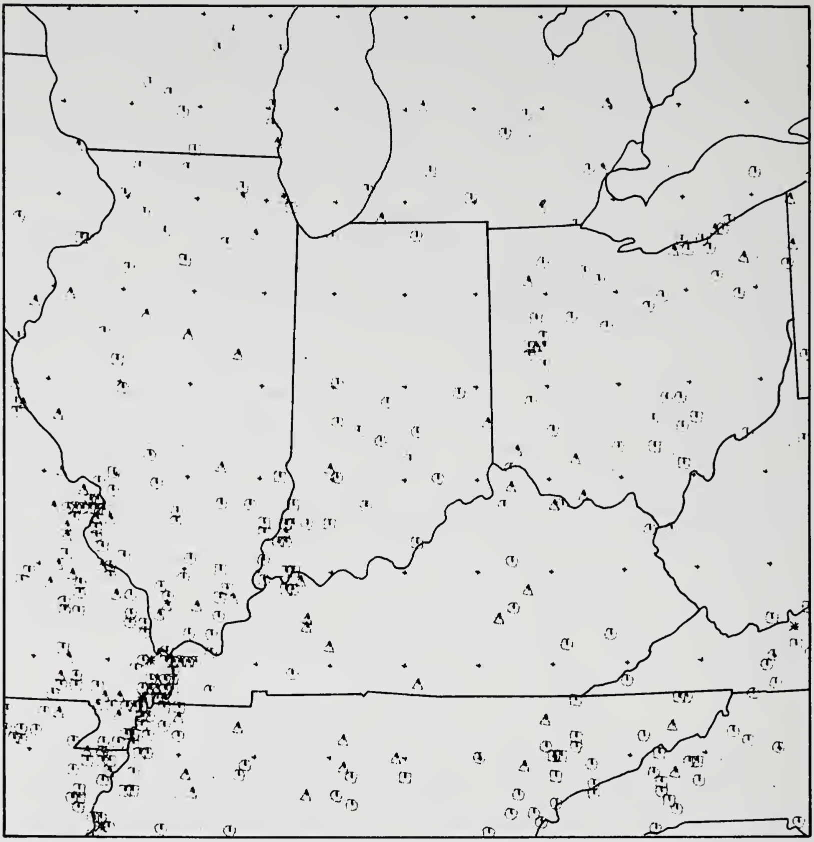

FIGURE 1. *Map of Indiana and surrounding states showing the location of earthquake epicenters*

$$I = I_0 - N \log_{10} \frac{\sqrt{x^2 + h^2}}{h}$$

where I_0 is the intensity at the epicenter, N is a coefficient of absorption, x is the epicentral distance and h the focal depth. For the Midwest N has been determined by Varma and Blakely (6) to be 3.5 when x and h are expressed in kilometers. We used an average value of 30 km. for h.

The procedure above results in a chronological list of intensities (Fig. 2) which is divided into decades and from which the largest intensity is selected and put into a list of extremes (Fig. 3).

Because we are using statistics of extremes, the cumulative probabilities, P_i can be computed using the relation

$$P_i = \frac{1}{N + 1}$$

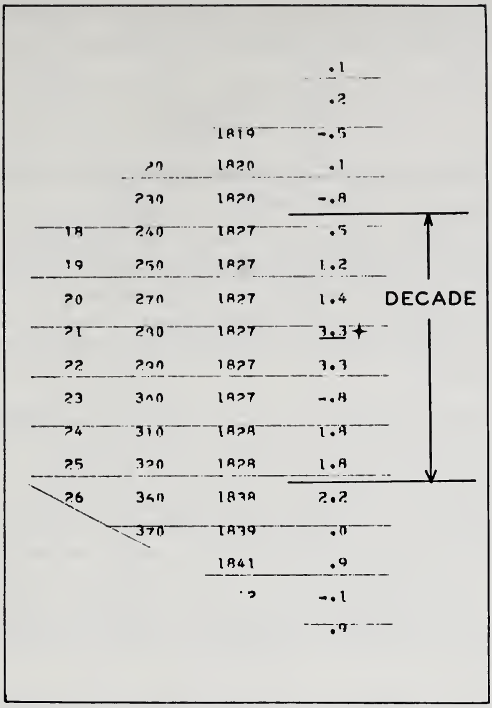

FIGURE 2. *A portion of our computed intensity list. Decades are delimited and the highest intensity selected.*

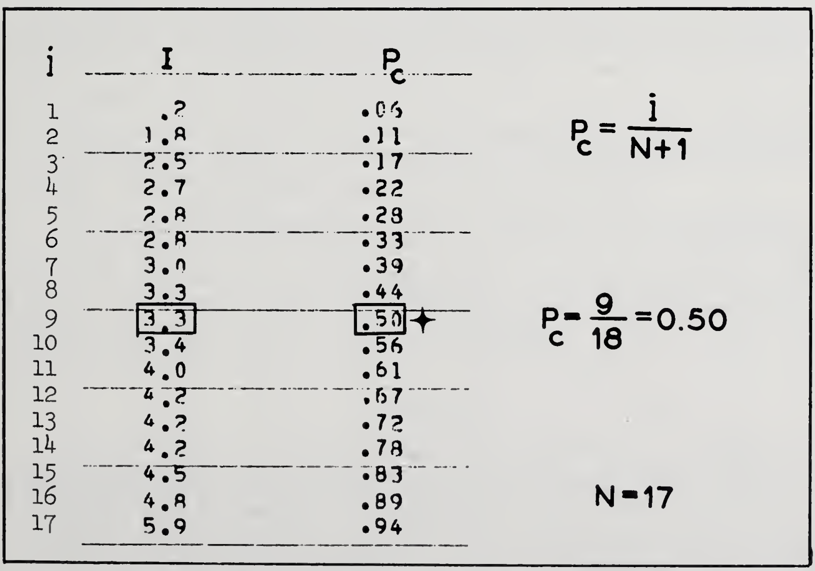

FIGURE 3. *A list of the largest intensities at Indianapolis illustrating the calculation of cumulative probabilities.*

where N is the total number of events in the list. Moreover, the theory states that the return period, T, may be determined from the equality

$$T_i = \frac{1}{1 - P_i}$$

where T_i is in the units of the time span from which the maxima were selected—in our case, decades.

If a phenomenon obeys the theory of extremes, the maximum values and their cumulative probabilities should fit along a straight line when plotted on extremal probability paper (4). The data from Figure 3 (our example is for Indianapolis) when plotted on such paper (Fig. 4) indicate that the statistics of extremes can be applied to Indiana seismicity.

Although the example (Fig. 5) is shown in graphical form, the return periods for specific intensities are determined analytically. A straight line is fitted to the data using the criterion of least squares. From the coefficients of this line, return periods can be calculated for any intensity. We chose intensities of IV, VI and VIII. The return periods for Indianapolis are 43, 189 and 1110 years, respectively (Fig. 5). Intensity IV is felt by many and dishes are rattled. Intensity VI causes minor damage and Intensity VIII causes considerable damage in ordinary buildings. For more details of these and other intensities see Wood and Neumann (7).

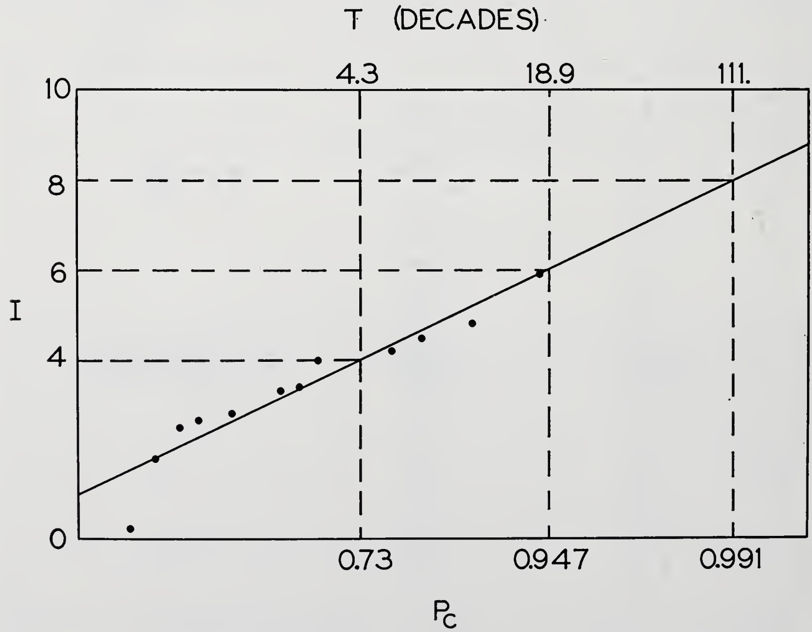

FIGURE 4. *The data for Indianapolis plotted on extreme probability paper.*

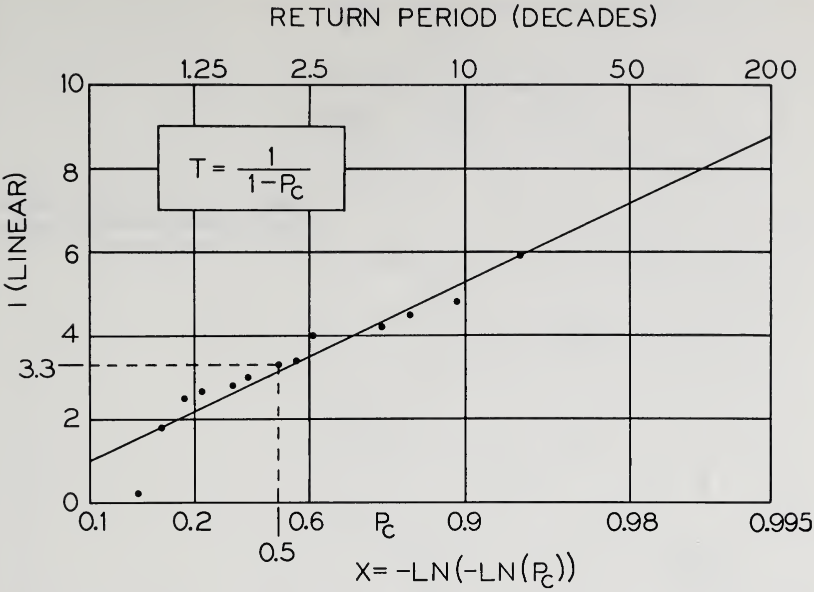

FIGURE 5. *An extreme probability plot used to get the return periods for any intensity at a location.*

In our example we have shown our procedure for one point, Indianapolis. The procedure was repeated for one-half degree intervals in latitude and longitude for all of Indiana. The data for the return periods of the three intensities were recorded on a map and contoured (Figs. 6 through 8). It should be emphasized that the contours are in decades. Thus the most active part of the state (Fig. 6) has a return period of 20 years for an intensity IV.

There is a band of low seismicity running from along a NW-SE line through the center of the state (Fig. 7). The least active area has a return period of 240 years for an intensity VI event.

The two regions of higher seismic activity (Fig. 8) are caused by earthquakes outside our state. The contoured area showing a return period of 700 years in eastern Indiana for an intensity VIII event is due to a seismically active area near Anna, Ohio. The 300-year return period in the southwestern corner reflects seismic activity of both the New Madrid, Mo. area and southern Illinois.

Conclusions

Indiana is not a seismically active area, nevertheless, its seismicity can be described. The northwest portion of the state has the lowest seismicity with a line of low seismicity extending from northwest to southeast through the center of the state. The southwestern portion of Indiana has the highest seismicity. This fact, coupled with the presence of alluvium in the Wabash and Ohio Valleys makes Evansville the city of highest seismic risk in the state.

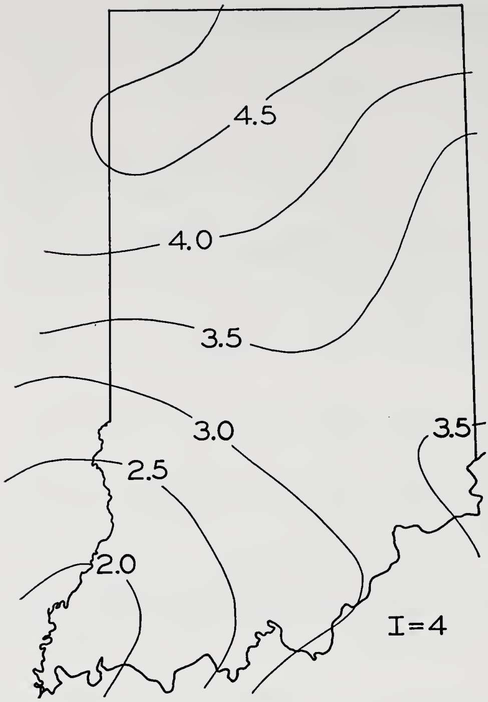

FIGURE 6. *Map of Indiana shawing return period in decades for seismic intensity IV.*

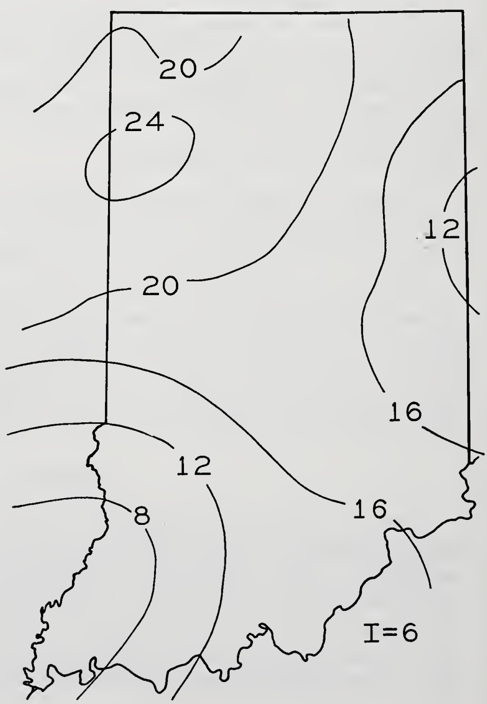

FIGURE 7. *Map of Indiana showing return period in decades for seismic intensity VI.*

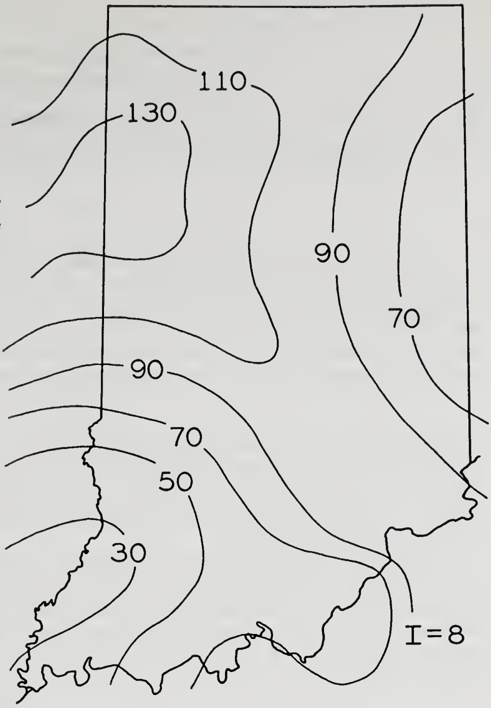

FIGURE 8. *Map of Indiana showing return period in decades for seismic intensity VIII.*

From maps of return period for various intensities, engineers can now compute the likelihood of damaging accelerations and, by taking local geology into account, design structures for seismic risk.

Acknowledgement

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