ESTIMATES OF THE EPICENTRAL GROUND MOTION IN THE CENTRAL AND EASTERN UNITED STATES

by

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SYNOPSIS

In this paper seismic ground motion from earthquakes in the central U.S. recorded at regional distances is used as a basis to make estimates of the strong ground motion that could be expected from future earthquakes in the central U.S.. The method used to back extrapolate the data into the near field is shown to be valid by use of data from earthquakes and underground nuclear explosions. The results of this study show that the estimated peak accelerations in the epicentral region are similar to that observed elsewhere throughout the world. The differences between these results and the lower values predicted by Nuttli[1] are also discussed.

INTRODUCTION

Although large earthquakes are much less frequent east of the Rocky Mountains than in California they nevertheless do occur. In addition, earthquakes in the east affect a much larger area than earthquakes of similar magnitude in California. Because of this difference in felt area between the central United States and California one cannot directly use the data from California. As no strong motion data exists from either smaller or large eastern earthquakes, the ground motion parameters must be inferred using a variety of approaches. In this paper we investigate one such method using as its basis the data from the 1968 central Illinois earthquake and the 1811-12 New Madrid earthquake published by Nuttli[1] to make estimates of the ground motion in the epicentral region of the 1968 earthquake and possible future earthquakes similar to the 1811-12 series of earthquakes. Although the same basic data was used by Nuttli our estimates of the peak ground acceleration are much larger than Nuttli's estimates.[1,2]

APPROACH

The method used is an approach similar to the approach used by Nuttli.[1] The key to the approach used by Nuttli to establish the ground motion for large central United States earthquakes is the assumption that a one-to-one correspondence exists between peak ground velocity and MM intensity. Estimates of the ground motion are obtained by back extrapolating the observed ground motion from the 1968 southern Illinois earthquake into the near field. Nuttli's approach was modified to account for the factors that will be discussed in detail below. Briefly, these modifications consist in the use of a different law to back extrapolate and using acceleration rather than velocity to correlate MMVII intensity between the small and large earthquakes.

There is little theoretical justification for back extrapolating far-field data into the near field. The maximum motion in the far-field is typically associated with longer period surface waves whereas in the near field it is associated with much shorter period body waves. Nuttli[1] used the attenuation equations

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$$A = K\,\Delta^{-a}(\sin\Delta)^{\frac{1}{2}}\exp(-\gamma\Delta) \qquad (1)$$

where a - 1/3 for the Airy phase and 1/2 for waves of other periods. These values are not generally applicable as they were derived for long period mantle Rayleigh waves. Even more importantly, the period and type of the waves with which the maximum ground motion is associated changes with epicentral distance whereas the back extrapolation used by Nuttli is for waves of given period.

The basis we use is empirical. Abundant data[3,4] obtained from the underground nuclear explosions shows near field data can be related to far-field data by the relation

$$\log(\text{accel}) = K + B\log(\text{Distance}) \qquad (2)$$

While sufficient data is not available for earthquakes to verify (2) Orphal et. al.[5] have shown that the available data does fit this form.

The choice to use acceleration as the basis to correlate the smaller earthquake with the larger earthquake is based on the primary consideration that stress and therefore damage in a structure is not a function of the peak ground velocity but of the relative velocity between the structure and the ground. The study by Newmark et. al.[6] shows that the relative velocity response spectra can be scaled from peak ground velocity in the frequency range of .5 hz to 2 hz. For frequencies greater than 2 hz the response spectra should be scaled relative to the ground acceleration. Because, most of the structures involved in both the 1968 earthquake[7] and in the 1811-12 series were stiff one and two story structures which typically have fundamental periods in the range of 5 to 20 hz, acceleration was chosen as the appropriate parameter to use for correlation purposes.

DATA

Nuttli[1] published estimates of peak sustained values of the vertical component of the ground acceleration and velocity observed at seismograph stations throughout the Midwest from the 1968 Illinois earthquake. To convert this to horizontal motion a least squares fit was made between the ratio of peak horizontal to peak vertical motion as a function of epicentral range using all the strong motion records available in the Cal Tech data file. We found that these ratios were not a function of epicentral distance and that the ratio between peak horizontal to peak vertical was 2.5 for both acceleration and velocity.

To convert from the sustained motion to the peak motion we made use of the results of Seed and Idriss,[8] and Ploessel and Slosson.[9] They concluded that the sustained value of the acceleration is about 2/3 of the peak value. The two correction factors give a conversion factor of 3.75 going from sustained vertical to peak horizontal.

RESULTS

Shown on Fig. 1 is a plot of the estimated peak horizontal acceleration obtained from Nuttli's data as described. Also shown is a least squares fit of the form of equation 2 to the data. The important parameter is B; the attenuation coefficient which was found to be -1.62. The viability of our approach is based on obtaining a good estimate of B. The main difficulty is having sufficient data available to properly estimate B. In the west, this would not be such a problem as one could use the data from other earthquakes to get reasonable estimates of B and only need the far-field data to obtain a reasonable estimate of the constant in equation 2. Because similar data does not exist in the east, we must indirectly assess our value. First, as only far-field date are used the most likely bias would be to underestimate B which would result in lower estimates of the epicentral accelerations. The value of -1.62 compares well with western data given in Table 1 and thus appears reasonable.

More importantly, in the epicentral region this rule of back extrapolation leads to peak accelerations in keeping with those observed in the western United States. For example, at the edge of the MMVII isoseismal line (20 km) the acceleration is about .03 g. At the median of the MMVII zone ($\sim$ 10 km) the g value is about .08 g. Considering: (1) that these values are average values; (2) that the results from the San Fernando earthquake show recorded variations of a factor of two from the mean, and (3) the spotty nature of the damage from the 1968 earthquake -- we can conclude that these estimates compare favorably with the recent most complete correlation between intensity and acceleration[10] which found the mean value of acceleration at MMVII damage is .13 g.

To scale from the small 1968 earthquake to some future large earthquake we assume that equation 2 is valid and that the value of B found above applies. An estimate of the constant in equation 2 is obtained by assuming that a one-to-one correspondence exists between the estimated peak ground acceleration for the 1968 at the MMVII isoseismal and the MMVII isoseismal for the large earthquake which is assumed to be the same as observed from the 1811-12 series. The justification for this is: (1) MMVII is established primarily on chimney damage. Because chimnies are stiff, brittle structures one would expect their damage to correlate well with peak acceleration, (2) the lower MM intensities are established using more subjective data therefore difficult to correlate with any ground motion parameter, and (3) very little data exists to establish meaningful relations between intensity and acceleration for intensities greater than MMVII. These results are also shown on Fig. 1.

In order to verify our prediction of the level of strong ground motion at large epicentral distances the available worldwide data was reviewed for those earthquakes which had significantly less attenuation than western United States earthquakes. There are several such earthquakes with recorded ground motion data at large epicentral distances.[11,12,13] This data is given on Fig. 1. Also shown on Fig. 1, for reference, is the 1952 Kern County earthquake.

It is seen from Fig. 1 that large accelerations do occur at large epicentral distances. In addition the response spectra of these earthquakes show both significant high and low frequency content. Extensive chimney damage suggests that the ground motion from the 1811-1812 New Madrid earthquakes contained significant high peak g level ground motion consistent with the data shown on Fig. 1.

COMPARISONS WITH NUTTLI'S RESULTS

Nuttli[1,2] used the same basic data and arrived at much lower estimates of ground motion. For example, at the MMVII isoseismal Nuttli's estimates of the acceleration (consistantly converted) is about a factor of 4 lower.

This difference comes about because while equation 1 used by Nuttli is appropriate to back extrapolate a given surface wave group into the near field, the peak ground motion is not associated with the surface wave groups of period 1 to 3 seconds in the near field but with body waves of much shorter period. Nuttli[1] noted that the rule he used may not be valid in the strong motion region. In order to confirm the validity of his results Nuttli compared the results of his extrapolation to the data compiled by Nicholls et. al..[14] Nuttli concluded that his estimate of peak ground velocity of 1.2 in./sec at the MMVII isoseismal is consistent with the 2 in./sec value of ground velocity suggested by Nicholls as the onset of minor change.

The comparison made by Nuttli[1] is questionable for several reasons. First, Nicholls et. al.[14] define the 2 in./sec level as the division between safe zone (little risk of minor damage) and minor zone which is defined as the formation of new fine cracks either in plaster or dry wall points or the opening of old cracks. This correlates better with MMVI than MMVII. Nicholls et. al. also delineate a major damage level of 7.6 in./sec, defined as serious cracking or dry wall, fall of material, and possible structural damage. This definition more closely corresponds to MVII, and agrees with the results of Trifunac and Brady.[10] Secondly, Nuttli associated the peak motion with waves of period 1-3 seconds and longer. However, the type of structures effected by the earthquake were stiff high frequency type, hence relative to Nuttli's results one would not expect a correlation between velocity and damage to be appropriate. On the other hand ground motion from blasting compiled by Nicholls et. al. is primarily in the high frequency range of 8 cps and greater. This would cause significant amplification in the type of structures affected by the 1968 earthquake.

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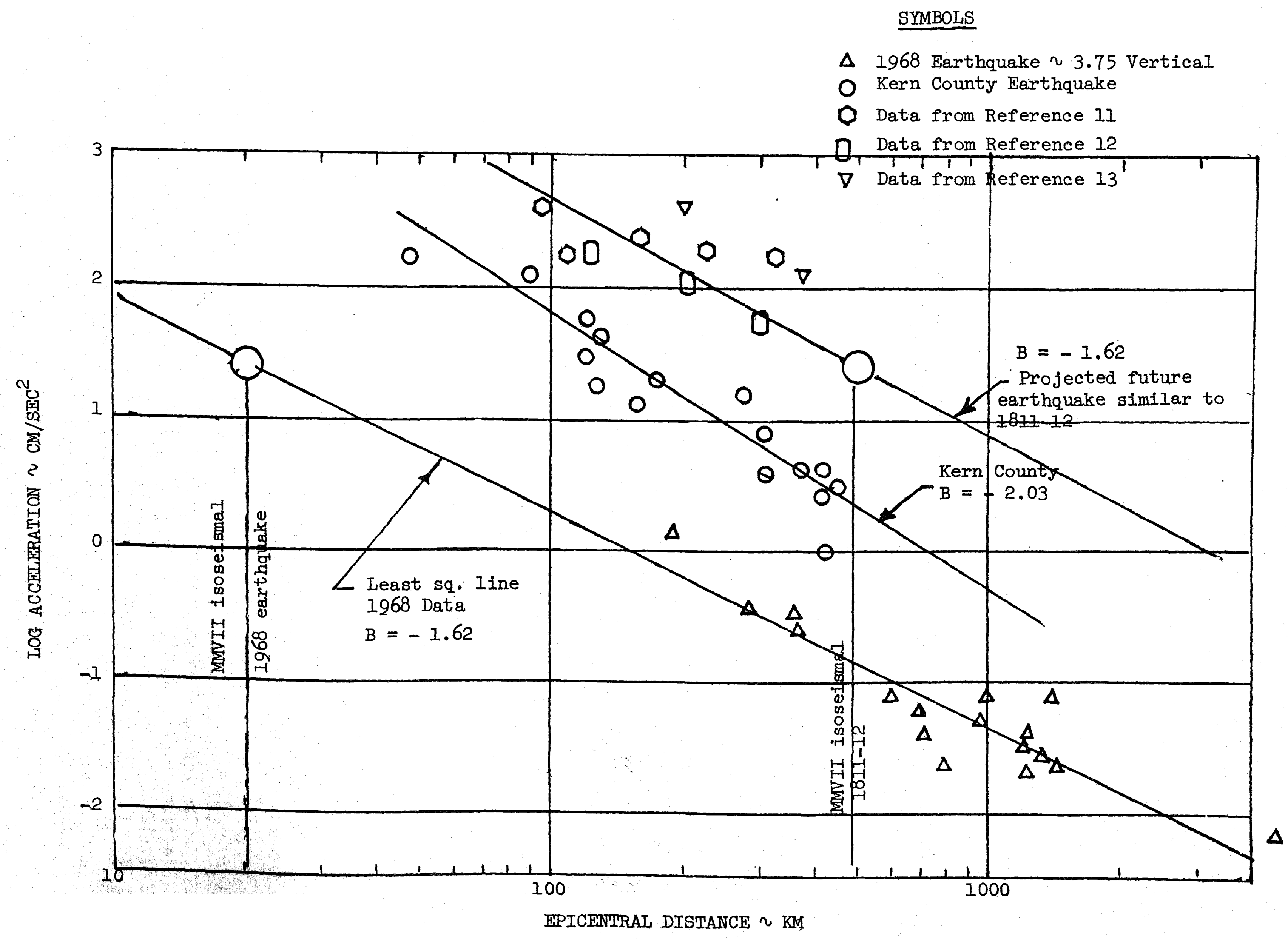
TABLE I

Attenuations Coefficients for Selected Events

Event	Type	Soil Conditions at Recording Sites	Attenuation Coefficient B
BOXCAR	Explosion	all rock stations	-1.63
RUILSON	Explosion	soil/rock	-2.03
San Fernando	Earthquake	all rock stations	-1.63
Kern County	Earthquake	soil/rock	-2.03


SYMBOLS
1968 Earthquake ∿ 3.75 Vertical
Kern County Earthquake
Data from Reference 11
Data from Reference 12
Data from Reference 13
LOG ACCELERATION ∿ CM/SEC²
EPICENTRAL DISTANCE ∿ KM
3
2
1
0
-1
-2
10
100
1000
MMVII isoseismal
1968 earthquake
Least sq. line
1968 Data
B = - 1.62
B = - 1.62
Projected future
earthquake similar to
1811-12
Kern County
B = - 2.03
MMVII isoseismal
1811-12