RELATIVE SEISMIC HAZARD ASSESSMENT FOR THE NORTH CENTRAL UNITED STATES

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SUMMARY

Probabilistic seismic hazard differences at six sites distributed throughout the North Central United States are discussed in this paper. The emphasis in this discussion is directed towards assessments of (1) present uncertainty on causative mechanisms of seismicity in this relatively low seismic intraplate region, and (2) implications of this uncertainty on seismic design practice commonly adopted for this region. Results of this study illustrate that important differences in predicted seismic exposure exist among the sites examined for certain defensible seismicity models; however, current practice would suggest that relatively uniform seismic design criteria are to be applied throughout this region.

INTRODUCTION

Seismic design criteria for critical facilities located in the North Central United States (NCUS) are commonly recommended and/or are assessed using a broadly defined seismicity model established on the basis of spatial extent of mildly deformed Paleozoic sedimentary strata. The use of this broadly defined model implies that all sites located at the interior of this region have similar levels of seismic exposure, and thus, applied design criteria tend to be similar.

It is however observed that the pattern of historical seismicity documented over the past 200 years is not uniform throughout the large NCUS region. In addition, Precambrian basement geologic structure below the mildly deformed Paleozoic strata is known to be complex on the basis of interpretation of geologic and geophysical data. Alternative seismicity models are therefore established to reflect these patterns of historical seismicity and major basement geologic structures. The impact of these alternative seismicity models on seismic design assessments is quantitatively evaluated by performing probabilistic seismic hazard computations for six sites distributed throughout the NCUS.

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PROBABILISTIC SEISMIC HAZARD ANALYSIS

Methodology

Annual frequencies of exceedance of a range of seismic intensities (Modified Mercalli Intensity Scale (MMI), Ref. 1) at six NCUS sites, for three alternative seismicity models, are computed using a standard algorithm described in Refs. 2 and 3. The MMI scale is preferred for this comparative study primarily because numerous intensity data points over a broad range of magnitudes and distances are available in the study region to quantify seismic intensity attenuation and associated uncertainty, whereas only few strong motion accelerograms are available and these are not sufficient for formal statistical derivation of acceleration or velocity attenuation models.

Alternative seismic source zonations, earthquake recurrence models and seismic intensity attenuation models formulated for input into the seismic hazard code from review and synthesis of available geologic and seismologic data are discussed below.

Seismic Source Zonations

Three alternative definitions of seismic source zonations are formulated for the NCUS study region. Seismicity of the study region is illustrated on Fig. 1.

Source Zonation 1

The first source zonation, commonly referred to as the Central Stable Region (CSR) of the North American continent (Ref. 4) is defined by the spatial extent of mildly deformed Paleozoic strata (Fig. 2). The condition of these mildly deformed strata attests to the long term tectonic stability of the CSR, which is primarily characterized by epeirogenic vertical uplift and subsidence. Seismicity of the CSR is not uniform (Fig. 1); however, the use of this broad region to define a uniform seismicity model is validated by assuming that the earthquake catalog (approximately 200 years for larger magnitudes) is of insufficient length to expose all seismogenic features in this low seismic region. On this basis, all localities in the CSR are characterized by an equivalent seismic potential.

Source Zonation 2

The second source zonation is formulated to reflect the distribution of major Precambrian basement structural features identified within the CSR (Fig. 3). Included among these major basement features are the Cincinnati-Kankakee-Findlay Arch System and adjacent Michigan Basin. A spatial correlation is observed for major seismicity of the CSR and the basement arch system. The use of these basement structural features (major arches and basins) to delineate seismic sources is supported by the above spatial correlation and also by the assumption that basement topographic features, particularly changes in gradients and highs, may localize and concentrate stress and thus be seismogenic (Ref. 5).

Source Zonation 3

The third seismicity model is established primarily on the pattern of seismicity observed over the previous two centuries. Areas of most important historical seismicity within the CSR (Fig. 1) are isolated as individual, contemporaneously active features and seismic potential of remaining localities in the CSR is characterized by residual seismicity not associated with the most active features. The validity of this seismicity model depends on the low rate of strain accumulation and release interpreted for the NCUS, thereby suggesting that assessments of seismic hazards in the near term should be primarily made on the basis of presently identifiable, i.e. seismically active, features.

Earthquake Recurrence Models

Annual frequencies of earthquake occurrence are derived by fitting the Gutenberg and Richter (Ref. 6) magnitude-frequency empirical relationship [Log N_c = a + bM; where N_c is the cumulative number of earthquakes per year] to seismicity observed in source zones interpreted for the study region. Schematic representations of sources contained in the three zonations are shown on Figs. 4, 5, and 6. In addition to sources located within the CSR, important seismic sources adjacent to the CSR are considered in the probabilistic analyses. These important sources include the Mississippi Embayment region surrounding the New Madrid, Missouri area, the site of great earthquakes in 1811 and 1812 and repeated modern activity (Ref. 7 & 8), and the Western Quebec Zone (Ref. 9) in SE Canada, a relatively high seismic intraplate region.

Earthquake recurrence models derived for interpreted complete intervals of the earthquake catalog (Refs. 10 & 11) are shown on Figs. 7, 8, and 9. In order to allow a comparison of seismicity of the various seismic sources, recurrence models shown in the above figures are normalized to illustrate annual frequencies of earthquakes, scaled to m_b-magnitude, per area of 10,000 Km^2.

Seismic Intensity Attenuation Model

A generalized MMI attenuation model, Eq. 1, derived by performing multiple regression analyses on numerous intensity observations for four Eastern U.S. earthquakes [magnitude range of 4.0 to 5.8 m_b] (Ref. 12) and verified for applicability at higher magnitudes (Ref. 11) is used in the seismic hazard computations. In addition, an alternative attenuation model, Eq. 2, established for a broader magnitude range [3.0 to 5.8 m_b] from approximately 2000 intensity observations for six earthquakes (Ref. 13) is used to illustrate sensitivity of seismic hazard results to choice of MMI attenuation model.

$$MMI\ (m_b,R) = 2.53 + 1.20\ m_b - .0027(R) - 1.84\ Log_{10}(R) \qquad (1)$$

$$\sigma\ I(m_b,R) = 1.0\ MMI \qquad [R \text{ in km.}, 4.0 \leq m_b \leq 7.0]$$

$$MMI\ (m_b,R) = -1.43 + 1.79\ m_b - .0018(R) - 1.83\ Log_{10}(R) \qquad (2)$$

$$\sigma\ I(m_b,R) = 0.85\ MMI \qquad [R \text{ in km.}, 3.0 \leq m_b \leq 7.0]$$

SEISMIC HAZARD RESULTS

Source Contribution To Seismic Hazard

Contributions of individual seismic sources in Source Zonation 2 and cumulative seismic hazard at one of the six sites examined are illustrated on Fig. 10. These results for site 6 located at the interior of the NCUS study region show that, (1) at low intensities, the host source (Michigan Basin) and the more seismic adjacent source (Arch Structure) contribute equally to seismic hazard, (2) at higher, damaging intensities, the host source dominates seismic hazard, and (3) important distant seismic sources (New Madrid and Western Quebec Zone) contribute a small fraction of the cumulative hazard.

Sensitivity of cumulative hazard results to the alternate attenuation model, Eq. 2, is illustrated on Fig. 10 as the dotted curve. Use of Eq. 2 reduces seismic hazard by approximately one-half intensity at various annual probabilities of exceedance.

Relative Seismic Hazard Differences Among Sites

Cumulative seismic hazard results for the six NCUS sites are compared for three alternative seismic zonations on Figs. 11, 12 and 13. Results are comparable among the sites for the first broadly defined CSR zonation (Fig. 11); the exception is for site 5 located nearer to the New Madrid area than the remaining sites and thereby is relatively more greatly affected at lower intensities by ground motion emanating from this higher seismicity region.

Results, however, substantially differ among sites for zonation 2 (Fig. 12) and particularly for zonation 3 (Fig. 13). For the latter model, seismic hazard differences amount to 2 MMI units at a given annual probability of exceedance. In Addition, seismic hazard at some sites is underestimated, relative to zonations 2 and 3, by using the broadly defined CSR zonation 1.

DISCUSSION

Intensity hazard differences among the NCUS sites examined in these analyses range to 2 MMI units for certain defensible seismicity model alternatives. These intensity hazard differences can be translated into approximately a factor of 4 difference in horizontal ground acceleration hazard among these sites by applying empirical correlations (Ref. 14 & 15). These seismic hazard differences are viewed to be significant and should be considered for seismic design in the region. In addition, further geologic and seismologic research seems to be required in order to reduce the uncertainty presently associated with formulations of seismicity models for this historically low seismic region.

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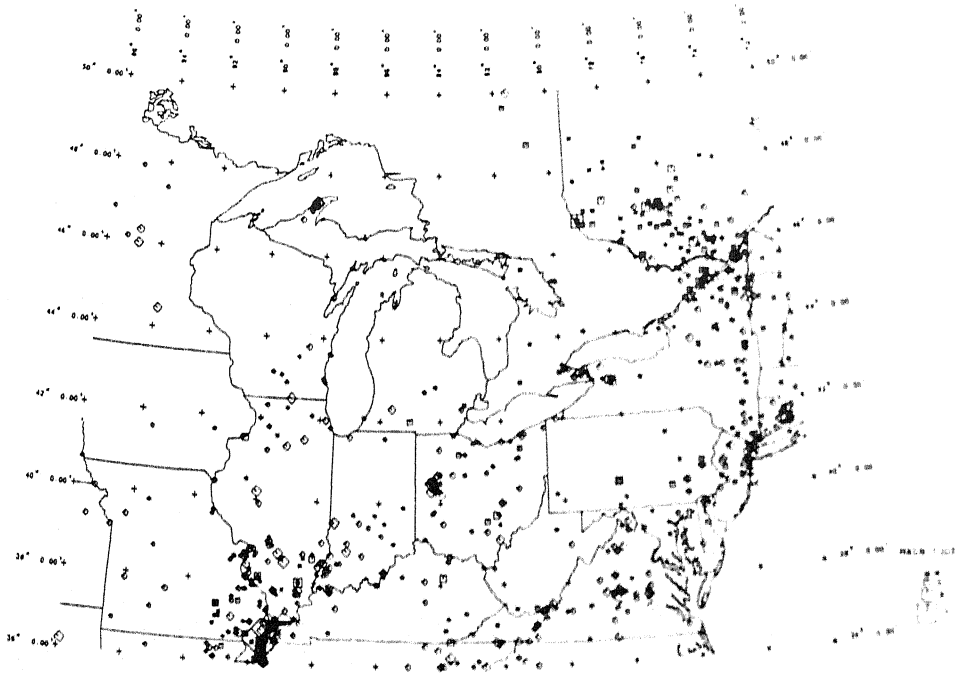

Fig. 1 Seismicity Map

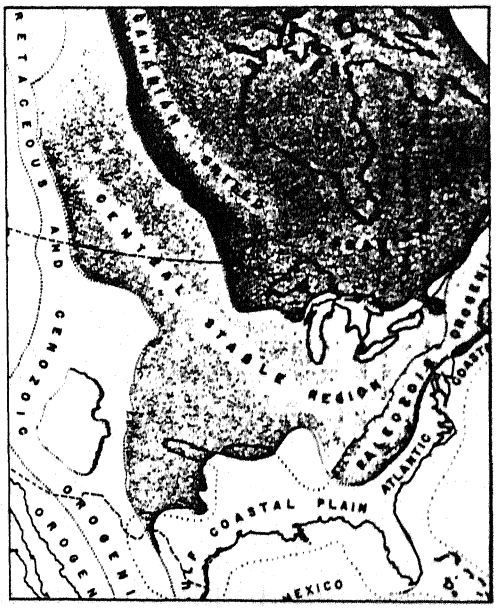

Fig. 2 Central Stable Region, Ref. 4

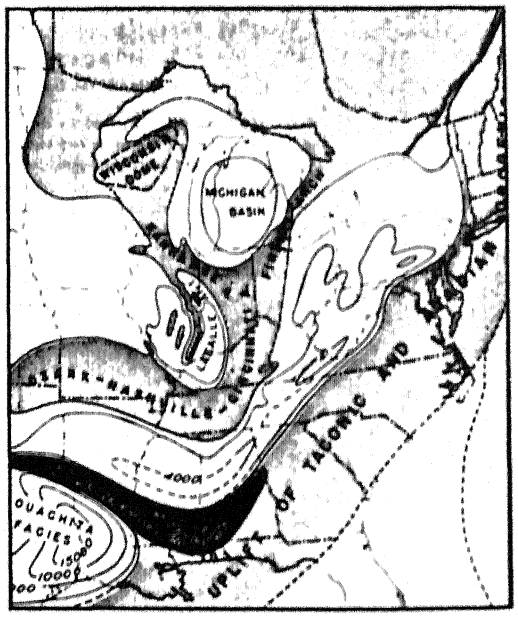

Fig. 3 Basement Structure, Ref. 4

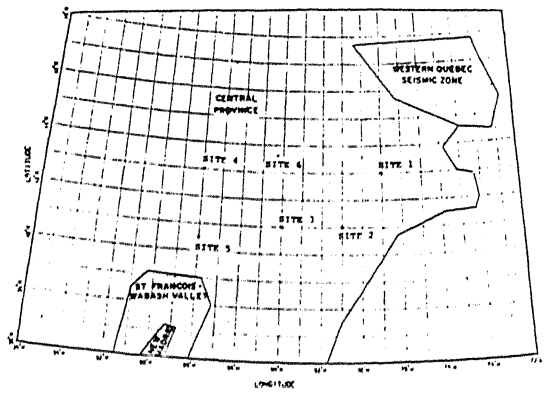

Fig. 4 Zonation 1

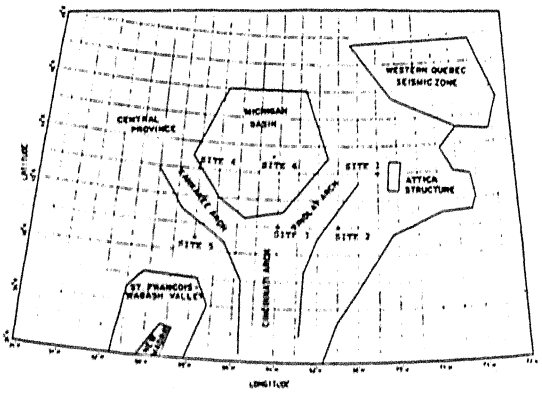

Fig. 5 Zonation 2

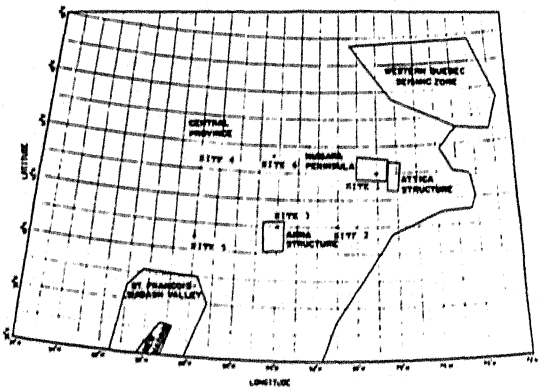

Fig. 6 Zonation 3

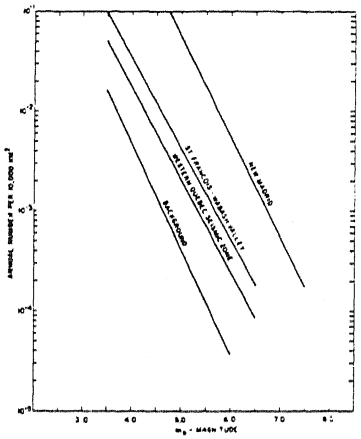

Fig. 7

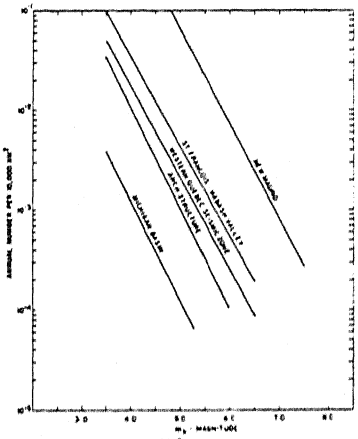

Fig. 8

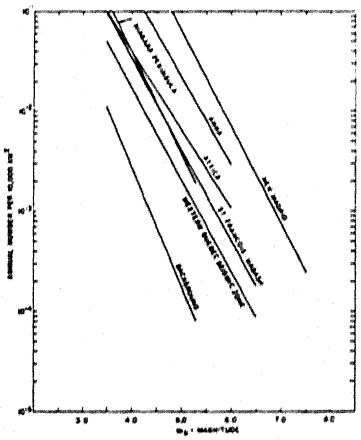

Fig. 9

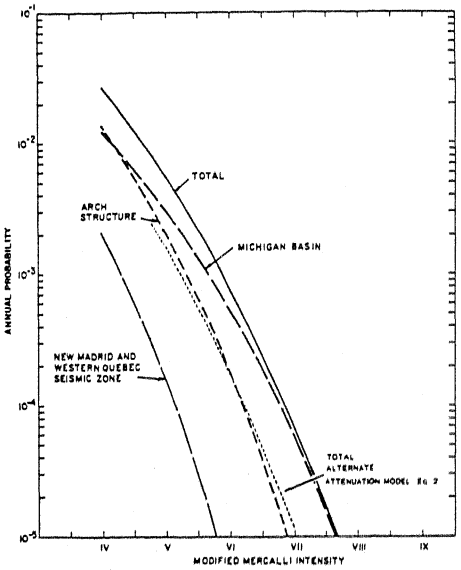

Fig. 10 Seismic Hazard at Site 6 for Zonation 2

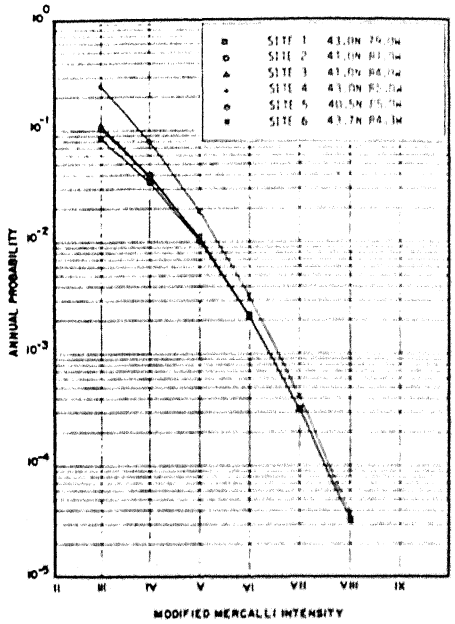

Fig. 11 Relative Hazard - Zonation 1

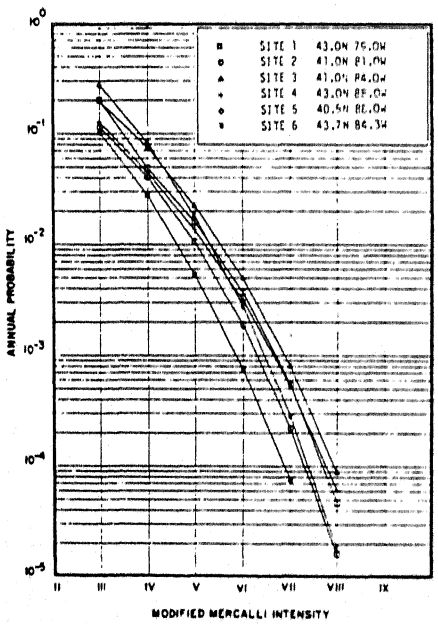

Fig. 12 Relative Hazard - Zonation 2

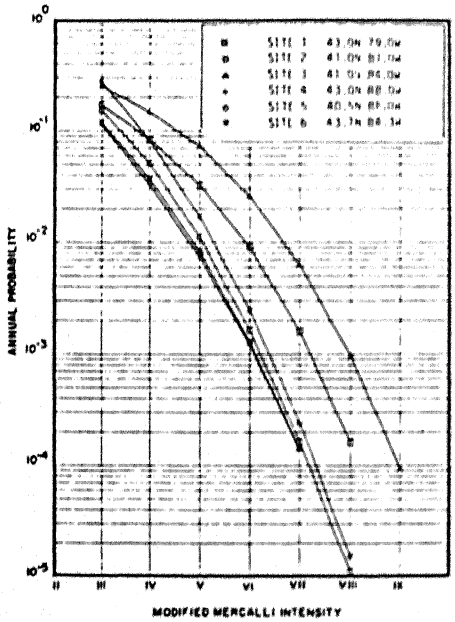

Fig. 13 Relative Hazard - Zonation 3