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Ground Motion for the Maximum Credible Earthquake in Kentucky

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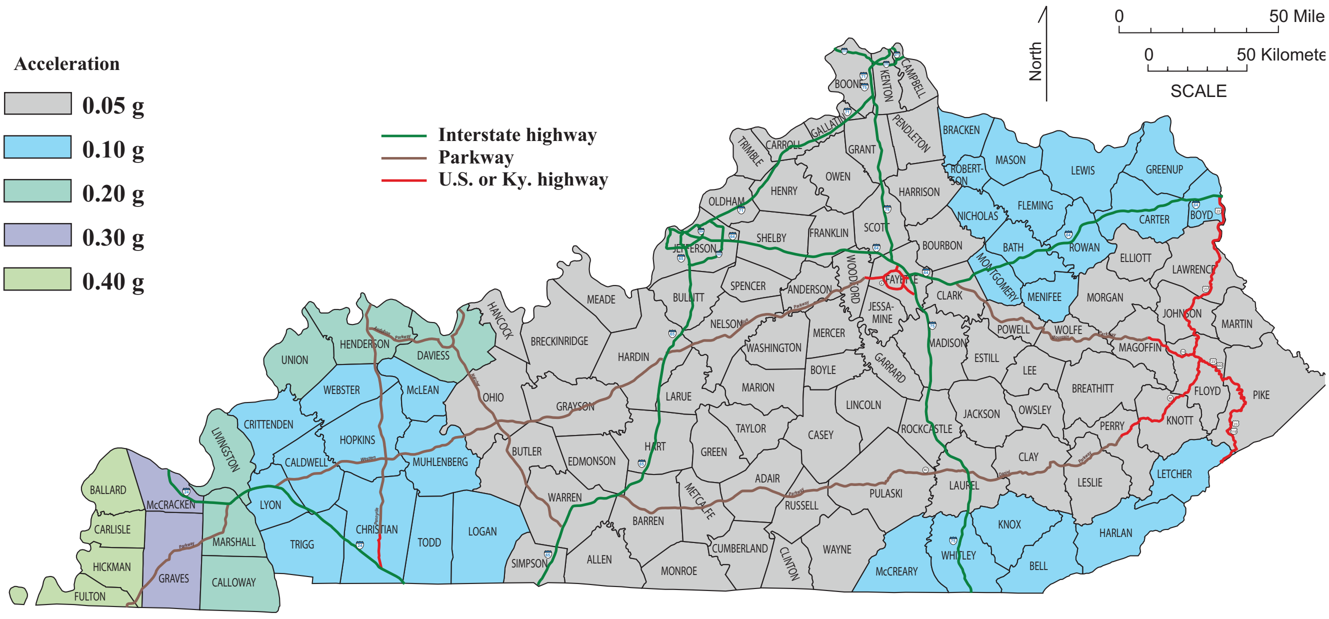

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Ground Motion for the Maximum Credible Earthquake in Kentucky

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Abstract

Although they are not frequent, earthquakes occur in and around Kentucky and pose certain hazards. Assessing seismic hazards is challenging, however, because of a lack of observations. The best estimates of ground motions that could be expected if the maximum credible earthquake occurs in or around Kentucky are depicted in maps showing peak ground acceleration and short-period (0.2 second) and long-period (1.0 second) response accelerations with 5 percent critical damping on hard rock. Another consideration for seismic safety is that the maximum credible earthquake has a long recurrence interval, from 500 to 1,000 years in the New Madrid Seismic Zone and from 2,000 to 5,000 years in the Wabash Valley Seismic Zone.

These maps can be used for seismic safety design for buildings, bridges, dams, and other structures. In combination with local geologic and geotechnical information, these maps can also be used to develop a variety of hazard mitigation strategies, such as land-use planning, emergency planning and preparedness, and lifeline planning.

Introduction

Earthquakes such as the 1980 Sharpsburg, Ky., earthquake (moment magnitude[1] M_w 5.2) (Street and Foley, 1982) and the 2008 southern Illinois earthquake (M_w 5.2) (Herrmann and others, 2008) have periodically occurred in and around Kentucky throughout history. The most widely felt and damaging earthquakes in the state are the great earthquakes of the winter of 1811-12, which were centered in northeastern Arkansas, northwestern Tennessee, southwestern Kentucky, and southeastern Missouri—the New Madrid Seismic Zone (Nuttli, 1973). The 1811-12 earthquakes, of modified Mercalli intensity (MMI) VII to IX, are reported to have caused moderate to heavy damage throughout much of the commonwealth. Table 1 shows the relationship between MMI, peak ground acceleration, perceived shaking, and potential damage. The 1980 Sharpsburg earthquake (MMI VII) caused significant damage ($3 million) in Maysville (Street and Foley, 1982).

Earthquakes are not well understood because the mechanisms causing them are still not clear in the central United States, and they are difficult to predict. Yet they continue to occur in and around Kentucky and pose certain hazards (i.e., potential to cause harm). Assessing the seismic hazards is challenging, however. Three sets of seismological parameters—earthquake magnitude and location, occurrence frequency, and ground-motion attenuation (how strong the ground shaking will be at a site a specified distance from an earthquake's source)—are needed for seismic hazard assessment. These parameters have a large uncertainty associated with them because of a lack of observations in the central United States. The exact boundary of the New Madrid Seismic Zone is still difficult to define, even though it is the most active and well

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[1] Moment magnitude is a measure of earthquake size calculated from the seismic moment of the earthquake (a measure of the strength of an earthquake, particularly of the low-frequency wave motion). It is considered the most valid size calculation for earthquakes measuring 7 to 7.5 on the Richter scale. From Jackson (1997).

Table 1. Relationship between perceived shaking, potential damage, MMI and PGA.

Perceived Shaking	not felt	weak	light	moderate	strong	very strong	severe	violent	extreme
Potential Damage	none	none	none	very light	light	moderate	moderate/ heavy	heavy	very heavy
PGA (%g)	< 0.17	0.17–1.4	1.4–3.9	3.9–9.2	9.2–18	18–34	34–65	65–124	> 124
MMI	I	II–III	IV	V	VI	VII	VIII	IX	X+

studied seismic zone in the central United States. The estimated moment magnitude for the largest event of the New Madrid series ranges from 7 to 8—a large range. Earthquakes are also infrequent in the central United States, especially large ones that have significant impact on humans and the built environment. Recurrence interval estimates for large earthquakes range from about 500 to 1,000 years in the New Madrid Seismic Zone to about 2,000 to 5,000 years in the Wabash Valley Seismic Zone; they are even longer in other zones. Several ground-motion attenuation relationships are available for the central United States, but all are based on numerical modeling and sparse strong-motion records from small earthquakes.

Although earthquakes cannot be prevented and are difficult to predict, disasters caused by them can be mitigated. Mitigation is the most effective and viable approach to dealing with seismic hazards. Seismic hazard assessment is the basis for development, adaptation, and implementation of mitigation policies and measures. Seismic hazard maps, depicting a level of ground motion with an associated recurrence interval in a region, are developed from a seismic hazard assessment.

Ground-Motion Hazard Maps

Different kinds of seismic hazard maps are being produced from seismic hazard assessments. Probabilistic seismic hazard analysis (PSHA) and deterministic seismic hazard analysis (DSHA) are the most commonly used methods of assessment. PSHA and DSHA use the same seismological input parameters, but define and calculate seismic hazard fundamentally differently. In PSHA, seismic hazard is defined as the ground motion with an annual probability of being exceeded (i.e., probability of exceedance in one year) and calculated from a triple integration (i.e., a pure mathematical modeling). PSHA was developed from the approximation of an earthquake as a single point source (i.e., a point-source model for earthquakes) (Cornell, 1968; McGuire, 2004). In modern seismology, however, an earthquake is considered a finite fault, not a single point; this is particularly true for large earthquakes, which are of safety concern. The mathematical formulation of PSHA has been found to be incorrect (Wang and Zhou, 2007; Wang, 2009). Therefore, PSHA is not consistent with modern earthquake science (Wang and Zhou, 2007; Wang, 2009), and results from PSHA are difficult to understand and use. For example, PSHA has been used to develop national seismic hazard maps (Frankel and others, 1996, 2002; Petersen and others, 2008). Use of the national hazard maps in the central United States has caused problems in many communities, such as Memphis, Tenn. (Stein and others, 2003), and Paducah, Ky. (Wang, 2003, 2005). As a result, the 2008 national seismic hazard maps have not been recommended for use in the new edition of the "NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures," published by the Building Seismic Safety Council (Kircher and others, 2008).[1] The U.S. Geological Survey (2009) also cautioned that "the 2008 national seismic hazard maps should not be substituted for the model building code design maps nor should they be used with ASCE/SEI 41 or 31 for seismic rehabilitation or evaluation."[2]

In DSHA, seismic hazard is defined as the maximum ground motion from a single earthquake or set of earthquakes, and is calculated directly from statistics on earthquakes and ground motion. Although DSHA is not the preferred method, it has

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[1] NEHRP stands for the National Earthquake Hazards Reduction Program, authorized by the U.S. Congress.

[2] AESC/SEI 31 and 41 are standards for seismic rehabilitation of existing buildings, put together by the American Society of Civil Engineers' Structural Engineering Institute.

been more widely used because of its advantages: (1) it is an easily understood method of estimating seismic hazard and (2) its results are clear to the analyst (earth scientist), user (engineer), and general public (Reiter, 1990).The ground motion specified for bridge design in California is the deterministic ground motion from the maximum credible earthquake (MCE) (Caltrans, 1999). The deterministic ground motion from the maximum considered earthquake is used for seismic design of buildings in California (BSSC, 1998, 2004; Kircher and others, 2008). The maximum considered earthquake, defined by the Building Seismic Safety Council (1998), has a similar meaning as the maximum credible earthquake commonly defined in DSHA. So we see that in California, DSHA, not PSHA, is used to develop the design ground motion for buildings, bridges, and other structures.

DSHA has been used to determine ground-motion hazards associated with three earthquake scenarios: the expected earthquake, probable earthquake, and maximum credible earthquake for bridge and highway engineering design in Kentucky (Street and others, 1996; Wang and others, 2007). The expected earthquake is defined as the earthquake that could be expected to occur any time in the next 50 to 75 years. The probable earthquake is defined as the earthquake that could be expected to occur in the next 250 years. The maximum credible earthquake is defined as the maximum event considered likely to occur in a reasonable amount of time in and around Kentucky (Fig. 1). The phrase "reasonable amount of time" is defined by the historical or geologic record. For instance, the reasonable amount of time for the maximum earthquake in the New Madrid Seismic Zone is about 500 to 1,000 years, based on paleoseismic records. The reasonable amount of time for the maximum earthquake in the Wabash Valley Seismic Zone is about 2,000 to 5,000 years. Associated time histories (ground shaking intensity varying with time at a site) were also developed for expected earthquakes, probable earthquakes, and maximum credible earthquakes (Street and others, 1996; Wang and others, 2007).

Three maps (Figs. 2–4) for the maximum credible earthquake scenario are published here. Figure 2 shows peak ground acceleration (PGA) measured in *g* (the acceleration due to the earth's gravity). As shown in Table 1, the higher the PGA, the more damage it will cause and the higher the assigned MMI. Thus, PGA can be used as a measure of seismic hazard. Figures 3 and 4 show the short-period (0.2 second) and long-period (1.0 second) response accelerations with 5 percent critical damping (how quickly the vibration dissipates), also measured in *g*. The response acceleration is used to measure the response of a single-degree-of-freedom system (i.e., a single spring, mass, and damper) to the earthquake ground motion. In engineering, buildings and other structures can be simplified as a single-degree-of-freedom system with a predominant period (or frequency) and critical damping. Two periods, short (0.2 second) and long (1.0 second), and 5 percent critical damping are of specific interest to engineers. Therefore, the maps showing short-period and long-period response acceleration with 5 percent critical damping are also produced for use by engineers. As shown in Figures 2–4, the higher response acceleration means higher PGA or higher seismic hazard. Caution must be exercised when the response acceleration maps are used for other purposes.

Explanation

Uncertainty is inherent in these hazard maps because of inherent uncertainties in the seismological parameters used to construct the maps. The hazard maps predict the maximum median ground motion on hard rock for the MCE in each county. The ground motion is the best estimate (median), *not* a worst-case scenario, if the earthquake that has a maximum impact on the county occurs. For example, the best estimate of PGA on hard rock for McCracken County is 0.3 g if an earthquake of moment magnitude 7.7 occurs in the New Madrid Seismic Zone. The best estimate of PGA on hard rock for Henderson County is 0.2 g if an earthquake of moment magnitude 6.8 occurs in the Wabash Valley Seismic Zone. The ground motion may vary slightly across each individual county. These maps can be used for seismic safety consideration for buildings, bridges, dams, and other structures. As discussed earlier, the MCE has a long recurrence interval, varying from 500 to 1,000 years in the New Madrid Seismic Zone to 2,000 to 5,000 years in the Wabash Valley Seismic Zone to much longer in other zones. The long recurrence interval

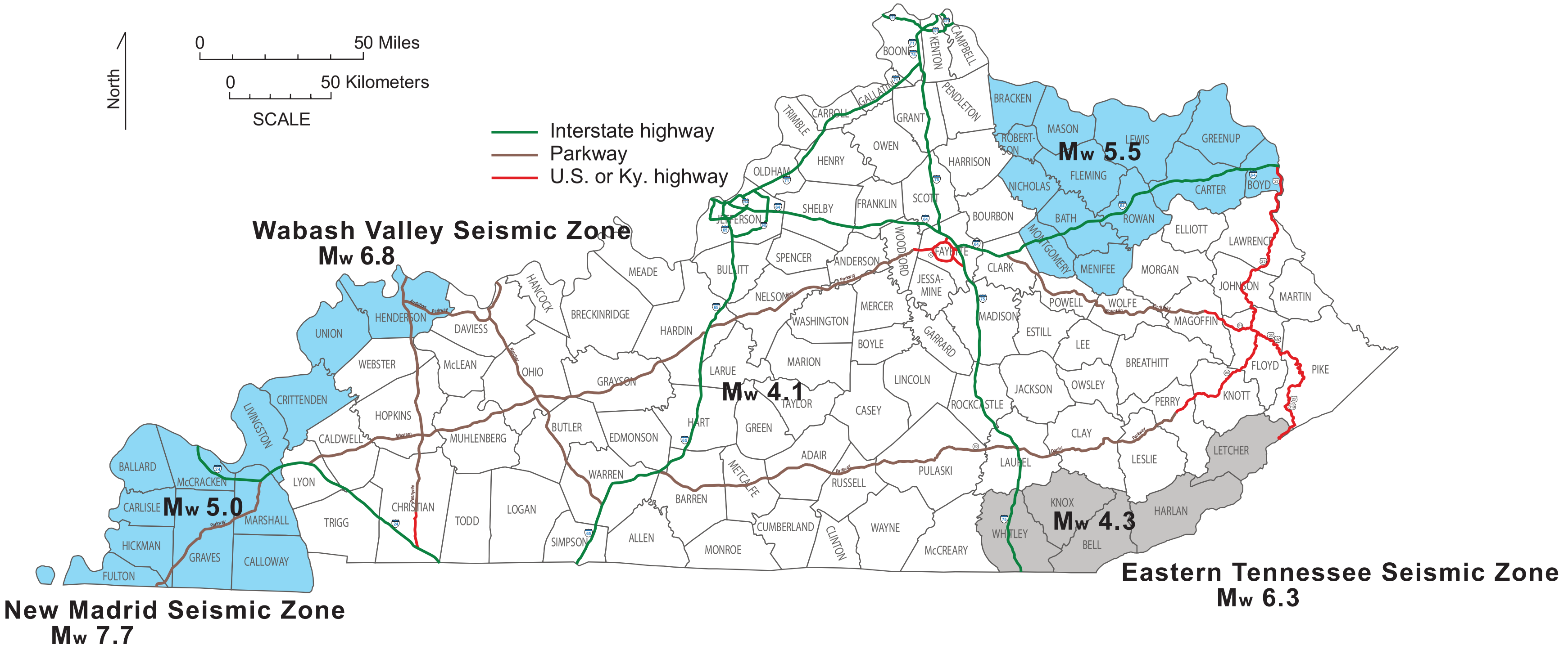

Figure 1. Maximum credible earthquakes in and around Kentucky.

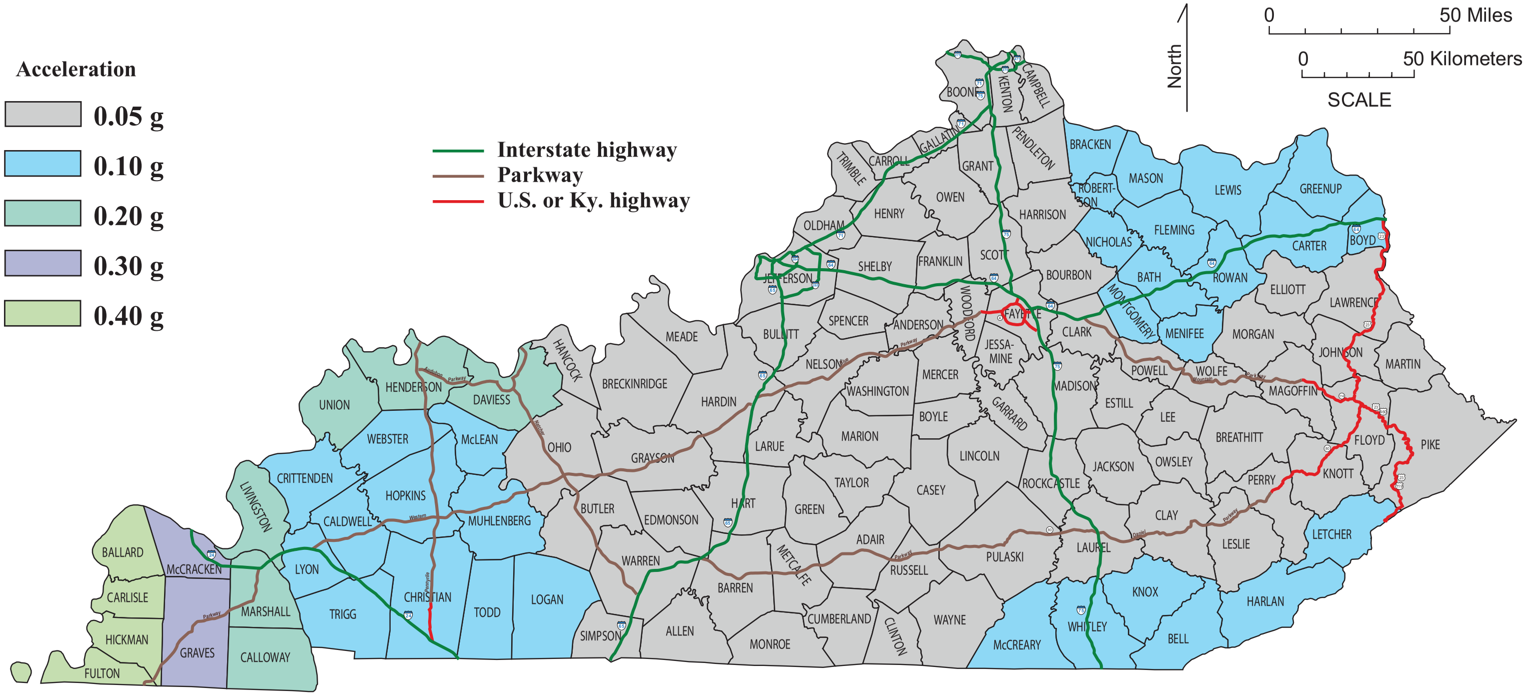

Figure 2. Peak ground acceleration, measured in *g*, on hard rock from the maximum credible earthquake in Kentucky.

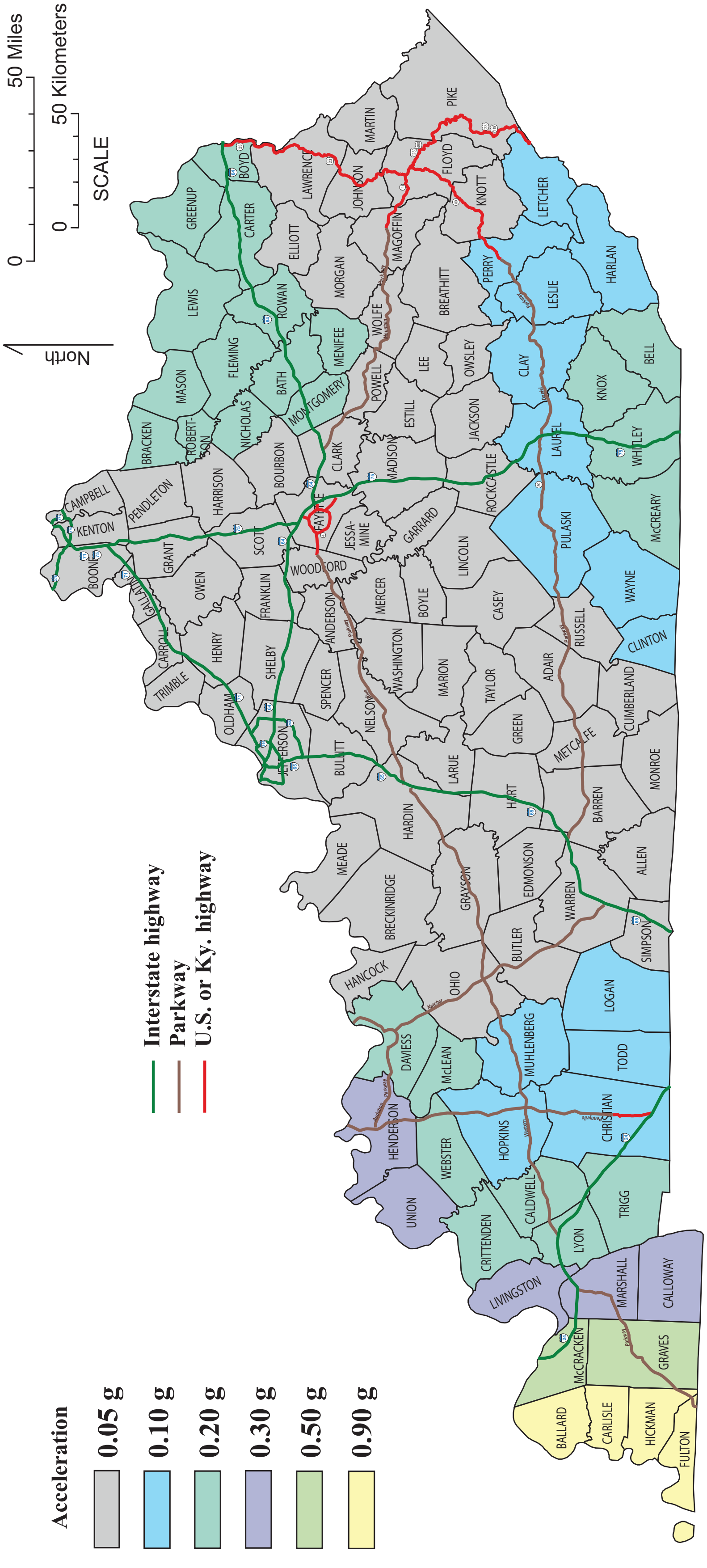

Figure 3. Response acceleration, measured in *g*, for short-period (0.2 second) with 5 percent critical damping on hard rock from the maximum credible earthquake in Kentucky.

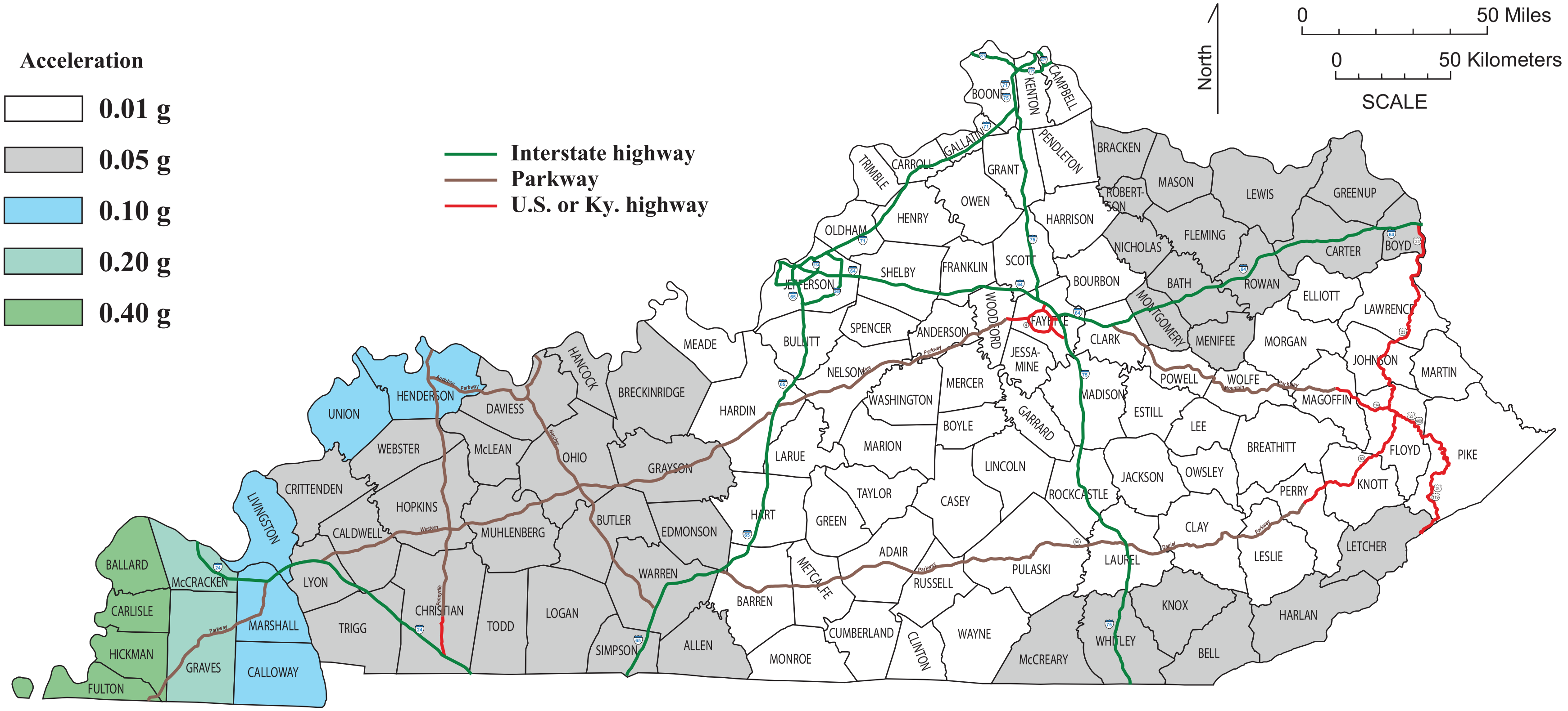

Figure 4. Response acceleration, measured in *g*, for long-period (1.0 second) with 5 percent critical damping on hard rock from the maximum credible earthquake in Kentucky.

of the MCE is another important factor for seismic safety consideration.

Seismic hazards are also affected by local geologic and geotechnical conditions. For example, ground motion can be amplified or even deamplified by near-surface soft soils. Liquefaction or landslides can also be triggered by strong ground motion. Therefore, in combination with local geologic and geotechnical information, these maps can be used to develop a variety of hazard mitigation strategies, such as land-use planning, emergency planning and preparedness, and lifeline planning.

The hazard maps should not serve as a substitute for site-specific seismic hazard assessment.

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