Research Report
KTC-07-02/SPR246-02-1F

KENTUCKY TRANSPORTATION CENTER

SEISMIC EVALUATION OF BRIDGES ON AND OVER THE PARKWAYS IN WESTERN KENTUCKY
SUMMARY REPORT

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Research Report
KTC-07-02/SPR246-02-1F

SEISMIC EVALUATION OF BRIDGES ON AND OVER THE PARKWAYS IN WESTERN KENTUCKY – SUMMARY REPORT

by

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16. Abstract

This report (KTC-07-02/SPR246-02-1F) provides an overall summary on the seismic investigative study performed on bridges on/over the five parkways in Western Kentucky. The comprehensive study was further divided into the followings tasks, each reported separately as follows:

(1) The first report of this study (KTC-07-03/SRP246-02-2F) involved data collection and field inspection of bridges on/over the parkways. The resulting inventory contains data of three hundred fifty-one (351) bridges on/over the parkways, detailing their construction type, soil profile, present condition, etc.

(2) In KTC-07-04/SPR246-02-3F, a preliminary seismic evaluation and ranking was performed on all bridges within the inventory. Details of the evaluation and ranking procedure are outlined. In this task seventeen (17) bridges, that are deemed susceptible to major earthquakes, were identified.

(3) Detailed seismic evaluations of the seventeen (17) bridges were subsequently carried out using time-history analysis for a projected 250-year seismic event. The results of the analysis are presented in KTC-07-05/SPR246-02-4F.

(4) KTC-07-06/SPR246-02-5F presents the preliminary evaluation and ranking of bridge embankments along the parkways.

(5) The last report, numbered KTC-07-07/SPR246-02-6F, provides the latest seismic hazard maps for the expected earthquake (EE), probable earthquake (PE), and maximum credible earthquake (MCE), which will be used in seismic analysis and design of highway infrastructures in Kentucky.

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SUMMARY REPORT

Introduction

Most of the bridges on and/or over the parkways in western Kentucky were designed and constructed prior to the implementation of stringent seismic design specification. Past earthquake events, such as the 1989 Loma Prieta Earthquake and the 1994 Northridge Earthquake in California, as well as other seismic events around the world, showed how debilitating an earthquake can be to a nation's infrastructures.

The state of Kentucky allows both commercial and recreational vehicles to use its parkways. These parkways are of high priority and should remain accessible all the time. Hence, it is essential that the parkways remain functional and operational following an earthquake event. For bridges on and/or over the parkways, they and their corresponding approaches and embankments have not been evaluated for a seismic event. Due to the potential social economic impact on the Commonwealth of Kentucky and its surrounding states, a seismic evaluation is essential to identify potential vulnerability for projected seismic events.

The objective of this study is to assess the seismic risk of bridges and their corresponding embankments along the parkways in western Kentucky. There are five parkways, and they are the Audubon Parkway, Edward Breathitt Parkway (formerly Pennyrile Parkway), Julian Carroll Parkway (formerly Purchase Parkway), Wendell Ford Western Kentucky Parkway, and William Natcher Parkway. The bridges and their corresponding embankments were evaluated for projected 50-years and/or 250-years seismic events, respectively. The 50-years and 250-years seismic events are defined as events with a 10% probability of being exceeded in 50-years and 250-years, respectively, or seismic events with a 90% probability of occurrence in the next 500-years and 2,500 years, respectively. The goal of this study is to identify critical bridges and embankments that are considered to be susceptible to projected seismic events, and to make recommendations, where applicable.

Research Significance

The proposed work required the evaluation and inspection of the condition of bridges on and/or over the parkways. The results from the investigation will provide state engineers and other officials with information delineating the current conditions of these bridges. In addition, the analytical investigations will identify bridges that are vulnerable to the projected seismic events, and thus will allow local and state officials, or bridge owners in general, to mitigate partial or total collapse of bridges, to prepare pre- and post-earthquake plans, or to exercise other course of actions.

Research Tasks

This report is the first (1st) in a series of six reports for this Project: "Seismic Evaluation of Bridges along Western Kentucky Parkways". The six-report series represents a comprehensive study to evaluate the seismic vulnerability of bridges, and the corresponding embankments, on and/over the Parkways. This report is numbered as KTC-07-02/SPR246-02-

1F, and is titled "Seismic Evaluation of Bridges on and over the Parkways in Western Kentucky – Summary Report". The report is intended to provide a summary of the results of the comprehensive study which was divided into the following tasks and reports.

NOTE: This report is the first (1st) in a series of six (6) reports for Project SRP 246: "Seismic Evaluation of Bridges along Western Kentucky Parkways". The six (6) reports are:	
Report Number:	**Report Title:**
(1) KTC-07-02/SPR246-02-1F*	Seismic Evaluation of Bridges on and over the Parkways in Western Kentucky – Summary Report
(2) KTC-07-03/SPR246-02-2F	Site Investigation of Bridges on and over the Parkways in Western Kentucky
(3) KTC-07-04/SPR246-02-3F	Preliminary Seismic Evaluation and Ranking of Bridges on and over the Parkways in Western Kentucky
(4) KTC-07-05/SPR246-02-4F	Detailed Seismic Evaluation of Bridges on and over the Parkways in Western Kentucky
(5) KTC-07-06/SPR246-02-5F	Seismic Evaluation and Ranking of Embankments for Bridges on and over the Parkways in Western Kentucky
(6) KTC-07-07/SPR246-02-6F	Seismic-Hazard Maps and Time Histories for the Commonwealth of Kentucky

* Denote current report

KTC-07-03/SRP246-02-2F

Site Investigation of Bridges on and over the Parkways in Western Kentucky

Jin-dong Hu, Tong Zhao, Issam Harik, and Jian Xie

The objective of the report is to accumulate information regarding the bridges along the parkways and to investigate their conditions. The information gathered serves as an underpinning for identifying, ranking, and prioritizing bridges in accordance with their seismic vulnerability.

In this process, a total of three hundred fifty-one (351) bridges are identified in the Kentucky Transportation Cabinet (KyTC) Bridge Inventory along the five parkways: Audubon Parkway, Edward Breathitt Parkway (formerly Pennyrile Parkway), Julian Carroll Parkway (formerly Purchase Parkway), Wendell Ford Western Kentucky Parkway, and William Natcher Parkway (Fig. 1).

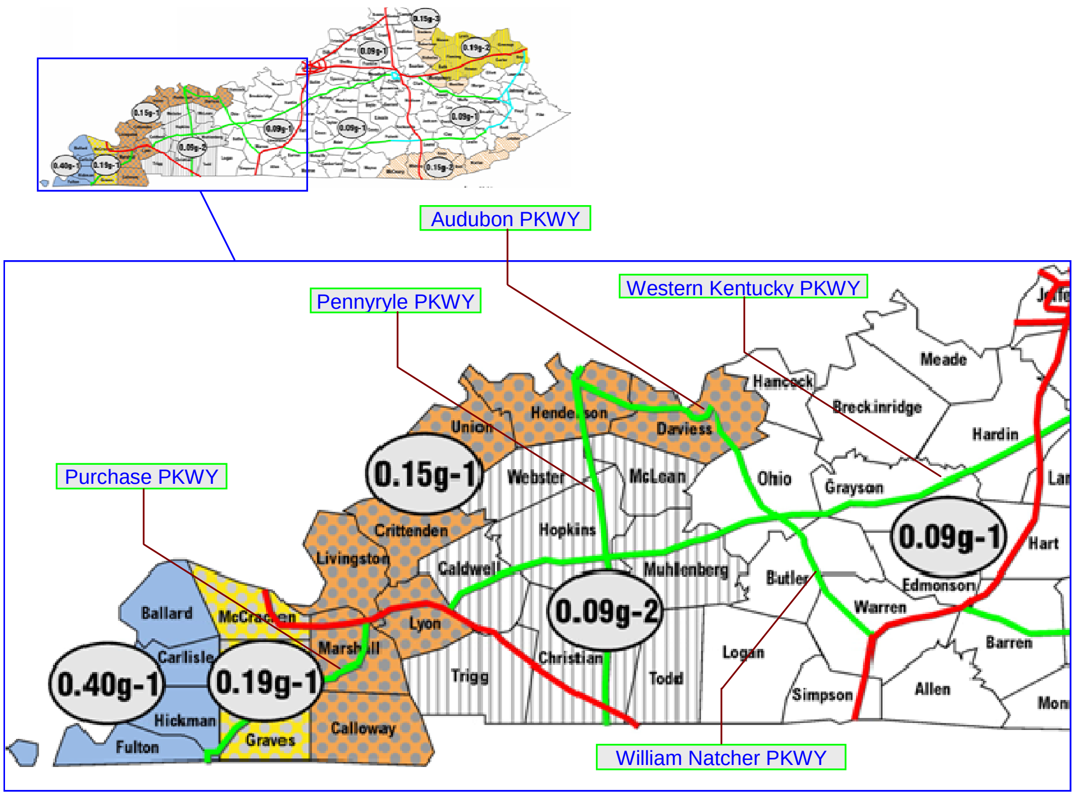


Fig. S.1 – Identification of the five parkways in Western Kentucky

General information related to the bridges was first collected from the existing bridge drawings, maintenance records and regional geological maps. Of interest, is pertinent information such as: bridge location with respect to the seismic zone, construction type, dimensions, soil type, etc. Site inspection followed after all the information of the bridges, except for culverts, was gathered. and a bridge inventory for the parkways was created. A typical site inspection form for the task is presented in Fig. 2. The inspection results together with all other information related to all bridges was stored in a bridge database called Seismic Inventory of Bridges (SIB), created in Microsoft Access.

Typical types of bridges on and/or over the parkways are of multi-span continuous composite steel girder, multi-span steel plate girder, simple span steel, multi-span reinforced concrete box girder, and reinforced concrete culverts (Note that culverts are excluded in the subsequent seismic evaluation). None of the bridges on and/or over the parkways has an overall span exceeding 500 ft or 150 m. The Green River Bridges are the only ones on the parkways that cross a waterway. The superstructure of the Green River Bridge on the Audubon parkway is of a steel plate-girder type. The main girders of the superstructure of each of the Green River Bridges on the Western Kentucky parkway have a total length of 1813 ft or 552.6 m. The bridge consists of nine main spans supported by concrete piers and abutments.

Fifty one percent of the bridges found on and/or over the parkways are skewed. The highest Number of bridges on and/or over the parkways is found in Hopkins County (53 bridges), followed by Graves County (48 bridges), Ohio County (31 bridges), Daviess County (27 bridges), Henderson County (25 bridges), Muhlenberg County (24 bridges), Christian County (21 bridges), Marshall County (21 bridges), Warren County (17 bridges), Grayson County (16 bridges), Hardin County (16 bridges), Butler County (12 bridges), Webster County (11 bridges), Caldwell County (9 bridges), Lyon County (9 bridges), Fulton County (8 bridges), and Hickman County (3 bridges). The distribution of all the bridges is presented in Tables 1 – 5 of Report Number KTC-07-03/SPR246-02-2F.

The information gathered provides an invaluable source of data for subsequent seismic evaluation which is required to identify, rank, and prioritize seismically vulnerable bridges and their embankments. Additionally, it assists state and local officials in pre-earthquake preparation plans, and forms the basis to develop post-earthquake emergency response, inspection, and evaluation plans. Furthermore, the site inspection records provide information delineating the current conditions of the bridges in order to facilitate future comparisons with post-earthquake conditions immediately after possible occurrence of an earthquake; through these comparisons significant changes can be detected and further insight studies can be carried out.

GENERAL	GPS Location	Longitude: W88˚53.400'	Latitude: N36˚31.074'
	Bridge Number	38-0051-B00012	
	Year Built: *1966*	County: Fulton	Crossing: Jackson Purchase PKW
	Have modifications been made since the bridge was constructed? *No.*		If *yes*. Please list them (Structure or load).
	Does the bridge cross a body of water?	*Yes No*	
	Has the bridge been seismically retrofitted?	*Yes No*	
	Is it a rigid box culvert?	*Yes No*	
SUPERSTRUCTURE	Is the superstructure integral with the abutments?	*Yes No*	**Comments:**
	Does the superstructure contain box girders?	*Yes No*	
	Is there lateral movement under traffic loading?	0 2 4 6 8	
	Is the bridge likely to collapse in an earthquake after toppling failure of the bearings?	0 2 4 6 8	
	Would gross movement of superstructure cause instability?	0 2 4 6 8	
	Is the bridge skewed?	No	
	Is there any unusual gap or offset at an expansion joint?	7.62cm	
BEARINGS	Type: *Rocker* *Elastomeric* *Sliding* *Muti-ratation*	Condition?	Fair
	If there are pedestals, are the bearings likely to overturn in an earthquake?	**<u>0</u>** 2 4 6 8	
	Does the bridge with less than 3 girders have exterior girder supported on the seat edge?	*Yes No*	
	Are the bearing seats under the abutment end-diaphragm continuous?	*Yes No*	
	Are there any girders supported on individual pedestals or columns?	*Yes No*	
	The longitudinal support length measured in a direction perpendicular to the support at abutments.		
SUBSTRUCTURE	Is the abutment a cantilever earth-retaining abutment?	*Yes No*	
	Are the reinforced concrete columns monolithic with the superstructure?	*Yes No*	
	Is there horizontal or vertical movement or tilting of the abutments, columns or piers?	**<u>0</u>** 2 4 6 8	
	Is there unusual or extensive erosion of soil at or near any of the substructure units?	**<u>0</u>** 2 4 6 8	
	Are abutment-slop failures possible in an earthquake?	**<u>0</u>** 2 4 6 8	
OTHER	Risk is small **Note:** The condition scale "0 2 4 6 8" in the "**SUPERSTRUCTURE**", "**BEARING**", and "**SUBSTRUCTURE**" categories identifies the magnitude of the risk for the function under consideration. A bold and underlined **<u>0</u>** identifies the lowest value or risk while a **<u>8</u>** is used for the highest value or risk. The case when none of the values are bold and underlined implies that an evaluation was not possible due to access or when a judgment could not be made.		

Fig. 2 – Typical site inspection form

Note: Bridge BIN 38-0051-B00012 is used for illustrative purposes.

KTC-07-04/SRP246-02-3F

Preliminary Seismic Evaluation of Bridges on and over the Parkways in Western Kentucky

Jian Xie, Issam Harik, Tong Zhao, and Jin-Dong Hu

The five parkways in Western Kentucky are located in a region that is greatly influenced by the New Madrid and the Wabash Valley Seismic Zones. In this study, a preliminary seismic evaluation of the bridges on and/over over the parkways was carried out. The objective is to establish a ranking for the bridges that were compiled in the previous study (KTC-07-03/SPR246-02-2F). The ranking would identify bridges that are susceptible to projected earthquake events; which in turn assists in prioritizing bridges for the subsequent detailed evaluation.

In this process, the 1995 Seismic Retrofitting Manual for Highway Bridges by the Federal Highway Administration (FHWA) served as a guide for the preliminary seismic evaluation. The methodology accounts for structural vulnerability, seismic and geotechnical hazards, and bridge importance, in ranking the bridges. Fig. S.3 shows a flow-chart delineating the ranking procedure. The ranking system was programmed into the Seismic Inventory of Bridges (SIB), created in Report KTC-07-04/SRP246-02-2F, to expedite the ranking procedure. The bridges in the SIB Bridge Inventory were evaluated based on projected 50-year and 250-year seismic events (Fig. S.4), and ranked in accordance with a scale of zero (i.e., least vulnerable to a seismic event) to 100 (i.e., most vulnerable to a seismic event). The 50-years and 250-years seismic events are defined as events with a 10% probability of being exceeded in 50-years and 250-years, respectively, or seismic events with a 90% probability of occurrence in the next 500-years and 2,500 years, respectively.

Preliminary analysis and ranking identified 17 bridges that were deemed critical. The 17 bridges have an average ranking of 58, with a highest bridge rank of 75. The 17 bridges were constructed in the 1960s, in which, seismic design was not taken into consideration. The selected bridges are of different construction types which include reinforced concrete, prestressed concrete and concrete steel composite bridges. The parkway, county, bridge identification number, seismic performance category, and ranking, of the 17 bridges are summarized in Table S.1.

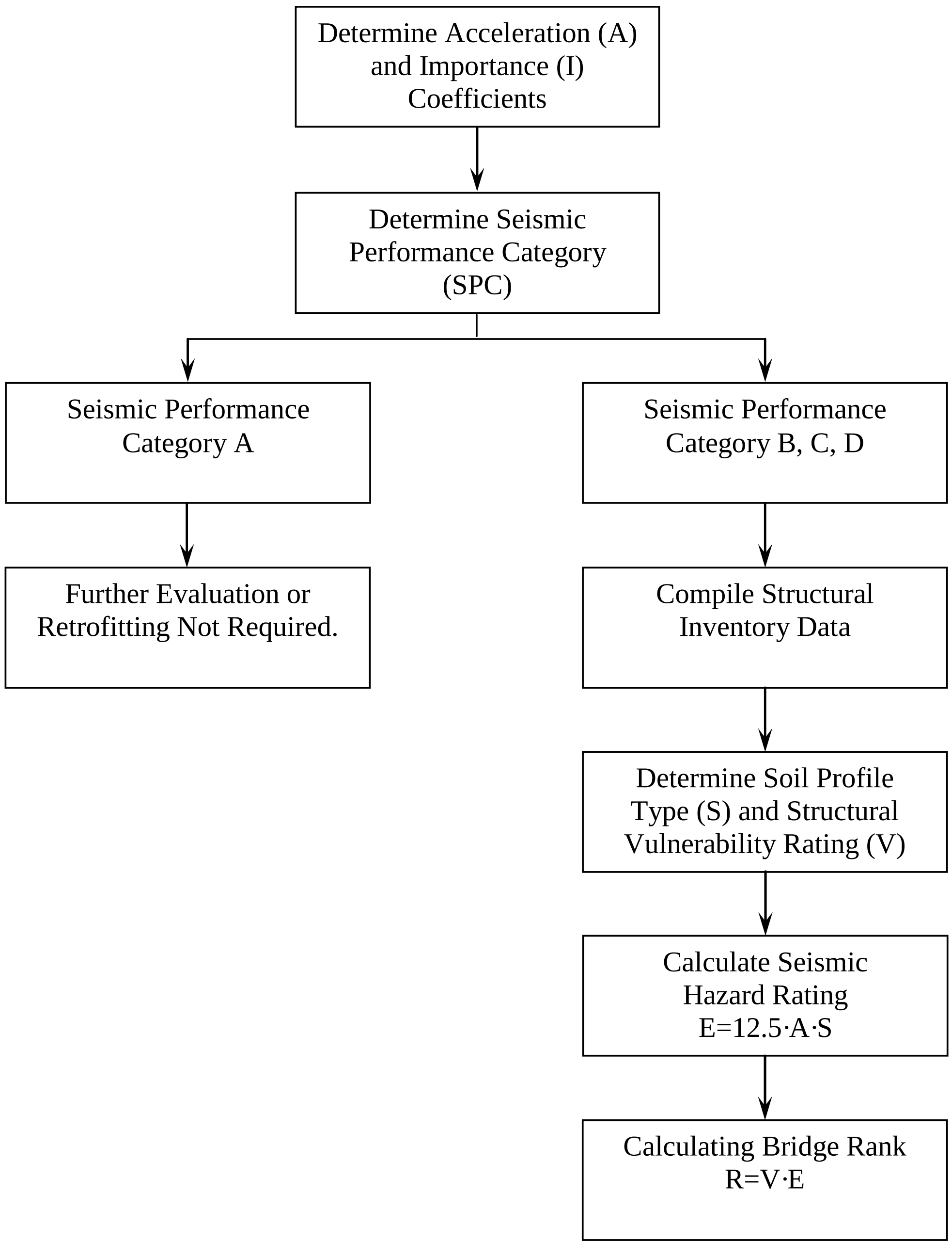
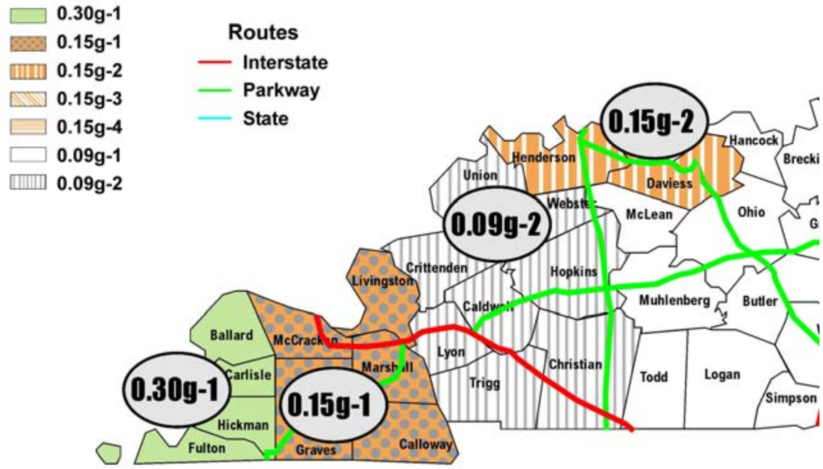
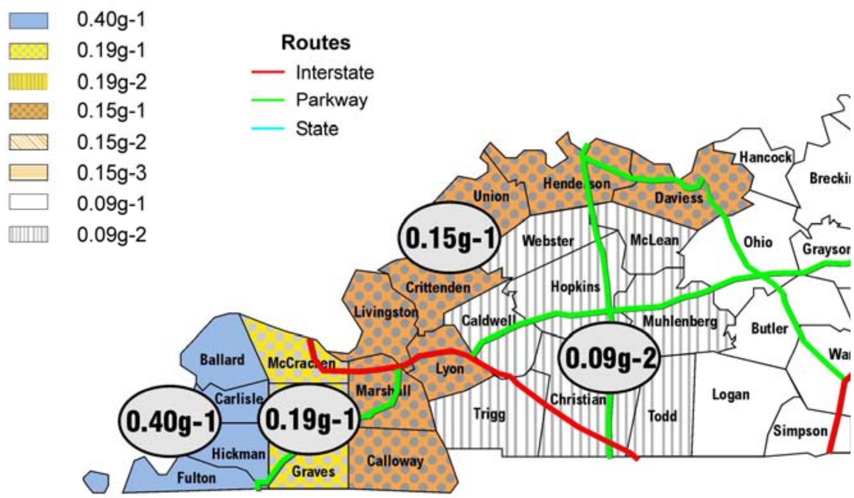


Fig. S.3 – Ranking system for preliminary seismic evaluation

(Ref: Seismic Retrofitting manual, Fig. 6)



(a) 50-year earthquake event



(b) 250-year earthquake event

Fig. S.4 – Seismic acceleration maps for Western Kentucky

Notes:

50-year earthquake event implies that there is a 90% probability for the projected earthquake not being exceeded in 50 years.

250-year earthquake event implies that there is a 90% probability for the projected earthquake not being exceeded in 250 years.

Table S.1: Bridges that are deemed critical based on the preliminary analysis and ranking

No.	Parkway	County	BIN Number	SPC	Drawing Number	R
1	Purchase	Fulton	38-0051-B00012	D	16696	75.0
2			38-0307-B00015	D	16649	75.0
3			38-9003-B00053	D	16694	75.0
4			38-9003-B00053P	D		75.0
5			38-9003-B00054	D	16695	75.0
6			38-9003-B00054P	D		75.0
7			38-9003-B00055	D	16561	75.0
8			38-9003-B00055P	D		75.0
9	Purchase	Hickman	53-0094-B00050	D	16566	75.0
10			53-1529-B00056	D	16567	75.0
11			53-9003-B00068	D	16565	75.0
12	Audubon	Daviess	30-9005-B00060	C	17494	38.0
13			30-9005-B00061	C	17464	38.0
14	Purchase	Graves	42-9003-B00157	C	16527	35.1
15			42-9003-B00157P	C		35.1
16	Pennyrile	Webster	117-9004-B00071[a]	B	16858	8.4
17			117-9004-B00071P	B		8.4

Note: [a] 48.6-53.3-53.3-53.3-53.3-53.3-48.53 (Seven Spans, RC)

KTC-07-05/SRP246-02-4F

Detailed Seismic Evaluation of Bridges on and over the Parkways in Western Kentucky

Jian Xie, Issam Harik, and Tong Zhao

This study presents the results of the detailed seismic evaluation of the 17 bridges that are deemed vulnerable to a seismic event in Report KTC-07-05/SRP246-02-3F. Of interest are the performances of the following bridge components, for the projected 250-year seismic event: expansion joints, bearings, columns, and footings. Detailed analysis was not carried out for the projected 50 year seismic event since they were deemed 'not critical' under that projection. It should be noted that seismic performances of the abutments and liquefaction potential of these bridges are reported in the report numbered KTC-07-06/SPR246-02-5F.

In this study, a capacity/demand (C/D) ratio method was employed in the assessment. The method evaluates the individual bridge components (i.e. expansion joints, bearings, columns, and footings) and investigates their ability to resist a projected seismic demand. Complete details of the method are presented in this report. The seismic demand (D) of the individual bridge components were determined via the generation of three-dimensional finite element models for the selected bridges and the use of time-history spectra response for a projected 250-year seismic event. In general, the capacities and/or demands can be forces, displacements, or other quantities defining the components' performance. The method provided a straight-forward approach in assessing the components in which a calculated C/D ratio of less than 1.0 indicates that component failure may occur during the design earthquake, and consequent retrofitting of such components may be required.

Table S.2 provides a summary of C/D ratios of the selected bridges for the detailed evaluation. As of consequence, a summary of component deficiencies of these bridges is also provided in Table S.3. More information regarding the method and results can be found in KTC-07-05/SPR246-02-4F.

ges on and over Parkways in Western Kentucky

Bridge Identification Number (BIN)	Capacity/Demand (C/D) ratios of different bridge components											
	Joints and/or Bearings		Columns and/or Footing									Bridge Ranks
	r_{bd}	r_{bf}	r_{ec}	r_{ef}	r_{ca} (Cap)	r_{ca} (Footing)	r_{cs} (Cap)	r_{cs} (Footing)	r_{cc}	r_{cv}	r_{fr}	
38-0051-B00012	1.28	3.97	0.29	0.62	1.00	0.62	-	0.37	0.99	0.29	2.48	75.0
38-0307-B00015	1.28	5.50	0.36	0.78	1.00	0.78	-	0.40	1.17	1.51	3.13	75.0
38-9003-B00053 38-9003-B00053P	1.26	1.56	0.47	0.23	1.00	1.00	-	0.62	1.50	2.37	0.91	75.0
38-9003-B00054 38-9003-B00054P	1.30	0.90	0.23	0.15	1.00	1.00	-	0.30	0.74	1.15	0.58	75.0
38-9003-B00055 38-9003-B00055P	1.19	1.19	0.38	0.33	1.00	1.00	-	0.56	1.21	1.75	0.67	75.0
53-0094-B00050	1.33	5.51	0.35	0.55	1.00	0.55	-	0.39	1.14	1.34	1.09	75.0
53-1529-B00056	1.30	4.42	0.27	0.39	1.00	0.39	-	0.30	0.88	0.76	1.16	75.0
53-9003-B00068	1.07	0.85	0.28	0.39	1.00	0.39	-	0.31	0.91	0.28	0.79	75.0
30-9005-B00060	1.27	1.38	2.20	2.72	1.00	1.00	-	1.65	6.95	3.99	2.72	38.0
30-9005-B00061	1.39	1.20	2.07	2.33	1.00	1.00	-	1.55	6.87	2.48	2.33	38.0
42-9003-B00157 42-9003-B00157P	1.20	1.32	-	-	-	-	-	-	-	-	-	35.1
117-9004-B00071 117-9004-B00071P	0.99	2.15	0.76	1.14	1.00	1.00	-	0.67	2.42	3.78	1.14	8.4

Note: C/D ratio value less than 1.0 is highlighted in the table
Cells indicated with (-) represent C/D ratios are not applicable in these cases
r_{bd} = Joint/bearing displacement C/D ratio
r_{bf} = Joint/bearing force C/D ratio
r_{ec} = Column force C/D ratio
r_{ef} = Footing force C/D ratio
r_{ca} = Anchorage C/D ratio of cap or footing
r_{cs} = Splice C/D ratio of cap or footing
r_{cc} = Transverse conferment C/D ratio
rc_v = Column shear C/D ratio
r_{fr} = Footing rotation/yeiding C/D ratio

Table S.3: Summary of Seismic Deficiencies of Selected Bridges

Bridge Identification Number (BIN)	Ranking	Seismic Deficiencies
38-0051-B00012	75.0	- Footing flexural capacity - Column shear capacity - Column flexural capacity
38-0307-B00015	75.0	- Footing flexural capacity - Column shear capacity - Column flexural capacity
38-9003-B00053 38-9003-B00053P	75.0	- Footing flexural capacity - Column shear capacity - Column flexural capacity
38-9003-B00054 38-9003-B00054P	75.0	- Bearing seat capacity - Footing flexural capacity - Column shear capacity - Column flexural capacity
38-9003-B00055 38-9003-B00055P	75.0	- Footing flexural capacity - Column shear capacity - Column flexural capacity
53-0094-B00050	75.0	- Footing flexural capacity - Column shear capacity - Column flexural capacity
53-1529-B00056	75.0	- Footing flexural capacity - Column shear capacity - Column flexural capacity
53-9003-B00068	75.0	- Bearing seat capacity - Footing flexural capacity - Column shear capacity - Column flexural capacity
30-9005-B00060	38.0	-
30-9005-B00061	38.0	-
42-9003-B00157 42-9003-B00157P	35.1	-
117-9004-B00071 117-9004-B00071P	8.4	- Bearing seat capacity - Footing flexural capacity - Column flexural capacity

KTC-07-06/SRP246-02-5F

Seismic Evaluation and Ranking of Embankments for Bridges on and over the Parkways in Western Kentucky

Han-Shan Ding, Issam Harik, and Ching Chiaw Choo

The objective of this study is to provide a preliminary assessment on the vulnerability of abutments for bridges on and/or over the parkways under the projected seismic events. Abutments of the bridges along the parkways were investigated for their stability, and the foundations of the bridges were checked against liquefaction potential.

Analytical procedures were developed to examine several stability potentials, and the results were expressed in the form of capacity/demand (C/D) ratios; similar to the ones used in the evaluation of bridge components. In general, an abutment with a capacity/demand (C/D) ratio that is greater than unity is deemed to have no risk of instability. In case of a capacity/demand ratio that is less than unity, an abutment's displacement during an earthquake event was estimated. The method for estimating abutment displacements for C/D ratio less than unity is presented in the report. Fig. S.5 shows a flow chart delineating the abutment or slope stability procedure.

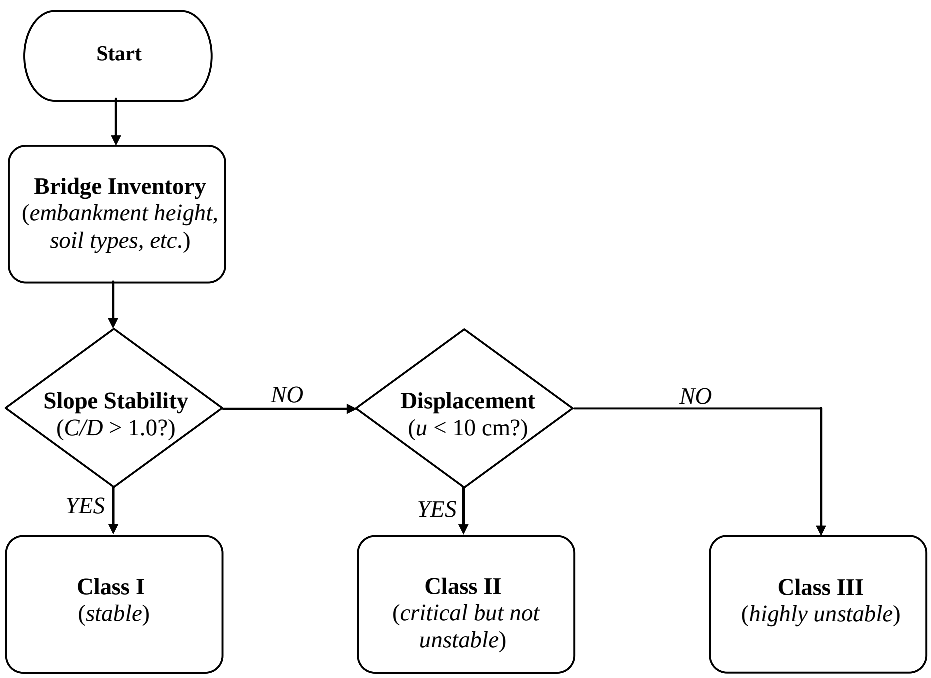


Fig. S.5 – Abutment/slope stability assessment

A loss of shear strength, as soil softens or liquefies under the agitation of ground movement, during an earthquake was also investigated in this study. Several methodologies have been developed over the years by different researchers to investigate the liquefaction potential of foundation soil during an earthquake event. In this study, methods developed by

Seed and Idriss (1971) and other researchers (Youd and Perkins 1978; Seed 1979; Seed and Idriss 1982; Seed et. al. 1985; Youd et. al. 2001) were used to calculate the factor of safety (*FS*) of a given foundation soil. Following the calculation of the factor of safety, a computation of Liquefaction Potential Index (LPI) derived by Iwasaki et. al. (1982. a and b) was performed. The LPI provides indication of the degree of liquefaction. Detail accounts of the methods used to estimate the factor of safety and liquefaction potential index are presented in the report. Fig. S.6 shows a flow chart delineating the estimation of liquefaction potential of a given foundation.

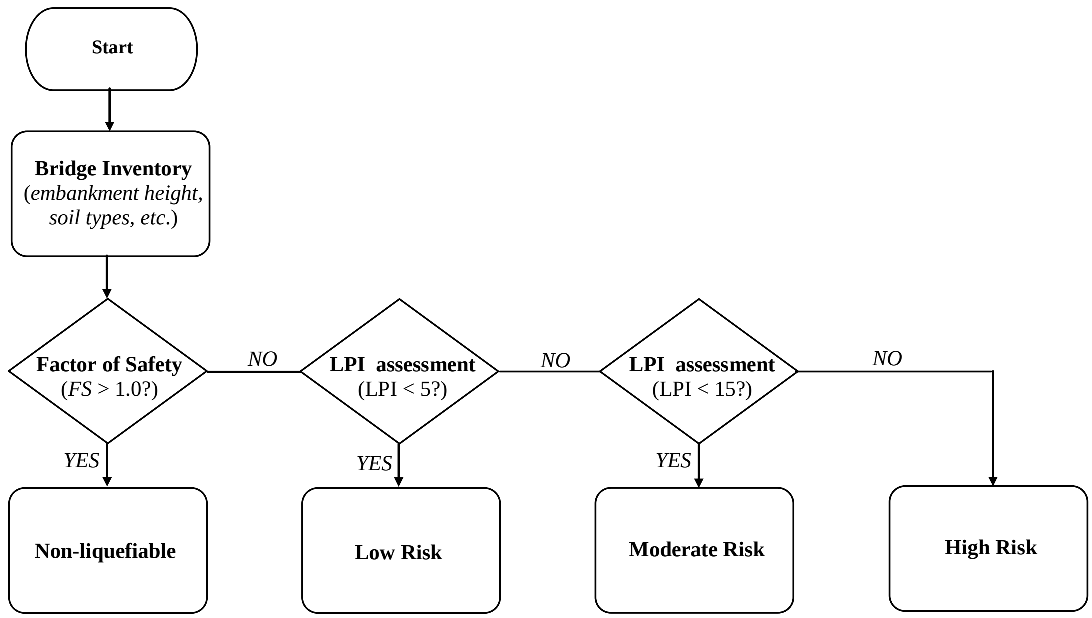


Fig. S.6 – Liquefaction potential assessment process

In order to provide a qualitative assessment, the stability and liquefaction evaluations were used to form the basis of embankment ranking as shown in Table S.4. In this task, the bridges contained in the bridge inventory established prior to this task were evaluated in accordance with the methods described in the report. To assist government officials (i.e. city, county, state, etc.) in identifying bridge embankments that are seismically vulnerable, the embankments in each of the counties were ranked starting from the one with the highest seismic risk. For instance, all bridge embankments classified as having category A in a county will be ordered numerically such as A1, A2, and so forth, with bridge A1 being the most susceptible to seismic hazard, A2 being the second most susceptible in that county, and so forth. The most 'critical' embankments are listed in Tables S5 and S6.

Table S.4: Embankment ranking category

Category	Descriptions
C	Slope stability class **I** (stable), **low** liquefaction potential or **non-liquefiable**, and/or combination
B	Slope stability class **II** (critical), **moderate** liquefaction potential, and/or combination
A	Slope stability class **III** (unstable), **high** liquefaction potential, and/or combination

Table S.5: Ranking of *Critical* Bridge Embankments along Western Kentucky Parkways for a 50-Year Event Earthquake.

County	BIN[1,2]	PGA[3]	Slope Stability C/D ratio[4]	Liquefaction Potential[5]	Embankment Ranking[6]
Butler	16- 9007-B00061	0.09g	0.14	Low	A1
Caldwell	17-9001-B00033 & 17-9001-B00033 P	0.09g	0.62	Low	A1
Christian	24-9004-B00099	0.09g	0.77	Low	A1
Daviess	30 9005 B00059 & 30 9005 B00059 P	0.15g	0.18	High	A1
	30-9005-B00058 & 30-9005-B00058 P	0.15g	0.12	Moderate	A2
	30-9007-B00082 & 30-9007-B00082 P	0.15g	0.41	Moderate	A3
	30-9005-B00060	0.15g	0.24	Low	A4
	30-9007-B00081 & 30-9007-B00081 P	0.15g	0.29	Low	A5
	30-9007-B00089 & 30-9007-B00089 P	0.15g	0.30	Low	A6
	30-9005-B00063	0.15g	0.31	Low	A7
	30-9007-B00085 & 30-9007-B00085 P	0.15g	0.32	Low	A8
	30-9005-B00061	0.15g	0.34	Low	A9
	30-9007-B00083	0.15g	0.49	Low	A10
Fulton	38-9003-B00055 & 38-9003-B00055 P	0.30g	0.17	High	A1
	38-0307-B00015	0.30g	0.18	High	A2
	38-9003-B00053 & 38-9003-B00053 P	0.30g	0.21	High	A3
	38-0051-B00012 & 38-0051-B00012 P	0.30g	0.24	Moderate	A4
	38-9003-B00054 & 38-9003-B00054 P	0.30g	0.29	Moderate	A5
Graves	42-9003-B00170 & 42-9003-B00170 P	0.15g	0.39	Moderate	A1
	42-0058-B00096	0.15g	0.10	Low	A2
	42-9003-B00154 & 42-9003-B00154 P	0.15g	0.10	Low	A3
	42-9003-B00175	0.15g	0.16	Low	A4

1 As defined in the Kentucky Transportation Cabinet (KyTC) Bridge Inventory
2 The letter 'P' stands for parallel bridges
3 PGA is the peak ground acceleration defined in Street et. al. (1996)
4 Slope stability C/D ratio computation is presented in Chapter 2
5 Liquefaction potential determination is presented in Chapter 3
6 Only bridges with rank classification of A (Critical) are listed herein. A bridge with a ranking of A1 is more susceptible to damage than a bridge with a ranking of A2 in that particular county

Table S.5 (Cont'): Ranking of *Critical* Bridge Embankments along Western Kentucky Parkways for a 50-Year Event Earthquake

County	BIN[1,2]	PGA[3]	Slope Stability C/D ratio[4]	Liquefaction Potential[5]	Embankment Ranking[6]
Graves	42 9003 B00162 & 42 9003 B00162 P	0.15	0.19	Low	A5
	42 9003 B00177 & 42 9003 B00177 P	0.15	0.2	Low	A6
	42 9003 B00176 & 42 9003 B00176 P	0.15	0.22	Low	A7
	42 9003 B00155 & 42 9003 B00155 P	0.15	0.24	Low	A8
	42 9003 B00169	0.15	0.26	Low	A9
	42 9003 B00172	0.15	0.26	Low	A10
	42 9003 B00160	0.15	0.3	Low	A11
	42 9003 B00156 & 42 9003 B00156 P	0.15	0.31	Low	A12
	42 9003 B00165 & 42 9003 B00165 P	0.15	0.35	Low	A13
	42 0944 B00180	0.15	0.4	Low	A14
	42 1748 B00128	0.15	0.42	Low	A15
	42 9003 B00167 & 42 9003 B00167 P	0.15	0.43	Low	A16
	42 0121 B00111	0.15	0.52	Low	A17
	42 0301 B00028	0.15	0.52	Low	A18
	42 9003 B00161	0.15	0.55	Low	A19
Grayson	No bridges listed as 'critical'				
Hardin	47 31W B00108	0.09	0.72	Low	A1
Henderson	51 9005 B00072	0.15	0.14	Low	A1
	51 9004 B00069	0.15	0.39	Low	A2
	51 9004 B00062 & 51 9004 B00062 P	0.15	0.51	Low	A3
	51 9004 B00111	0.15	0.6	Low	A4
	51 9004 B00065	0.15	0.61	Low	A5

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5 Liquefaction potential determination is presented in Chapter 3
6 Only bridges with rank classification of A (Critical) are listed herein. A bridge with a ranking of A1 is more susceptible to damage than a bridge with a ranking of A2 in that particular county

Table S.5 (Cont'): Ranking of *Critical* Bridge Embankments along Western Kentucky Parkways for a 50-Year Event Earthquake

County	BIN[1,2]	PGA[3]	Slope Stability C/D ratio[4]	Liquefaction Potential[5]	Embankment Ranking[6]
Hickman	53 0094 B00050	0.3	0.24	High	A1
	53 9003 B00068	0.3	0.3	Low	A2
Hopkins	54 9004 B00015	0.09	0.35	Low	A1
	54 9001 B00137 & 54 9001 B00137 P	0.09	0.45	Low	A2
	54 9001 B00143 & 54 9001 B00143 P	0.09	0.47	Low	A3
	54 9001 B00144 & 54 9001 B00144 P	0.09	0.47	Low	A4
	54 9001 B00136 & 54 9001 B00136 P	0.09	0.54	Low	A5
	54 9004 B00095 & 54 9004 B00095 P	0.09	0.56	Low	A6
	54 9001 B00145 & 54 9001 B00145 P	0.09	0.57	Low	A7
	54 9004 B00014 & 54 9004 B00014 P	0.09	0.7	Low	A8
	54 9001 B00140 & 54 9001 B00140 P	0.09	0.77	Low	A9
	54 9001 B00146 & 54 9001 B00146 P	0.09	0.81	Low	A10
Lyon	No bridges listed as 'critical'				
Marshall	79 0795 B00012	0.15	0.17	Low	A1
	79 9003 B00064 & 79 9003 B00064 P	0.15	0.23	Low	A2
	79 9003 B00074 & 79 9003 B00074 P	0.15	0.3	Low	A3
	79 0408 B00103	0.15	0.31	Low	A4
	79 1422 B00050	0.15	0.33	Low	A5
	79 9003 B00066	0.15	0.37	Low	A6
	79 9003 B00076 & 79 9003 B00076 P	0.15	0.44	Low	A7
	79 0348 B00102	0.15	0.51	Low	A8
	79 9003 B00068	0.15	0.66	Low	A9

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5 Liquefaction potential determination is presented in Chapter 3
6 Only bridges with rank classification of A (Critical) are listed herein. A bridge with a ranking of A1 is more susceptible to damage than a bridge with a ranking of A2 in that particular county

Table S.5 (Cont'): Ranking of *Critical* Bridge Embankments along Western Kentucky Parkways for a 50-Year Event Earthquake

County	BIN[1,2]	PGA[3]	Slope Stability C/D ratio[4]	Liquefaction Potential[5]	Embankment Ranking[6]
Muhlenberg	89 9001 B00096 & 89 9001 B00096 P	0.09	0.34	Low	A1
	89 9001 B00094 & 89 9001 B00094 P	0.09	0.37	Low	A2
	89 9001 B00093 & 89 9001 B00093 P	0.09	0.41	Low	A3
	89 9001 B00109 & 89 9001 B00109 P	0.09	0.42	Low	A4
Ohio	92 9007 B00063 & 92 9007 B00063 P	0.09	0.28	Low	A1
	92 9007 B00075 & 92 9007 B00075 P	0.09	0.32	Low	A2
	92 9001 B00134 & 92 9001 B00134 P	0.09	0.42	Low	A3
	92 9001 B00133 & 92 9001 B00133 P	0.09	0.62	Low	A4
Warren	No bridges listed as 'critical'				
Webster	117 9004 B00074 & 117 9004 B00074 P	0.09	0.79	Low	A1

1 As defined in the Kentucky Transportation Cabinet (KyTC) Bridge Inventory
2 The letter 'P' stands for parallel bridges
3 PGA is the peak ground acceleration defined in Street et. al. (1996)
4 Slope stability C/D ratio computation is presented in Chapter 2
5 Liquefaction potential determination is presented in Chapter 3
6 Only bridges with rank classification of A (Critical) are listed herein. A bridge with a ranking of A1 is more susceptible to damage than a bridge with a ranking of A2 in that particular county

Table S.6: Ranking of *Critical* Bridge Embankments along Western Kentucky Parkways for a 250-Year Event Earthquake

County	BIN[1,2]	PGA[3]	Slope Stability C/D ratio[4]	Liquefaction Potential[5]	Embankment Ranking[6]
Butler	16 9007 B00061	0.09	0.14	Low	A1
Caldwell	17 9001 B00033 & 17 9001 B00033 P	0.09	0.62	Low	A1
Christian	24 9004 B00099	0.09	0.77	Low	A1
Daviess	30 9005 B00058 & 30 9005 B00058 P	0.15	0.12	High	A1
	30 9005 B00059 & 30 9005 B00059 P	0.15	0.18	High	A2
	30 9005 B00060	0.15	0.24	Moderate	A3
	30 9007 B00081 & 30 9007 B00081 P	0.15	0.29	Moderate	A4
	30 9007 B00082 & 30 9007 B00082 P	0.15	0.41	Moderate	A5
	30 9007 B00089 & 30 9007 B00089 P	0.15	0.3	Low	A6
	30 9005 B00063	0.15	0.31	Low	A7
	30 9007 B00085 & 30 9007 B00085 P	0.15	0.32	Low	A8
	30 9005 B00061	0.15	0.34	Low	A9
	30 9007 B00083	0.15	0.49	Low	A10
	30 9007 B00094 & 30 9007 B00094 P	0.15	0.58	Low	A11
	30 9007 B00088 & 30 9007 B00088 P	0.15	0.69	Low	A12
	30 9007 B00092	0.15	0.87	Low	A13
Fulton	38 9003 B00055 & 38 9003 B00055 P	0.4	0.17	High	A1
	38 0307 B00015	0.4	0.18	High	A2
	38 9003 B00053 & 38 9003 B00053 P	0.4	0.21	High	A3
	38 0051 B00012	0.4	0.24	High	A4
	38 9003 B00054 & 38 9003 B00054 P	0.4	0.29	High	A5
Graves	42 9003 B00177 & 42 9003 B00177 P	0.19	0.2	High	A1

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2 The letter 'P' stands for parallel bridges
3 PGA is the peak ground acceleration defined in Street et. al. (1996)
4 Slope stability C/D ratio computation is presented in Chapter 2
5 Liquefaction potential determination is presented in Chapter 3
6 Only bridges with rank classification of A (Critical) are listed herein. A bridge with a ranking of A1 is more susceptible to damage than a bridge with a ranking of A2 in that particular county

Table S.6 (Cont'): Ranking of *Critical* Bridge Embankments along Western Kentucky Parkways for a 250-Year Event Earthquake

County	BIN[1,2]	PGA[3]	Slope Stability C/D ratio[4]	Liquefaction Potential[5]	Embankment Ranking[6]
Graves	42 9003 B00176 & 42 9003 B00176 P	0.19	0.22	High	A2
	42 9003 B00170 & 42 9003 B00170 P	0.19	0.39	Moderate	A3
	42 1748 B00128	0.19	0.42	Moderate	A4
	42 0058 B00096	0.19	0.1	Low	A5
	42 9003 B00154 & 42 9003 B00154 P	0.19	0.1	Low	A6
	42 9003 B00175	0.19	0.16	Low	A7
	42 9003 B00162 & 42 9003 B00162 P	0.19	0.19	Low	A8
	42 9003 B00155 & 42 9003 B00155 P	0.19	0.24	Low	A9
	42 9003 B00169	0.19	0.26	Low	A10
	42 9003 B00172	0.19	0.26	Low	A11
	42 9003 B00160	0.19	0.3	Low	A12
	42 9003 B00156 & 42 9003 B00156 P	0.19	0.31	Low	A13
	42 9003 B00165 & 42 9003 B00165 P	0.19	0.35	Low	A14
	42 0944 B00180	0.19	0.4	Low	A15
	42 9003 B00167 & 42 9003 B00167 P	0.19	0.43	Low	A16
	42 0121 B00111	0.19	0.52	Low	A17
	42 0301 B00028	0.19	0.52	Low	A18
	42 9003 B00161	0.19	0.55	Low	A19
	42 9003 B00166 & 42 9003 B00166 P	0.19	0.58	Low	A20
	42 0339 B00143	0.19	0.72	Low	A21
	42 9003 B00159 & 42 9003 B00159 P	0.19	0.82	Low	A22
	42 9003 B00157 & 42 9003 B00157 P	0.19	0.84	Low	A23

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Table S.6 (Cont'): Ranking of *Critical* Bridge Embankments along Western Kentucky Parkways for a 250-Year Event Earthquake

County	BIN[1,2]	PGA[3]	Slope Stability C/D ratio[4]	Liquefaction Potential[5]	Embankment Ranking[6]
Grayson	No bridges listed as 'critical'				
Hardin	47 31W B00108	0.09	0.72	Low	A1
Henderson	51 0425 B00137 & 51 0425 B00137 P	0.15	18	Low	A1
	51 9005 B00072	0.15	54.1	Low	A2
	51 9004 B00069	0.15	28.6	Low	A3
	51 9004 B00062 & 51 9004 B00062 P	0.15	26	Low	A4
	51 9004 B00111	0.15	27.3	Low	A5
	51 9004 B00065	0.15	18	Low	A6
	51 9004 B00064	0.15	15	Low	A7
	51 9004 B00073 & 51 9004 B00073 P	0.15	27	Low	A8
	51 9005 B00074	0.15	26.1	Low	A9
	51 9005 B00075	0.15	20.89	Low	A10
Hickman	53 0094 B00050	0.4	0.24	High	A1
	53 9003 B00068	0.4	0.3	Moderate	A2
	53 1529 B00056	0.4	0.52	Moderate	A3
Hopkins	54 9004 B00015	0.09	0.35	Low	A1
	54 9001 B00137 & 54 9001 B00137 P	0.09	0.45	Low	A2
	54 9001 B00143 & 54 9001 B00143 P	0.09	0.47	Low	A3
	54 9001 B00144 & 54 9001 B00144 P	0.09	0.47	Low	A4
	54 9001 B00136 & 54 9001 B00136 P	0.09	0.54	Low	A5
	54 9004 B00095 & 54 9004 B00095 P	0.09	0.56	Low	A6
	54 9001 B00145 & 54 9001 B00145 P	0.09	0.57	Low	A7

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6 Only bridges with rank classification of A (Critical) are listed herein. A bridge with a ranking of A1 is more susceptible to damage than a bridge with a ranking of A2 in that particular county

Table S.6 (Cont'): Ranking of *Critical* Bridge Embankments along Western Kentucky Parkways for a 250-Year Event Earthquake

County	BIN[1,2]	PGA[3]	Slope Stability C/D ratio[4]	Liquefaction Potential[5]	Embankment Ranking[6]
Hopkins	54 9004 B00014 & 54 9004 B00014 P	0.09	0.7	Low	A8
	54 9001 B00140 & 54 9001 B00140 P	0.09	0.77	Low	A9
	54 9001 B00146 & 54 9001 B00146 P	0.09	0.81	Low	A10
Lyon	No bridges listed as 'critical'				
Marshall	79 9003 B00076 & 79 9003 B00076 P	0.15	0.44	Moderate	A1
	79 0795 B00012	0.15	0.17	Low	A2
	79 9003 B00064 & 79 9003 B00064 P	0.15	0.23	Low	A3
	79 9003 B00074 & 79 9003 B00074 P	0.15	0.3	Low	A4
	79 0408 B00103	0.15	0.31	Low	A5
	79 1422 B00050	0.15	0.33	Low	A6
	79 9003 B00066	0.15	0.37	Low	A7
	79 0348 B00102	0.15	0.51	Low	A8
	79 9003 B00068	0.15	0.66	Low	A9
	79 9003 B00073	0.15	0.69	Low	A10
	79 641 B00126	0.15	0.77	Low	A11
Muhlenberg	89 9001 B00096 & 89 9001 B00096 P	0.09	0.34	Low	A1
	89 9001 B00094 & 89 9001 B00094 P	0.09	0.37	Low	A2
	89 9001 B00093 & 89 9001 B00093 P	0.09	0.41	Low	A3
	89 9001 B00109 & 89 9001 B00109 P	0.09	0.42	Low	A4
Ohio	92 9007 B00063 & 92 9007 B00063 P	0.09	0.28	Low	A1
	92 9007 B00075 & 92 9007 B00075 P	0.09	0.32	Low	A2
	92 9001 B00134 & 92 9001 B00134 P	0.09	0.42	Low	A3

1 As defined in the Kentucky Transportation Cabinet (KyTC) Bridge Inventory
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Table S.6 (Cont'): Ranking of *Critical* Bridge Embankments along Western Kentucky Parkways for a 250-Year Event Earthquake

County	BIN[1,2]	PGA[3]	Slope Stability C/D ratio[4]	Liquefaction Potential[5]	Embankment Ranking[6]
Ohio	92 9001 B00133 & 92 9001 B00133 P	0.09	0.62	Low	A4
Warren	114 0884 B00050	0.09	0.83	Low	A1
Webster	117 9004 B00074 & 117 9004 B00074 P	0.09	0.79	Low	A1

1 As defined in the Kentucky Transportation Cabinet (KyTC) Bridge Inventory
2 The letter 'P' stands for parallel bridges
3 PGA is the peak ground acceleration defined in Street et. al. (1996)
4 Slope stability C/D ratio computation is presented in Chapter 2
5 Liquefaction potential determination is presented in Chapter 3
6 Only bridges with rank classification of A (Critical) are listed herein. A bridge with a ranking of A1 is more susceptible to damage than a bridge with a ranking of A2 in that particular county

Based on this preliminary investigation, 30% of bridge embankments are rated as 'critical', which present embankments that have unstable slopes and high risk of liquefaction for projected 50-year event earthquakes. 36% of the bridges are rated as 'critical' for projected 250-year event earthquakes. For these bridge embankment, it is recommended that a more detailed and sophisticated analysis be carried out.

KTC-07-07/SRP246-02-6F

Seismic Hazard Maps and Time Histories for the Commonwealth of Kentucky

Zhenming Wang, Issam Harik ,Edward Woolery, Baoping Shi, and Abheetha Peiris

The design of infrastructures (i.e. building or bridges alike) to 'safely' resist earthquake relies heavily on one's ability to predict the loadings closely. In the States, the engineering community has been using the seismic designs and standards that are based on the experience learned in the coastal California. In bridge, and in building, design, the deterministic ground motion is commonly specified based on the Maximum Credible Earthquakes (*MCE*) – a practice that started in the state of California. In this study, seismic hazard maps for maximum credible earthquake (*MCE*) specifically for the state of Kentucky have been developed for use in the design and analysis of highway bridges.

MCE is defined as the maximum event considered likely in a reasonable amount of time. The phrase "reasonable amount of time" is defined by the historical or geological records. 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 4,000 years. Thus, the probability that MCE ground motion could be exceeded over the bridge life of 75 years varies from zone to zone, about 7% to 14% in the New Madrid Seismic Zone, 2% to 4% in the Wabash Valley Seismic Zone, and less than 2% percent in other zones.

In addition to MCE seismic hazard maps, two other seismic hazard maps are also developed in this process: the Expected Earthquakes (*EE*) and the Probable Earthquakes (*PE*) seismic hazard maps. The expected earthquakes (*EE*) are small earthquakes that could occur at any time during the life span of a bridge; which is 75 years. The probable earthquakes (*PE*) are earthquakes of moderate sizes that could occur in the next 250 years. The three sets of seismic hazard maps will depict the peak horizontal ground accelerations for the short-period (0.2 second) and the long-period (1.0 second) spectral accelerations considering 5 percent damping. The two periods considered are consistent with the periods in most codes (e.g. IBC).

Figs. S7 and S8 show peak horizontal ground acceleration for the short-period (S_s at 0.2 second) and the long-period (S_1 at 1.0 second) for expected earthquakes (*EE*). Figs. S9 and S10 show peak horizontal ground acceleration for the short-period (S_s at 0.2 second) and the long-period (S_1 at 1.0 second) for probable earthquakes (*PE*). Figs. S11 and S12 show peak horizontal ground acceleration for the short-period (S_s at 0.2 second) and the long-period (S_1 at 1.0 second) for maximum credible earthquakes (*MCE*). Details of the derivation can be found in KTC-07-07/SPR246-02-6F.

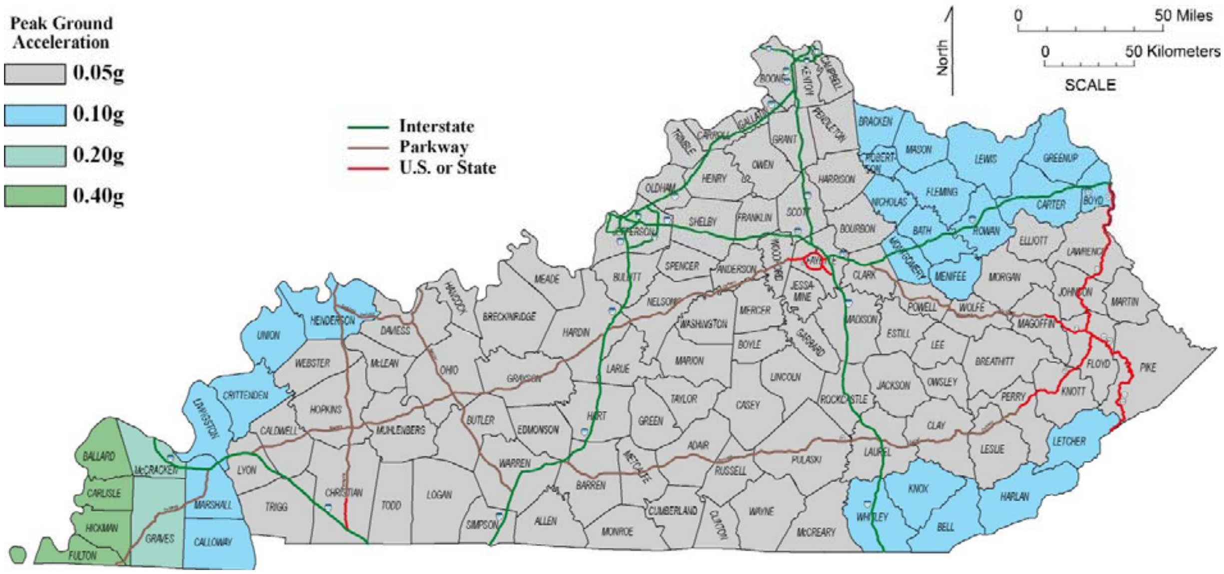

Fig. S.7 – 0.2-second Expected Earthquake (*EE*) Spectral Response Acceleration, S_S (5% of Critical Damping), Site Class A (Hard Rock)

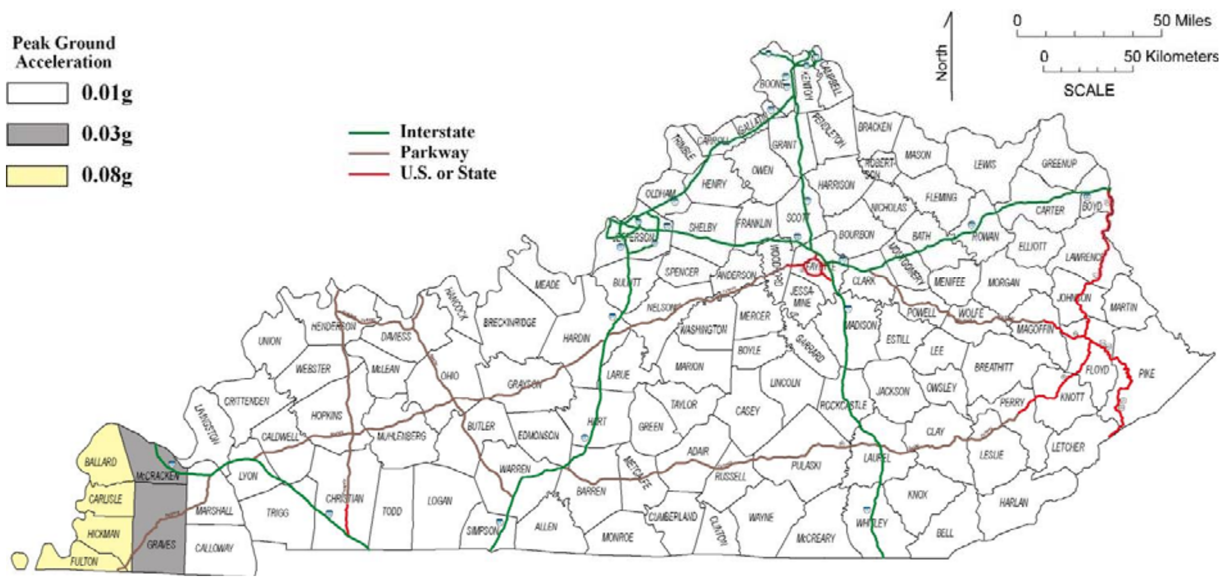

Fig. S.8 – 1.0-second Expected Earthquake (*EE*) Spectral Response Acceleration, S_1 (5% of Critical Damping), Site Class A (Hard Rock)

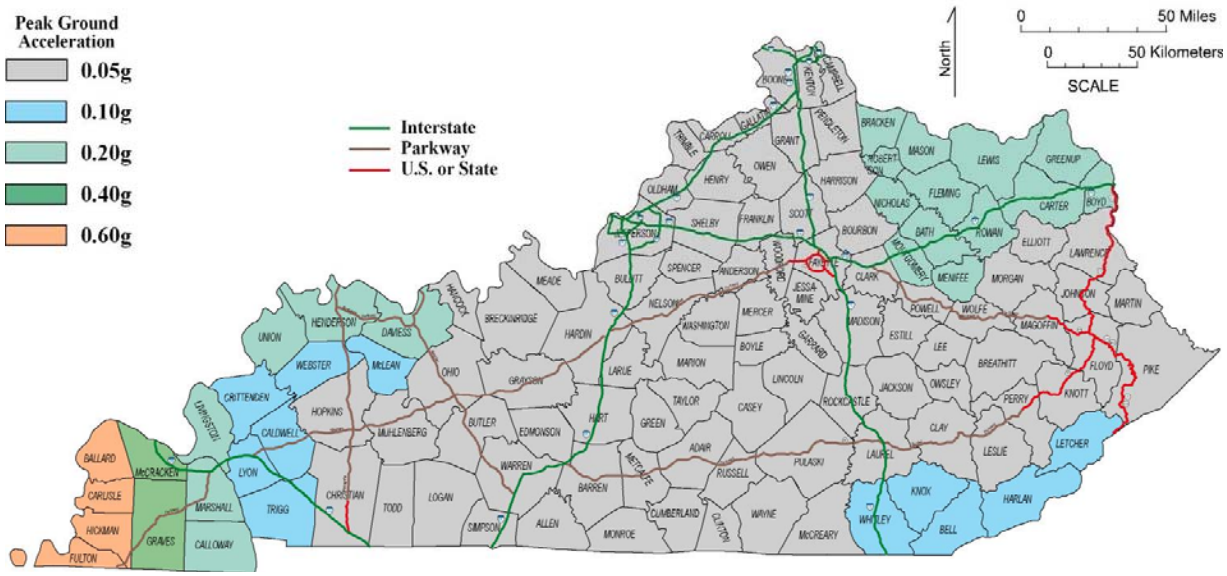

Fig. S.9 – 0.2-second Probable Earthquake (*PE*) Spectral Response Acceleration, S_S (5% of Critical Damping), Site Class A (Hard Rock)

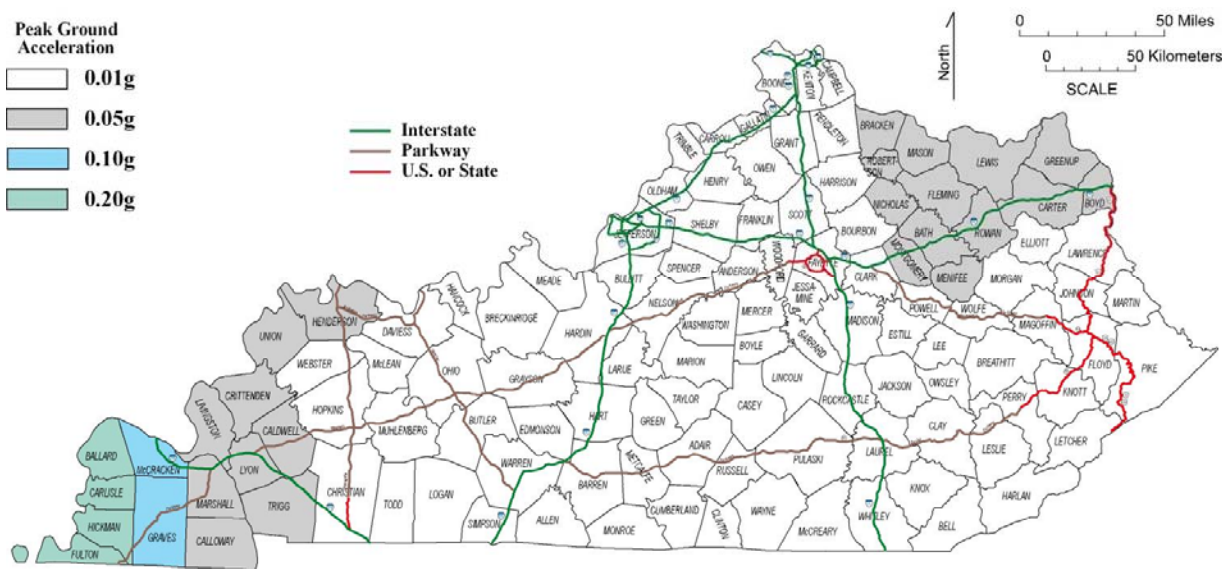

Fig. S.10 – 1.0-second Probable Earthquake (*PE*) Spectral Response Acceleration, S_1 (5% of Critical Damping), Site Class A (Hard Rock)

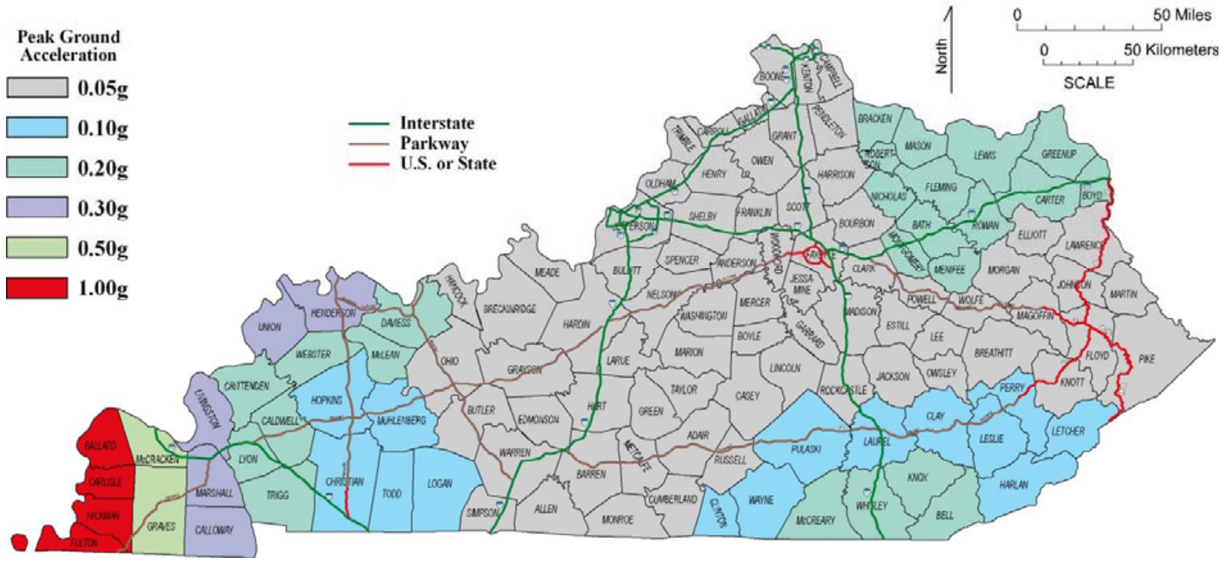

Fig. S.11 – 0.2-second Maximum Credible Earthquake (*MCE*) Spectral Response Acceleration, S_S (5% of Critical Damping), Site Class A (Hard Rock)

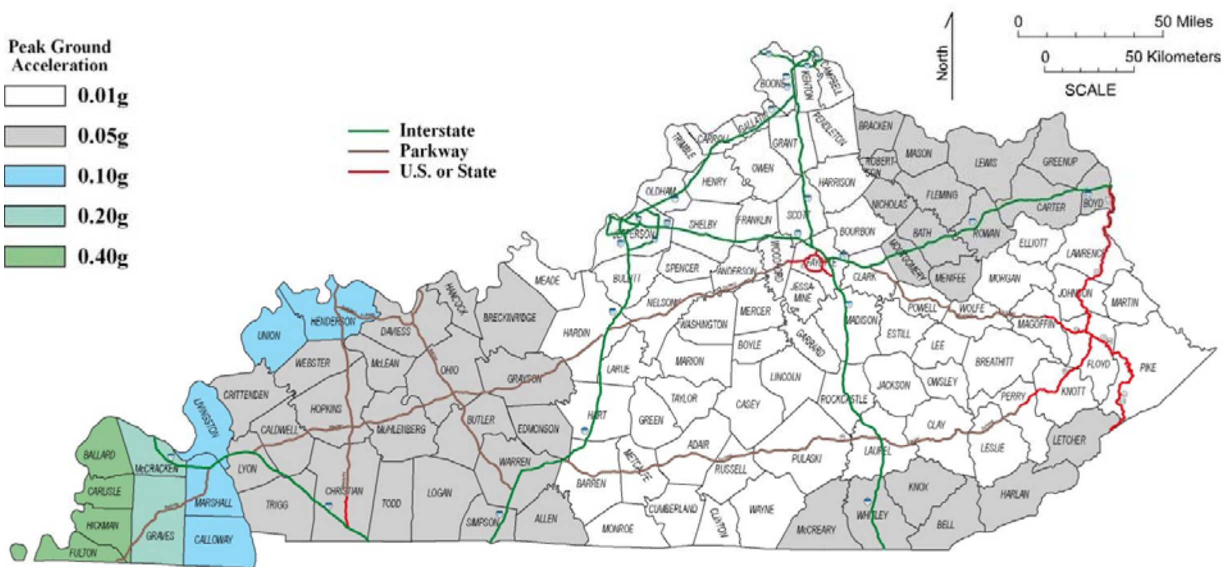

Fig. S.12 – 1.0-second Maximum Credible Earthquake (*MCE*) Spectral Response Acceleration, S_1 (5% of Critical Damping), Site Class A (Hard Rock)

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