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SEISMIC EVALUATION OF HIGHWAY BRIDGES—PHASE I

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DRAFT FINAL REPORT

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by

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16. Abstract

The primary objective of the study was to establish the guidelines for screening, assessing, and ranking Indiana bridges for seismic upgrade. The outcome of the study is a complete strategy for the detailed structural assessment of Indiana highway bridges subjected to seismic forces. The structural evaluation is conducted using a nonlinear time-history analysis of the bridge for simulated or actual records. The specific soil conditions at the site are accounted in terms of the ground motion. From the time history analysis the maximum structural response including displacements, bending moments, shear and axial forces are computed. A weighted evaluation of the ratio of expected demand to available capacity is conducted next. A seismic rating is established based on the weighted evaluation. The bridges are classified into three different categories: high, moderate and low seismic risk. In the case of bridges falling in the high and moderate categories, the weighted seismic rating can be used to establish strengthening needs. The same type of analysis could be used to evaluate different strengthening schemes.

In the case where the bridge inventory is substantial, the proposed strategy in this study would be more effective helped by a preliminary first level screening of the bridge population. Several first level screening procedures available in the United States are evaluated in this study. First level screening procedures are used in the qualitative ranking of seismic bridges with respect to seismic risk. They are simplified methods for use in extensive highway networks and are the first steps in a comprehensive evaluation strategy. The Indiana Department of Transportation has conducted a preliminary first level screening of the bridge population in the southern part of the state. Several bridges have been identified as presenting a high level of seismic risk. The approach proposed in this study could be used to further refine the preliminary ranking, and to evaluate different strengthening schemes.

It must be pointed out that the soil-structure interaction of bridge structures is a developing area. Many questions remain to be answered regarding the proper modeling of the foundation and the surrounding soil. The proposed evaluation strategy can be improved by means of a field evaluation of dynamic characteristics of a representative sample of bridge foundations and soil conditions in the critical southern part of the state.

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SEISMIC EVALUATION OF HIGHWAY BRIDGES- PHASE I

Implementation Report

An approach for the ranking of bridges under seismic attack is proposed in this study. In a large bridge population, a first level preliminary assessment of seismic risk is recommended. The Indiana Department of Transportation has conducted such a preliminary first level evaluation. This evaluation is identifying many of the bridges in the category of high risk. The strategy presented in this study can be used in the detailed evaluation of the critical bridges to refine the level of risk. It can also help in the evaluation of strengthening schemes. Also, field studies to learn the dynamic characteristics of the critical bridges must be conducted in parallel with the analytical studies. The field studies are needed because of the uncertainties associated in the modeling of soil-foundation structure interaction with the more refined methods available to date.

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CHAPTER 1

INTRODUCTION

1.1 Background and Problem Statement

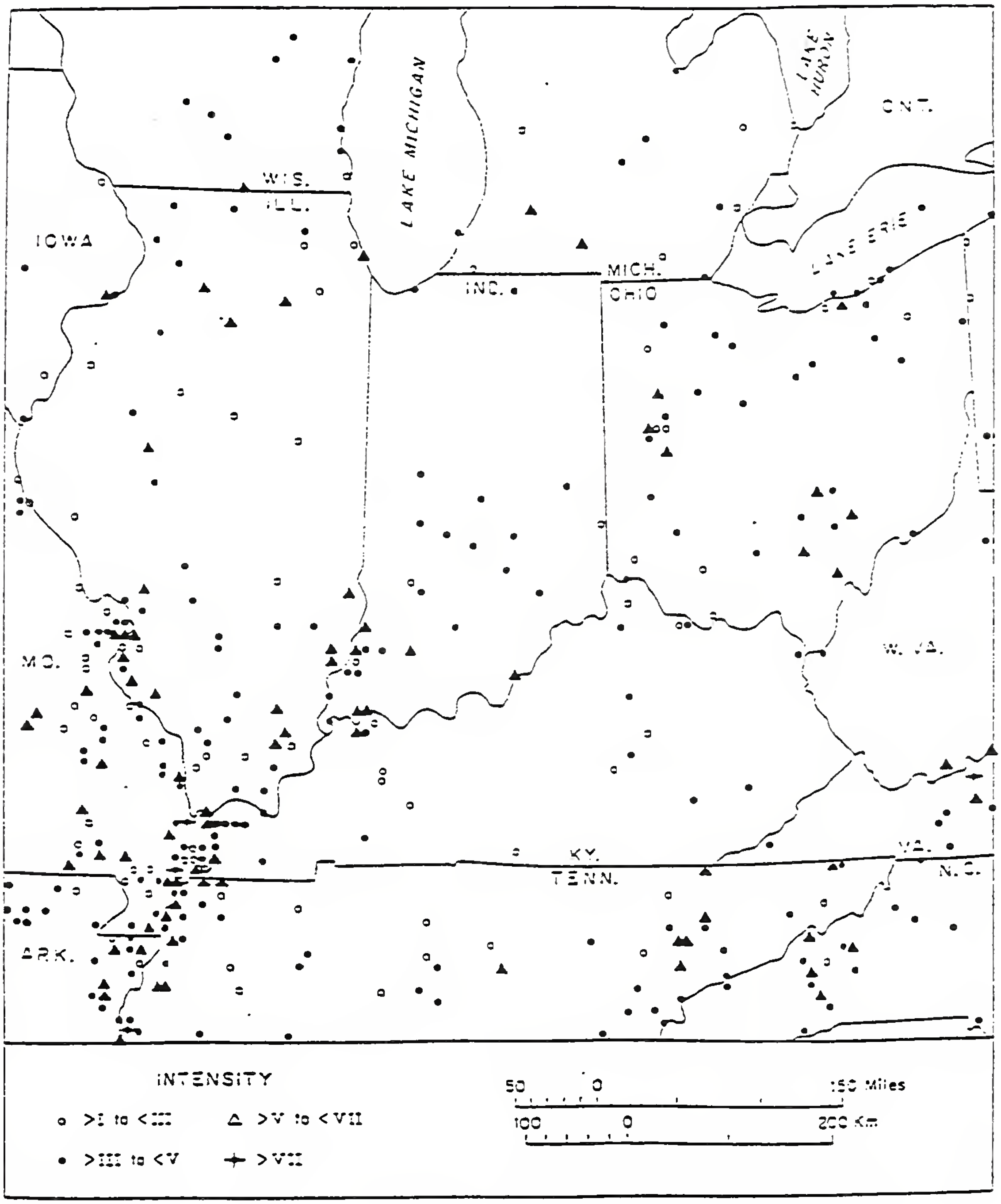
The relatively recent bridge failures during the October 17, 1989 Loma Prieta earthquake, and the January 17, 1994 Northridge earthquake have focused public attention on the dimension of the seismic hazard of highway bridges. Most of the older bridges are at high risk during a strong ground motion because they were built with very little if any attention to seismic effects. Many appear to be vulnerable even in regions of the United States considered of moderate to low seismicity. The state of Indiana and a large portion of the Midwest falls in this category. In Indiana specifically the counties of Gibson, Posey and Vanderburg in the southwest corner present the highest concern regarding bridge safety against earthquakes.

It is often postulated that the New Madrid fault system poses the greatest earthquake risk to the state of Indiana. The New Madrid Zone (NMSZ) encompasses a wide area including western Kentucky, western Tennessee, northeastern Mississippi, northeastern Arkansas, southeastern Missouri, up to the Wabash Valley fault zone in southern Illinois and southwestern Indiana. Figure 1.1 shows an outline of the New Madrid fault complex. Efforts are now directed at further dividing the large NMSZ into two distinct earthquake zones: the Wabash Valley Fault Zone (WVFZ), covering southern Illinois and southwestern Indiana and the more active "smaller" NMSZ covering western Kentucky, western Tennessee, northeastern Arkansas and southeastern Missouri. In 1811-1812, the NMSZ experienced the greatest series of three earthquakes ever in American history. Estimated by seismologists at a magnitude of up to 8.8 in the Richter scale, this earthquake was by comparison about a thousand times more powerful than the 1989 Loma Prieta earthquake in California. Since 1811, the NMSZ remains active with approximately 500 earthquakes of magnitude greater than 3 in the Richter scale recorded between 1822 and 1974 (Ouyang, 1990). Furthermore, since 1974 over 2000 earthquakes have been detected in the NMSZ. Although most of them have been below the threshold of human perception, their existence clearly indicates the high level of seismic activity in the region.

Predicting earthquakes is an inexact science at best, but the US Geological Survey estimates a 40 to 60 percent chance that an earthquake of magnitude Richter 6 or larger will occur in the next 10 years. Nevertheless, it is clear that the seismic risk of the bridge infrastructure in the southern part of Indiana is high. In other words, it is the combination of the possible high magnitude, although infrequent, of the earthquake with the types of bridges, what makes for a situation of high seismic risk. Even a not so strong earthquake would present serious concern in regard to bridge performance because the older bridges have been designed with little or no attention to seismic effects.

It must be noted that large attention is paid to the potential of an earthquake in the NMFZ because of the possible high magnitude. However, for the area around Evansville it has been postulated that a relatively moderate earthquake in the Wabash Valley Fault Zone (WVFZ) could be of greater concerns regarding possible liquefaction problems. Seed and Idriss (1982) explain the cause of liquefaction as follows: " If a saturated sand is subjected to ground motion, it tends to compact and decrease in volume; if drainage is unable to occur, the tendency to decrease in volume results in an increase in pore pressure, and if the pore water pressure builds up to the point at which it is equal to the overburden pressure, the effective stress becomes zero and the sand losses its strength completely, and it develops a liquefied state." Much of the area around Evansville is underlain primarily by lake deposits consisting of clay, silt and sand and relatively recent alluvium along the Ohio river flood plain. Kabayali (1993) studied the vulnerability of Evansville due to soil liquefaction. He indicated that the areas underlain by alluvial deposits are more susceptible to liquefaction, and concluded that: "a large earthquake with epicenter in the WVFZ would generate ground motion in bedrock well over the threshold value of 0.1g to cause liquefaction in the Evansville area. Damage to bridges arising from liquefaction of abutment or foundation soils is characterized by movements of abutments, spreading and settlement of abutment fills, horizontal displacement or tilting of piers, severe differential settlement of abutment or pier, and overall foundation failure. Clearly, the design of bridge structures to withstand liquefaction presents major and sometimes insurmountable difficulties.

Figure 1.1 Map of Ohio Valley Region Showing the Location of Known Epicenters (Blakely and Varma, 1976).



1.2 Study Objective

The objective of the study was to develop a strategy for the ranking of highway bridges under seismic effects. This strategy should help the Indiana Department of Transportation in the screening, and the evaluation of strengthening schemes for highway bridges in the southern part of the state. In this study, several first level screening procedures used in the United States are discussed. First level screening procedures have the purpose of identifying key bridges in need of further evaluation regarding seismic safety. These procedures are helpful in reducing the level of engineering effort for large numbers of bridges and should be part of a comprehensive assessment strategy.

1.3 Benefits of the Study

A program for seismic bridge ranking and strengthening is needed, but it is also costly. Significant economic benefits can be gained from a sensible ranking of the bridge inventory. Additional economic and performance benefits can be derived from an in-depth investigation of different possible strengthening alternatives. The Indiana Department of Transportation is conducting a preliminary first level screening of the bridge population in the critical southwestern region of the state. This initial screening is recommended in this study as part of a complete strategy for the improvement of the state's bridge inventory. The approach discussed in this study can aid the state DOT to verify and to further refine the first level screening. It can also aid in the evaluation of potential strengthening schemes.

CHAPTER 2

FIRST LEVEL SCREENING METHODS

2.1 Introduction

Evaluation and seismic strengthening of existing highway bridges can be accomplished in three stages (ATC/FHWA, 1983):

a. Preliminary screening- a process to identify and rate bridges that need to be evaluated for seismic retrofit.

b. Detailed evaluation- a quantitative evaluation of the seismic capacity of an existing bridge to determine the need, and overall effectiveness of alternate strengthening measures.

2.2 Preliminary Screening

The seismic strengthening of **all** vulnerable bridges in a previously unattended network from the seismic standpoint, such as southern Indiana's, is often economically unfeasible. Thus, a simplified and preliminary method to identify and rank critical bridges is desirable. The intent of a preliminary screening procedure is to develop an strategy on which to base a seismic strengthening program.

2.2.1 ATC/FHWA Guidelines on Screening Procedures

In 1983, the FHWA issued an outline of guidelines for the empirical and subjective determination of a bridge ranking index to facilitate the development of a strategy for seismic strengthening of bridges. These guidelines are general with a national scope. Based on these general guidelines different states have developed their local preliminary screening methods. To establish the seismic ranking of a bridge under these guidelines, three main factors must be considered:

1. The importance ranking of the bridge as a vital transportation link.

2. The seismicity rating of the bridge site.

3. The vulnerability rating of the structural system.

The seismic bridge ranking is a combination of the these individuals ranking with/without weighing factors. The importance rating is a function of the following conditions:

- Amount of traffic on or under the bridge.
- major evacuation route.
- Length and number of lanes.
- Support for special utilities, water, power, gas and communication lines.
- Population density near the bridge site to attempt to quantify potential for loss of life.
- Primary route for emergency traffic.
- Proximity of the bridge to special types of structures, such as dams or nuclear power plants.

The seismicity ranking depends on the given coefficient of the ground acceleration for the site. The structural vulnerability rating is determined separately for the superstructure and the substructure, with the critical one controlling. The superstructure vulnerability addresses the possibility of a bearing or expansion joint failure. The vulnerability of the superstructure is determined regarding the collapse of structural components like columns, piers, and abutment failure due to ground liquefaction.

2.2.2 Other states preliminary screening methods

Several states have proposed or used preliminary screening procedures:

i. California: Gates, 1990, Maroney, 1988, and Roberts, 1991.
ii. New York: Buckle, 1990.
iii. Washington: Babei and Hawkins, 1991.

A summary of the screening procedures is give in Table 2.1. ATC/FHWA, California and New York use weight factors. These factors multiply the respective rating index and then the products are added to obtain the overall ranking. The Washington approach does not use weight factors. In the Washington procedure, the worth of the bridge is incorporated in the final ranking as a separate factor, while New York incorporates it as part of the importance factor. For all the screening procedures discussed above, the higher the numerical value of the overall ranking index for a particular bridge, the higher its vulnerability to suffer damage during an earthquake, and therefore the higher the priority for seismic strengthening.

2.3 Summary

The issue of potential bridge damage due to liquefaction of sandy soils is superficially treated in the methods developed by the states. They refer to the FHWA guidelines that are not site specific and lack detailed evaluation procedures to assess the potential for liquefaction. Another limitation of the preliminary screening procedures is that they do not provide quantitative information regarding the bridge behavior and extent of structural damage under a severe earthquake. Therefore, these methods are of little help in the development and evaluation of strengthening schemes. However, they are useful in the comparative and qualitative evaluation and ranking of the bridges in a large inventory. Thus, making the task of upgrading a large highway network feasible from the economic and practical standpoint.

Table 2.1 Preliminary Screening Procedures

	ATC/FHWA 6-2 83/007	California, Phase II	Washington (proposed)	New York
rank, R	$R=IW_1+SW_2+VW_3$ I=importance (0-10) S= seismicity (0-10) V= vulnerability (0-10)	$R= I^*+S^*+V^*$ Factors (0-1)	R=(I+W)S*V W= worth	same form as ATC/FHWA, but I includes worth factor
weight	W_1, W_2, W_3 (sum = 10.0)	*factor included (sum = 1.0)	no factors	W_1, W_2, W_3, (sum = 10.0)
range	0 - 100	0 - 1.0	0 - 950	0 - 100
Imp. Factor I	Important Bridges= 6-10 Other = 0-5	$I^*= r_1x0.08 +$ adtx0.12 + $d_1x0.05$ where r_1 = route type adt = ave. daily traffic d_1 = detour length	$I=10(r_1d_1+u+r_2d_2)$ where r_1, and d_1 are as for Calif., and r_2=route type crossed d_2=detour length for route crossed u=utility lines fact.	$I=a(r_1d_1+r_2d_2+u+adt)$ +b(rep.$/strength.$) where r_1,r_2,d_1,d_2,u,adt are as defined previously."a" and "b" are weighting factors. rep.$=replacement cost strength.$=retrofit cost to new seismic criteria
Worth Factor W			$W = 0.1 \cdot [adt \cdot \frac{cost_1}{cost_2}]^{1/2}$ where adt=ave. daily traffic $cost_1$=replacement cost of segment likely to collapse $cost_2$=strengthening cost	
Seism. Factor S	S=25A, where A is peak ground accel. coeff. (10% prob. of execeedance in 50 years)	S=A*0.18/0.7g A=peak ground accel. based on shortest distance to an active fault and an assumed attenuation mod.	$S=(AK)^{1.5}$, A same as ATC, K=factor relating exposure period to remaining life of bridge	S=c*A*F, A same as ATC, "c" weighting factor, and F = foundation factor, or site coefficient (1-3)
Vuln. Factor V	Moderate to High (6-10), low to moderate (0-5), elements: bearings, piers, abutm.and liq. potential	Piers and footings: V=L*0.16+Skew x0.05+Col.x0.18 +Conf.x0.18, L=tot.length Skew=angle of skew, Col.=single or mult., Conf.=col. conf.	For superst. V=1-4, single span=1 cont. seat abut.=2 multispans=3	Low, V<4 Moderate, V= 4-6 High, V>6 elements: bearings, cols., piers, footings, abutments and liquefaction potential

CHAPTER 3

EVALUATION STRATEGY

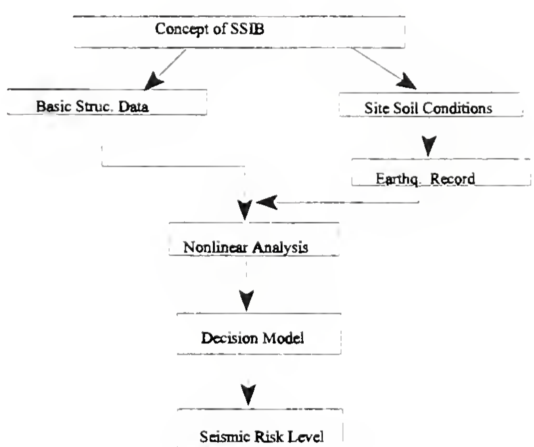
3.1 Introduction

The proposed strategy envisions an evaluation of the bridge population in the Posey, Vanderburg, Warrick, Pike, Gibson, and Spencer Counties. A procedure such as the ATC/FHWA 83, discussed in Chapter 2, could be used to conduct a preliminary first level evaluation. Next, the bridges identified with high seismic risk could be evaluated using the quantitative detailed approach presented in this chapter with the goal of developing an acceptable strengthening strategy.

3.2 Seismic Screening of Indiana Bridges (SSIB)

SSIB is an interactive approach for seismic screening, assessing seismic vulnerability and ranking Indiana's bridges for possible seismic upgrade. In SSIB a nonlinear time-history analysis of the bridge structure is carried out accounting for soil conditions at the site. The analysis can be conducted using real or synthetic ground motion records. By means of this analysis, the dynamic longitudinal and horizontal displacements of the bridge superstructure are calculated. Also, bending moments, axial forces and shears in both superstructure and substructure are calculated for the selected ground motions. Critical modes of failure are identified by comparing the calculated effects against available capacities. A ranking index is calculated on the basis of the ratios of demand to available capacity. The seismic risk is calculated with incorporation of theory of fuzzy sets and fuzzy logic. Figure 3.1 illustrates the concept of SSIB.

Figure 3.1 SSIB Concept



CHAPTER 4

CONCLUSIONS AND IMPLEMENTATION

4.1 Conclusions

The primary objective of the study was to establish the guidelines for screening, assessing, and ranking Indiana bridges for seismic upgrade. The outcome of the study is an overall strategy for the detailed structural assessment of Indiana highway bridges under seismic forces. The structural evaluation is conducted using a non-linear time-history analysis of the bridge for simulated or actual records. The specific soil conditions at the site are accounted in terms of the ground motion. From the time- history analysis the maximum structural response including displacements, bending moments, shear and axial forces are computed. A weighted evaluation of the ratio of expected demand to available capacity is conducted next. A seismic rating is established based on the weighted evaluation. The bridges are classified into three different categories: high, moderate and low seismic risk. In the case of bridges falling in the high and moderate categories, the weighted seismic rating can be used to establish strengthening needs. The same type of analysis could be used to evaluate different strengthening schemes.

In the case where the bridge inventory is substantial, the proposed strategy would be more effective after a preliminary first level screening of the bridge population. Several first level screening procedures available in the United States are evaluated in this study. First level screening procedures are used in the qualitative ranking of seismic bridges with respect to seismic risk. They are simplified methods for use in extensive highway networks and are the first steps in a comprehensive evaluation strategy. The Indiana Department of Transportation has conducted a preliminary first level screening of the bridge population in the southern part of the state. Several bridges have been identified as presenting a high level of seismic risk. The approach proposed in this study could be used to further refine the preliminary ranking, and to evaluate different strengthening schemes.

It must be pointed out that the study of soil-structure interaction in bridge structures is a developing area. Many questions remain to be answered regarding the proper modeling of the foundation and the surrounding soil. The proposed evaluation strategy can be improved by means of a field evaluation of dynamic characteristics of a representative sample of bridge foundations and soil conditions in the critical southern part of the state.

4.2 Implementation

An approach for the ranking of bridges under seismic attack is proposed in this study. If many bridges need to be ranked regarding the risk of failure during an earthquake, a first level preliminary assessment of the bridge population is recommended. The Design division of the Indiana Department of Transportation has conducted such a preliminary first level evaluation. This evaluation has identified many of the bridges in the category of high risk. The strategy presented in this study can be used in the detailed evaluation of the critical bridges to refine the estimates of preliminary evaluation schemes. It is also helpful in the evaluation of strengthening schemes. Field studies to learn the dynamic characteristics of the critical bridges must be conducted in parallel with the analytical studies. The field studies are needed because of the uncertainties associated in the modeling of soil-foundation structure interaction with the more refined methods available to date.

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