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Evaluation of Seismic Hazard Assessments for Indiana

Introduction

The AASHTO Bridge Specification for the Seismic Design of Bridges (NCHRP, 2001) is currently under review by the Indiana Department of Transportation (INDOT). These specifications make reference to the United States Geological Survey published probabilistic earthquake hazard maps for the United States, which are based on current knowledge of past earthquake activity and geological constraints on earthquake potential (Frankel et al. 1996, 2002). In order to gain more understanding of the seismic hazard specific to Indiana as expressed in the specifications, this project was requested with the objectives of reviewing available seismic hazard assessments, analyzing the seismic hazard on a county by county basis, analyzing the recent seismicity and its implications for seismic hazard in the state, and making recommendations for seismic hazard monitoring. The study also includes an intercomparison of methodologies used for determining the shear wave velocity in surface unconsolidated sediments, which significantly affects the ground motion shaking levels in the probabilistic seismic hazard assessments.

Findings

1. We have reproduced the probabilistic seismic hazard calculation following the USGS methodology for the state of Indiana and provided details for the shaking level on each county of the state. We have investigated the sensitivity of these results to one of the most important factors affecting the seismic hazard which is the maximum magnitude of the 1811-1812 New Madrid earthquakes. The original seismic hazard maps [*Frankel et al.*, 1996; *Frankel et al.*, 2002] were constructed assuming firm-rock sites.

2. We have assessed the hazard on a county by county basis, taking into account that the local soil conditions produce amplification or deamplification of shaking in regions with soft or unconsolidated sediments relative to firm-rock sites. We have used a completely probabilistic method to incorporate site effects into the calculation. These preliminary results give a first order estimate that spatially illustrates the potential effect of geology. These preliminary low-resolution results show that there may be significant amplification in the central part of the state, including the greater Indianapolis area, due to thick sediments filling in ancient bedrock valleys. These are demonstration maps that do not yet have the resolution required for operational use, but serve as a proof-of-concept for the probabilistic site effect methodology.

3. We have collected and compiled 28 new borehole shear wave velocity profiles, and 9 new refraction profiles. We carried out a detailed comparison in order to describe the advantages and disadvantages of the different methods for providing inputs for the probabilistic hazard calculation. The uncertainties in the shear wave velocity data for the particular site studied, near Pigeon Creek, are on the order of 60 m/sec. Ground motion simulations with SHAKE91 show that an uncertainty of 60m/sec in this type of profile produces an uncertainty in the output amplification factors of less than 0.5. These data were used to help constrain the preliminary geology based shear wave velocity model used in the probabilistic site effect calculation.

4. The June 18, 2002 Darmstadt earthquake (M_b=5.0, M_w=4.5) was the largest felt earthquake in Indiana since 1968 and the second largest felt earthquakes this century. High quality broadband digital instruments provided data for modeling the full earthquake waveform so that a more accurate

moment magnitude M_w and depth could be determined. Temporary stations that we installed directly after the event provided a lower detection threshold and dense data for precise location of a magnitude 1.2 aftershock. With this data, the precise location of the causative fault was interpreted [*Kim*, 2003; *Hamburger et al.*, 2002]. In particular, the accurate depths indicate that source models for rupture in the Wabash Valley should extend to at least 19 km depth. This large fault area should be taken into account in characteristic earthquake models used in seismic hazard calculations in the future. The Indiana PEPP network recorded two additional felt events, a magnitude 2.9 in the Wabash Valley and a magnitude 4.0 near Bardwell, KY. The number and magnitudes of these events is consistent with the magnitude-frequency relationship for events in the Central and Eastern US. Statistically, given these rates 2 magnitude 5 or greater events are expected to occur in a 10 year period. Uncertainties in the magnitude frequency relation would be reduced if small events recorded by PEPP were routinely incorporated into the USGS catalogs used for the seismic hazard estimates.

5. Recommendations are made for seismic monitoring with the objective of improving information used in hazard estimates for infrastructure planning. The recommendations include installing an adequate strong motion network, given the average recurrence times of one magnitude 5 earthquake every 10 years. Recording these events is critical for ground-truthing the probabilistic seismic hazard estimates. Because of the existing backbone of reliable weak motion and broad band seismometers, the situation could be greatly improved at reasonable cost. Concerning seismological equipment, we recommend 1) upgrading all stations to 3-component sites to measure shear wave propagation characteristics, and 2) installing digital strong motion instruments, especially in urban areas that coincide with the potential for relatively high amplification as revealed in this study. Bridge decks, abutments, and free-field sites near bridges are often monitored with strong motion instruments to provide data on shaking levels and information for validating bridge design decisions. In the southwestern part of the state and couties that risk elevated shaking levels because of general geological conditions, new and rehabilitated bridges should be considered for monitoring as part of any strong motion network upgrade. Concerning technical operations, we recommend the following: 1) implement a real time data exchange with CERI-Memphis, who can assume a large load of the operational tasks at little additional expense, 2) install robust real-time connections at the schools hosting the PEPP network equipment, 3) implement an automatic event associator that can efficiently integrate data coming from many local operational centers into a coherent earthquake catalog. Concerning maintenance, the cost and resources required here are adequately covered. Concerning operations, it is clear that additional personnel are required, at least a ¼ time analyst, either at CERI or IU to create and maintain the operational processing of the data, which has currently fallen far behind. Funding for these operations through the PEPP program ceased in 2003. Another reason operations are lagging is the mixture of coal mining blasts and small earthquakes unique to Indiana that complicates the analysis task. This leads to the final recommendation for automating blast/earthquake discrimination. This is important in assuring that the hazard level assumed in probabilistic assessments is not artificially elevated because of misidentification of blasts as earthquakes. The probabilistic seismic hazard estimates to date are entirely based on theoretical and empirical relations for earthquake occurrence and seismic wave propagation. Improved seismic monitoring data will provide valuable constraints on earthquake source distribution, seismic velocity models, and wave propagation characteristics that can significantly impact the hazard estimates for future large earthquakes in the region.

Implementation

The demonstration probabilistic seismic hazard maps show how geologic structure could potentially affect the seismic hazard in Indiana, however the input data do not have the resolution necessary for making planning decisions. Future versions of the maps, which could also be generated for different probability levels, should be planned that would use a database with higher resolution information on shear wave velocity structure. Soil data, SPT data, and CPT seismic cone data at bridges and other INDOT construction sites, if collected or compiled on a routine basis, would make a significant contribution to improving the resolution of these maps. These future maps would provide information at the level necessary for planning and budgeting, though site specific studies will still be needed for engineering.

Higher resolution maps, however, are not planned for implementation by INDOT in the near future.

INDOT could choose to contribute to seismic monitoring efforts in the state, especially for strong ground motions, as part of the implementation plan to provide a long term data set for bridge design decisions. This action is also not planned for implementation by INDOT in the near future.

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