A Comprehensive Geophysical Investigation to Assess Seismic Hazards in the Wabash Valley Seismic Zone: A Case Study of the New Harmony Fault (1434-95-G-2620)

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Non-Technical Summary
New geologic evidence showed that in the last several thousand years southern Indiana and Illinois have experienced several large earthquakes centered on the Wabash River valley region. This study focuses on measurement of low-magnitude earthquakes not detectable with existing seismograph networks. In 1995 we operated twenty state-of-the-art seismograph stations near a series of known faults in the region, ten of the stations were deployed as an array over a one-km radius. The experiment was concluded in mid-June, 1996 and the data has now been processed and stored at the IRIS Data Managment Center. Preliminary estimates based on 20 days out of 220 days of recordings show about 40 events recorded per day, mostly from coal mine and quarry explosions. Nevertheless, 25 events have been identified as earthquakes in the region associated with known faults. We can an expected total of 100 - 300 low-magnitude events to be identified and located by the Wabash Valley array.

Investigation Undertaken.

Objectives. The objective of this study is to identify and catalog microearthquake activity associated with the Wabash Valley Seismic Zone (WVSZ) near the center of the Illinois Basin (Figure 1a). In the last 200 years historical records of earthquakes (Nuttli, 1979) indicate many small and intermediate-size earthquakes have been centered on a series of north-striking faults (Ault and Sullivan, 1982) over a wide area in southeastern Illinois and southwestern Indiana. In 1968, and again in 1987, two significant earthquakes (m_b = 5.5 and 5.2) occurred in southern Illinois and were felt as far away as Canada. In the past five years our understanding of earthquake hazards in this area has been changed through identification of hundreds of liquefaction features believed to be the result of local earthquakes centered on the Wabash Valley area (Munson and Munson, 1996). The main conclusion is that the area has experienced repeated earthquakes of M = 6.7 or larger during Holocene times. Given the low attenuation of seismic waves within the central U.S., a repetition of an earthquake of this magnitude would have a devastating effect on the region.

Based on a standard *b*-value of 1.0 from Nuttli's (1983) catalog we should expect to see about 300 events of magnitude 0 per year in this region. The Saint Louis Network (SLU) catalog, however, lists only 3 earthquakes of magnitude less than 1.0. This discrepancy is most likely

due to detection limits in the older data. In spite of the clear concentration of activity in this area, the WVSZ remains one of the most poorly studied segments of the midcontinent seismic zone. This project addressed the gap in seismicity coverage by installing a phased array of ten closely spaced stations with continuous recording, in conjunction with ten stations deployed in a nearby triggered network. Such phased arrays have proven to be the most reliable method of identifying low-level microearthquake activity. These studies will address a range of tectonic and seismological issues related to long-range earthquake forecasts and mitigation of earthquake hazards in this region.

Instrumentation and Site Location. Twenty digital, high-frequency three-component sesimic instruments were borrowed from the IRIS-PASSCAL facility for a seven-month interval from late November, 1995 through mid-June, 1996. Ten sites were selected at 20 - 30 km intervals centered about the known faults of the WVSZ such as the New Harmony Fault and near prehistoric liquefaction observations in the WVSZ. Sites were chosen for their low-noise conditions and near-surface bedrock. Each site was a stand-alone system with 24-bit digital recorders and disk data storage. Seven of the sites had 2-Hz triaxial sensors buried 0.5 m to further reduce noise. Because three of the sites were in regions of thick, glacial deposits, we used a 12-component string of 4.5 Hz triaxial geophones, buried and spread out in a 55-meter-long, linear array. These ten sites constituted a conventional triggered monitoring network with recording at 250 sps with a 30 s pre-event memory.

Our 10-component phased array covered an area approximately one km in diameter near the center of anticipated seismic activity. Each site had an L-22 sensor operating continuously at 40 sps. One of the sites was also equipped with a broad-band, three-component sensor (Guralp CMG-40) sampling continuously at 5 sps and triggered at 100 sps. Time signals were recorded using a crystal-oscillator clock updated by a GPS receiver at hourly intervals.

Processing. During the experiment data were downloaded weekly, stored on 150 DAT tapes, converted to SEGY format and temporarily archived onto a one-Tbyte mass storage system at Indiana University. Since the conclusion of the experiment almost all of the 210 days of raw data (140 Gbytes) has been converted to a SEED format and shipped to the IRIS-PASSCAL Data Managment Center (DMC) essentially fulfilling our archiving obligation to IRIS and the USGS. These data have recently been released for public access through IRIS.

The first step in identifying an event (defined as either an earthquake or an explosion) involves automated computation of four detection parameters at one second intervals: semblance, power, azimuth, and slowness. A preliminary detection semblance algorithm flags peaks for P waves when the semblance is above a threshold value. If the parameters are consistent with a seismic wave arrival, the interpreter selects the interval for detailed interactive processing using software developed under the IRIS Joint Seismic Program. In the interactive processing a 50x50 grid of slowness vectors is computed using a slant-stack algorithm. The maximum power on a semblance polar (f-k) plot identifies the azimuth and slowness of the P phase (and S) of the event. Using this azimuth, a plot of semblance as a function of time and slowness confirms (or modifies) the initial P and S picks. After the analyst confirms that the event is a real seismic event, the final azimuth and slowness are used to stack the array to obtain a best-beam trace for subsequent analysis.

Hypocenter Location. After the array data are processed, array best-beams are merged with triggered station data using a custom piece of software we wrote to determine whether an event is locatable and to inter-relate triggered and continuous data streams. The scheme we use keeps all waveform segments that overlap with array beams. If no beam waveform is present, the procedure reverts to a 'voting scheme' where data are ignored if less than 3 network stations recorded overlapping waveform segments. We have found that the latter situation is rare, and nearly 100% of all detections occur on the array with some fraction of the network stations also recording the event.

Once the triggered data are merged with the array data, we use a program developed at the University of Colorado called *dbpick* to measure P and S phase arrival times on triggered stations. We then locate each event using an interactive front end to a newly developed location code (*genloc*) described by Pavlis and Wagle (1996). This code is particularly important for our work because it allows inclusion of slowness vector measurements from the array as data for constraining the location. The interactive user interface (dbgenloc) allows us to easily fix the event depth. For clear explosions we fix the depth to 0. For earthquakes, the depth is not fixed unless it is required to obtain a stable solution.

This final catalog preparation is still in incomplete for this grant period. Our current catalog covers only approximately 50 of the 220 days of recording. We are currently focusing on the last 70 days of the experiment when the data quality is highest. At the time of the writing of this report (July 1998) we have picked and located a total of 359 seismic events.

Magnitude estimations. Magnitudes for approximately 28 events have been calculated using two independent methods for estimating earthquake size. Traditional magnitude scales such as the local magnitude (M_L) or body wave magnitude (M_b) usually look at the amplitude of ground motion in a narrow frequency band. The moment magnitude (M_w) is a magnitude scale derived from the seismic moment, a physical quantity related to the parameters of the fault movement that produced the earthquake. We make such magnitude calculations based on the frequency spectra of earthquake P arrivals. Below a corner frequency related to the duration of the earthquake, and above a lower corner related to the instrumentation, there should be a "flat" area that can be scaled to a seismic moment. We are also investigating another non-traditional magnitude scale based on duration of the event. The advantage of such a "duration magnitude" is that it should be largely free from instrumentation and site effects. A local duration magnitude scale developed by M. W. Hamburger (pers. comm.) for use with the analog seismographs at Indiana University was applied to our Wabash Valley events and shows a good correlation with our independent M_w calculations.

Results

To date we have made a preliminary analysis of approximately 50 out of the total of 220 days of recording. We are detecting approximately 40 events per day, most of which are mining and quarry explosions. A minimum of 25 events have been tentatively identified as earthquakes. Twenty of these earthquakes have been located within the study area using P and S arrival times and slowness vector measurements. Some locations are along the surface trace of known faults. Current work is focused on processing this enormous data set to extend this

catalog over the duration of the experiment.

References

Ault, C. H. and D. M. Sullivan (1982), Faulting in southwest Indiana: Indiana Geological Survey, National Regulatory Commision Pub., CR-2908, 51 p.

Munson, P. J. and C. A. Munson, (1996), Paleoliquefaction evidence for recurrent strong earthquakes since 20,000 years BP in the Wabash Valley area of Indiana, unpublished report to U. S. Geological Survey, *Open File Report,* 137 p.

Nuttli, O. W. (1979), Seismicity of the central United States, *Reviews in Engineering Geology*, IV, 67-93.

Nuttli, O. W. (1983), Catalog of Central United States Earthquakes since 1800 of m_b >3.0, St. Louis University, St. Louis, Mo.

Reports Published

Bear, G. W., A. J. Rudman, and J. A. Rupp (1996), The Wabash Valley fault system: Recurrent basement faulting near the center of the Illinois Basin, *GSA Abs. with Prog.*, **28**, no. 7

Bear, G. W., G. L. Pavlis, A. J. Rudman, M. W. Hamburger, T. Stigall, H. Al-Shukri, B. M. Pope and L. Pugh, 1996, Preliminary results of the Wabash Valley seismic monitoring experiment (abstract), *Seis. Res. Lett.*, v. **67**, 32.

Bear, G. W., M. W. Hamburger, G. L. Pavlis, B. M. Pope and A. J. Rudman (1996), The Wabash Valley seismic experiment (abstract), *EOS Trans. Amer. Geophys. Union*, **77**, F513.

Bear, G. W., 1997, Integration of seismic reflection and potential field analyses: architecture of precambrian sedimentary basins in Indiana, Illinois and Kentucky, *Ph.D thesis*, Indiana University.

Pavlis, G. L and P. Wagle (1996), Generic seismic event location (abstract), *EOS Trans. Amer. Geophys. Union*, **77**, F452.