FINAL TECHNICAL REPORT

For the Period:

August 1, 2004 – January 31, 2007

Prepared for:

University of Nevada, Las Vegas Research Foundation
Las Vegas, Nevada

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Earthquakes in Southern Nevada - Uncovering Hazards and Mitigating Risk:
A Research Study by the University Of Nevada, Las Vegas

April 25, 2007

For Submittal to:

United States Department of Energy
Operations Division
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Contracting Officer: Eric M. Simpson

LEGAL NOTICE

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1.0 GENERAL INFORMATION

1.1 Introduction and Purpose

This report describes the progress made on the "Earthquakes in Southern Nevada - Uncovering Hazards and Mitigating Risk" project from August 1, 2004 through January 31, 2007.

The "Earthquakes in Southern Nevada - Uncovering Hazards and Mitigating Risk" project is being conducted as part of a grant awarded to the UNLV Research Foundation (UNLVRF) by the U.S. Department of Energy, Office of Science. Project research is being conducted by the University of Nevada, Las Vegas (UNLV), College of Science and Engineering. The Principal Investigator is Barbara Luke, PhD and Director, Engineering Geophysics Laboratory, UNLV.

The overall goal of this study is to improve understanding of the earthquake hazard in the Las Vegas Valley and to assess the state of preparedness of the area's population and structures for the next big earthquake.

Research related to the project is being conducted in eight major task objectives, as follows:

1. Enhance the seismic monitoring network in the Las Vegas Valley
2. Improve understanding of deep basin structure through active-source seismic refraction and reflection testing
3. Improve understanding of dynamic response of shallow sediments through seismic testing and correlations with lithology
4. Develop credible earthquake scenarios by laboratory and field studies, literature review and analyses
5. Refine ground motion expectations around the Las Vegas Valley through simulations
6. Assess current building standards in light of improved understanding of hazards
7. Perform risk assessment for structures and infrastructures, with emphasis on lifelines and critical structures
8. Encourage and facilitate broad and open technical interchange regarding earthquake safety in southern Nevada and efforts to inform citizens of earthquake hazards and mitigation opportunities

1.2 DOE Award Number/Name of Recipient

DOE Award # DE-FG02-04ER63855

Recipient: UNLV Research Foundation
University of Nevada Las Vegas
8311 W. Sunset Road, Suite 200
Las Vegas, NV 89113

1.3 Project Title/Name of Project Direct and Principal Investigator

Project Title: Earthquakes in Southern Nevada - Uncovering Hazards and Mitigating Risk

Authorizing Official: Wilbur “Bud” Pittinger, Executive Director, UNLV Research Foundation

Principal Investigator: Barbara Luke, Director, UNLV Engineering Geophysics Laboratory

1.4 Date of Report/Period Covered by Report

Report Date: April 25, 2007
Period Covered by Report: August 1, 2004 – January 31, 2007

2.0 PROGRESS TOWARDS GOALS

2.1 Accomplishments and Major Activities

The project enhanced research infrastructure at UNLV through acquisition of equipment and hiring of personnel. The key equipment acquisition was a “minivib” seismic vibrator with trailer and truck. In shakedown testing we learned that energy from the equipment can be detected up to a mile away in a sedimentary setting. We also purchased survey-grade GPS equipment for geologic mapping, various computers, and more. We hired a geophysical research associate who became trained on the equipment. Unfortunately the person did not stay with the project, nor did his replacement. We are again searching to fill that position. It is our goal that the position will remain funded indefinitely.

Many people at UNLV were positively impacted by the grant, including four UNLV professors, a research associate, and numerous graduate students and undergraduate students.

Objective 1: Enhance the seismic monitoring network in the Las Vegas Valley

We have worked with the University of Nevada Reno, to continue to upgrade and install additional seismometers in the Las Vegas Valley. Over the granting period, we have installed a new real-time seismic station at Red Rock visitor center. This site gets about 1 million people per year visiting the center. For the first time, we are now seeing low magnitude earthquakes in the Valley. In addition, we have upgraded the station at the Las Vegas Natural History Museum. This station tends to be very noisy, so we are attempting to find a sensor that will be useful at this location. The installations are a slow process, but stations have been steadily increasing over time.

Objective 2: Improve understanding of deep basin structure through active-source seismic refraction and reflection testing

We have acquired seismic reflection/refraction data at three field sites. One site is located south of Henderson, NV on the Black Hills fault. This fault has been mapped as a seismic hazard, but the estimated potential earthquake is debated. We acquired data across the suspected southern extent of the fault to help refine the fault length. This data feeds directly into the magnitude of a potential earthquake. The longer the fault is, the larger potential magnitude earthquake that is possible. Our data shows that there is an extension of the fault that is buried and that the fault is in fact longer then previously mapped.

The second field site is in Hidden Valley, NV. This is located near the location of the new airport in Jean, NV. We are investigating this basin to determine whether the basin was formed via volcanic processes, currently active normal faulting or a combination of the processes. Currently, our data indicate that this valley was formed from past volcanic activity and should not pose a seismic hazard to the surrounding area.

The third field site is in Henderson, NV. This location is in the River Mountains at the base of a new housing development. There were two fault traces mapped by the geologists in this area. We acquired seismic reflection/refraction data to determine the extent of the faulting in the sub-surface. We have found that not only do these faults propagate into the sub-surface, but there are also two additional fault strands associated with this zone. In addition, we have seen evidence that there have been a series of ruptures in the past by identifying a colluvial wedge (a surface feature that forms from a series of previous faulting events). This fault zone should be considered active and a seismic hazard potential for the Las Vegas Valley.

Objective 3: Improve understanding of dynamic response of shallow sediments through seismic testing and correlations with lithology

To establish the lithology and differences in lithology across the basin, we collected lithology data from ~1150 wells. Only wells deeper than 12 m were accepted. The deepest well is nearly 2000 m deep and ends in the bedrock that forms the bottom of the basin. We modeled the data in both 2-D and 3-D. These models show that as much as two thirds of the lower basin-fill sediments are Miocene and Oligocene age sediments that are likely to be well compressed, and thus, stiffer than the younger, Quaternary sediments. The Quaternary sediments range from gravel to clay, with the clay, a less stiff material that allows greater amplification of waves, forming a belt that trends NW-SE from the northwestern basin to the east-central part of the basin and from there trends N-S to the southeastern part of the basin.

We developed new techniques for collecting and processing seismic surface wave data to develop shear wave velocity profiles of the subsurface. We collected passive- and active-source data, and processed the two datasets jointly. We developed computer algorithms for processing the multi-channel data to build multi-mode dispersion curves. We also improved capabilities to invert surface wave datasets by incorporating more advanced forward models. We incorporated two complementary forward models, one using multiple modes with a plane wave solution and the other using a superposition of energy for cylindrical wave propagation. The models are inserted into an inversion shell, which was developed by others, that uses both/either a linearized technique and a simulated annealing approach.

Surface wave measurements were made at several sites across the Valley. One test was made on the UNLV Engineering Geophysics Test Site using the new Minivib.

We collected and processed a downhole shear dataset for the UNLV Engineering Geophysics Test Site to use as ground truth in development work for surface wave inversion research.

We augmented our shear wave velocity database for Las Vegas valley by mining public records. This involved first gaining the cooperation of local geotechnical engineering firms to identify sites where shear wave velocity data had been measured. Then we screened public records from the Clark County Development Services Division to locate the data. Clark County representatives set up an internet link so that geotechnical reports can be queried and accessed from UNLV. All of our velocity data are posted online at www.ce.unlv.edu/egl/lv_archives .

We built a new, rudimentary shallow shear-wave velocity model for the Las Vegas valley in the software TECBase.

The geotechnical engineers worked to assign seismic site classifications to hundreds of locations of critical facilities in the County (bridges, schools, hospitals, police and fire stations, etc.). Classifications were based on available shear wave velocity data and lithologic data from the project's well log database.

Objective 4: Develop credible earthquake scenarios by laboratory and field studies, literature review and analyses

Geologic mapping was completed to determine the length of River Mountains/Frenchman Mountain fault and the Decatur/Eglington fault, which relates to maximum credible earthquakes. Both faults were found capable of having earthquakes of M6.5 – 7.0.

We developed ground-shaking projections for the Las Vegas valley through microzonation. Data were compiled from the USGS database for 67 faults within 150 km of Las Vegas. This set was screened down to ten key faults according to most recent evidence of movement. We searched earthquake ground motion databases and selected twenty-two earthquake time histories appropriate for use as input records in site response analyses.

Objective 5: Refine ground motion expectations around the Las Vegas Valley through simulations

We conducted thousands of one-dimensional site response analyses using the widely known computer program SHAKE in Monte-Carlo simulation, to build site response envelopes for the two zones. A key challenge in site response analysis was properly parameterizing the deep sediment column. Results were published in a Ph.D. dissertation.

We also completed a Monte-Carlo simulation to investigate the standard practice of using 30-m depth averaged shear wave velocity to characterize dynamic response of sites. We found that reliance on that single value can be misleading; it is preferable to also consider characteristics of deeper media and variability within the shallow subsurface.

Another sensitivity study was initiated using the program SHAKE to investigate the effects of the relative abundance of clay and gravel in the shallow soil column on projected ground motion. This work supported seismic site classifications, mentioned above.

The collection of the various additional geologic and geophysical data sets has taken place over the granting period. The University of Nevada Reno has been able to connect ShakeMap to the existing strong motion instrumentation in the Las Vegas Valley. The integration of the geologic and geophysical data into this system has not been a simple task and to date has not occurred.

Objectives 6 and 7: Assess current building standards in light of improved understanding of hazards. Perform risk assessment for structures and infrastructures, with emphasis on lifelines and critical structures.

We constructed a building-by-building database of the building stock of the essential structures and combined this with information about local soil conditions and used the approaches outlined in the Federal Emergency Management Agency's publication, FEMA 154 Rapid Visual Screening of Buildings for Potential Seismic Hazards and the software package, HAZUS-MH, along with geographical information systems to integrate the databases and perform the loss estimation.

Data Collection: We confined our investigation to the seismic risk assessment of essential structures: 3 hospitals; 46 fire stations; 10 police stations; and 266 schools for a total of 325 facilities consisting of 1,002 individual buildings. The buildings were under the jurisdiction of Clark County, the City of North Las Vegas, the City of Las Vegas, the City of Henderson, and the Clark County School District (CCSD). In general, the construction documents were accessed through an electronic database, microfiche, and/or the actual documents.

As mentioned above, we classified the sites according to NEHRP (FEMA 1997), which range from A for hard rock to E for very soft or otherwise earthquake-susceptible soils. Extrapolating the results from a site-conditions map of nearby areas of California yielded a predicted NEHRP class of D for the entire Las Vegas basin. Site classes for the buildings considered ranged from B (i.e., average rock) to D with C (i.e., dense soil) and D predominating.

Rapid Visual Screening (FEMA 154): Our inventory included wood frame, light-metal frame, tilt-up construction, and reinforced masonry buildings. The results of the analysis allowed us to quantify and assign an appropriate "score" for each general building type and/or individual building characteristic(s) for one of three defined seismicity regions (i.e., either high, moderate, or low). The resulting "score" values for each building were tallied and used to determine the final "structural score" for each building.

The final scores obtained were then compared to a pre-established “cut-off” score of 2.0. This “cut-off” score implies that there is a 1% chance that a particular building will collapse using the 1996 USGS MCE ground shaking parameters. As a result, any buildings that were determined to have a probability of collapse greater than 1% were classified as not meeting the performance criterion for the RVS analysis.

We performed the RVS methodology twice. First applying the appropriate quantitative scores for a USGS-specified high seismicity region to all buildings analyzed, (i.e., “All High”), and second using the 1996 USGS MCE parameters to determine the appropriate seismicity region and scores. The “all high” method was more conservative as shown in Fig. 1, with 32% or 321 of the buildings analyzed not meeting the performance criterion; whereas, the 1996 USGS MCE method yielded a total of 232 buildings not meeting the performance criterion (i.e., 23.2%). In general we noted that there was a difference of 89 buildings or 8.9% between the “all high” method and the 1996 USGS method, with the “all high” method being more conservative.

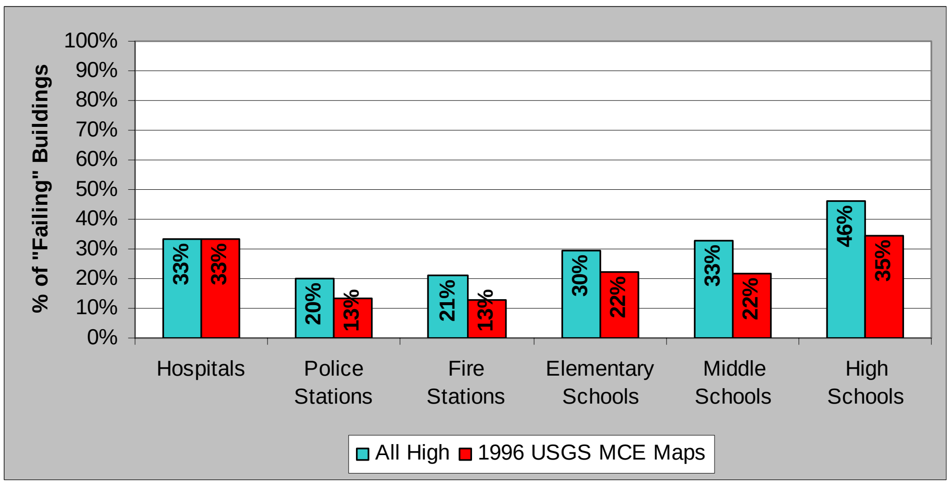

Figure 1: Rapid Visual Screening methodology results by Building Use. (“Failing” indicates greater than 1% probability of collapse)

HAZUS-MH: We established spatial relationships for the buildings using the GIS platform in HAZUS. HAZUS contains pre-defined capacity-demand and fragility curves for 15 generalized building types, which we used to determine discrete probability values for five different damage states (i.e., none, slight, moderate, extensive, and complete/collapse). We subsequently plotted the discrete damage state probabilities to obtain the corresponding discrete probability distribution functions for each building.

Two distinct HAZUS analyses were also performed; one incorporated a M6.9 event located on the Frenchman Mountain fault, and the other utilized ground-shaking parameters specified by the 2002 USGS maximum considered earthquake (MCE) with a 2,500-year return period. We used the same acceptability measure utilized by the RVS methodology; that is, a building is considered to not meet the performance criterion when the probability of collapse is greater than 1%. See Fig. 2. For the M6.9 Frenchman analysis 308 (i.e., 30.7%) of all the buildings analyzed did not meet the performance criterion, and for the 2002 USGS MCE analysis 136 (i.e., 13.6%) of the total buildings analyzed did not meet the performance criterion. Comparing the two analysis methods reveals a difference of 172 buildings (i.e., 17.1%), with the M6.9 Frenchman analysis producing the most conservative results.

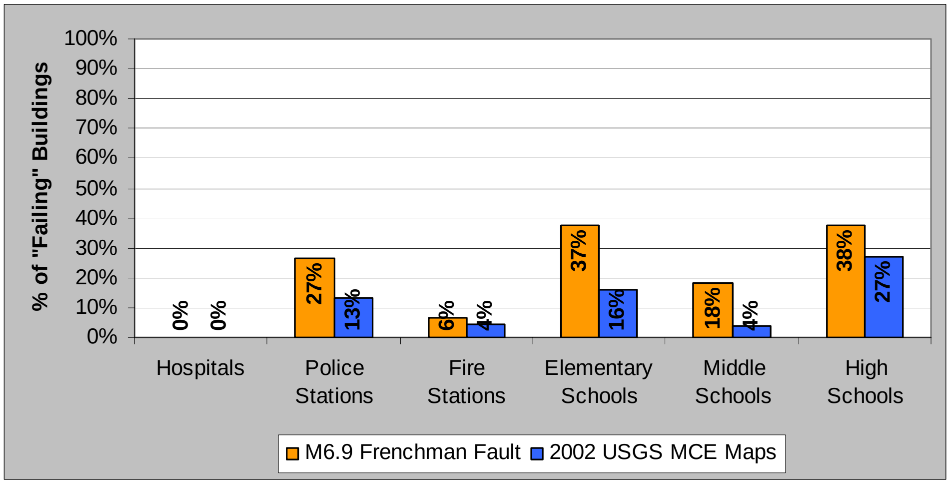

Figure 2: HAZUS-MH methodology results by building use. (Failing" indicates greater than 1% probability of collapse.)

Subsequently, we performed a comparison between the RVS and HAZUS methods using RVS 1996 USGS MCE and HAZUS 2002 USGS MCE, which showed that there was an overall difference of 96 "failing" buildings between the two methodologies with the RVS methodology being more conservative (see Figure 3).

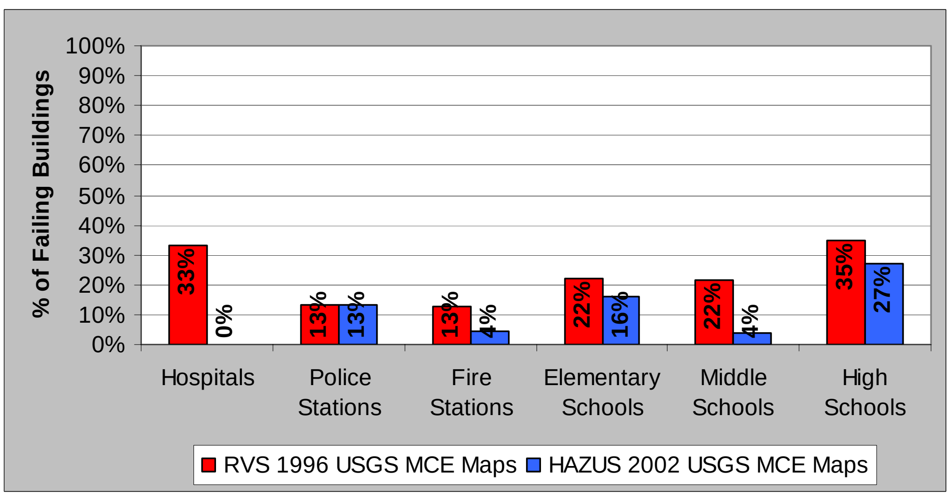

Figure 3: RVS-HAZUS USGS MCE results by Building Type ("Failing" indicates greater than 1% probability of collapse)

We compiled a list of buildings most prone to seismic damage using the results of all four analyses. Any building that did not meet the performance criterion for all four methods would pose a significant threat, that is 47 buildings (i.e., approximately 5% of all buildings). We also generated two separate lists containing the buildings that did not meet the performance criterion for RVS (232 structures) and HAZUS (85 structures). Results can be seen at http://www.isu.edu/engineer/earthquake/.

Objective 8: Encourage and facilitate broad and open technical interchange regarding earthquake safety in southern Nevada and efforts to inform citizens of earthquake hazards and mitigation opportunities

Project team members attended numerous technical meetings, conferences and workshops for presentations and technical exchange.

Since the inception of the outreach program for Earthquakes in Southern Nevada we have participated in a total of seventeen events within the community. We have developed relationships with various agencies/organizations who now request us a regular participant in their events. Some of these organizations include the Red Rock Canyon Visitors Center, Sun City Anthem Retirement Community and several local elementary schools.

We developed a display for use at outreach events. It centers around a 25-lb capacity shake table and a demonstration kit for home emergency preparedness.

We developed documentation that was added to a report to FEMA helping to identify Southern Nevada's earthquake hazards and risks. This report also outlined the goals, objectives and activities of the outreach program. We contracted with local television station KUNV to produce and air public service announcements about earthquake safety and preparedness. We launched a project website was launched which contains general information about seismic activity, Las Vegas Valley fault maps, safety information and a brief description about the project: http://earthquakes.unlv.edu.

Publications related to the Project:

X. Jin and B. Luke, 2006, "Comparison of three surface wave measurements and a seismic downhole measurement in a complex-layered system," *Site and Geomaterial Characterization*, Ed. A. Puppala, D. Fratta, K. Alshibli, and S. Pamukcu, Geotechnical Special Publication 149, American Society of Civil Engineers, Reston, VA, 212-219.

X. Jin, B. Luke, J. Louie, 2006, "Comparison of Rayleigh wave dispersion relations from three surface wave measurements in a complex-layered system," *Proceedings*, GeoCongress 2006, ed. D. J. DeGroot, J. T. DeJong, J. D. Frost, and L. G. Baise, American Society of Civil Engineers, Reston, VA, CD-ROM, 6 pp.

Y, Liu, 2006, "Site response projections for deep sediment columns and earthquake microzonation for the Las Vegas Basin," Ph.D. dissertation, University of Nevada Las Vegas.

B. Luke, W. Taylor, J. Wagoner, Y. Liu, and Q. Su, 2006, "Correlating a sparse seismic data set with lithology for site amplification investigations," *Proceedings*, Second International Conference on Engineering Geology and Geotechnical Engineering, Wuhan, China, June 2006. *Invited presentation.*

H. Murvosh, B. Luke, B. McLaurin, T. Higgins, and W. Quinn, 2006, "Research and development of Las Vegas valley Vs(30) map," *Proceedings*, 40th Annual Symposium on Engineering Geology and Geotechnical Engineering. Idaho State University, Pocatello.

H. Murvosh, B. Luke, W. J. Taylor, Y. Liu, X. Jin, 2006, "Characterizing shallow shear wave velocities in fabulous Las Vegas: Processes and site selections," *Proceedings,* Symposium on the Application of Geophysics to Engineering and Environmental Problems, Environmental and Engineering Geophysical Society, Denver. CD-ROM P-180, 1325-1333.

R. Sack, B. Luke, A. Ebrahimpour, and J. Keller, 2006, “Seismic risk assessment of essential buildings in Clark County, Nevada.” *Proceedings*, 8th U.S. National Conference on Earthquake Engineering, Earthquake Engineering Research Institute, CD-ROM, paper no. 342.

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Q. Su, B. Luke, and T. Higgins, 2006, “Site classification for seismic risk assessment of essential structures in Clark County, Nevada,” *Proceedings*, 40th Annual Symposium on Engineering Geology and Geotechnical Engineering. Idaho State University, Pocatello. *Recognized for best student presentation.*

Y. Liu, B. Luke, S. Pullammanappallil, J. Louie, and J. Bay, 2005, “Combining active- and passive-source measurements to profile shear wave velocities for seismic microzonation,” *Earthquake Engineering and Soil Dynamics*, ed. R. W. Boulanger, M. Dewwolkar, N. Gucunski, C. Juang, M. Kalinski, S. Kramer, M. Manzari and J. Pauschke, Geotechnical Special Publication 133, American Society of Civil Engineers, Reston, VA , 977-990.

W. J. Taylor and C. dePolo, 2005, “Quarternary faults in Southern Nevada and the Central Basin and Range Province,” Program with Abstracts, 2005 Annual Meeting, Association of Engineering Geologists, v. 48, July, p. 88.

W. J. Taylor, E. Fossett and J. Wagoner, 2005, “Tectonic controls on the Tertiary and Quaternary development of Las Vegas Basin, Nevada: Seismological Society of America, on-line abstracts, http://www3.seismosoc.org/abstracts.

Y. Liu and B. Luke, 2004, “Role of shallow soils in defining seismic response of a deep basin site subjected to high-energy explosive loading,” *Proceedings,* 11th International Conference on Soil Dynamics and Earthquake Engineering and 3d International Conference on Earthquake Geotechnical Engineering, ed. D. Doolin, A. Kammerer, T. Nogami, R. B. Seed, and I. Towhata, Stallion Press, 17-24.

ATTACHMENTS

Attachment 1	X. Jin and B. Luke, 2006, “Comparison of three surface wave measurements and a seismic downhole measurement in a complex-layered system,” *Site and Geomaterial Characterization*, Ed. A. Puppala, D. Fratta, K. Alshibli, and S. Pamukcu, Geotechnical Special Publication 149, American Society of Civil Engineers, Reston, VA, 212-219.
Attachment 2	X. Jin, B. Luke, J. Louie, 2006, “Comparison of Rayleigh wave dispersion relations from three surface wave measurements in a complex-layered system,” *Proceedings*, GeoCongress 2006, ed. D. J. DeGroot, J. T. DeJong, J. D. Frost, and L. G. Baise, American Society of Civil Engineers, Reston, VA, CD-ROM, 6 pp.
Attachment 3	Y, Liu, 2006, “Site response projections for deep sediment columns and earthquake microzonation for the Las Vegas Basin,” Ph.D. dissertation, University of Nevada Las Vegas.
Attachment 4	B. Luke, W. Taylor, J. Wagoner, Y. Liu, and Q. Su, 2006, “Correlating a sparse seismic data set with lithology for site amplification investigations,” *Proceedings*, Second International Conference on Engineering Geology and Geotechnical Engineering, Wuhan, China, June 2006. *Invited presentation.*
Attachment 5	H. Murvosh, B. Luke, B. McLaurin, T. Higgins, and W. Quinn, 2006, “Research and development of Las Vegas valley Vs(30) map,” *Proceedings*, 40th Annual Symposium on Engineering Geology and Geotechnical Engineering. Idaho State University, Pocatello.
Attachment 6	H. Murvosh, B. Luke, W. J. Taylor, Y. Liu, X. Jin, 2006, “Characterizing shallow shear wave velocities in fabulous Las Vegas: Processes and site selections,” *Proceedings,* Symposium on the Application of Geophysics to Engineering and Environmental Problems, Environmental and Engineering Geophysical Society, Denver. CD-ROM P-180, 1325-1333.
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Attachment 11	W. J. Taylor and C. dePolo, 2005, “Quarternary faults in Southern Nevada and the Central Basin and Range Province,” Program with Abstracts, 2005 Annual Meeting, Association of Engineering Geologists, v. 48, July, p. 88.
Attachment 12	W. J. Taylor, E. Fossett and J. Wagoner, 2005, “Tectonic controls on the Tertiary and Quaternary development of Las Vegas Basin, Nevada: Seismological Society of America, on-line abstracts, http://www3.seismosoc.org/abstracts.
Attachment 13	Y. Liu and B. Luke, 2004, “Role of shallow soils in defining seismic response of a deep basin site subjected to high-energy explosive loading,” *Proceedings,* 11th International Conference on Soil Dynamics and Earthquake Engineering and 3d International Conference on Earthquake Geotechnical Engineering, ed. D. Doolin, A. Kammerer, T. Nogami, R. B. Seed, and I. Towhata, Stallion Press, 17-24.