

## MAPPING GROUND-SHAKING HAZARD FOR LAS VEGAS, NEVADA (USA)

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### ABSTRACT

Las Vegas, Nevada is situated in a deep, normal-fault-bounded, alluvium-filled basin located in the western United States. Seismic response in the basin has strong geographic correlation. Historic records of ground motions show significant amplification in the east-central, lowest-lying parts of the basin. The zone of significant amplification corresponds to concentrations of clay-rich sediments. In much of the rest of the basin, the alluvium is predominantly coarse-grained and of mixed grain size. A three-dimensional map of shallow shear wave velocities is required to feed seismic hazard investigations. Using this and other site parameterization information, a ground-shaking hazard map is being developed through one-dimensional equivalent-linear analyses, with particular care paid to appropriate site parameterization for deep sediments. Investigations to date point to a model for the Las Vegas basin comprising two response units, where one having predominantly clay in the upper 30 m is expected to have higher ground motions than the rest of the basin. A site response envelope for each unit can be developed through Monte Carlo simulation based on seismic hazard analyses for all known significant sources. Results feed structural analyses of critical facilities and lifelines.

Keywords: site amplification, site response analysis, Las Vegas

### INTRODUCTION

Las Vegas, Nevada (USA) is situated in a deep, normal-fault-bounded, alluvium-filled basin located in the western United States (Fig. 1). Gravity and seismic studies indicate complex basin geometry with the pre-Cenozoic boundary as deep as 5 km (Langenheim et al., 2001) (Fig. 2).

New studies are showing that the earthquake hazard in the Las Vegas Basin is more significant than previously thought (Fossett, 2005; dePolo et al., 2006). For example, the Black Hills fault, located to the south of the Basin, was only recently found to have potential for a  $M_w = 6.9$  event with a slip rate as high as  $0.1 \text{ mm yr}^{-1}$  (Fossett, 2005). The earthquake hazard comes from a number of Quaternary faults within 100-150 km of the Basin (U.S. Geological Survey Quaternary Fault and Fold Database of the United States; <http://earthquake.usgs.gov/regional/qfaults/>) including throughgoing tectonic faults within and bounding the Basin (Fig. 3). A recent deep seismic imaging campaign imaged some of these Quaternary faults penetrating into the basement rock, indicating that they are tectonic in origin (Snelson et al., 2005).

At the University of Nevada Las Vegas a team of geologists, seismologists, geotechnical engineers and structural engineers has formed to characterize the earthquake hazards and risks in the population centers of southern Nevada, which encompass the Las Vegas Basin and its surroundings. The project spans faults characterization, delineation of regional and local geologic structure, shallow sediment characterization, site

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response projection, and structural response analyses for critical facilities. The purpose of this paper is to present recent progress in differentiating site response units and projecting their characteristic site response through analyses of shallow sediment columns, within the context of the overall project.

## **ZONATION DRIVEN BY OBSERVED SITE AMPLIFICATION AND LITHOLOGY**

Because seismograph coverage in the basin has been inconsistent over time, the database of recorded earthquake events is sparse. However, proximity to the Nevada Test Site (about 100 km) yielded numerous weak-motion datasets from underground nuclear weapons testing, and a fortuitous recording of one  $M_L$  5.6 earthquake, which occurred in the vicinity of the Nevada Test Site (Fig. 4). Recordings from these events reveal site amplification factors from five to ten or more in the east-central, lowest-lying parts of the Basin with respect to sites on the Basin margins, situated near rock (Su et al., 1998; Rodgers et al., 2006).

The amplifications most likely result from combined effects of local and regional structure, basin geometry and response of the shallow sediment column. Here, we explore the role of the latter in site response for the Las Vegas Basin.

Observed amplifications suggest construction of two overall response units based on lithology (Liu, 2006). (We use the term “lithology” in its broad sense to apply to all manner of basin-fill sediments, whether indurated or not.) A lithologic database was compiled from 1150 well logs recorded by the regional Water District (Taylor et al., 2005). From this, we consider predominant lithology over the upper 30 m. The “fine sediment” response unit is defined where clays predominate in the upper 30 m. It encompasses the region of highest observed amplifications. This is in the low-lying east-central portion of the Basin. All other lithologies are combined into the second, “coarse sediment” response unit. These comprise primarily coarse- and mixed-grain size deposits. The Basin contains few lithologies dominated by silts or sands. The response unit boundaries generally coincide with those of the Basin’s alluvial fans (Fig. 5). Carbonate cementation to form rocklike “caliche” occurs throughout the Basin. Sediments recorded as such in the lithologic logs are mapped into the coarse-sediment category, regardless of the type of sediment that has been cemented.

## **SITE RESPONSE ANALYSES**

A first-generation site response analysis was conducted by Liu (2006) using the well-known one-dimensional equivalent-linear method (Schnabel et al., 1972; Idriss and Sun, 1992), with the computer program SHAKE2000 (Ordóñez, 2000). The sediment column was parameterized to a depth of 400 m. This depth was selected following an iterative process using weak-ground-motion data whereby projections were matched to measured responses from nuclear test events (Liu and Luke, 2004). The preferable approach would be to model the entire sediment column, placing the base at the pre-Cenozoic “bedrock” surface. For the Las Vegas Basin, having depths in excess of 2 km, this is not feasible because little is known about the lithology and velocity structure of the sediment column at such depths, and even less is known about the material damping and modulus reduction with shear strain at depth. Another option would be to terminate the profile at so-called “engineering bedrock,” which is the depth at which the  $V_s$  reaches 2500 feet per second, or 760 m/s. For the Las Vegas Basin this can occur at various depths. Some sites show very high velocities at very shallow depths due to the presence of caliche. And on the other hand, velocities lower than this threshold have been measured to 200 m depth. A benchmark analysis for a site in the Las Vegas Basin where the engineering bedrock criterion was satisfied at a depth of approximately 50 m showed that it was not possible to capture measured response using such a shallow sediment column (Liu and Luke, 2004).

The shear wave velocity ( $V_s$ ) profile is a key input parameter for site response analysis. Due to recent changes in building codes and rapid development of the Basin, many new  $V_s$  measurements are being made and placed in the public record. The data are being fed into a graphical imaging program to be interpolated into a three-dimensional map of  $V_s$ . Studies are underway to use the much richer lithologic database to

guide the 3-D interpretation of  $V_s$  (Luke et al., 2006; Murvosh et al., 2006). An early version of this model, presented here purely to illustrate the process, appears in Fig. 6.

For the analysis described here, only twelve  $V_s$  datasets were used to characterize the response units, seven from the fine-sediment unit and five from the coarse-sediment unit. These datasets derived from combined active- and passive-source surface wave testing (Liu et al., 2005). Most are less than 200 m deep, and the shallowest extends only 50 m. Assuming a normal distribution, the characteristic  $V_s$  profile for each unit was defined by a mean and interpreted standard deviation (Fig. 7). Standard deviations were assigned from the sparse datasets using engineering judgement. For damping and modulus reduction, generic, depth-adjusted values were used (e.g., Stokoe and Darendeli, 2001).

To test the site parameterizations, Liu (2006) studied ground motions measured during four nuclear tests and the Little Skull Mountain earthquake. Deconvolved data from two sites near rock on the perimeter of the Basin were used as input motion. Spectral response envelopes for each unit were generated through Monte Carlo simulation. Ten thousand simulations were run for each unit. Outcomes were compared to 61 responses measured at 26 sites across the Basin. For the fine-grained response unit, the 95th percentile response envelope generally bracketed measured ground motions up to 1.3-second periods. For the coarse-grained unit, because  $V_s$  data were so sparse, the standard deviation was large and the response tended to be overestimated (Liu, 2006).

Once validated, the process can be applied to build characteristic strong-motion response spectra for each of the two units. A target “bedrock” response spectrum was constructed for each unit using attenuation relationships of Sadigh et al. (1997) and Abrahamson and Silva (1997), considering the six Quaternary faults from the USGS database that were determined to be significant. Nineteen input ground motions were selected from the PEER Strong Motion and Nevada Seismological Laboratory databases to fit the target spectra. The scaled response from the Little Skull Mountain earthquake was also used. Monte-Carlo simulation was applied to build response envelopes.

Summary spectra (5% damping) for the fine-sediment response unit are shown in Fig. 8, in the form of an envelope bounded by the maxima of the mean and 95th percentile responses. For the 95th percentile response, peak ground acceleration is 0.31 g, and peak spectral acceleration is 1.1 g, at 0.3-sec period. Amplification factors, considering 84th percentile motion at bedrock and 94th percentile at ground surface, are 1.6, 2 and 1.8 for peak ground acceleration (PGA), 0.2-second spectral acceleration (SA) and 1-second SA, respectively. The spectral envelope is compared to deterministic design spectra from the Uniform Building Code (ICBO, 1997) for the appropriate site classes (C, very dense soil and soft rock; and D, stiff soil) in Fig. 8. The UBC is conservative for peak ground acceleration but underestimates peak spectral acceleration and long-period motion with respect to the simulations. Summary results for the coarse-sediment response unit (not shown) are similar, and even higher than for the fine-sediment response unit. We would expect to see smaller, not larger, amplifications in the coarse-grained media. This expected behavior might be overshadowed by the sparsity of the velocity dataset. The hypothesis will be rigorously tested in the future, when analyses can be repeated with a more robust velocity dataset.

### SOILS CHARACTERIZATION FEEDS STRUCTURAL RESPONSE ANALYSES

Results of the site response analyses feed investigations of structural response. Emphasis is placed on critical facilities and lifelines including fire and police stations, hospitals, schools, bridges, and pipelines. The only geotechnical input for these analyses is the seismic site classification per the International Building Code (ICC 2006). This classification is assigned based on  $V_s$  if available, and lithology otherwise (Su et al., 2006).

The risk assessment of critical buildings included 325 different facilities (1,002 individual buildings) consisting of 46 fire stations, 3 hospitals, 10 police stations, 184 elementary schools, 51 middle schools and 31 high schools (Sack et al., 2006). The “Rapid Visual Screening (RVS) of Buildings for Potential Seismic

Hazards” of the U. S. Federal Emergency Management Agency (FEMA) and the software HAZUS-MH Level II (also by FEMA) were used in this study. A 1% probability of building failure was used as the cut-off point of acceptability for both deterministic event (i.e., a given earthquake scenario: a M6.9 event on the Frenchman Mountain fault) and probabilistic approach using the Maximum Considered Earthquake of the U.S. Geological Survey (USGS). The final phase in the assessment was the formulation of a list of buildings most prone to seismic damage. This was accomplished by incorporating the results of four analyses using RVS and HAZUS. It was noted that any building that “failed” all four methods could pose a significant threat. As a result, a list of 47 buildings, approximately 5% of the buildings considered, was identified. These buildings require more detailed analyses, to include site-specific  $V_s$  measurements.

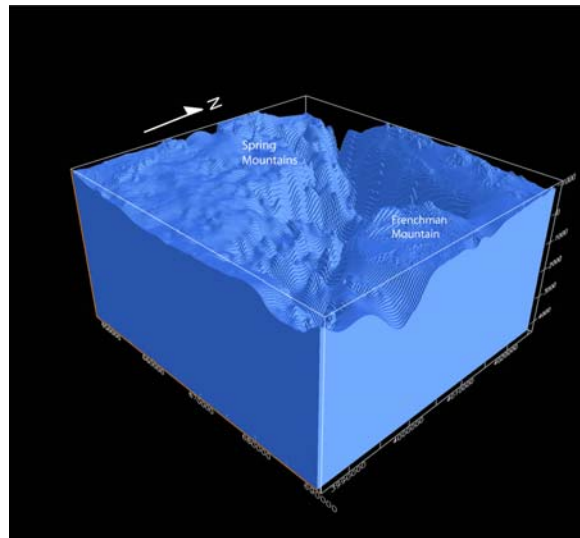
The work on highway bridges was performed with help from the Nevada Department of Transportation (NDOT) in which 786 bridges were considered in the study region (Porter, 2006). The risk analysis comprised two components: (1) importance analysis, and (2) vulnerability analysis. The importance analysis takes into account average daily traffic, detour length, bridge length, pedestrian traffic, railroad traffic and defense route. The vulnerability analysis was completed by utilizing the FEMA software HAZUS-MH Level II. The latter analysis incorporated information on the structural systems, combined with geotechnical site classification. The final product of this study is a bridge priority list that can help the NDOT Bridge Department in identifying bridges with high seismic risk. Bridges receiving significantly large risk scores will be analyzed in detail to determine whether they are candidates for retrofit or replacement.

## CONCLUSIONS

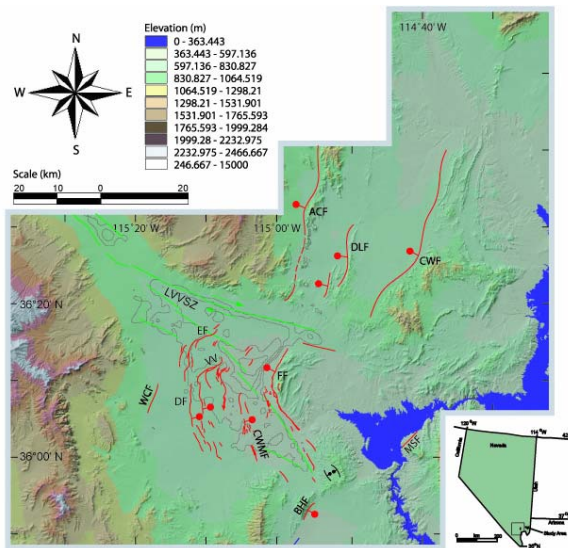
The earthquake hazards and risks for the Las Vegas Basin are greater than previously thought. Site response measurements and analyses indicate that ground motions are amplified on the clay-rich Basin floor. A first-generation Monte-Carlo simulation considering credible events on known Quaternary faults in the region yielded a projected response envelope for this unit having 95<sup>th</sup>-percentile PGA of 0.31 g and  $S_{a(max)}$  of 1.1 g at 0.3 sec, representing amplification factors up to two or more with respect to bedrock. An identical analysis for the coarse and mixed-grain size deposits in the Basin yielded amplifications that were even higher, but with far greater uncertainty, due to the sparse supply of  $V_s$  data. Basin-wide, ground motion projections are likely to increase as more and better information is incorporated about basin geology and velocity structure of shallow sediments, and about local faults, particularly those in the near-field. Results feed detailed response analyses of critical structures that fail screening tests.



**Figure 1. Las Vegas Basin. Landsat image processed by Michael Rymer, U.S. Geological Survey, North is to the top. Image width is about 120 km.**

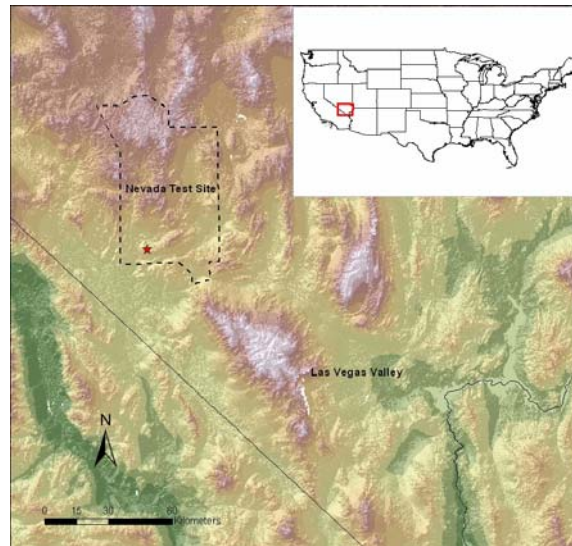


**Figure 2. Pre-Cenozoic surface of Las Vegas Basin, according to model of Langenheim et al. (2001)**

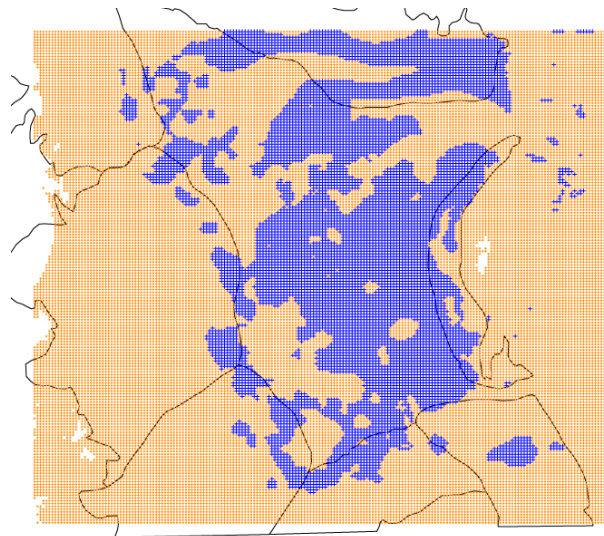


**Figure 3. Faults of the Las Vegas Basin (Bell, 1981; Bell and Smith, 1980; Bingler, 1977; Castor et al., 2000; Matti and Bachuber, 1985; Matti et al., 1987; Matti et al., 1999)**

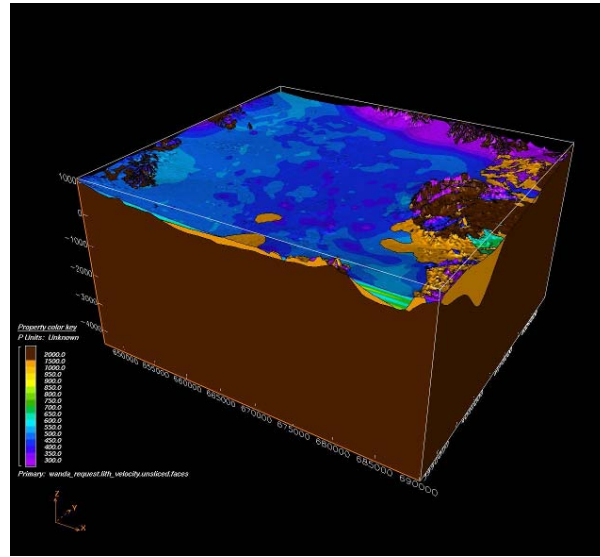




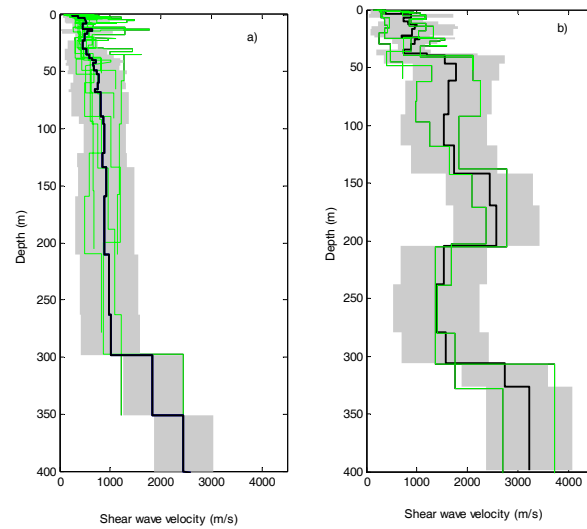
**Figure 4. Seismic sources for events studied were within the Nevada Test Site. Star marks epicenter of Little Skull Mountain earthquake.**



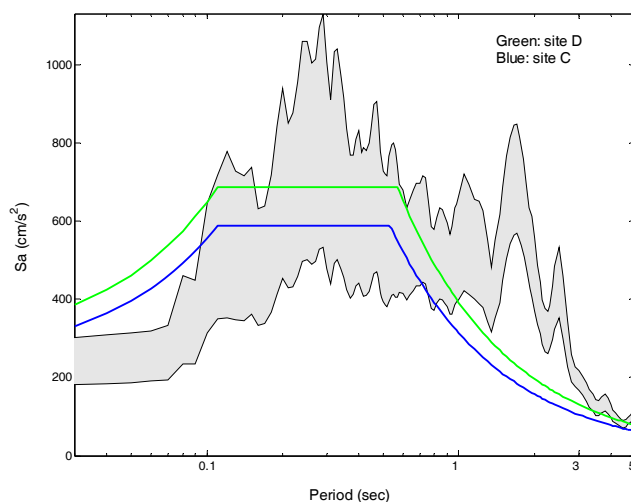
**Figure 5. Las Vegas Basin: predominant lithologies in the upper 30 m, and approximate boundaries of fans. Blue – clay; Orange – other, predominantly coarse and mixed-grain size media. North is to the top.**



**Figure 6. Las Vegas Basin: Conceptual map of  $V_s$  interpolated using lithologic data**



**Figure 7.  $V_s$  profiles for (a) fine-sediment and (b) coarse-sediment response unit. Black – mean; grey – interpreted 95% confidence interval; green – measured. From Liu (2006).**



**Figure 8. Results of Monte Carlo simulation for the fine-grained response unit, enveloping peak mean and 95<sup>th</sup> percentile response. For comparison, generic design spectra from the Uniform Building Code for two site classes are also shown. From Liu (2006).**

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