Earthquake Hazard Class Mapping by Parcel in Las Vegas Valley

J. N. Louie1, S. K. Pullammanappallil2, A. Pancha2, and W. K. Hellmer3

1Nevada Seismological Laboratory, Nevada System of Higher Education, MS 0174, University of Nevada, Reno, NV 89557; PH (775) 784-4219; FAX (775) 784-4165; email louie@seismo.unr.edu
2Optim Seismic Data Solutions, 200 S. Virginia St. Suite 560, Reno, NV 89501; PH (775) 236-5891; FAX (775) 287-2581; email satish@optimsoftware.com
3Clark County Department of Development Services, 4701 W. Russell Rd., Las Vegas, NV 89118; PH (702) 455-8095; email wkh@co.clark.nv.us

ABSTRACT

Clark County, Nevada completed the very first effort in the United States to map earthquake hazard class systematically through an entire urban area. The County and the City of Henderson contracted with the Nevada System of Higher Education to classify about 500 square miles including urban Las Vegas Valley, and exurban areas considered for future development. The Parcel Map includes 10,721 surface-wave array measurements that classify individual parcels on the NEHRP hazard scale. We introduce a “C+” Class for sites with Class B average velocities but soft surface soil. The measured Parcel Map shows a clearly definable C+ to C boundary on the west side of the Valley. The C to D boundary is much more complex. Using the parcel map in computing shaking in the Valley for scenario earthquakes is crucial for obtaining realistic predictions of ground motions. Despite affecting only the upper 30 meters, the Vs30 geotechnical shear-velocity from the Parcel Map shows clear effects on 3d shaking predictions computed at frequencies from 0.1 Hz to 1.0 Hz.

INTRODUCTION

A significant challenge for engineers and urban planners is how to meet the demand for life safety while not making the cost of building impossibly expensive. Two municipalities in southern Nevada, together with the Nevada System of Higher Education, have addressed this challenge with a comprehensive Earthquake Parcel Mapping program (Louie et al., 2011a). A systematic campaign of ten thousand microzonation measurements across the Las Vegas urban area was the main component of the Parcel Mapping program. With the measurements completed, the partners can now assess the effects that the Parcel Map measurements will have on earthquake ground-shaking predictions, using newly realistic and accurate ShakeZoning procedures (Louie et al., 2011b).

Motivation and objectives. Having a regional microzonation map that correctly identifies the seismic site class provides a valuable asset to a developing
community (Louie et al., 2011b). Microzonation helps assure that structures can be safely designed to meet building code requirements, without experiencing unnecessary additional costs due to the inherent conservatism associated with selecting a default parameter value. Undeveloped areas will take full benefit of this information to plan new construction and developed areas will also benefit when repairs, alterations or additions are performed. When microzonation is used together with data constraining the shear velocity of an urban basin at kilometer depths, such as Murvosh et al. (2011) for Las Vegas Valley, it is possible to gain improved knowledge of how subsurface geology is likely to affect ground motion.

**Background.** Measurement of shear-wave velocity (Vs) in the shallow subsurface is essential for the estimation of seismic hazard, the development of seismic-hazard maps, and the calibration of recorded ground motion data. The site class measurements are represented by the average shear wave velocity value for the top 100 feet or 30 meters (Vs100-foot or Vs30-meter) as per IBC 2006 Section 1613.5.5. It is an integral to seismic design of structures per the International Building Code and International Residential Code, (IBC) and (IRC) respectively.

Before methods for direct measurement of Vs30 became more cost-effective (Louie, 2001), earthquake-hazard mapping had generally relied upon extrapolation of statistical averages of a few measurements along geological units. Wills et al. (2000) built a microzonation map of all of California from only 500 spot measurements of Vs30. Thelen et al. (2006) and Scott et al. (2006) made systematic examinations of the spatial variance of Vs30 from transects of closely spaced measurements stretching across the Los Angeles and Las Vegas urban areas. The velocities would not correlate with any existing soil or geologic mapping, with the standard deviations of the average Vs30 in any unit much larger than the differences in the average between units. These results motivated Clark County and the City of Henderson to embark on a program of comprehensive microzonation measurement.

Earthquake-hazard mapping should not stop with shallow Vs measurement. The earthquake source, wave-propagation path, and site effects must be combined into a prediction of ground-shaking intensities at a building site, for each of the likely earthquake scenarios that could produce damaging shaking. The USGS ShakeMap tool (Wald et al., 1999) is one of the current, comprehensive means of making scenario computations. ShakeMap is based only on the statistics of relatively sparse recordings of the motions of historical earthquakes. Once shaking levels are predicted from individual scenarios, the scenarios can be combined into a probabilistic seismic hazard map (Frankel et al., 1996).

Our new ShakeZoning procedure for seismic hazard mapping will properly apply the physics of wave propagation through a geologically complex earth. Our Parcel Mapping results in Las Vegas Valley allowing us to predict wave propagation and shaking amplification across terrain that has been measured to an unprecedented degree of detail, for a US city. This paper will to show some of the effects of the new Parcel Map on earthquake-hazard assessment in southern Nevada, by providing the map as a ShakeZoning input.

The purpose of ShakeZoning (Louie et al., 2011a; known earlier as MA-CME) was initially to provide a community velocity model and seismic modeling
environment for Nevada urban areas. Las Vegas is subject to earthquake hazards both from below the local basin, and from earthquake faults up to 200 km away. ShakeZoning computations feed geological and geotechnical results such as the Parcel Map to the E3D code (Larsen et al., 2001) from LLNL for elastic wave-propagation computation. E3D was most recently vetted for ground-shaking prediction at the March 24-25, 2004 Next Generation Attenuation (NGA) Workshop. Such vetting helps to physically and geologically validate ShakeZoning results. Comparing ShakeZoning seismogram output against earthquake recordings would complete validation.

METHODS

Conduct of Surveys for Parcel Mapping. The Nevada System of Higher Education (NSHE) was contracted by Clark County Department of Development Services (CCDDS) and the City of Henderson (CoH) to create a soil classification map based on site-specific shear-wave velocities (“microzonation map”) of the urbanized part of the County. NSHE subcontracted Optim SDS to perform this work under their supervision. The areas characterized included the urbanized and urbanizing areas of Unincorporated Clark County, the urbanized area of the City of Henderson, and portions of the City of Las Vegas within Las Vegas Valley; plus certain outlying planned developments.

Optim SDS performed all necessary tasks for completion of the work, including field data acquisition, data processing and reports, working with University personnel. Optim SDS measured shear velocity as a function of depth at each of the locations using the refraction-microtremor (ReMi) surface array technique. Louie (2001) developed the refraction microtremor technology as a rapid and cost-effective method of measuring Vs30-meter to meet the IBC code (BSSC, 1997), and to derive site conditions. The technology is owned by the State of Nevada, licensed to Optim, and commercially available as SeisOpt®ReMi™ (© Optim 2001-2011). This method has been peer reviewed and blind tested against borehole measurements, and MASW and SASW surface-wave results (Louie, 2001; Liu et al., 2005; Stephenson et al., 2005; Thelen et al., 2006). Refraction microtremor is a volume-averaging surface-wave measurement, averaging velocities where geology is laterally variable, thus providing a more appropriate measure of site effects on earthquake wave propagation than single-point data obtained from downhole logs.

The NEHRP/IBC Site Class is calculated from the measurement results using the equations and tables provided in the 2006 International Building Code book. Note that even though Vs100-foot (Vs30-meter) values may give you an average velocity that is Site Class A or B, additional criteria defined in the same section of the IBC 2006 code book must be applied by a geotechnical engineer.

In determining the appropriate measurement density to be used, Optim SDS utilized Southern Nevada Technical Guidelines as a basis for a data density of about one velocity sample per 36 acres (0.146 km²). In several areas, due to proximity to key infrastructure, identified geology of interest, and velocity anomalies discovered in the data set as the project progressed, data density was increased to better define the interpolated modeled surface in those areas. All seismic array locations were intended
to maintain an average test coverage or data density of one array per 36 acres (0.146 km²) with no less than 1000 feet (0.3 km) measured midpoint to midpoint between each array location.

Nominally, each site was measured by a linear ReMi array with 24 channels of vertical geophones spaced at 8 meters (Figure 1). Ambient noise microtremor was recorded using standard vertical 4.5 Hz geophones recorded at a rate of two milliseconds for intervals of 30 seconds each. In all, a total of 12 to 20, 30-second recordings were collected for each seismic array. In addition, hammer hits using an 8-pound or 10-pound sledge and strike plate were collected at approximately 5 m and 10 m off both ends during normal passive data collection, to increase high frequency energy and resolution at 0.5- to 5-m depths. This systematic addition of “active noise,” in line with the refraction microtremor arrays, helped us avoid the intramethod variability discussed by Cox and Beekman (2011).

![Figure 1. Photos of two geophone arrays recorded for the Parcel Map.](image)

The noise records were processed using the SeisOpt® ReMi™ software (© Optim, Inc., 2001-2010) that uses the refraction microtremor method (Louie, 2001). Processing steps were: 1) create a velocity spectrum (p-f image) from the noise data by wavefield transformation; Rayleigh-wave dispersion-curve picking along a "lowest-velocity envelope" bounding the energy appearing in the p-f image; and 3) interactive shear-wave velocity-profile modeling. The modeling can be subjective and must be done with a constraint that a minimum number of layers be used.

Quality assurance of results begins by plotting of the modeled velocity profiles within each section, to assure consistency. If one model differs from surrounding measurements, or is anomalous given known topographic changes, remodeling or re-picking of the dispersion curve may be needed. If there are anomalously high-velocity layers within the upper 100 feet, the reliability of low-frequency dispersion curve picks is examined. If the site is classified as Class B, the high frequency data are more carefully scrutinized to ensure there is velocity information to determine layers in the upper 20 feet. “Blind” tests were periodically conducted to test the repeat ability of the data and analysis results. Seismic data were collected using comparable acquisition equipment by geophysicist James O’Donnell, of Las Vegas, independently at the same location of seismic arrays obtained by Optim SDS. Interpreter bias in dispersion picking and in modeling are key causes of
variation in refraction microtremor results, so the blind tests employed entirely different interpreters.

**Earthquake Ground-Shaking Prediction.** The ShakeZoning tools assemble the available geological and geophysical data sets into a numerical grid for wave-propagation computation, as described by Louie (2008) and Louie et al. (2011a). We will show here an example grid to compute the shaking induced in Las Vegas Valley (LVV) by the June 1992 magnitude 5.5 Little Skull Mountain (LSM) earthquake.

The grid includes basin-thickness and geotechnical data at various scales (Louie et al., 2011a; b). The ShakeZoning tools interpolate the disparate data sets onto a regular grid, following instructions for how one data set may take precedence over another where they overlap. For the LSM model, three datasets are combined in this way: 1) the regional geologic map controls the default shallow geotechnical Vs30-meter, 250 m/s for basin sites and 760 m/s for rock sites; 2) the Las Vegas refraction microtremor transect, sites by B. Luke at UNLV, stratigraphy correlated to 1145 wells by W. Taylor of UNLV and G. Wagoner of LLNL, all from Scott et al. (2006); and 3) the raw 10721 Parcel Map measurement results discussed below.

We set up the LSM scenario computation in the ShakeZoning tools to yield 0.1-Hz waves on a 236 NE-SW by 501 NW-SE by 41-node deep grid with a dh=dx=dy=dz grid spacing of 0.5 km. The grid includes the LSM source zone near its NW end. A model of intrinsic seismic attenuation “Q” was developed following Olsen et al. (2003). For this historical earthquake the earthquake source parameters are provided by Smith et al. (2001). Source parameters for scenario earthquakes are derived from the USGS Qfaults database (USGS and CGS, 2010). The grids completed by ShakeZoning are fed to the E3D code (Larsen et al., 2001) from LLNL for elastic wave-propagation computation on workstations or a small Linux cluster.

**RESULTS**

**Parcel Mapping.** ReMi data from a total of 10721 sites were acquired, processed and submitted to CCDDS and the CoH. Figure 2 shows representative results from sites yielding velocities in the NEHRP B, C, and D ranges. Figure 3 shows the complete microzonation map generated using ArcGIS and the Vs100-foot (Vs30-meter) values determined from the distribution of seismic arrays. The method of krigging was used to produce this map.

J. O’Donnell conducted parallel “blind” tests at 93 randomly selected sites. He analyzed and modeled the blind-test data independently of Optim SDS and NSHE, to test for interpreter bias. The blind-test Vs100-foot velocities were on average only 0.26% percent higher (5 ft/sec out of an average Vs100-foot of about 2000 ft/sec; or 1.5 meter/sec out of an average Vs30-meter of about 610 m/sec) than the velocities obtained at the same sites by Optim SDS. This tiny average difference shows that there was no significant systematic bias in the data analysis or modeling procedures. The root-mean-squared (RMS) difference between O’Donnell’s blind analyses and Optim SDS’s is 4.92% (98 ft/sec or 30 m/s RMS difference). Only six of the 93 blind-test sites showed a difference with a magnitude greater than 10%, and the greatest
difference was only 13.55%. These results show the consistent high quality of the Parcel Mapping measurements.

Figure 2. Parcel Map p-f (left) and Vs(z) (right) results from typical sites having velocities in the NEHRP class ranges B (upper), C (middle), and D (lower). Note scale changes on each plot.

It is to be noted that, based purely on the Vs100-foot value, Site Class B values would be shown in the microzonation map (figure 3). IBC 2006 Section 1613.5.5 states that: “The rock categories, Site Classes A and B, shall not be used if there is more than 10 feet (3048 mm) of soil between the rock surface and the bottom of the spread footing or mat foundation.” So, when the values suggest Class B, site-specific consideration should be made (depth of foundation, competency of rock etc.) before deciding whether it is a Site Class B. At most of the higher-velocity sites, our shear-velocity profiles show more than 10 feet (3.0 m) of low-velocity soil at the surface. Accordingly, we are suggesting a Site Class we call “C+” to describe these areas, denoted with red in figure 3.
Figure 3. Map showing the IBC seismic zoning results of the Earthquake Parcel Mapping projects sponsored by Clark County and the City of Henderson. Gray lines are municipal and state boundaries. The IBC “D” zone is medium blue; the IBC “C” zone is green; and the proposed IBC “C+” zone is red.

The measured Parcel Map shows a clearly definable C+ to C boundary on the west side of Las Vegas Valley (red to green in figure 3). The boundary may be associated with the bases of the alluvial fans emanating from the Spring Mountains, where the sediments become finer-grained (Scott et al., 2006). The C to D boundary (green to blue) is on the other hand much more complex, and difficult to associate with any known geological features.

**Earthquake Ground-Shaking Prediction.**

The Little Skull Mountain earthquake scenario is one possible example out of the eight additional faults in the USGS Qfaults database (2010) that the USGS National Hazard Maps (Frankel et al., 1996) rate as probabilistically important to seismic shaking potential in Las Vegas Valley. We use the LSM scenario at 0.1 Hz here to demonstrate the crucial effects the Parcel Map results have on even low-frequency ground shaking in the Valley. Figure 4 shows this effect, unexpectedly strong given that the wavelengths of the 0.1-Hz waves modeled are 100 times larger than the 30-meter depth extent of the Parcel Map measurements.
At such long wavelengths the effects of the Vs30-meter variations found in the Parcel Map (figure 4, upper left) should be minuscule. The amplifications (red) and de-amplifications (blue) are predicted in figure 4 (upper right) from the measured Vs30 relative to the IBC assumptions only, by the one-dimensional equations in the IBC Code (2006) and in ShakeMaps (Wald et al., 1999). The 1-d amplifications are up to 64% in figure 4 (upper right). These amplifications should only appear at much higher frequencies, above 1 Hz. The 0.1-Hz waves should respond mostly to the geologic basin, figure 4 (lower left).

However, figure 4 (lower right) shows 0.1-Hz amplifications, relative to an IBC default geotechnical map, of up to 36%. The 30-meter-deep Parcel Map was the only variant between the two ratioed scenarios. This is from fully 3-d, physically and geologically accurate ShakeZoning computation. Further, the unexpectedly high amplification (red on figure 4, lower right) is not predicted at the location of the lowest Parcel Map velocities, nor at the greatest basin depth, nor steepest basin-floor slope. As well, the 64% de-amplifications (blue) on the west side of the Valley predicted by the 1-d model in figure 4 (upper right) are not supported by the realistic 3-d computations. This observation suggests that the current IBC may be too permissive in some higher-velocity areas.

DISCUSSION AND CONCLUSIONS

The Parcel Mapping project was completed successfully for Clark County and the City of Henderson. In all, 10721 individual seismic arrays/lines were assigned, deployed and spatially located in a systematic manner, maximizing the density of the database coverage within urban Clark County. This achievement has put southern Nevada at the forefront of earthquake-hazard mitigation efforts worldwide.

Based on the GIS seismic shear-velocity database developed by NSHE and Optim SDS, the project provides Clark County and the City of Henderson a single shear-wave velocity-based Parcel Map with contoured values corresponding to the site classifications of the IBC and NEHRP definitions for site class. Velocity databases from the CCDDS and the CoH were integrated into a single Vs database and the interpolated velocity map was based on the entire joint database, providing seamless interpolation across the CCDDS and CoH boundaries. This Parcel Map provides city planners, building officials, design professionals, and researchers alike the opportunity to determine the actual site class value of a particular parcel before a single site-specific investigation is performed. The Parcel Map is available to anyone through http://gisgate.co.clark.nv.us/openweb/

We show the shallow microzonation of the Parcel Map to be an essential component in the accurate prediction of earthquake ground shaking across Las Vegas Valley. This is true even at low frequencies that are of interest mostly to the taller buildings in the area. Additional scenario computations are under development, for the eight dangerous earthquake faults in the region, and for higher wave frequencies, up to 1 Hz. The ShakeZoning tools developed in this effort are available at http://crack.seismo.unr.edu/ma, to aid engineers and planners in the region.
Figure 4. Maps of the Las Vegas Valley (LVV) section of the tilted LSM ShakeZoning scenario grid. (upper left) Default geotechnical map with ~9000 Parcel Mapping Project Vs30-meter measurements included on top of the IBC defaults. (upper right) Shaking amplification expected from the ratios of measured geotechnical velocities over the IBC default velocities, under a simple 1-d model. Amplification of 120% or more is shown as red, and de-amplification to 80% or less is blue. (lower left) LVV map showing the basin floor in shaded relief. (lower right) ShakeZoning PGV ratio map comparing the 0.1-Hz results of the LSM scenario, comparing the Parcel Mapping result against the IBC default result. Even at these very low frequencies, where shallow geotechnical velocities should have minimal effect, comparing the physically correct ShakeZoning computation against the IBC defaults shows surprisingly large and complex patterns of amplification (red) and de-amplification (blue), greater than 20%.

REFERENCES


