The Clark County Parcel Map and Effects on Earthquake Ground Motions in Las Vegas Valley

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Outline

- Nevada Earthquake Research
- The Clark County Parcel Map
- How Vs30 affects 0.1-0.5-Hz shaking
- Nevada ShakeZoning vs. ShakeMap
- Simple Probabilistic Hazard Mapping

Definition: \( \text{Vs30} = \text{Average Vs to 30 m depth} \)
Seismology Timeline for Nevada

- **1940-1960:** M4+ induced Lake Mead
- **1970s:** NEHRP & USGS funds set
- **1972:** <0.5M in Las Vegas
- **1992:** M5.7 LSM event, largest in So. NV
- **2007:** >2.0M in Las Vegas
Seismology Timeline for Nevada

- For 15 years, 20,000 houses permitted every year
Feb. 2008 Wells M6.0 - A Low-Probability Event

1.0 sec SA (%g) with 2% Probability of Exceedance in 50 Years
USGS Map, Oct. 2002rev

Wells

Reno

Las Vegas

USGS Map, Oct. 2002rev
Zero government aid for reconstruction!

Photos by Marilyn Newton, Reno Gazette-Journal
Seismology Timeline for Nevada

- 4x population increase - more EQ risk
- Possibly greater EQ hazard than realized in 1970s-80s
- USGS funding is level at $150k/year
- DOE-funded nuclear-test readiness built capacity 2001-2005
Las Vegas Transect

Most of Strip, Downtown

July 2003

79 sites total

1000 well logs & geologic mapping

DOE funding
Las Vegas Transect
Some correlation to faulting, soil type?
Does extrapolating $V_s$ work?

- $V_s$ assigned to soil-map units using central-City measurements.
Role of the Municipality

- Clark County (CC) mapped “Special Geotechnical Consideration” areas in 1990s
- CC won awards in the 2000s for fostering IBC compliance
- IBC requires assessment of Vs30 for every build or remodel
  - Even for a plumber putting an air conditioner on a roof!
- So. NV builders demanded a Vs30 map
  - Reduce need for site studies
Clark County & Henderson Parcel Map: A Municipal Project for IBC Enforcement

10,721 Measurements

Urban Areas of County

1 array per 20 acres per IBC
= 8 arrays per km²
< NZ$10,000 per km²
Parcel Mapping

Refraction Microtremor Surface-Wave Arrays

Every One Hand-Modeled

24-chan arrays, 200 m long
Blind Tests of Parcel Map

- Different:
  - Equipment
  - Field crew
  - Dispersion interpreter
  - Vs(z) modeler

- Match to Map Values:
  - 6 of 93 blind tests >10% off
  - 13.55% max diff.
  - 0.26% bias of average
  - 4.92% RMS difference
Clark County & Henderson Parcel Map

Parcel Classification for IBC

NEHRP C & D classes

“C+” class for NEHRP B velocities with soft surface

Entire map online at www.clarkcountynv.gov
Build Parcel Map into ShakeZoning

*Does it Make a Difference to Ground Motions?*

ShakeZoning Geotech Map

Warmer colors: lower Vs30 (meter)

Parcel Map on top of IBC default Vs30
Granularity of measurements

Correlations with elevation & fan provenance, not slope

LV
LA

Eglinton Fault
North Las Vegas
Las Vegas
Henderson

Frenchman Mtn. Fault
Black Hill Fault

“STRIP”
Decatur Fit
Statistics of the Parcel Map

*Bill Savran, SDSU-Scripps*

- Two distinct site classes from the histogram plot
- Bedrock and basin fill
- NEHRP Default Vs30:
  - Bedrock: 760 m/s
  - Alluvium: 500 m/s
- Caliche in western Las Vegas Valley responsible for some higher velocity measurements.
Fractal Dimension: \[ D = \frac{5 - \beta}{2} \] (Carr 1995)

- Linear fall on log-log spatial spectrum shows fractal nature, self-similarity at different scales.
Modeling Spatial Heterogeneity – W. Savran

- Pink noise decays as $1/f$ on the Fourier spectrum.

**Spatial Power Spectra E–W**

Pink Noise + IBC Default

$$y = 0.95518x^{-1.7117}$$

Fractal Dimension: $D = 1.6442$
• Created a synthetic Vs30 data set preserving the spatial statistics of the Parcel Map.

• Effective method for modeling the near-surface heterogeneities of Vs30.

• Cannot replicate the deterministic features seen in the Parcel Map.

• Potentially useful outside of Las Vegas Valley where some Vs30 are known.
What Next for the Parcel Map?

Map North Las Vegas

Predict scenario ground motions with ShakeZoning

Create a Nevada Earthquake Response System
Parcel Map Motivates “Nevada ShakeZoning”

- Goal is to predict earthquake shaking
  - For hazard mapping, planning
  - Building-code development and enforcement
  - Provide time histories of shaking to designers

- Next-Level ShakeZoning for Nevada
  - Based on: Wave Physics
  - Geological & Geotech data: Parcel Map unsurpassed
  - Validated against Nevada earthquake records - Flinchum paper revised for BSSA
  - Open-source NSZ software & data: crack.seismo.unr.edu/NSZ
ShakeZoning: Combines Faults, Basins, Geotech

Black Hills Fault in Google Earth with USGS Qfaults trace
Adding Physics

- Black Hills M6.5 scenario
  - Short trace but 4-m scarps noted
- LLNL’s Viscoelastic finite-difference solution
  - 0.5-Hz frequency
  - 0.20-km grid spacing
  - A few hours on a small cluster
- Mode conversion, rupture directivity, reverberation, trapping in basins
Black Hills M6.5 Scenario Results

- Max Peak Ground Velocity (PGV) > 140 cm/sec
- PGV over 60 cm/sec (yellow) bleeds into LVV through Railroad Pass
- Large event for a short fault
  - Add to hazard probabilistically
- Need to know how likely
Validating With Records of the 1992 Little Skull Mtn. M5.7 Basin depth models from Saltus and Jachens, and Langenheim, USGS

Unique geotechnical coverage from Clark County Parcel Map

B. Flinchum BSSA Paper (revised)
Good and Bad Seismogram Fits at 0.1-0.2 Hz

B. Flinchum BSSA Paper (revised)
Peak Horizontal Ground Velocities at 0.1-0.2 Hz

B. Flinchum
BSSA Paper (revised)
Surprising Effect of Parcel Map Over IBC Defaults

PGV Map at 0.1 Hz by NSZ for LSM M5.7

Amplification, %

PGV Ratio Map: Parcel Map over IBC at 0.1 Hz
Factor of 2 Effect of Parcel Map at 0.5 Hz

1-D Amplification Used in IBC, ShakeMap

3-D Amplification from ShakeZoning

Black Hills Fault Mw6.5 Grid Clark Co. Over IBC 1-D Amplification

PGV Ratio Map at 0.5 Hz

M6.5 Black Hills

Black Hills M6.5 Next-Level ShakeZoning Amplification Clark Co. Over IBC

PGV Ratio Map at 0.5 Hz
Compare ShakeMap to **ShakeZoning**

- Yellow is 60 cm/sec on both
- Geotech estimated from topography

- **ShakeZoning** shows trapping in basins
- Hazard map is difficult to predict

NSZ predicts *less* shaking in bedrock than SM
Many Fault Scenarios in Southern Nevada

- In and around Las Vegas Valley

dePolo, 2008, NBMG Map 167
Frenchman Mtn. Fault M6.7 ShakeZoning

Frenchman Mountain Mw6.7 Next-Level ShakeZoning with Clark Co. Parcel Mapping, 0.5 Hz
Effect of Parcel Map Over IBC Defaults - FMF M6.7

1D: IBC and ShakeMap

PGV Ratio Map at 0.5 Hz

3D: ShakeZoning

PGV Ratio Map at 0.5 Hz
Pushing the Predictions Through HAZUS

Open-source NSZ software & data: crack.seismo.unr.edu/NSZ

Frenchman Mountain Mw6.7 Next-Level ShakeZoning with Clark Co. Parcel Mapping, 0.5 Hz

- $8.6 Billion Loss
- 287-610 Casualties

Nevada ShakeMap Scenario Frenchman Mountain Mw6.7

- $4.8 Billion Loss
- 22-58 Casualties
Nevada Earthquake Response System

- **Before an Earthquake:**
  - Identify a million possible fault segments
    - Critical to ramp up paleoseismology and EQ network
    - Need Parcel Maps of all population centers
  - Compute physics-based shaking for each segment, to 2 Hz
    - Years of runs on medium-sized clusters
  - Gather results from grid computes into a 5 petabyte database
    - Hardware only $0.25 million
Nevada Earthquake Response System

After an Earthquake:

- **1 minute** - locate hypocenter, notify emergency responders
- **2 minutes** - initial ShakeZoning summed from 5 Pb database, update responders
- **10 minutes** - fault-rupture inversion available (uses database)
- **11 minutes** - sum final ShakeZoning from database, update responders if needed
Conclusions

- Basin trapping leads to worst-case shaking.
- 10,721 Parcel Map measurements completed in 3 years for IBC compliance in Clark County.
- NSZ validated at 0.1-Hz for Las Vegas region with 1992 LSM recordings.
- The Parcel Map has surprisingly large effects on ground motions predicted from physics.
- Nevada ShakeZoning predicts twice the damage and five times the casualties as ShakeMap, for the Las Vegas worst case.
With Many Scenarios, Define Probabilistic Hazard

- How do we induce communities to become more resilient to earthquakes?

(dePolo, 2008, NBMG Map 167)
Combine NSZ Scenarios *Probabilistically*

\[
\lambda(u \geq u_0) = \sum_M \sum_{\text{source}_j} \text{rate}(M, \text{source}_j) P(u \geq u_0|\text{site}_i, \text{source}_j, M)
\]

- \(\lambda = \) annual frequency of exceeding ground motion \(u_0\)
- \(\text{rate}(M, \text{source}_j) = \) annual rate of occurrence for an earthquake with magnitude \(M\) at source location \(j\)
- \(P = \) probability of ground motions \(u \geq u_0\) at site \(i\), if an earthquake occurs at source location \(j\) with magnitude \(M\)
- After Frankel et al., *USGS OFR 2007–1175*
Combining Scenarios: Thresholding?

- **Exceedance Level** $L_e$ - PGV of 30 cm/s, for example.

- **Thresholding** - If no scenario gives PGV over Exceedance Level of 30 cm/s at a site, the site’s Annual Rate of Exceedance is Zero.

- In zonation and public policy, sharp lines are untenable.
  - Neighbors want fair treatment

- **Excess PGV Increases A.R.E.**
  - not keeping rate($M$, source) separate from P(site, source, $M$)

\[
A.R.E.(\text{scenario}) = \text{rate(\text{scenario})} \cdot \left(\frac{\text{PGV}}{L_e}\right)^{1/2}
\]
Simple Probabilistic Hazard Map for Lake Tahoe

- Annual Rate of Exceedance for PGV of 30 cm/s

7x10^{-5}/year

Gretchen Schmauder
Ph.D. Thesis
Simple Probabilistic Hazard Map for Lake Tahoe

- Annual Rate of Exceedance for PGV of 30 cm/s

Gretchen Schmauder
Ph.D. Thesis

WT-DPF Full South Source

WT-DPF Full North Source

WT-DPF North Segment South Source

PGV rate

PGV rate

PGV rate

ARE of PGV=0.3 m/s, at C.00007/yr

1.6E-4

38.826

39.278

-120.15

-119.87

39.278

-120.15

-119.87

39.278

-120.15

-119.87

38.826

7x10^-5/year

7x10^-5/year

7x10^-5/year

Nevada

STUDY AREA

California

LV

LA

SD seismic

1883

Geological Laboratory
Simple Probabilistic Hazard Map for Lake Tahoe

- Annual Rate of Exceedance for PGV of 30 cm/s

Gretchen Schmauder
Ph.D. Thesis
Simple Probabilistic Hazard Map for Lake Tahoe

- A.R.E. 30 cm/s PGV

- NT-SLF South Source
  - 1x10^-4/year

- NT-SLF North Source
  - 1x10^-4/year

- IVF South Source
  - 5x10^-5/year

Gretchen Schmauder
Ph.D. Thesis
Simple Probabilistic Hazard Map for Lake Tahoe

- Annual Rate of Exceedance for PGV of 30 cm/s

Gretchen Schmauder
Ph.D. Thesis
Thank You
Wells, NV M6.0 2/21/2008

- ShakeMap PGV shows bulls-eyes at stations and CIIM – felt reports – zipcode centroid points
- Includes geotechnical Vs from topo slope
Wells, NV
M6.0
2/21/2008

- **ShakeZoning** uses 3D Saltus and Jachens 1995 USGS basins from gravity.
- Directivity up, **eastward**.
- Note **channeling** by basins and **tunneling** between basins.
Wells, NV M6.0 2/21/2008

- PGV map from SZ
- 3D physics-based ground motions trapped in basins.
- Directivity up, eastward.
NW-dip E directivity matches recorded PGVs better than E-dip W directivity.
How to Extrapolate Shallow $V_s$

- Correlate 75 $V_s$ measurements against stratigraphic model.
- Stratigraphy interpolated between >500 water-well logs.
Extrapolated vs. Measured

- Comparisons along Cheyenne-to-Tropicana transect.

**Comparison of Vs30 Prediction and Data**

- Well-Log Predictions
- UNR Transect Vs30 Measurements

**TRANSECT DISTANCE SOUTH OF CHEYENNE, KM**

**VS30, KM/S**

- 700
- 600
- 500
- 400
- 300
- 200
- 100
- 80
- 60
- 40
- 30
- 20
- 10
- 0
Validation of Las Vegas ShakeZoning Basin Response to 1992 Little Skull Mtn. Earthquake

- To validate NSZ we modeled the M5.7 Little Skull Mountain (LSM) earthquake
  - Largest earthquake in Southern Nevada
  - To date, best-recorded earthquake within Las Vegas Valley
Data Processing

- Rotate synthetics from tilted grid, to match recorded components
- Integrate observed seismograms
  - SAC trapezoidal integration
- Band-Pass Filter 0.1-0.6 Hz
  - Remove grid dispersion
  - Remove low-frequency noise
Near-Field Calibration

Velocity, cm/s

Time, Seconds

East–West

North–South

Vertical

Synthetic

Observed

ST01

Nevada

California

LV

LA
Differential Travel Times

- Can’t see S waves in synthetic, used R-P times
- R-P from source is sub-parallel to data S-P
- R-P in Las Vegas basin is much slower, shows late phases

\[ R - P(x) = \frac{x}{V_R} - \frac{x}{V_P} \]
With Many Scenarios, Define Probabilistic Hazard

- Recurrence Intervals:
  - Black Hills - 15 ka
  - Frenchman Mtn. - 45 ka

- e.g., PGV at UNLV:
  - ~20 cm/s from BHF
  - ~15 cm/s from FMF

- Combine rates *per annum*:
  - >15 cm/s at 0.0001 p.a.
  - >20 cm/s at 0.00007 p.a.
Feb. 21, 2008
M6.0 event near Wells, NE Nevada.

NSL ShakeMap estimates effect of assumed soils on peak ground velocity (PGV) contours.

Presently, Vs30 is only estimated from topographic slope for Nevada ShakeMaps.
Wells, NV
M6.0
2/21/2008

- E-shallow-dip fault from initial Dreger CMT.
- Hypocenter deep on fault.
- Directivity up, westward.
Wells, NV
M6.0
2/21/2008

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NSL ShakeMap estimates effect of assumed soils on peak ground velocity (PGV) contours.

Presently, Vs30 is estimated from topographic slope only for Nevada ShakeMaps.
Abbott tripled the local gravity coverage.

Model 2, developed from local research, defines the basins more sharply.

Soil Strength Map
Mogul Magnitude 5.0 Scenario Basin Model 2

West Reno basin may be 1 mile deep. Its steep walls will trap earthquake waves.

Soils are assumed to be softer (yellow to green) in basins, harder (blue) in bedrock.

A. Pancha, J. Scott, M. Clark developed Vs30 transect and map.
Mogul, NV
M5.0
4/25/2008

- Vertical strike-slip fault from initial Dreger CMT.
- Hypocenter centered on fault.
- Abbott & Louie basin.
Mogul, NV
M5.0
4/25/2008

- Vertical strike-slip fault from initial Dreger CMT.
- Hypocenter centered on fault.
- Abbott & Louie basin.

Over 5 cm/s motions near Mogul
Basins Amplify Ground Motion
Mogul, NV M5.0 4/25/2008

- Vertical strike-slip fault from initial Dreger CMT.
- Hypocenter centered on fault.
- Widmer basin.

Additional basin details near Mogul yield a more complex PGV map. (Yellow at 5 cm/s.)

Basins amplify ground motion, but in complex patterns.
West Reno, NV M5.0 4/25/2008

Why does the NOAA station on volcanic hill show the largest PGV?

M5.0 Mogul 1-Hz E3D Scenario vs.
4/25/08 M5.0 Shakemap Stations

- Measured PGV, cm/s
- Abbott & Louie Basins
- Saltus & Jachens Basins
- Widmer Basins

PGV, cm/s

NOAA SKYF RENO RFNV WGLF UNRN RF05 PICO SMRN NMHS UNRX SWTP SPHI HVGC BMHS P06A SSFS PEA SF02 RF08 LOVE MOGL RFMA HUMA RNO1 WYRD CRWR
Saltus & Jachens basins not as deep or detailed, but include volcanic-filled basins.
Mogul, NV M5.0 4/25/2008

- Vertical strike-slip fault from initial Dreger CMT.
- Hypocenter centered on fault.
- Saltus & Jachens basins.

Objective is to match computed shaking to recordings of April 25, 2008 event at stations.

Over 5 cm/s motions predicted near Mogul and central Reno.

All basins amplify ground motion.
Reno Deep ReMi

- July 2012 USGS-funded project by Optim SDS: Travis West, Satish Pullamanappallil, Aasha Pancha.
- 3.2-km W-E array of 30 4.5-Hz geophones, Sigmas
The Little Skull Mountain Earthquake

- Epicenter is ~120 km Northwest of Las Vegas
- Magnitude 5.6
- Normal faulting with a small left-slip component
- Strike: N60°E
- Dip: 70°
- Hypocentral depth: 11.7 km

Ken Smith et al., 2001
Peak Horizontal Ground Velocities

Channeling along basins

Epicenter of LSM
Modeled Region
Las Vegas Region

Las Vegas
Henderson

Horizontal PGV, cm/s
0.0
1.5
Horizontal Ground Amplification

\[ v = f \lambda \]

\[ d \text{ Max Amp} \approx \frac{v}{4f} \]
Southern Nevada Scenarios

- All faults have normal slip
- USGS Qfaults used for source characteristics
- Dip assumed to be 60° if not otherwise specified
- Maximum fault depth is 15 km
  - Assumed to be square if length <15 km
- For faults in basins, Neogene basin thickness data used for top depth
  - E3D not accurate for rupture into soft basin sediments
Frenchman Mountain Fault M6.7 Scenario

Possible Scarp in Neighborhood

Event Inside the LVV Basin
ShakeMap for Frenchman Mtn. M6.7

- Wald et. al (1999)
- M6.7 Frenchman Mountain Scenario
  - Sample PGV output from ShakeMap Statistics
- For comparison, plotted ShakeMap PGV in color instead of contours.
Eglington Fault Scenario

- Max PGV 45 cm/s for ShakeZoning, 25 cm/s for ShakeMap
California Wash Fault M7.0

- SZ Max PGV >200 cm/s
- SM Max PGV 88 cm/s
Sheep - East Desert Ranges M5.5
Sheep - East Desert Ranges Scenario

Image from Google 2011
References


