Ground Motions for Mapping Liquefaction and Earthquake-Induced Landslide Hazard Zones in California

Rui Chen, Tim McCrink, Mike Silva, and Chuck Real
California Geological Survey (CGS)

• Background
• Liquefaction and earthquake-induced landslide hazard assessments for zoning
• Ground motion parameters
• Potential improvements
In accordance with the Seismic Hazards Mapping Act
- Delineate zones requiring detailed site-specific investigation
- Mandatory compliance for most developments
- Disclosure

Type of hazards:
- Liquefaction
- Earthquake induced landslides

On-going process
Example of Regulatory Seismic Hazard Zone Maps in California

- State Mining and Geology Board (SMGB) develops specific zoning criteria
- CGS engineering geologists collect data, evaluate hazards, delineate hazard zones, and publish hazard zone maps
- Liquefaction:
  - Areas with prior liquefaction
  - Borehole, geology and ground water data
- Earthquake Induced Landslides:
  - Existing landslides (landslide inventory maps)
  - Topography and shear strength (based on geology)
- Simple hazard analysis methods
- Ground motion parameters from PSHA
Liquefaction Hazard Analysis for Hazard Zone Mapping

- Two essential parameters: cyclic stress ratio (CSR) and cyclic resistance ratio (CRR)
  - \( CSR = 0.65 \left( \frac{a_{\text{max}}}{g} \right) \left( \frac{\sigma_v}{\sigma_v'} \right) r_d \), where \( a_{\text{max}} \) is Peak ground acceleration (PGA) (Seed and Idriss, 1971)
  - \( CRR \) estimated empirically from field test data
- Factor of Safety for liquefaction:
  - \( FS = \frac{CRR_{7.5}(MSF)}{CSR} = \frac{CRR_{7.5}}{(CSR)(MWF)} \)
  - \( CRR \) – empirical curves based on clean-sand and M7.5, apply magnitude scaling factor (MSF) for other magnitudes
  - Inverse of MSF (magnitude weighting factor or MWF) is applied to \( a_{\text{max}} \) to get M-weighted PGA (i.e., pseudo PGA) as liquefaction opportunity
Landslide Hazard Analysis for Hazard Zone Mapping

- Slope susceptibility to earthquake-induced landslide is defined by yield acceleration \( a_y \) calculated from Newmark’s equations:
  \[
  a_y = (FS - 1)g \sin \alpha
  \]
  \( \alpha = \) sliding angle (degrees, from horizontal)

- Assumptions to simplify analysis for zone delineation
  - Unsaturated, infinite slope failure \( (\alpha = \beta, \text{slope gradient angle}) \)
  - Cohesionless: strength defined only by angle of internal friction \( (\phi) \)
  \[
  FS = \frac{\tan \phi}{\tan \beta}
  \]

- Newmark displacement \( (D_N, \text{in cm}) \) estimated from Jibson (2007) regression:
  \[
  \log D_N = -2.710 + \log \left[ \left( 1 - \frac{a_c}{a_{max}} \right)^{2.335} \left( \frac{a_c}{a_{max}} \right)^{-1.478} \right] + 0.424M
  \]
  \( a_{max} = \text{PGA}, a_c = a_y \text{ (critical or yielding acceleration)}, M = \text{modal magnitude} \)

- Zoning criteria: \( D_N > 5 \text{ cm} \) and all mapped existing landslides
Ground Motion Parameters for Hazard Zone Mapping

**Liquefaction hazard:**
- PGA
- Modal magnitude for PGA

**Earthquake-induced landslide hazard:**
- Magnitude-weighted PGA (i.e., pseudo PGA)

**PSHA hazard level:**
- 10% in 50 years, specified in Seismic Hazards Mapping Act (Based on recommendations of the Advisory Committee for the Act as documented in CGS, 2004)
• **Software**: *nshmp-haz*, Java codebase by USGS NSHMP (available on GitHub, Peter Powers)

• **PSHA model**: USGS model for the 2014 update of NSHMs, including source models, ground motion models, and logic trees

• PSHA and deaggregation on a 0.005-degree (≈ 500-m) grid

• Site conditions incorporated, site $V_{S30}$ value obtained from statewide $V_{S30}$ map by Wills et al. (2015)

• **Hazard-weighted approach for $MWF$ calculation to obtain pseudo PGA using detailed (binned) deagg results**:

$$MWF = \sum [(MWF)_i \left(\frac{\nu_i}{\nu}\right)]$$

$(MWF)_i$ is magnitude weighting factor for $i^{th}$ magnitude-distance bin (using mean M), $\nu_i$ is hazard contribution of the $i^{th}$ bin, and $\nu$ is the total hazard.
Map of Geology-Based $V_{S30}$ (Wills et al., 2015)
Magnitude Weighting Factor

Revised Idriss Cetin et al. (2004)
Idriss (1999)

Map showing locations of Marrica, Bachelor Mountain, Murphys Hot Springs fault, San Felipe fault zone, Tres Picos, and Pecanita. The graph plots earthquake magnitude against magnitude scaling factor (MWF) with data from various sources including Revised Idriss, Idriss (1999), Ambraseys (1985), Atkinson (1996), Atkinson and Stokoe, and Wood and Noble. The map also highlights Quaternary Faults.
Improvements, Limitations and Future Development

• Two new elements:
  ➢ Incorporation of site condition
  ➢ Hazard-weighted approach for MWF calculation

• Limitations:
  ➢ Only use a couple of ground motion parameters from PSHA
  ➢ Specified hazard level (10% in 50 years) is somewhat arbitrary

• Future work/improvement:
  ➢ Continue to map more quads and improve existing maps
  ➢ Liquefaction zoning based on estimates of ground deformation
  ➢ Use fully probabilistic hazard analysis approaches?
Summary

• Ground motion parameters required for delineating regulatory seismic hazard zones are PGA, pseudo PGA, and modal magnitude with 10% exceedance probability in 50 year

• These parameters are derived using the current UGSG PSHA model, i.e., PSHA model for the 2014 update of NSHM. We will be using the 2018 model once it becomes available

• Methods for delineating seismic hazard zones are much simplified and there is room for improvements

• Zoning process is a screening process, the goal is to delineate zones that require detailed, site-specific geotechnical investigation