Probabilistic Liquefaction Potential Hazard Mapping of Davis County, Utah For an M7.2 Earthquake Scenario

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OUTLINE

1. Introduction
2. Literature Review
3. Problem statement and objectives
4. Mapping process
5. Results and Discussion
6. Conclusion
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3. Problem statement and objectives
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5. Results and Discussion
6. Conclusion
What is liquefaction?
In soil liquefaction, saturated sandy soil deposits lose their strength and behave as a viscous liquid rather than as a solid.

Liquefaction mechanism
1. Seismic waves propagating through soil generate shear deformation and collapse loose granular soil.
2. Contraction of granular structure increases pore water pressure.
3. Increase of pore water pressure reduces intergranular or effective stress.
4. When effective stress decreases to a critical level, the material transforms from a solid state into a viscous state and liquefaction has occurred.

(Youd 2018)
What are the consequences?

- Sand boil
- Flow failure
- Ground settlement
- Ground oscillation
- Lateral spread
What is lateral spread?

• Lateral/horizontal displacement of a soil layer riding on liquefied soil
• Either down a gentle slope or toward a free face
• Most pervasive damage of liquefaction
• In response to a combination of gravitational and earthquake forces
• Displacements generally less than a few meters.

(Yould 2018)
INTRODUCTION  TYPES OF LIQUEFACTION MAPS

• Liquefaction Susceptibility Maps
  • Show liquefaction hazard based on soil natural resistance
  • Do not consider size or amplitude of strong ground motion
  • Based on surficial geologic maps with no subsurface information

• Liquefaction Potential Maps
  • Combine liquefaction susceptibility with seismic input
  • Demand can be a deterministic scenario event or a probabilistic estimate

• Ground Failure Maps
  • Consider liquefaction potential
  • Consider the amount of horizontal or vertical displacement
OUTLINE

1. Introduction
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3. Problem statement and objectives
4. Mapping process
5. Results and Discussion
6. Conclusion
LITERATURE REVIEW  LIQUEFACTION

Liquefaction triggering models

1. Deterministic
   • Earliest efforts in Japan on the SPT data of the 1964 Niigata earthquake by Kishida (1966)
   • SPT-based procedures later evolved by Seed et al. (1994 and 1995)
   • First CPT-based procedures developed by Zhou (1980) using the 1978 Tangshan earthquake data
   • $V_s$-based correlation was developed by Youd et al. (2001)
   • With advent of new case histories, Idriss & Boulanger (2004, 2006) reevaluated the correlations

2. Probabilistic
   • Number of researchers, including Liao et al. (1988) and Liao and Lum (1998), and more recently Youd and Noble (1997) and Toprak et al. (1999) tried to develop formally probabilistically based correlations.
   • Cetin et al. (2004) took advantage of the Maximum Likelihood Estimation method to develop their probabilistic model
Lateral spread models

- First attempts by Hamada et al. (1986) and Youd & Perkins (1987)
- Bartlett & Youd (1992, 1995) combined earlier models and developed an MLR model along with a more extensive database of lateral spread case histories
- Youd et al. (2002) later revised the MLR model and added other case histories
- Bardet et al. (2002) developed a four-parameter MLR model for mapping purposes by eliminating the geotechnical parameters from the MLR model of Bartlett and Youd (1992, 1995)
- Gillins & Bartlett (2013) developed an MLR model for mapping purposes that includes geotechnical factors based on the soil type
1. Liquefaction triggering maps
   • Liquefaction potential map of Davis County (Keaton and Anderson 1995)
   • Probabilistic liquefaction triggering map for Salt Lake Valley (Erickson et al. 2006)
   • Liquefaction potential map of Salt Lake County (Olsen et al. 2007) for a M7 scenario earthquake
   • Liquefaction potential map of Salt Lake County (Hinckley 2010)
   • Liquefaction potential map of Weber County (Gillins & Bartlett 2013)

2. Lateral spread displacement maps
   • Lateral spread potential map of Salt Lake County (Olsen et al. 2007) for a M7 scenario earthquake
   • Lateral spread potential map of Salt Lake County (Hinckley 2010)
   • Lateral spread potential map of Weber County (Gillins & Bartlett 2013)
1. Introduction
2. Literature Review
3. Problem statement and objectives
4. Mapping process
5. Results and Discussion
6. Conclusion
PROBLEM STATEMENT AND OBJECTIVES

Study area:
Davis County, Utah

Earthquake Scenario:
M7.2, Wasatch fault, Weber section

Epicenter:
41.087 N, 111.997 W (9km below ground)
1. Introduction
2. Literature Review
3. Problem statement and objectives
4. Mapping process
5. Results and Discussion
6. Conclusion
MAPPING PROCESS

- Liquefaction triggering analysis
  \[ P(L) \]

- Lateral spread analysis
  \[ P(LS > y) = P(LS>y | L) P(L) \]
## MAPPING PROCESS

<table>
<thead>
<tr>
<th>Analysis type</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquefaction triggering (Cetin et al. 2004)</td>
<td><img src="equation.png" alt="Equation" /></td>
</tr>
<tr>
<td>Lateral spread (Gillins &amp; Bartlett 2013)</td>
<td><img src="equation.png" alt="Equation" /></td>
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</tbody>
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### Liquefaction triggering (Cetin et al. 2004)

\[ P(L) = \Phi \left( - \frac{N_{1.60,cs} - 13.32 \cdot \ln(CSR) - 29.53 \cdot \ln(M_w) - 3.7 \cdot \ln(\sigma'_v) + 16.85}{2.70} \right) \]

### Lateral spread (Gillins & Bartlett 2013)

\[ P[D_H > y|L] = 1 - \Phi \left( - \frac{y - \log(D_H)}{\sigma_{\log(D_H)}} \right) \]

\[ \log(D_H) = -8.208 + 1.318M_w - 1.073\log R^* - 0.016R + 0.0337\log S + 0.592\log T_{15} - 0.683x_1 - 1.2x_2 + 0.252x_3 - 0.04x_4 - 0.535x_5 \]
MAPPING PROCESS

\[ M_w = 7.2; \text{ constant} \]

Seismic

Geotechnical/Geological

Topographic

PGA from USGS ShakeMap at coarser grid points; bilinear interpolation

\[ R; \text{ using haversine distance and coordinates of grid points and energy source} \]

All geotechnical variables come from boreholes

if any borehole within the 95 m distance select randomly from them

else randomly select from boreholes within the same geologic unit

Groundwater table from current USGS active wells; weighted average

Slope from 1-arc sec DEM maps; Slope tool in ArcGIS
Sources of uncertainty:

- Seasonal changes in groundwater table
- Missing values of fines content and soil unit weight in boreholes
- Geospatial uncertainty associated with using boreholes within the same geologic unit
- Uncertainty of the empirical models
MAPPING PROCESS  UNCERTAINTIES

Approaches of handling uncertainty:

1) Sample random values
2) Use median values
3) Sample random values \( n \) times (Monte-Carlo)

\[ y = f(\underline{x}) \]
Seasonal changes in groundwater table
MAPPING PROCESS  UNCERTAINTIES

Missing values of fines content and soil unit weight in boreholes

1. Same soil type & same geologic unit
2. Same soil type & all geologic units
3. All soil types & all geologic units
Geospatial uncertainty associated with using boreholes within the same geologic unit

Any borehole within the 95 m?
- **YES**, select randomly from them
- **NO**, randomly select from boreholes within the same geologic unit
1. Introduction
2. Literature Review
3. Problem statement and objectives
4. Mapping process
5. Results and Discussion
6. Conclusion
RESULTS & DISCUSSION

Number of Monte-Carlo simulations

The higher the better but computationally more expensive

Results converge after 100 simulations
RESULTS & DISCUSSION

Quantification of uncertainty

- 50th percentile (median); 50% of times probabilities are higher, 50% of times probabilities are lower

- 16th and 84th percentiles; one standard deviation away from median in normal distributions. In non-normal distributions, the 84th percentile represents a conservative value in that it has only a 16% chance of being exceeded and the 16th percentile is its counterpart.
RESULTS & DISCUSSION
RESULTS & DISCUSSION

16th percentile Probabilities of liquefaction triggering
RESULTS & DISCUSSION

50th percentile Probabilities of liquefaction triggering
RESULTS & DISCUSSION

50th percentile Probabilities of liquefaction triggering

(Keaton and Anderson 1995)
RESULTS & DISCUSSION
50th percentile Probabilities of lateral spread displacement exceeding 0.1 meters
50th percentile Probabilities of lateral spread displacement exceeding 0.3 meters
RESULTS & DISCUSSION

50th percentile Probabilities of lateral spread displacement exceeding 0.6 meters
50th percentile Probabilities of lateral spread displacement exceeding 1.0 meters
1. Introduction
2. Literature Review
3. Problem statement and objectives
4. Mapping process
5. Results and Discussion
6. Conclusions
Under the given earthquake scenario, the following conclusions are drawn from this study:

1. Most of the areas prone to liquefaction hazard are not residential, and the only important items in Davis County that are prone to liquefaction are (1) interstate highway I-15 section between West Bountiful and Farmington, (2) South-west parts of Syracuse, and (3) western side of West Point. Also, with a lower confidence level, parts of Layton, Clearfield, and Sunset might be prone to liquefaction based on the 84th percentile map.

2. The uncertainty of the mapping process was insignificant for most parts of the liquefaction triggering map. However, this uncertainty becomes more significant for lateral spread hazard maps. Spatial distribution of the uncertainty over the county showed that the uncertainty is largest when probabilities of lateral spread predictions are in the range between 15% to 75%.
3. Parts of the cities located at the northern part of the county including West Point (population: 10,603), Layton (population: 72,413), Syracuse (population: 26,668), Kaysville (population: 29,799), and Farmington city (population: 21,983) could experience lateral ground displacements exceeding 0.1 meters. Exceeding higher horizontal ground displacement thresholds is not very likely for most of the major cities. The only zone having a moderate probability of lateral spread exceeding 10 meters is the south-west part of Layton.

4. The most important factors in lateral spread analysis of this study were found to be (a) distance to the source of energy, (b) geologic unit, and (3) ground slope.
The following items could be considered in future studies:

1. The uncertainty of this mapping process was quantified as a whole. Uncertainty of each source of uncertainty could be quantified separately.

2. This mapping process can be repeated for other counties of Utah or other states or even for Davis County under different earthquake scenarios.

3. The maps produced in this study are based on available and varying quality geotechnical data. The mapping process is directly affected by the quality and quantity of the subsurface data. Hence, collecting more data would help improve understanding of site profiles, soil properties, groundwater conditions, etc. Some of the models are capable of incorporating CPT data as well.
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References

Thank You
Questions?