Utah Liquefaction Advisory Group (ULAG)

Probabilistic Liquefaction Hazard Mapping for Davis, Weber and Salt Lake Counties

February 12, 2018
Salt Lake City, Utah

Steven F. Bartlett, Ph.D., P.E.
University of Utah
Types of Liquefaction Displacement

Port of Kobe, 1995 Kobe, Japan Earthquake

Ground Settlement

2010 Christchurch Earthquake
Types of Liquefaction Displacement

Lateral Spread

Power poles are pulled over by their wires as they can’t be supported in the liquefied ground. Underground cables are pulled apart.

**Lateral Spreading**
River banks move toward each other. Cracks open along the banks. Cracking can extend back into properties, damaging houses.

Fine sand and silt liquefies, and water pressure increases.

Lateral Spread

1964 Niigata, Japan Earthquake
Types of Liquefaction Displacement

Valdez, 1964
Alaska
Earthquake

Flow Failure

Seward, 1964
Alaska
Earthquake
Types of Liquefaction Hazard Maps

- Liquefaction Susceptibility Maps
- Liquefaction Potential Maps
  - Scenario Maps
  - Probabilistic-Based Maps
- Ground Failure Maps
  - Lateral Spread
  - Ground Settlement
Utah’s Plan for Developing the Next Generation of Liquefaction Hazard Maps

Objective 1

Develop Probabilistic Liquefaction Hazard Maps for Urban Counties in Utah

Salt Lake County
Utah County
Davis County
Weber County
Cache County
Utah’s Plan for Developing the Next Generation of Liquefaction Hazard Maps

Objective 1 (cont.)

Types of Maps

(1) Liquefaction Triggering Maps
(2) Lateral Spread Displacement Hazard Maps
(3) Liquefaction-Induced Ground Settlement Maps
Utah’s Plan for Developing the Next Generation of Liquefaction Hazard Maps

Objective 2

Develop ARC GIS Programs for Implementing Probabilistic Mapping Procedures for Other Regions in U.S.

- Strong ground motion hazard estimates from PSHA and National Strong Motion Mapping Program
- User methods based on ArcGIS algorithms
Utah’s Plan for Developing the Next Generation of Liquefaction Hazard Maps

Objective 3

Establish and Populate a Subsurface Geotechnical Database for Public Use

- Geotechnical Evaluations
- Land Use Planning
- Research
- Potential Partners
  - UDOT
  - Salt Lake County and Cities
Utah’s Plan for Developing the Next Generation of Liquefaction Hazard Maps

Objective 4

Education and Public Outreach

• User Friendly Maps
• Assist Counties in Implementation and Ordinances
• Outreach Seminars and Website
Previous Work

FY 2004

• Geotechnical Database (N. Salt Lake Co.)
• M7.0 lateral spread displacement hazard map (N. Salt Lake Co.) published in *Earthquake Spectra*.

FY 2005

• Geotechnical Database (S. Salt Lake Co.)
Mapping Inputs

Groundwater Depth Map
Mapping Inputs

Digital Elevation Model
Mapping Inputs

Estimates of peak ground acceleration (Wong et al., 2002)
Lateral Spread Displacement Hazard – N. Salt Lake Co.
Probabilistic liquefaction potential map
Salt Lake Co. – (2002 USGS Input)
Previous Work

FY 2006 & 2007

2.1.1 Task 1: Development of CPT and SPT correlations (University of Utah) ............................................................... 7
2.1.2 Task 2: Correlation of Subsurface Geologic and Geotechnical ArcGIS™ Database with Surficial Geologic Mapping (Utah Geological Survey) ................................................................. 8
2.1.3 Task 3: Mapped mean annual probability of triggering liquefaction for southern Salt Lake County (University of Utah) ........................................................................................................... 8
2.1.4 Task 4: Mapped probability of triggering liquefaction for a scenario earthquake for Salt Lake County (University of Utah) ........................................................................................................ 8
2.1.5 Task 5: Mapped mean annual probability of lateral spread exceeding displacement thresholds of 0.1, 0.3 and 1.0 meters for northern Salt Lake County (University of Utah) ........................................... 9
2.1.6 Task 6: Mapped lateral spread horizontal displacement for a scenario event for northern Salt Lake County (University of Utah) ........................................................................................................ 9
2.1.7 Task 7: Synthesis report of seismically induced ground displacement in Salt Lake County (University of Utah, Simon-Bymaster, Inc., and Utah Geological Survey) ........................................... 9
2.1.8 Task 8: CPT subsurface investigations in downtown Salt Lake City (University of Utah and ConeTech) .......................................................................................................................... 12
2.1.9 Task 9: Map production and report delivery (University of Utah and Utah Geological Survey) .................... 12
Previous Work

FY 2006 – 2007 (cont.)

2.1 Methods and Tasks – Phase IV, FY 2007

2.1.1 Task 1: Collection and preliminary geologic analysis of surface and subsurface data to identify data gaps and data-collection requirements for future hazard mapping efforts in Utah Valley (Brigham Young University, University of Utah, Utah Geological Society) .......................................................... 8

2.1.2 Task 2: Completion of probabilistic lateral spread hazard maps and deterministic lateral spread hazard map for a scenario earthquake for southern Salt Lake County (University of Utah) .............. 10

2.1.3 Task 3: Development of liquefaction-induced settlement map for Salt Lake County (Brigham Young University, University of Utah) ...................................................................................... 10

2.1.4 Task 4: Map production and report delivery (University of Utah, Brigham Young University and Utah Geological Survey) ...................................................................................... 10

FY 2008 (No Funding)

FY 2009 (No Funding)

FY 2010 (No Funding)
Probabilistic liquefaction potential maps for 2500 and 500-year return periods

Legend
- Very High, >1.0 m
- High, 0.3 - 1.0 m
- Moderate, 0.1 - 0.3 m
- Low, 0 - 0.1 m
- Minimal, 0 m
- Special Study
- Great Salt Lake
Probabilistic ground settlement maps for 2500 and 500-year return periods
M 7.0 Lateral spread displacement map
15 percent chance of exceedance
M 7.0 ground settlement map
15 percent chance of exceedance
Downtown Displacement Investigations

Salt Palace Convention Center: 9ft Maximum Documented Displacement (Lower Bonneville)

Rose Wagner Performing Arts Center: 2ft Maximum Documented Displacement

Pioneer Park

Zone of Potential Faulting: 10ft Maximum Documented Displacement (Lower Bonneville)

Matheson Courthouse

Salt Lake City Library

City and County Building

Downtown Displacement Investigations

Approximate CPT Sounding Locations

Possible Extension of the Warm Springs Fault

HORIZONTAL DISTANCE ALONG EXPLORATION LINE (M)
(Measured From the Southeast Corner of 500W and 400S)
Previous Work

FY 2008 (No Funding)
FY 2009 (No Funding)
FY 2010 (No Funding)
FY 2010 (Partial Funding from WBWCD for Mapping Weber Co.)
FY 2011 (USGS –Funding for Mapping Weber Co.)
Weber County Liquefaction Hazard Mapping

(1) Silty Gravels, \( x_1 = 1 \)
(2) Coarse Sand/Sand & Gravels, \( x_2 = 1 \)
(3) Clean Fine/Medium Sands, \( x_3 = 1 \)
(4) Silty Sands, \( x_4 = 1 \)
(5) Silts, \( x_5 = 1 \)

**Fig. 3.** \( T_{15} \) versus \( T_{15,cs} \) according to soil index
Weber County Liquefaction Hazard Mapping

\[
\log(D_H) = b_o + b_{\alpha} \alpha + b_1 M + b_2 \log(R^*) + b_3 R + b_4 \log(W) + b_5 \log(S) + \\
b_6 \log(T_{15,cs}) + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 + a_5 x_5
\]

\[
\frac{\log(D_H)}{-8.453 + 1.348 \cdot M_w - 1.068 \cdot \log(R^*) - 0.017 \cdot R + 0.334 \cdot \log(S) + \\
+ 0.588 \cdot \log(T_{15,cs}) + 0.278}
\] (4.2)

\[
\frac{\log(D_H)}{-8.795 + 1.348 \cdot M_w - 1.068 \cdot \log(R^*) - 0.017 \cdot R + 0.453 \cdot \log(W) + \\
+ 0.588 \cdot \log(T_{15,cs}) + 0.278}
\] (4.3)
Figure 3.1. Predicted lateral spread displacement using (a) eqn. (3.3), or (b) eqn. (3.4), versus measured lateral spread displacement from the case history database of Youd et al., 2002.
Weber County Liquefaction Hazard Mapping

Figure 5.4. 50th percentile probabilities of liquefaction triggering given a 500-year seismic event; Weber County, Utah.
Weber County Liquefaction Hazard Mapping

Figure 5.5. 50th percentile probabilities of liquefaction triggering given a 2,500-year seismic event; Weber County, Utah
Weber County Liquefaction Hazard Mapping

Figure 5.6. 50th percentile probabilities of lateral spread displacement exceeding 0.1 meters given a 500-year seismic event; Weber County, Utah
Weber County Liquefaction Hazard Mapping

Figure 5.7. 84th percentile probabilities of lateral spread displacement exceeding 0.1 meters given a 500-year seismic event; Weber County, Utah.
Figure 5.10. 50th percentile probabilities of lateral spread displacement exceeding 0.1 meters given a 2,500-year seismic event; Weber County, Utah
Figure 5.11. 84th percentile probabilities of lateral spread displacement exceeding 0.1 meters given a 2,500-year seismic event; Weber County, Utah.
Previous Work

FY 2013 (FEMA – Funding for Salt Lake Co.)
FY 2014 (USGS – Funding for Mapping Utah Co.)
1. Develop a new model ordinance for liquefaction hazards based on input and feedback from municipalities, technical advisory groups, and others.
2. Educate various municipalities and their stakeholders regarding risk-based decision making and hazard mitigation using the newly developed hazard ordinance that is coupled with the recently developed ULAG liquefaction hazard maps and support and encourage the implementation/adoption of the new liquefaction hazard ordinance in the various municipalities along the urban Wasatch Front.
3. Develop methods to apply the liquefaction hazard maps to assess post-event traffic interruptions resulting from liquefaction-induced damage.
4. Educate the next generation of Utahans about earthquake hazards by focusing on a secondary education outreach curriculum and program delivered to Salt Lake and Weber Counties.
Lateral Spread Displacement Map
Salt Lake Co. (85th Percentile Maps)
Ground Settlement Map
Salt Lake Co. (85th Percentile Maps)
Utah Co Mapping Procedure

Step 1. (START) Select mapping pixel, extract values by raster

No. continue to the next pixel

Geology Raster
Free-Face Raster
Slope Raster

Step 2. Randomly select $T_{15,es}$ from its distribution per geologic unit. Solve for $G$

Step 3. Randomly select $\mathcal{L}$ from the $\mathcal{L}$-hazard curve at the mapping pixel

Step 4. Simulate error in lateral spread model, then solve for $\log D_H$

Step 5. Reached 200,000 Simulations?

Step 6. Develop $D_H$-hazard curve from outputted $\log D_H$ distribution

Step 7. Solved all mapping pixels?

Yes

Output $D_H$ hazard maps by extracting values from $D_H$-hazard curve at return periods of interest

Step 8. (END)
Utah Co Mapping Procedure
Utah Co Mapping Procedure
Utah Co Mapping Procedure
Current Work

FY 2017 (USGS & UDOT – Funding for Mapping Utah Co.)

• Subsurface Data Collection
• Map Davis Co using methods for Utah Co.
• Map Salt Lake Co. using methods from Utah Co.
• Map Weber Co. using methods from Utah Co.
Liquefaction Evaluation in Gravelly Soils using Dynamic Cone Penetration Test (DPT) and Shear Wave Velocity

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Research Sponsors

- US Geological Survey
- US Bureau of Reclamation
- National Science Foundation
## Gravel Liquefaction in the Literature

<table>
<thead>
<tr>
<th>Year</th>
<th>$M_w$</th>
<th>Earthquake</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1891</td>
<td>7.9</td>
<td>Mino-Owari, Japan</td>
<td>Tokimatsu &amp; Yoshimi (1983)</td>
</tr>
<tr>
<td>1905</td>
<td>7.1</td>
<td>Messina, Italy</td>
<td>Baratta (1910)</td>
</tr>
<tr>
<td>1906</td>
<td>8.2</td>
<td>San Francisco, CA</td>
<td>Yould and Hoose (1978)</td>
</tr>
<tr>
<td>1948</td>
<td>7.3</td>
<td>Fukui, Japan</td>
<td>Ishihara (1985)</td>
</tr>
<tr>
<td>1975</td>
<td>7.3</td>
<td>Haicheng, China</td>
<td>Wang (1984)</td>
</tr>
<tr>
<td>1976</td>
<td>6.5</td>
<td>Friuli, Italy</td>
<td>Sirovich (1996)</td>
</tr>
<tr>
<td>1978</td>
<td>7.4</td>
<td>Miyagiken-Oki, Japan</td>
<td>Tokimatsu &amp; Yoshimi (1983)</td>
</tr>
<tr>
<td>1995</td>
<td>7.2</td>
<td>Kobe, Japan</td>
<td>Kokusho &amp; Yoshida (1997)</td>
</tr>
<tr>
<td>1999</td>
<td>7.6</td>
<td>Chi-Chi, Taiwan</td>
<td>Chu et al (2000)</td>
</tr>
</tbody>
</table>
Gravel Liquefaction Sites

- Mw 6.9 Borah Peak, Idaho
- Whiskey Springs
- Larter Ranch
- Pence Ranch
Gravel Liquefaction in Older Dams

- Liquefaction hazard recognized after construction
- Liquefaction evaluation & remediation are often “multi-million dollar” decisions
Becker Penetration Test (BPT)

- SPT & CPT unreliable in gravels because of particle size
- BPT Developed in Canada in late 1950s
- 6.6 inch diameter, 10 ft. long double core barrel driven into ground
- Measures blows/30 cm, NBC
Correlation Between Becker & SPT Blow Counts

Harder and Seed (1986)
SPT Liquefaction Triggering Curve

Youd et al (2001)
iBPT Correlation with SPT $N_{60}$

Figure 5. Correlation between medians of iBPT $N_{B30}$ from tip measurements, and SPT $N_{60}$; high quality (HQ) data from four sites

De Jong et al (2017), JGGE
Limitations of Becker Testing

- High cost of mobilization & testing often limits BPT to major projects
- Uncertainty with correction factors for BPT
- Uncertainty with correlations between BPT NBC or iBPT $N_{B30}$ and equivalent sand SPT $N_{60}$
Chinese Dynamic Cone Penetrometer, DPT

- Capable of penetrating loose to moderately dense gravels
- Relatively fast, simple, and economical
- Can be used for routine projects.
- Liquefaction triggering curve directly based on field performance data
Chinese Dynamic Cone Penetration Test (DPT)

2.5 times the SPT energy

Cao, Yuan, Youd and Rollins (2012), ISC4, Brazil
Cao et al (2013), JGGE,
DPT Penetration Resistance ($N'_{120}$)

- $N'_{120} = N_{120} \left(\frac{100 \text{ kPa}}{\sigma'_v}\right)^{0.5}$

- Reported every 10 cm but multiplied by 3 to get the equivalent value for 30 cm

- No consideration of fines content at present
Gravel Liquefaction in $M_w 7.9$ Wenchuan China Earthquake in 2008

118 Gravel Liquefaction Sites in Chengdu Plain

2008 $M_w 7.9$ Wenchuan Earthquake

Sand & Gravel Ejecta
Lateral Spread at Banqiao School

8 inch differential settlement

3 ft lateral spread displacement
### Soil Profile and DPT Log from Chengdu

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Log</th>
<th>Description of Soil Profile</th>
<th>DPT Blow Counts /30cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td></td>
<td>Brown to yellow silty clay; uniform</td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td></td>
<td>Brown to yellow gravelly soils; loose to less loose; the diameter of cobble ranges up to 25 cm</td>
<td></td>
</tr>
<tr>
<td>15.0</td>
<td></td>
<td>Dense yellow gravelly soils; glaciofluvial deposit; some cobble weathered seriously and can be broke by hand</td>
<td></td>
</tr>
</tbody>
</table>

**10 blows/30 cm**

Layer that liquefied

---

*(b) Banqiao School, Mianzhu (Site 3)*

*Cao et al (2013), JGGE*
DPT Liquefaction Triggering Curve

$M_w = 7.9$

Cao et al (2013), JGGE, August
Core samples from borehole near a DPT sounding showing gravelly and cobbly composition of sediment penetrated beneath Chengdu Plain
**Energy Transfer measurements in China**

Hammer lifting mechanism

Hammer

Top or guide rod

Anvil

PDA energy measuring device

Rope to maintain rod verticality

10-cm chalked tick marks on rod

**Standard DPT Procedure**

Avg. Energy Transfer = 90%

Std. Dev. = 8.6%

Cao et al (2013), JGGE, August
Comparison DPT & CPT Triggering Curves

Cao et al. (2013)

Boulanger & Idriss (2014)
Research Questions for DPT

- Can we reduce the spread in DPT triggering curves with additional data points?
- Will liquefaction Factor of Safety from DPT be similar to that from BPT?
- Can use of SPT hammer energy give acceptable results after energy correction?
Vs Measurements in Chengdu

- MASW measurements performed & interpreted by Dr. Zhenzhong Cao
- 24 - 4.5 Hz receivers at 2 m spacing
- Source was hammer blows
Vs Liquefaction Triggering Curve
Chengdu Plain Data – 47 Sites

M_w = 7.9
P_L = 70% 50% 30%

Chengdu Plain Data – 47 Sites
Vs Triggering Curves for Sand

Andrus & Stokoe 2000

$M_w = 7.5$

Kayen et al. 2013

$M_w = 7.5$
Possible Explanations

- Sediments may be older and have higher Vs for the same CRR
- Gravel content may increase the Vs for the same matrix relative density
- MASW may be averaging Vs and obscuring low velocity layers
- Errors in properly interpreting the Vs profile
Pence Ranch Idaho, $M_w 6.9$ Borah Peak EQ
Pence Ranch Idaho, Borah Peak EQ

- $M_w 6.9$ with PGA of 0.39g
- 8 DPT holes (4 SPT and 4 DPT hammer energy)
- PDA Energy measurements
- Comparison with 4 BPT profiles (Andrus, 1986)

Source: Les Youd
Layout of Test Holes Pence Ranch

Simplified from Andrus (1986)
Drill Rig with Two Hammer Weights

CME 85 with Dual Hammers

DPT Hammer 340 lb (154 kg)

SPT Hammer 140 lb (64 kg)
Comparison of BPT & DPT Holes

\[ N_{120} = N_{\text{measured}} \left( \frac{E_{\text{Delivered}}}{E_{\text{Chinese DPT}}} \right) \]
Comparison of BPT & DPT Holes

Unit C - Liquefied
Unit D – Mix Liq/Non-Liq
Unit E – Non-Liq

DPT 1L

DPT 2H

\[ N_{120} = N_{\text{measured}} \left( \frac{E_{\text{Delivered}}}{E_{\text{Chinese DPT}}} \right) \]
Comparison of $N'_{120}$ with Two Hammer Energies

\[ N_{120} = N_{\text{measured}} \left( \frac{E_{\text{Delivered}}}{E_{\text{Chinese DPT}}} \right) \]
Comparison of BPT & DPT
Liquefaction Evaluation

DPT Based Evaluation

BPT Based Evaluation

Used MSF = $10^{2.24}/M_w^{2.56}$
Whiskey Springs, $M_w6.9$ Borah Peak EQ

- $M_w6.9$ with PGA of 0.5g
- 2 BPTs (Harder, 1986)
- 4 DPTs with 2 Hammer Energies

Source: Les Youd
Whiskey Springs, Borah Peak EQ
Liquefaction Evaluation

DPT Based Evaluation

BPT Based Evaluation
Larter Ranch, $M_w 6.9$ Borah Peak EQ

- $M_w 6.9$ with PGA of 0.5g
- 4 BPTs (Andrus 1986)
- 8 DPTs with 2 Hammer Energies
Larter Ranch, Mw6.9 Borah Peak

EAST

- BPC-1
- DPT 1L
- DPT 2H

Zone of Fissures

Major Fissure

- B Med. Dense to Dense Silty Sandy Gravel
- C Loose to Med. Dense Silty Sandy Gravel
- D Med. Dense to Dense Silty Sandy Gravel

C Liquefied layer

BPC-3
- DPT 5H
- DPT 6L

BPC-2
- DPT 3H
- DPT 4L

Direction of Movement

BPC-4
- DPT 7L
- DPT 8H

Buckled Sod

Thousand Springs Creek

WEST

Local Elevation in meters

- 32
- 28
- 24
- 20
- 16
- 12
- 8
- 4
- 0

0 4 8 m
Comparison of BPT & DPT Holes
Larter Ranch, Idaho

DPT 7L

DPT 8H

Liquefied Layer

\[ N_{120} = N_{measured} \left( \frac{E_{Delivered}}{E_{Chinese \ DPT}} \right) \]
Manta Port, 2016 $M_W 7.8$ Ecuador EQ
Manta Port, $M_w 7.8$ Earthquake

- Rock Breakwater & Embankment
- Pile Supported Piers
- Pile-supported wharf
- Rock berm with backfilled area
Manta Port, $M_w 7.8$ Earthquake
Damage to Piles from Lateral Spread

Damage to Battered Piles
Manta Port, $M_w 7.8$ Ecuador EQ

Sand & Silt eruption

Liquefiable layer (Sandy Gravel)

Cracks

Settlement 40-50 cm

Shear Failure

Plastic Hinge

Courtesy GeoEStudios, Prof. Xavier Vera-Grunauer
Gradational Composition
Manta Port, $M_w 7.8$ Ecuador EQ

- PGA of 0.60 g
- 7 DPT soundings (150 kg weight-0.67m)
- Energy Measurements
- 7 Vs profiles from MASW

**Dynamic Penetration Test (DPT-1')**

W.L: water level in the earthquake time (18h58).

The critical zones in the resistance profile were adopted for the liquefaction evaluation.

Courtesy GeoEStudios, Prof. Xavier Vera-Grunauer
Lixouri & Argostoli Ports, Cephalonia Earthquake
2014 M6.1 Cephalonia Earthquake

Lateral Spreading at port

Sand and gravel ejecta
Lixouri Port, Cephalonia Earthquake

- Mw 6.1 with PGA of 0.53g
- 5 DPT soundings with SPT hammer
- PDA energy measurements
- Could not penetrate at 2 additional locations

Collaboration with Profs. Adda and Dimitrios Zekkos, Univ. of Michigan
DPT Testing at Lixouri Port
Cephalonia Greece

Track-mounted penetrometer

PDA Energy Measurement
Results from DPT at Lixouri Port

Layer that Liquefied

Layer that Liquefied

P_L=30%
Argostoli Port, Cephalonia Earthquake

- $M_w6.1$ with PGA = 0.35g
- 4 DPT holes at 3 sites
- PDA measurements
Results from DPT at Argostoli Port

DPT N'120

Depth, z (m)

Layer that liquefied

Liquefaction

No Liquefaction

CSR, CRR

DPT N'120

P_L = 30%

Loc 11

Loc 12

Loc 13

Loc 11

Loc 12

Loc 13
MASW Shear Wave Testing
Prof. Dimitrios Zekkos, Univ. of Michigan
Avasinis, Italy (1976 Friuli Earthquake)
**Avasinis, Italy (Friuli Earthquake)**

- Gravel liquefied in Mw 6.5 (May 1976)
- Mw 6.0 (Sept 1976)
- Mw 5.6 (Sept 1977)
- Three test sites liquefied and one site did not.
- DPTs at two hammer energies per site
Gravelly Sand Ejecta (Friuli Earthquake)
Avasinis, Italy (Friuli Earthquake)

soil profile

- gravelly fill
- water table
- 7 cm clay layer
- gravelly alluvium

Depth (m)
- 16.03
- 16.80

Depth below Ground, $z$ (m)

Normalized Shar Wave Velocity, $V_{S1}$ (m/s)

From Cross-hole Test

Normalized SPT blowcount $(N_1)_{60}$ (blow/0.3m)

Depth below Ground, $z$ (m)
Fig. 5. Grain size distributions of Avasinis sediments: (*) four sites from F. Sgoibino (private communication), liquefied or suspected of liquefaction. (¶): from the site investigated in the present study, extensive liquefaction
DPT Testing at Avasinis

Testing with 154 kg Hammer - 0.67 m drop

PDA Testing – 75% energy transfer
MASW Testing Friuli Earthquake

Collaboration with INGV (Italian Institute for Geophysics and Volcanology)
Avasinis, Italy $M_w 6.1$ Friuli Earthquake

Soil Profile
- Gravelly Clayey Silt
- Gravelly Sand
- 7 cm Clay Layer

Critical Layer

Depth (m)

DPT $N'_{120}$ or SPT ($N_1$)$_{60}$

Shear Wave Velocity, $V_{S1}$ (m/s)

Relative Density, $D_r$ (%)
Avasinis, Italy Vs Triggering Curves

Andrus & Stokoe 2000

Kayen et al. 2013

Shear Wave Velocity, $V_{s1}$
Seward, Alaska (1964 Alaska Earthquake)
Lateral spreading compressed the deck and displaced bent towards river

Source: McCulloch & Bonilla, 1970
Seward, Alaska $M_w$9.2 Earthquake

- 8 DPT holes to 50 ft in less than 2 days
- PDA Energy measurements
- 2 hammer energies at each of four sites
- Nearby cross-hole $V_s$ measurements
Seward Alaska Resurrection River

Liquefiable layer $V_s = 235$ m/s

Figure 7. Crosshole Shear Wave Velocities Measured at Seward Test Site 1
Summary of DPT Results All Sites

$P_L = 85\%  70\%  50\%  30\%  15\%$

$M_w = 7.5$

Corrected DPT blows/0.3m $N'_{120}$
Summary of $V_{s1}$ Results All Sites

![Graph showing the relationship between CSR, CRR, and Shear Wave Velocity, $V_{s1}$ (m/s) for various sites including Liquefaction-Chengdu, No Liquefaction-Chengdu, Borah Peak, Friuli, Manta, Cephalonia, and Seward. The graph includes lines indicating $P_L = 70\% 50\% 30\%$ and $M_w = 7.5$.](image-url)
$V_{s1}$ vs DPT $N'_120$ For all Data
$V_{s1}$ vs DPT $N'_{120}$ For all Data
Preliminary Conclusions

- With energy and magnitude corrections, DPT yields liquefaction factors of safety comparable to BPT.
- DPT results to date correctly estimate liquefaction triggering at sites where gravels have liquefied.
- DPT can generally penetrate gravels with lower SPT hammer energy, but correlations less reliable for higher density and larger gravel particle size.
- Chinese DPT can provide a simpler, more economical, approach for evaluating liquefaction in gravel relative to the Becker penetration test (BPT).
Questions?
Hazard Mapping Update

Ben Erickson
February 12, 2018
Hazard Mapping Overview

- Gather Area Data
  - Geologic Maps
  - Historic Records
  - Available GIS
  - Review Our Archives
  - Available State Data
- Build Relationships with local government
- Collect Report from local government
- Review federal data (FEMA, NRCS, Etc)
Utah Geological Survey GeoData Archive System

The UGS GeoData Archive System, part of our Geologic Data Preservation Project, contains Utah geologic- and wetlands-related scanned documents, photographs (except aerial), and other digital materials (resources) from our files and those gathered from other agencies or organizations in one web-based system.

Individual data collections are accessible using the Data Collections links. Resources available to general users are all in the public domain or from the public record. Metadata describing each resource is searchable, along with map searching for resources that are local or site-specific in nature. Users are also encouraged to search the UGS Library for books and similar materials. Upon searching for specific resources, they may be viewed directly, or downloaded to your local device. Not all resources may be available to all users due to copyright and/or distribution restrictions.

https://geodata.geology.utah.gov
### Geotechnical Database

<table>
<thead>
<tr>
<th>ID</th>
<th>GEOTECH ELG NO</th>
<th>DATE</th>
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[Image: geology.utah.gov]
Database Expansion

• Partnering with Weber State University
• Gain Experience
  – GIS
  – Database entry
  – Geologic data
  – Engineering reports
• Expedite entry time
UDOT Partnership

• Pilot project to extract subsurface data from boring and test pits
  – Soil/Rock units & classification
  – Groundwater depth
  – SPT Counts
  – Laboratory Data (Atterberg limits, consolidation/expansion, shear strength)

• A selected area to develop a process of data entry
DIGGS Format

- Data Interchange for Geotechnical and Geoenvironmental Specialists Format
- An effort to standardize geotechnical data
  - Developed by government and private organizations
    - United States Federal Highway Administration (FHWA)
    - United Kingdom Highways Agency (UKHA)
    - Eleven United States Departments of Transportation
    - United States Geological Survey (USGS)
    - United States Army Corps of Engineers (USACE)
    - United States Environmental Protection Agency (US EPA)
    - United States Navy (USN)
    - Construction Industry Research and Information Association (CIRIA)
    - United Kingdom Association of Geotechnical and Geoenvironmental Specialists (AGS)
    - Consortium of Organizations for Strong-Motion Observation Systems (COSMOS)
    - The University of Florida
    - The University of New Hampshire
    - Petrochemical Open Standards Consortium (POSC)
    - Major software vendors including Keynetix, gINT, and EarthSoft
• DIGGS is designed to assist anyone who wants to send or receive geotechnical or geoenvironmental information such as owner agencies, companies associated with software and databases, academic institutions, industry organizations

• DIGGS is an electronic data transfer format. It is not:
  – A software product
  – A database structure
• Converting data to DIGGS
  – Excel plugin tool, Keynetix contact required to obtain the tool (http://www.keynetix.com/diggs/)
  – Website zipped csv files to xml (http://diggsml.org/diggs/)
• Diggs to GIS
  – ArcMap/Pro
  – GoogleEarth
Subsurface Mapping
Summary

- Archive Public Access – More data available to the public
- UDOT – Continuing partnership to increase database
- Better Mapping – The scope and detail of the data will allow for increased understanding of the subsurface
Questions?