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Part 1 of 4

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LUCKY or GOOD?
Importance of Engagement & Culture in Business Conduct/Ethics.

PRESENTER: PHILIP KING, PE
President, SynchroPile, Inc.

DATE: March 31, 2017

Today’s presentation is available for free to all GBA Members. For information about the presentation or for information about GBA membership, please contact:

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Professor and Jennie C. and Milton T. Graves Chair in Engineering

The University of Texas at Austin
The Increasing Role of Seismic Measurements in Geotechnical Engineering

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University of Texas at Austin

First Annual Geo-Houston Conference
Rice University
Houston, TX
31 March 2017
Outline

1. Brief Background
   - emphasize small-strain field measurements
   - laboratory tests used for parametric studies

2. Present a Number of Examples
   - static and dynamic problems

3. Show the Link Between Field and Laboratory Seismic Measurements

4. Concluding Remarks
1. Background: Role of Seismic (Stress Wave) Measurements

1. Soil Profile
2. Field: Linear $V_s$ (and $V_p$)
3. Lab: Linear and Nonlinear $G$ and $D$

1. Soil Profile:
- Sand (SP)
- Silt (ML)
- Clay (CH)
- Sand (SW)
- Clay (CL)

2. Field: Linear $V_s$ (and $V_p$)

3. Lab: Linear and Nonlinear $G$ and $D$

$G_{\text{max}} = \rho V_s^2$

$D_{\text{min}}$

Shear Strain, $\gamma$, %
Depth, m
$V_s$, m/s
$G$, MPa
0.001 0.1
1a. Field: **Seismic Measurements**

**Objective:** measure time, $t$, for a given stress wave to propagate a given distance, $d$ ... then velocity $= \frac{d}{t}$

**Key characteristics:**
1. small-strain (linear) measurements
2. proper sources
3. oriented receivers
Field Measurements with Compression (P) and Shear (S) Waves

<table>
<thead>
<tr>
<th>Wave Type</th>
<th>Particle Motion</th>
<th>Distortion</th>
<th>Wave Velocity</th>
<th>Small-Strain Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>←→</td>
<td></td>
<td>$V_p$</td>
<td>$M_{\text{max}} = \frac{\gamma_t}{g} V_p^2$</td>
</tr>
<tr>
<td>S</td>
<td>↑↓</td>
<td></td>
<td>$V_s$</td>
<td>$G_{\text{max}} = \frac{\gamma_t}{g} V_s^2$</td>
</tr>
</tbody>
</table>
Small-Strain Seismic Measurements

Small-strain wave propagation: \( G_{\text{max}} = \frac{\gamma_t}{g} V_s^2 \)

Shear Stress, \( \tau \) (kPa)

Shear Strain, \( \gamma \) (%)

Initial Loading Curve

\( G_{\text{max}} \)
Field Seismic Methods

1. Crosshole
2. Downhole (Seismic CPT)
3. P-S Suspension Logger
4. Surface Waves
1b. Laboratory: **Combined Resonant Column and Torsional Shear (RCTS) Test**

![Diagram of the Combined Resonant Column and Torsional Shear (RCTS) Test]

- **Confining Chamber**
- **Magnet**
- **Accelerometer**
- **Drive Coil**
- **Top Cap**
- **Soil**
- **Fixed Base**
- **Torsional Excitation**
Laboratory Parametric Studies

a. $\log V_s - \log \sigma_0$

b. $G - \log \gamma$

- Confining Pressure, $\sigma_0$, kPa
- Silty Sand (Small Strain, $\gamma < 0.001\%$)

$$G_{\text{max}} = \left(\frac{\gamma_t}{g}\right) V_s^2$$

$$\sigma_{\text{cell}} = \sigma_1$$
Small-Strain $V_p$ and $V_s$ Measurements: Piezoelectric Transducers

Note: Confining chamber not shown.
2. **Examples:** Applications and Case Histories

- static loading conditions
- dynamic loading conditions
Static Loading Conditions

1. Site Characterization
   - layering, ground water table, etc.
   - underground structures
   - tunnel investigations *
   - dams, levees, etc. *
   - SMW landfills

2. Process Monitoring
   - grouting evaluations
   - ground improvement studies *
   - areas of deterioration
   - sample disturbance

3. Movements under Static Loads
   - footing settlements *
   - retaining wall movements

4. Link Between Field and Lab *
General Approach

Estimate Material Quality

Evaluate Changed Condition

Good Material

Field

Improved Zone

Before

After
Site Characterization: Tunnel Investigation
SASW Testing Arrangement and Planes of Investigation

“Crown” Investigation Plane

Springline Investigation Plane

Receivers Source

SASW Array Axes

Rock
Grout
Liner
Conducting SASW Tests

Small Hammer

Accelerometers
Interpreted $V_S$ Profile Behind Tunnel Wall at Springline

Results:
1. high-quality concrete
2. thickness: ~ 0.3 m
3. no voids
4. rock stiffer than liner
Site Characterization: Proposed Locations of Water Tunnel Shafts

Vancouver Harbor

Possible Tunnel Alignment
Vancouver Harbor

SASW Testing Locations

Area 1

Area 2

Area 3
\( V_s = A_s \left( \frac{\sigma_o'}{P_a} \right)^{n_s} \)

- \( A_s = V_s \) at \( \sigma_o' = 1 \text{ atm} \)
- \( K_o \) assumed equal to 0.5
**Vs Profiles in Area 1: Relative Character and Variability of Granular Materials?**

**Shear Wave Velocity (fps)**

- **Vs Profiles for:**
  - Dense Gravel
  - Dense Sand
  - Imperial Valley, Soft Sands, Silts and Clays

- **SASW No.:**
  - N 01
  - N 02
  - N 03

**Area 1**

(Assumed Water Table = 8 ft)

**Vs Profiles for:**

- Median $V_s$
- 16th and 84th Percentiles ($N \geq 3$)

**Best Fit**

$V_s = A_s (\sigma'_0/\rho_a)^{n_s}$

(Assumed $A_s = 896$ fps; $n_s = 0.23$)

**Shear Wave Velocity (fts)**

- **SASW Profiles:**
  - Median $V_s$
  - 16th and 84th Percentiles ($N \geq 3$)

**VS Profiles for:**

- Dense Gravel
- Dense Sand
- Imperial Valley, Soft Sands, Silts and Clays

**Area 1, Zone 2**
**Vs Profiles in Area 2: Relative Character and Variability of Granular Materials?**

**Area 2**

(Assumed Water Table = 8 ft)

Note: Zone 1 deleted from statistical analyses and comparisons.

**SASW Profiles:**
- Median $V_s$
- 16th and 84th Percentiles ($N \geq 3$)

$V_s = A_s (\sigma'_o/P_a)^{n_s}$

**Best Fit**
- $A_s = 720$ fps
- $n_s = 0.20$
Liquefication Resistance from $V_S$ (Andrus and Stokoe, 2000)

Overburden-Stress Correction for $V_S$:

$$V_{s1} = V_s \left( \frac{P_a}{\sigma'_{vo}} \right)^{0.25}$$

$P_a = 100$ kPa

$\sigma'_{vo} = \text{depth} \times \gamma_t$

Fines Content:
- $< 5\%$
- $6$ to $34\%$
- $> 35\%$

M$_w = 7.5$

Cyclic Stress or Resistance Ratio, CSR or CRR

Stress-Corrected $V_S$, $V_{S1}$, m/s
Likelihood of Liquefaction Triggering

Effective Stress Normalized Shear Wave Velocity, $V_{S1}$ (fps)

- Average $V_{S1} = 882$ fps (269 m/s)
- Median $V_{S1}$ Profile for Zone 2 of Group 1
- Limiting Value for Triggering Liquefaction in Sand with Fines < 5%, Mw= 7.5, and Level Ground Conditions (Youd, Idriss et al., 2001)

Area 1
Zone 2
(Assumed Water Table = 8 ft)

Effective Stress Normalized Shear Wave Velocity, $V_{S1}$ (m/sec)

- Limiting Value for Triggering Liquefaction in Sand with Fines < 5%, Mw= 7.5, and Level Ground Conditions (Youd, Idriss et al., 2001)

Area 2
Zone 2
(Assumed Water Table = 8 ft)
Dam Investigation: “Quality” of Alluvium within and beneath an Embankment Dam

Reservoir

~200 ft (60 m)

Pervious and Semi-Pervious Downstream Shell

Embankment Core

Pervious Upstream Shell

Foundation Alluvium

Bedrock
Approximate SASW Testing Locations

- Toe Road
- Source
- SASW Array
- Toe Road
- Crest Road
- Reservoir

2500 ft (~760 m)
SASW Test Locations - Downstream Face and Downstream Area

Note: All Testing Arrays Parallel to Crest

- Downstream Face
- Downstream Shell; Compacted Alluvium
- Bedrock
- 75 ft Natural Alluvium
- 25 ft

SASW Profiling Location and Depth
Gradation Curves from Field Samples of Foundation Alluvium

- **Cobbles**
- **Gravel**
- **Sand**
- **Silt**

**Dillon Dam**

- $D_{50} \sim 50 \text{ mm}$
- $C_u \sim 130$
- $PI = 0$
Statistical Analysis of Natural Alluvium

- **Shear Wave Velocity (ft/sec)**: The graph shows the variation of shear wave velocity with depth. The range of shear wave velocity is from 0 to 2500 ft/sec.
- **c.o.v. (coefficient of variation)**: The c.o.v. is a measure of relative variability. It is calculated as the standard deviation divided by the mean. The graph indicates the c.o.v. at different depths, with a highlighted zone of disturbance.
- **Zone of Disturbance**: The zone of disturbance is marked on the graph, indicating deleted Vs values.
- **Individual Vs Profiles**: Individual Vs profiles are represented by grey lines. The mean profile is highlighted in yellow. The profiles are shown with standard deviation (σ) indicated by yellow error bars.
- **Mean +/− σ**: The mean Vs profile is shown with error bars indicating the standard deviation.
- **No. of Profiles**: The number of profiles used in the analysis is indicated on the right side of the graph.

Mathematically:

\[
c.o.v. = \frac{\sigma}{\text{mean}}
\]

**Example Calculation**: For Avg. c.o.v. = 0.08, the formula can be used to understand the variability in the data.
Comparison of Mean $V_S$ Profiles - Natural Alluvium and Compacted Alluvium

**Results:**

1. Natural alluvium is stiff ($V_S \geq 300$ m/s); hence, dense.
2. Compacted alluvium in dam is similar to natural alluvium so:
   (a) dense and
   (b) not cemented.
3. No loose zone of alluvium under toe of dam.
4. Average c.o.v. $< 0.1$
Best-Fit Curve for the Field Log $V_S - \log \sigma_n'$ Relationship of the Natural Alluvium

**Results:**

1. $n_s = 0.32$ is reasonable for uncedmented gravelly soils.

2. $V_S$ at depth $\sim 1$ ft (0.3 m) equals 527 fps (161 m/s) which represents material with:
   - (a) large $D_{50}$ ($> 25$ mm),
   - (b) large $C_u$ ($> 35$) and
   - (c) no cementation.

3. $\log V_S - \log \sigma'_v$ is representative of a normally consolidated soil (... with no plasticity).

---

**Notes:**

Mean $V_S$ profiles in the depth range of 6 to 60 ft.
Calculated $V_{S1}$ Profile for Natural Alluvium Using $n_s = 0.32$

**Overburden-Stress Correction for $V_s$:**

$$V_{s1} = V_s \left(\frac{P_a}{\sigma'_v}\right)^{0.32}$$

$P_a = 100$ kPa

$\sigma'_v = \text{depth} \times \gamma_t$

**Average $V_{S1}$**

Assumed $\gamma_t \sim 138$ pcf

Avg. $V_{s1} = 1245$ fps  
(380 m/s)
Liquefaction Resistance from $V_S$

(Andrus and Stokoe, 2000)

Cyclic Stress or Resistance Ratio, CSR or CRR

Overburden-Stress Correction for $V_S$:

$$V_{s1} = V_s (P_a / \sigma'_{vo})^{0.25}$$

$P_a = 100$ kPa

$\sigma'_{vo} = \text{depth} \times \gamma_t$
Process Monitoring: Evaluating Compaction of a Thick Granular Fill

~N

Existing NPP Units 1 & 2

New Units 3 and 4

Vogtle Electric Generating Plant (NPP), Augusta, GA
Cross-Section of Backfill at Units 3 and 4

Notes: 1. Material in backfill is SP, SP-SM, SM; nonplastic fines.
2. Loose lifts of 12 in. (30 cm).
3. Minimum compaction of 95% modified Proctor (avg. ~ 98%).
Creating 90-ft (27.5-m) Deep Excavation
Relative Locations of Units 3 and 4

Plant Vogtle Units 3 and 4 foundation excavation, with water vapor rising from cooling towers in background. April, 2010.
Backfilling Nearly Complete

Unit 3

Unit 4

Aerial photograph of Vogtle 3 and 4 construction site. Unit 3 is located at left and top of photo and Unit 4 to the right and bottom. Heavy lift derrick crane foundation in center. August 11, 2011

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SASW Testing on Completed Backfill

Bulldozer Source

Center Geophone

First Geophone

Third Geophone
Seismic Testing during Backfilling Process

Unit 3
- First Set: 160 ft
- Second Set: 178 ft
- Third Set: 204 ft
- Fourth Set: 217 ft

Unit 4
- First Set: 155 ft
- Second Set: 179 ft
- Third Set: 197 ft
- Fourth Set: 217 ft
Are the Two Backfills Alike?

![Graph showing Shear Wave Velocity profiles for Unit 3 and Unit 4.](image)

- **Unit 3**
  - Shear Wave Velocity (m/sec) range: 0 to 600
  - Depth (m) range: 0 to 30

- **Unit 4**
  - Shear Wave Velocity (m/sec) range: 0 to 600
  - Depth (m) range: 0 to 30

---

**Median V<sub>S</sub> Profiles**

- Unit 3
- Unit 4
Do the Field and Lab $V_S$ Values Agree? (Could $V_S$ Profile be Predicted from Lab?)

Median $V_S$ Profile of Unit 4 ($K_o = 0.5$) 
- Best Fit ($A_S = 1018$ fps, $n_s = 0.23$ and $R^2 = 0.986$)
- 3 Lab RC Test ($K_o = 0.5$)
- Median $V_S$ Profile of Unit 4 ($K_o = 0.5$)
Depth to $V_s > 1000$ fps (300 m/s)

Unit 3

Unit 4

Base of Nuclear Island

Profiles

Median

~22 ft

~21 ft

$7V_s$ Profiles

Median

Base of Nuclear Island
Movements under Static Loading: Shallow Foundations on Granular Soil

Main Design Criteria

1. Bearing Capacity: \( Q_{\text{design}} = \frac{Q_{\text{ult}}}{F.S.} \)

2. Permissible Settlement: \( S \leq S_{\text{design}} \)

Approach
- Limit equilibrium analysis
- Requires strength parameters (\( \phi' \) and \( c' \))

Traditional Approach
- Based on SPT and CPT correlations
- Soil sampling is hard and/or expensive in granular soil so rarely performed
- Stresses and strains are undefined

New Framework
- Deformation-based analysis
- Stresses and strains are calculated
New Framework for Settlements Predictions

**Framework:**
- Requires Stiffness Parameters
- \( G \) Changing with \( \gamma \) and \( \sigma \)
- \( \nu \) Changing with \( \gamma \) (but presently assumed \( \nu = \text{constant} \))

1. Loading Applied
   - Applied Load, \( P \)

2. Load - Settlement Curve
   - Settlemnet, \( S \)
   - Point A

3. Stress - and Strain - Dependent Moduli, Load #1:
   - At Point A: Load #1
   - Shear Strain, \( \gamma \)
   - Shear Stress, \( \tau \)

4. Stress - and Strain - Dependent Moduli, Load #2:
   - At Point A: Load #1
   - Shear Strain, \( \gamma \)
Modeling with Dynamically Measured Soil Properties (MoDaMP)

**Step # 1** - Field Seismic Testing for $V_s$ - Depth Profile

**Step # 2** - Field $\log G_{\text{max}}$ – $\log \gamma$ Relationship

**Step # 3** - Dynamic Laboratory Tests for $G/G_{\text{max}}$ – $\log \gamma$ Relationships

**Step # 4** - Combine Field Seismic and Dynamic Laboratory Tests for $G$ – $\log \gamma$ Relationships

For each layer
PLAXIS Finite Element Model with MoDaMP

- 946, 15-node triangular elements
- 15 ft x 15 ft dimensions
- Footings are modeled as flexible
- Axisymmetric model
- The lower boundary is fixed in both direction
- The vertical boundaries are fixed only in horizontal direction
Load-Settlement Tests at the NGES Test Site

- Two, circular, reinforced concrete footings with diameters of 0.91 m (3.0 ft) and 0.46 m (1.5 ft).
- Loading with T-Rex as a reaction; Settlements measured with linear potentiometers

(Thank you Prof. Briaud!)
Example of How MoDaMP Works

Vertical Loading

Layer 1

Diameter=\(B=0.91\) m

Point X

Layer 2

0.5\(B\)

1.0\(B\)

1.5\(B\)

Point Y

Point Z

Rigid boundary

Load, \(P\), (kN)

Selected Load Levels on the Predicted Load-Settlement Curve

Curves Changing with Load Level

Load Levels on the Load-Settlement Curve

POINT X
(depth=0.5 B)

POINT Y
(depth=1.0 B)

POINT Z
(depth=1.5 B)
Load-Settlement Predictions with MoDaMP

Comparison of Predicted and Measured Settlements

- Load Levels at Which Vertical-Strain Profiles were Calculated
- Prediction with PLAXIS and MoDaMP2 (2nd modification)
- Estimated Working Stress Range

Diameter = 0.91 m
Load-Settlement Predictions with MoDaMP

Comparison of Predicted and Measured Settlements

Predicted Vertical Strains Beneath the Centerline of Footing

Points A, B and C are selected load levels on the load-settlement curve of the 0.91-m diameter footing.
Load-Settlement Predictions with MoDaMP

Comparison of Predicted Settlements with CPT- and SPT-based Methods

![Graph showing load-settlement predictions with MoDaMP. The graph compares measured and estimated settlements at different applied pressures. The graph includes predictions from PLAXIS and MoDaMP2 (2nd Modification), Burland and Burbidge (1985)-CPT based, and Schmertmann et al. (1978)-SPT based methods. The graph also indicates the estimated working stress range and the measured settlements.]
Dynamic Loading Conditions

1. Machine-Foundation Design
2. Vibration-Isolation Barriers
3. Earthquake Engineering
   site response, soil-structure interaction, liquefaction, etc.
4. Link Between Field and Lab
Dynamically Loaded Machine Foundations

Actual System

Equivalent System

Soil: $G$ = shear modulus
$\gamma_t$ = total unit weight
$\nu$ = Poisson’s ratio

$r_0$ is based on equal areas

$K_Z = \frac{4Gr_0}{(1 - \nu)}$

$C_Z = \left(\frac{3.4 r_0^2}{1 - \nu}\right) \sqrt{\rho G}$
Evaluating the Dynamic Response of the Machine Foundation System

\[ Q = Q_0 \sin \omega t \]

\[ Z = Z_0 \sin \omega t \]

From Richart, Hall and Woods, 1970
Link Between Field and Lab:

Estimating the Field $G - \log \gamma$ Relationship (Soil)

La Cienega
Depth = 185 m
Silty Sand (SM)
$s'\sigma = 25$ atm

$G_{\gamma, \text{field}} = \left(\frac{G}{G_{\text{max}}}\right)_\gamma \times G_{\text{max, field}}$
Link Between Field and Lab:

Estimating the Field G – log $\gamma$ Relationship (Rock)

Yucca Mt.
Depth $\geq$ 1000 ft
Topopah Spring Tuff
Tptpmn

Shearing Strain, $\gamma$, %
Concluding Remarks

1. Small-strain mechanical properties, expressed by $V_S$ or $G_{max}$, play an important role in Geotechnical Engineering.

2. Small-strain mechanical properties are critical in dynamic and static deformational analyses under working loads.

3. Field measurements of $V_S$ form the way to map nonlinear laboratory measurements to field behavior.

4. The importance of $V_S$ or $G_{max}$ (and also $V_P$ and $M_{max}$) will continue to grow in solving dynamic and static problems.
Thank you
Gary Tucker, P.G., C.P.G.

Chief Geophysicist
Tolunay-Wong Engineers, Inc.
Surface Faulting in the Greater Houston, Texas Area
Associated Risks, Impacts, and Solutions

Presented By:
John Gary Tucker, P.G., C.P.G.
Chief Geophysicist
March 31, 2017
TOPIC OUTLINE

• Associated Risks
• Definitions
• Houston Area Fault History
• Fault Investigation Standards
• Fault Impacts
• Potential Solutions
ASSOCIATED RISKS

- Structural Damages
- Foundation Damages
- Utility / Pipeline Damages
- Damage to Pavement (Driveways, Sidewalks, Roads)
ASSOCIATED RISKS

• Structural Damage
• Building Buckling
• Building Subsidence
ASSOCIATED RISKS

- Structural Damage
- Building Buckling
- Building Subsidence
ASSOCIATED RISKS

• Foundation Shifting
• Structure Separated from Foundation
• Structure Shifting
ASSOCIATED RISKS

- Foundation Shifting
- Structure Separated from Foundation
- Structure Shifting

STRUCTURE SEPARATED FROM FOUNDATION

FOUNDATION SHIFTING FROM GROUND

STRUCTURE SHIFTING FROM FOUNDATION
ASSOCIATED RISKS

- Drainage effected
- Causing water to pond
- Deterioration of subgrade
- Creating potential health hazard
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DEFINITIONS

• **Growth Fault**
  • Normal fault that continues to have movement during sedimentation and typically has thicker strata on the downthrown side.

• **Antithetic Fault**
  • A complimentary fault or minor secondary fault with a sense of displacement opposite to a growth fault.

• **Radial Fault**
  • Multiple faults whose fault planes strike outward from a common center. Typically associated with salt domes.

• **Active Fault**
  • A fault that has caused damage to manmade structures or a fault whose current rate of movement is sufficient to cause damage to manmade structures. A fault that has had movement in the last 10,000 years.

• **Fault Trace**
  • A line defined by the intersection of a fault surface with the land surface.
Figure 1. Growth and Antithetic Faults

- Growth fault
- Antithetic fault
- Low density evaporite layer
- Flow direction due to deferral of load of the overlying sediment
- Décollement Surface

Figure 2. Radial Faults

- Radial Faults
- Allochthonous Salt
- Infra-allochthonous Salt Sediments
- Salt Weld
HOUSTON AREA FAULT HISTORY

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  • Structural damages associated with surface faulting were noticed in the Spring Branch, Bunker Hill, Piney Point, Ellington Field, Hobby Airport, and elsewhere in the Houston Metropolitan area.
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    • Bill R. Elsbury – McClelland Engineers, Inc.
    • Lynn J. Ratcliff – McBride-Ratcliff and Associates, Inc.
    • Dewitt Van Siclen – Consulting Geologist
    • Carl E. Norman – University of Houston
    • Robert M. Valentine – Woodward-Clyde Consultants
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• **March, 1985**
  - "Recommended Standards of Practice for Investigating Geologic Faults in the Texas Gulf Coast Region" was published in the Houston Geological Bulletin, March 1985, Page 10.
FAULT INVESTIGATION STANDARDS

Recommended Standards of Practice for Investigating Geologic Faults in the Texas Gulf Coast Region

OBJECTIVES:

• “To present appropriate levels of investigative effort to provide information necessary for making sound judgments concerning the impact of geologic faults on development projects.”
• The guidelines are intended to satisfy the FHA-VA requirement for geologic fault studies.
• These studies do not represent an exact or absolute warranty, but rather they provide a means for the management of risk.
• The guidelines are divided into three levels of effort, termed as phases:

  • PHASE 1 – Basically a desktop study with a site visit to determine surface fault probability.
  • PHASE 2 – Involves a subsurface investigation to determine if a fault exists.
  • PHASE 3 – Involves delineating a fault trace and establishing a hazard band (a zone of limited development).
FAULT INVESTIGATION STANDARDS

PHASE 1

• Literature Review
• Remote Sensing Study
• Field Reconnaissance
Surface Fault Map Comparison

Rarely Do Published Maps Show the Same Surface Faults

USGS Principal Faults in the
Houston, Texas, Metropolitan Area
Shah and Lanning-Rush 2005

Historically Active Faults in the Houston
Metropolitan Area, Texas; Earl R.
Verbeek & Uel S. Clanton; 1981
AERIAL PHOTOGRAPH
False-color Infrared

Aerial Photograph Taken 1995

Verbeek Clanton Fault No. 53
Photographic Linear Feature

Texas Highway 35

Beltway 8

Clear Creek
AERIAL PHOTOGRAPH
False-color Infrared

Aerial Photograph Taken 1995

Verbeek Clanton Fault No. 53
Photographic Linear Feature

Texas Highway 35

Beltway 8

Clear Creek
Aerial Photograph Taken April 3, 1944

Verbeek Clanton Fault No. 53
Photographic Linear Feature

Verbeek Clanton Fault No. 41A
Photographic Linear Feature

Clear Creek

Texas Highway 35
AERIAL PHOTOGRAPH
Historical Aerial Photograph

Aerial Photograph Taken April 3, 1944

Verbeek Clanton Fault No. 53
Photographic Linear Feature

Verbeek Clanton Fault No. 41A
Photographic Linear Feature

Clear Creek

Texas Highway 35
FAULT INVESTIGATION STANDARDS

PHASE 1

- Literature Review
- Remote Sensing Study
- Field Reconnaissance

Probability of Fault?

- Low Complete
- Suspected
- High
FAULT INVESTIGATION STANDARDS

PHASE 1
- Literature Review
- Remote Sensing Study
- Field Reconnaissance

PHASE 2
Subsurface Investigation
- Test Holes with Electric Logging
- Correlating Stratigraphy

Probability of Fault?
- Low
- Suspected
- High

Surface Fault Present?
- No
- Yes

STOP
STOP
Phase II Geologic Fault Study Cross Section

Note: The fault plane is not cut by test holes
FAULT INVESTIGATION STANDARDS

PHASE 1
- Literature Review
- Remote Sensing Study
- Field Reconnaissance

PHASE 2
Subsurface Investigation
- Test Holes with Electric Logging
- Correlating Stratigraphy

Probability of Fault?
- Low Complete
- Suspected
- High

Surface Fault Present?
- No Complete
- Yes
FAULT INVESTIGATION STANDARDS

PHASE 1
- Literature Review
- Remote Sensing Study
- Field Reconnaissance

Probability of Fault?
- Low
- Suspected
- High

PHASE 2
Subsurface Investigation
- Test Holes with Electric Logging
- Correlating Stratigraphy

Surface Fault Present?
- No
- Yes

PHASE 3
Subsurface Investigation
- Test Holes with Electric Logging
- Correlating Stratigraphy
  - or -
Surface Investigation
- Field Identification
- Land Survey Methods

Complete
Phase III Geologic Fault Study Cross Section

Fault plane is cut by two test holes: BH-2 @ 217’ and BH-11 @ 252’

\[ \tan \theta = \frac{35}{10.9} \]

\[ \theta = 72.7° \]
Phase II/III Geologic Fault Study Cross Section

Fault plane is cut at Test Hole F-2 @172-ft
Fault Angle = 76°
Thus, the distance of the fault trace from F-2 to F-3 was about 43 feet.

Legend:
- Marker Beds
- Projected Fault Trace

CPS = Counts per Second
Ohm = Ohms
mV = millivolts
Phase III Geologic Fault Study Surface Investigation
Phase III
Geologic Fault Study Surface Investigation

Field Identification
• Pavement damage
• Wall damage
Phase III
Geologic Fault Study Surface Investigation

Land Survey Methods
• Line perpendicular to suspected fault trace elevation measured with survey level
FAULT IMPACTS

Key Characteristics

Damage due to surface faulting can be distinguished by certain characteristics as defined by Earl R. Verbeek, Karl W. Ratzlaff and Uel S. Clanton in “Faults in Parts of North-Central and Western Houston Metropolitan Area, Texas” in 1979, as follows:

• Damage to cultural features or structures is significantly more severe within a narrow (2 feet to 30 feet) rectangular and slightly curved band or zone than other areas.

• The band or zone of damage is parallel to and coincident with a topographic slope, (the fault scarp), that separates two blocks of land at different elevations.

• Damage to affected structures is consistent with vertical offset of the land surface as deduced from the fault scarp.
Note: Distance of Space
Manholes Placed on Each Side of the Fault

Pipe between manholes is allowed to “slip” inside the manholes.
Pipe 

Backfill

Natural Undisturbed Soils

Pipe

Vermiculite, or light weight, or loose fill, or compressible, or crushable type materials.
QUESTIONS?
GEO-HOUSTON 2017

March 31 at Rice University

Celebrating Houston