Geotechnical Innovations: From Research to Practice

Purdue Geotechnical Society Workshop

J. David Frost, Ph.D., P.E., P.Eng.
Professor & Vice Provost
Georgia Institute of Technology
Who knows what this is .....
Outline of presentation

• A few comments about innovation
• In-situ penetration tests
• Laboratory tests
• Geosynthetics
• Digital soils
• Non-disruptive technologies
• Full-scale tests
• Insight inspired innovation
• Emerging opportunities
A Definition of Innovation:

The successful exploitation of a new idea, method, device or system that creates a new dimension of performance.....
Innovation Path (iPath)

Applied Research       System Realization

Basic Research       Translational Research       Commercialization

Innovation Path (can be long and tortuous)

Academia tends to focus on this end…

Practice tends to focus on this end…

Innovation can begin/occur anywhere along the path

Invention not same as Innovation!
Innovation Characteristics

**TYPES**

- Transformational
- Incremental
- Device
- System
- Project specific
- Method

**METRICS**

- Relative to what base
- Cost to develop
- Revenue generated
- Return on investment
- Simplicity
## Characteristics of Innovators

<table>
<thead>
<tr>
<th>WHO</th>
<th>TRAITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Individual</td>
<td>• Inquisitive mind</td>
</tr>
<tr>
<td>• Group of individuals</td>
<td>• Willingness to explore</td>
</tr>
<tr>
<td>• Team</td>
<td>• Not afraid to fail</td>
</tr>
<tr>
<td>• Owner</td>
<td>• Pioneer spirit</td>
</tr>
<tr>
<td>• Thread of above</td>
<td>• Enjoys working at interfaces</td>
</tr>
</tbody>
</table>
Innovation Enablers/Detractors

SUPPORT FACTORS

• Situational
• Constraint motivated
• Insight inspired
• Accidental
• Environment driven

IMPEDIMENTS

• Resources
• Ethics
• Environment
• Competitors
• Constructability
• Sustainability
Cycle of Innovation

Rogers Diffusion “S” Curve

- One time event
- Short life
- Long life
- Multiple incarnations
Identified Geo-Innovations

- Electronic data acq.
- Data visualization
- Numerical analysis
- DEM
- Osterberg Load Cell
- System analysis
- Geosynthetics
- Ground improvement
- Suction piles
- Real-time monitoring
- Wave based char.
- Probabilistic methods
- Soil nailing
- Penetration testing
- Small strain
- New materials
- Higher resolution tools
- Tomography
In-Situ Penetration Tests
Penetration Testing
Vision Cone Penetrometer

(courtesy Hryciw)
Multi-sensor Technology

- Conventional 15 cm² CPT Module
- Multi-Friction Sleeve Penetrometer Attachment
  - Attachment Digital Housing
  - Attachment Digital Board
  - Dual Axis Inclinometer
  - Friction Sleeve
  - Mandrel
  - Førge #1
  - Førge #2
  - Førge #3
  - Førge #4
  - Digital Housing
  - Digital Board
  - Pore Pressure
  - Tip
  - 61 cm
  - 109 cm
  - 4.37 cm
Multi Friction Sleeve CPT Attachment Data

Test Site: Timian Yard - South Royalton, VT
Oper: JD, GLH, DF
MS #2: SM2
MS #1: SM1
MS #4: SM4
Date: Variable
Pen. Rate (cm/s): 2
Meas Rate (Sa/cm): 1
Notes: Response of Sleeve Texture to Silica Sand at the SRVT test site - APF Corrected

Multi Piezo Friction Sleeve CPT Attachment Data

Test Site: Shenton Park Sand Site
Oper: GLH, James, Andrew (Probadrill WA)
MS #2: 30H.25S3
MS #3: 30H1S3
MS #1: 30H.5S3
MS #4: 30H2S3
Date: 7/30/2004
Tip Conf: 15cm2 CPT
Pen. Rate (cm/s): 2
Meas Rate (Sa/cm): 1
Notes: MPFA - No fs, MS1

Multi Piezo Friction Sleeve CPT Attachment Data

Test Site: Shenton Park Sand Site
Oper: GLH, James, Andrew (Probadrill WA)
MS #2: 30H.5S3
MS #3: 30H1S3
MS #1: 30H.25S3
MS #4: 30H2S3
Date: 7/30/2004
Tip Conf: 15cm2 CPT
Pen. Rate (cm/s): 2
Meas Rate (Sa/cm): 1
Notes: MPFA - No fs, MS1
Integrated Digital Data Management
Laboratory Tests
Moist Tamping System

Schematic View of Moist Tamping System

Moist Tamped Specimen with Undercompaction Ratio of 3 %
Forces Applied to MT Specimen
Peak Stress Measurement

Avg. Peak Stress, kPa

Layer

Top 7

10 25 40 75%

Bottom 0

0 50 100 150 200

Layer

Bottom 0

0 50 100 150 200

Avg. Peak Stress, kPa

Target $D_R$
Global Response of Dilatant Specimens

H/D=2, Non-lubricated

H/D=1, Non-lubricated

H/D=1, Thin Lubricated

H/D=1, Thick Lubricated

50 kPa confining pressure
Typical Geomaterials

Steel

Geomembranes

Wood

FRP

Concrete
Interface Shear Device (End View)
Curved Shear Box

Shear Box on Top of Pipe Coupon

Photograph of the Underside of the Shear Box
Geosynthetics
Geosynthetics

(courtesy Hebeler)
Geosynthetics

(courtesy Hebeler)
Geosynthetics

(courtesy Hebeler)
Geosynthetics

(courtesy Hebeler)
Digital Soils
Tomography & Imaging Technologies
Serial Sectioning and Image Capture

Polishing Off 8μ → Capturing Images

Illustration of Reference Marks for Alignment

Cone for Removal Check

MultiPrep System

Leica DM 4000
Mosaic Generation

Four Neighboring Images with 20% Overlap
3-D Reconstruction

Slice used in 3D reconstruction

Dimensions of the Reconstructed Volume

- 20 mm
- 12 mm
- 8 μ
- 600 slices ≈ 5 mm
Reconstructed Ottawa 50-70 Block
3-D Reconstructed Specimens

Sub-volume of a specimen  
Extracted Pore Structure  
Extracted Particles
3-D Analysis: Pore Structure

A Volume of 256x256x300

3D Medial Axis of the Volume

Medial Axis Analysis:
- Shortest Paths
- Tortuosities

Colors represent relative distance (red - close, blue - far) to the nearest particle surface. (Particles are not shown)

Medial Axis Paths from Face 1 to Face 2

All Medial Axis Paths

Shortest Paths
3-D Particle Visualization
3-D Pore Visualization

Volume size: 117 x 87 x 65 voxels

Estimated pore size:
Length = 600 ~ 700 micron
Width = 200 ~ 300 micron
Height = 400 ~ 500 micron
• Surface Texture, roundness and sphericity influence strength properties and deformation characteristics of granular materials.

• There are few experimental studies that link strength properties and instability phenomena of unbound granular materials to their micro-properties.

Influence of particle surface toughness on friction and dilatancy angle under Plane strain Loading

(courtesy Al-Shibli)
Particle Shape Modeling in DEM

- Ellipses/Ellipsoids: Ting, Ng, Lin, others
- Superquadric: Williams et al.
- Polygons: Ghaboussi, Williams
- Bonded Clusters: Jensen, Bray, O'Sullivan
- Overlapping Clusters: Ashmawy, Sukumaran

(courtesy Sukumaran)
Non-disruptive Technologies
Machines
Jacking Forces

\[ JF_{\text{total}} = JF_{\text{face pressure}} + JF_{\text{friction}} \]
Intermediate Jacking Stations

- For Pipelines 36-inch and Larger
- Long Lead Time Items
- Must be inserted at Proper Location or they are useless
Full-scale Man-induced and Natural Tests
Osterberg Load Cell

(courtesy LoadTest)
Hurricane Storm Surge

(courtesy Santamarina)
Hurricane Storm Surge

Bathymetry: 200 kHz

Sub bottom profiling: 20 kHz

(courtesy Santamarina)
Insight Inspired
Shearing Mechanisms

Ottawa 20-30 Sand Specimen with Dyed Sand Layers

Structure Preservation After Shearing: Phenolic Resin (1% by weight)

Confining Stress = 50 kPa

Rod/Sleeve Displacement = 67.5 mm
Shearing Mechanisms

- Unaffected Zone
- Smooth Sleeve
- Direction of Sleeve Displacement
- Shear Zone
- Unaffected Zone
- Diamond Sleeve
- Direction of Sleeve Displacement
Discrete Element Modeling

Random Cluster Generation

Consolidation

Shearing
Discrete Element Modeling

- Smooth Surface
  \( \mu_{p-p} = 0.4 \)
  \( \mu_{p-c} = 0.3 \)
Normal Force

Displacement

Discrete Element Modeling

- Textured Surface
  \[ \mu_{p-p} = 0.4 \]
  \[ \mu_{p-c} = 0.3 \]
Emerging Opportunities
Gas Hydrate Bearing Sediments

Kvenvolden and Lorenson, 2001

(courtesy Santamarina)
Spatial Variability: Electrical Needle Probe

Varved Clay

(courtesy Santamarina)
In-Vivo Optical Molecular Imaging

The Kodak In-Vivo Multispectral Imaging System FX locates and monitors changes in molecular activity of specific cells and organs long before morphological changes can be detected……..

Editors Choice – Bioscience Technology March Innovations.

(courtesy Kodak)
Resistivity Tomography ERT  

(courtesy Santamarina)
Shear Wave Imaging – Stress around tunnels

(courtesy Santamarina)
Next Generation...
Thank You.

(courtesy Hebeler)