Celebrating Houston
Part 1 of 4
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gn engineers | scientists | innovators
Dennis Turner, P.E.

Engineering Manager
Fugro USA Land, Inc.
HARRIS COUNTY TOLL ROAD AUTHORITY
Sam Houston Tollway (East)
Ship Channel Bridge Corridor Reconstruction

Geotechnical Program Summary
ASCE Geo-Houston
March 31, 2017
Outline

- Project Description
- General Soil Conditions
- Field Load Test
- Foundation Systems
- Geotechnical Challenges
Span Layout
Tower Arrangement

- Sculpted, aesthetic tower shapes
- Built in stages, connected at 3 locations
Superstructure Cross-Section
Construction Stages
Site Geology

- Geologic Atlas of Texas
  - Boggy Bayou
  - Buffalo Bayou
  - Alluvial and Dredged Fill
  - Pleistocene Soils
  - Local Geohazards
Site Geology

- Pleistocene Soils
  - Slickensides
  - Secondary Structures
    - Calcareous Nodules
  - Ferrous Nodules
Geotechnical Studies

- Existing Data Review
  - Texas Turnpike Authority As-Built Drawings
  - Texas Turnpike Authority Geotechnical Reports – 111 Borings
  - HCTRA SH225/SHTIE Geotechnical Report – 15 Borings
- Preliminary Geotechnical Study
  - 20 Borings (150 to 300 ft depths)
- Design Geotechnical Studies
  - 65 Borings (up to 400 ft depths)
- Field Load Test Program
Geotechnical Studies
General Soil Conditions (South)

- South Side of Houston Ship Channel
  - Soft Ground
  - Historical Boggy Bayou – Alluvial and Dredged Fill up to 40+ ft.
  - Granular Strata in Select Locations at Depths of 60 – 100 ft.
  - Groundwater Influenced by Houston Ship Channel
General Soil Conditions (North)

- North Side of Houston Ship Channel
  - Soft Ground
  - Alluvial and Dredged Fill Up to 30+ ft.
  - General Cohesive Soil Profile with Some Granular Layers
  - Groundwater Influenced by Houston Ship Channel
Field Load Test Program

- Validate/Refine Design Soil Parameters
- Compare Predicted Capacity/Movements with Load Test Values
- Reduce Uncertainty (Risk) with Design Factors of Safety
- Validate Proposed QC/QA Methods in Project Specifications
Field Load Test Program

- LT-B – 8 ft. Diameter x 225 ft.
- LT-C – 8 ft. Diameter x 225 ft.
- LT-D – 4 ft. Diameter x 120 ft.
Field Load Test Program

- Sonicaliper
  - After Excavation/Before Reinforcing Steel
  - Confirm Plumbness
  - Confirm Diameter
  - Gauge Variability/Predicted Concrete Volume
Field Load Test Program

Ship Channel Bridge - Test Shaft LT-C
Houston, TX, 12/12/2016

VERTICAL PROFILE

Project Number: 04.10130070
SONICALIPER
Field Load Test Program

- Crosshole Sonic Logging (CSL)
  - Tubes/Conduit Attached to Rebar Cage
  - Test After Concrete Placement
  - Signal Return Can Indicate Quality of Concrete

*Shaft cross section with four tubes, six paths are tested.*
Field Load Test Program

- Thermal Integrity Profiling (TIP)
  - Thermocouple Wires Attached to Rebar Cage
    - Similar Spacing as CSL Tubes
  - Datalogger Collects Data After Concrete Placement
- Similar to Maturity Method
  - Higher Temperatures – More Concrete Cover/Bulge
  - Lower Temperatures – Less Concrete Cover/Necking/Voids
Field Load Test Program
Field Load Test Program
Field Load Test Program
Field Load Test Program
Drilled Shafts
Approach Foundations

- Drilled Shafts – 3- to 10-ft. Diameter
  - Typical – 4-ft. Diameter Shafts in Groups
  - Typical – 8- to 10-ft. Diameter Non-Redundant Shafts
  - Typical – Shaft Lengths up to about 150 ft.
- Groups of up to 30 Drilled Shafts
- Dense Granular Strata at Depth at Select Areas on South Approaches
- Utility and Existing Foundation Conflicts
- Permanent Casing in Select Locations
Main Pylon Foundations

- Drilled Shafts – 8-ft. Diameter
- Groups of 48 to 50 Drilled Shafts
- North Pylon Constructed in 2 Stages
- Shaft Lengths up to 250+ ft.
Construction QC/QA

- New HCTRA Specification Book
- Conventional Excavation, Slurry, Rebar, and Concrete Observations
- Sonicaliper
- Crosshole Sonic Logging
- Different Testing Frequencies by Risk Category
  - Main Pylon Drilled Shafts
  - Non-Redundant Drilled Shafts
  - Drilled Shaft Groups
Main Pylon Construction

- Large Diameter Drilled Shafts to Significant Depths (250+ ft.)
- 25 to 30 ft. of Retained Soil – Below Ship Channel Water Surface
- Anticipate Perimeter Drilled Shafts as Internal Braces
- Adjacent Site Usage Restrictions
- Underwater Tremie Slab
- North Pylon Constructed in 2 Stages
  - Protect Existing Bridge Transition Footing
Geotechnical Challenges

- Soft Ground (Alluvial/Dredged Fill)
- Protection of Existing Foundations
- Protection and Avoidance of Utilities
- Drilled Shafts through Dense Granular Strata at Depth
- Presence of Slickensided Clays and Granular Soil Layers
- Limited Staging Areas for Stockpiling Materials and Equipment
Questions
C. Vipulanandan, Ph.D., P.E.

Professor and Director of the Center for Innovative Grouting Materials and Technology (CIGMAT)

University of Houston
Geotechnical and Geological Characterization of Houston Area: Infrastructure Issues and New Technologies

C. Vipulanandan (Vipu), Ph.D., P.E.
Professor of Civil Engineering
Director of CIGMAT & THC-IT
University of Houston
Welcome to Houston

1. Oil Capital of the US/World

2. Largest Medical Center in the World

3. Space City (NASA)

4. Over 20% of the U.S. Beer is Produced

5. Engineering Challengers?
Engineering Challengers?

1. Owner: I Cannot See it?
   a. Geotech and Geology Issues?
   b. Where are the water pipes?
   c. Where are the Oil and Gas Wells?

2. Geo Engineer? How Can I Solve It?
   a. Geotech and Geology Issues?

3. Professor Research? Or Testing?
   a. Geotech and Geology Issues?
Faults in Houston, Texas
Reasons for Faulting? SALT DOMES

Ground Movement 0.2 to 0.8 inch/Year
Effects of Faults (Neighborhood?)

1. Drainage System Cracking

2. Roadway Cracking

3. Driveway Cracking

Can You Design?
Bayou City – Houston, Harris County, Texas

1. Greater Houston Population > 6 million

2. > 4,000 km of Bayous (2,500 miles)

3. Harris County > 5,500 sq.km

4. Houston > 1800 sq.km


6. Include it in Your Design?
Hurricane Ike Sept. 1-11, 2008

Category 2
What are the Magnitudes of Forces?

Notes:
1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10 m) above ground for Exposure C category.
2. Linear interpolation between wind contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

Basic Wind Speed—Western Gulf of Mexico Hurricane Coastline
Oil & Gas Wells in the United States: Houston?

History: Romans Developed Cement Over 2000 years ago?
EXPANSIVE SOILS IN THE US

Fig. 10. Occurrence and distribution of potentially expansive materials in the United States, 1977. (U.S. Army Corps Engineer Waterways Experiment Station)
Geological Formation

• The geology of Houston –Galveston area is complex due to cyclic deposition of sediments in the coastal plains of the Gulf of Mexico Basin.

• These sediments were deposited under a fluvial-deltaic to shallow-marine environments during the Miocene (25 – 5 Mya) to the Pleistocene periods (1.8 – 0.011 Mya).

• The Houston Galveston areas would have been mainly influenced the Brazos, Trinity and San Jacinto rivers.

• The Lissie and Beaumont Formation are the two dominant subdivisions of the Pleistocene system in the Houston-Galveston area.

• The rates of deposits of the deltaic formations were estimated to be between 2500-30,000 mm/1000 years based on the information provided by Aronow, (2000) and Galloway (2000 & 2005).
Geology of Houston


Coast

South

Elevation - FT
## Table 1. Summary of Some of the Data in the CIGMAT – SDB for Harris County

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Number of Data on In situ Test and Geo-Properties</th>
<th>Total Number of Data</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCP</td>
<td>Moisture Content</td>
<td>Liquid Limit (LL)</td>
</tr>
<tr>
<td>CH</td>
<td>1794</td>
<td>4979</td>
<td>2073</td>
</tr>
<tr>
<td>CL</td>
<td>1952</td>
<td>5337</td>
<td>2277</td>
</tr>
<tr>
<td>SC</td>
<td>136</td>
<td>253</td>
<td>84</td>
</tr>
<tr>
<td>Others*</td>
<td>2540</td>
<td>1568</td>
<td>503</td>
</tr>
<tr>
<td>Total</td>
<td>7422</td>
<td>12,137</td>
<td>6,097</td>
</tr>
</tbody>
</table>

### Remarks

- All TxDOT Projects
- Highest amount of data
- Large amount of data on CL and CH
- Combined GIS data system.

*Others: Sand, Silt, SP-SM, ML, SM, CL-ML.
Clay Soils (CH, CL) in Houston: LL & PL
Clay Soils in Houston (CH, CL): PI & LI
Clay Soils (CH, CL) Houston: Undrained Shear Strength
Penetrometers (Since 1846...)

**Dynamic/Sandy Soils**
- Penetrator
- Tube: 1.5 in. (38.1 mm)
- Hole: 0.1 in. (2.5 mm)
- Thread: 3/2 in. (25 to 50 mm)
- Point: 1 in. (25.4 mm)
- Ball: 1 in. (25.4 mm)
- 0.1 in. (2.5 mm)

**Static/Soft Soil**
- Penetrator
- Hole: 1 to 2 in. (25.4 to 50.8 mm)
- Tube: 18 to 30 in. (457 to 762 mm)
- Thread: 3/2 in. (25 to 50 mm)

**Dynamic Drive/Soil to Rock**
- Penetrator
- Thread: 3/2 in. (25 to 50 mm)
- Hole: 1 in. (25.4 mm)
- Knurled

**Notes:****
- Driving point is manufactured from AISI 4142 steel.
- Point is heated in an electric oven for 1 hour at 1550°F - 1600°F. Point is plunged point into approximately 25 gal. of tempering oil and moved continuously until adequately cooled.
- Dynamic Drive/Soil to Rock
- Dynamic/Sandy Soils
- Static/Soft Soil

**SPT (from ASTM D1586)**
- CPT (from ASTM D5778)
- TCP (from Tex-132-E)
How to Use the Data? Variation of Liquid Limit at 3 ft

Figure 13. Variation of liquid limit at a Depth of 3 feet with faults, channels and 100 year flooding.
Texas Cone Penetrometer (TCP) along I-10

Soft Soil $N_{TCP} < 20$
Microstructural and Geotechnical Properties of Houston-Galveston Area Soft Clays
Objectives

• The overall objective of this study is to investigate the general geotechnical property trends for the pockets of soft clays in Houston and Galveston located in southeast Texas.

• The specific objectives were as follows:
  – to investigate the microstructure and general statistical property trends (signature features) for the deltaic soft clay deposits; and
  – to verify the property correlation for the soft clays.
Data Collection

- Total Boreholes: 116
- The sampling depth: 12 to 40 m (40 to 120 ft)
- The water table: surface ~ about 6 m (20 ft) in the west side of Houston

Data locations in the Houston-Galveston area (number of data)
Distribution of Soft Soils

- Largest percentage: soft soils in the top 6 m (20 ft).
- Western part of Houston: encountered at 16 m (50 ft.).
- South-East region: located even much deeper.
Microanalysis

- Scanning Electron Microscope (SEM)
- Energy Dispersive X-ray Spectroscopy (EDS)
- Thermogravimetric Analyses (TGA)
- X-ray diffraction (XRD) analyses
Instruments for Microstructural Characterization

TGA Device

XRD Device
SEM analysis & EDS analysis

Structure and morphology of the soil sample under high vacuum conditions
Thermal Gravimetric Analysis (TGA)

- Indicates the presence of illite and/or montmorillonite clay minerals

### TGA analysis on soft clay soil  (sample #2)

<table>
<thead>
<tr>
<th>Weight (%) loss during Heating</th>
<th>25-120 °C</th>
<th>120-600 °C</th>
<th>600-850 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample #2</td>
<td>0.738</td>
<td>0.504</td>
<td>2.668</td>
</tr>
</tbody>
</table>
XRD Analysis

- Illite clay mineral
  \((K,H_3O)(Al,Mg,Fe)\_2(Si,Al)\_4O\_10(OH)\_2,(H_2O)\)
# Statistical Analysis

<table>
<thead>
<tr>
<th>Type of Soil</th>
<th>MC (%)</th>
<th>LL (%)</th>
<th>PL (%)</th>
<th>PI (%)</th>
<th>Bulk Density (pcf)</th>
<th>Dry Density (pcf)</th>
<th>Su (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CL Soil (Data Set=58)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>13-59</td>
<td>22-49</td>
<td>8-40</td>
<td>6-30</td>
<td>98-137</td>
<td>62-120</td>
<td>1-3.7</td>
</tr>
<tr>
<td>Mean</td>
<td>23.9</td>
<td>33.5</td>
<td>17.5</td>
<td>17.1</td>
<td>121.9</td>
<td>99.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>8.7</td>
<td>6.2</td>
<td>5.4</td>
<td>5.4</td>
<td>8.3</td>
<td>11.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Var</td>
<td>76.4</td>
<td>38.9</td>
<td>29.7</td>
<td>29.4</td>
<td>68.3</td>
<td>127.2</td>
<td>0.6</td>
</tr>
<tr>
<td>COV (%)</td>
<td>36.6</td>
<td>18.6</td>
<td>31.1</td>
<td>31.8</td>
<td>6.8</td>
<td>11.4</td>
<td>27.3</td>
</tr>
<tr>
<td>N</td>
<td>58</td>
<td>38</td>
<td>36</td>
<td>34</td>
<td>58</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td><strong>CH Soil (Data Set=58)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>19-47</td>
<td>50-109</td>
<td>20-37</td>
<td>27-72</td>
<td>97-135</td>
<td>71-113</td>
<td>1.5-3.7</td>
</tr>
<tr>
<td>Mean</td>
<td>33.6</td>
<td>70.6</td>
<td>26.5</td>
<td>44.5</td>
<td>114.7</td>
<td>86.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>6.6</td>
<td>15.9</td>
<td>4.7</td>
<td>13.0</td>
<td>8.7</td>
<td>10.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Var</td>
<td>42.9</td>
<td>253.8</td>
<td>22.2</td>
<td>168.1</td>
<td>76.0</td>
<td>101.4</td>
<td>0.4</td>
</tr>
<tr>
<td>COV (%)</td>
<td>19.5</td>
<td>22.6</td>
<td>17.8</td>
<td>29.2</td>
<td>7.6</td>
<td>11.7</td>
<td>19.8</td>
</tr>
<tr>
<td>N</td>
<td>58</td>
<td>40</td>
<td>33</td>
<td>34</td>
<td>54</td>
<td>54</td>
<td>58</td>
</tr>
</tbody>
</table>

**Note:** 1 pcf = 0.157 kN/m³, 1 psi = 9.895 kPa.
Probability Density Functions

Su (CL Soil) and Su (CH Soil)

Beta Distribution

Probability density functions for Su (kPa) of CL and CH Soils
Comparison of liquid limit and moisture content

<table>
<thead>
<tr>
<th></th>
<th>Soft CL Soils</th>
<th>Soft CH Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean Moisture Content (COV)</strong></td>
<td>23.9% (36.6%)</td>
<td>33.6% (19.5%)</td>
</tr>
<tr>
<td><strong>Mean LL (COV)</strong></td>
<td>33.5% (18.6%)</td>
<td>70.6% (22.6%)</td>
</tr>
</tbody>
</table>
Most of the clay data were located between montmorillonite and illite.
Dry unit weight versus Moisture content

Total of 116 data

\[ q_d = 128.54941 - 1.24869 \times MC \]

\[ R^2 = 0.82822 \]
Undrained Shear Strength vs. Moisture Content

CL Soil

Log Su = 0.61566 - 0.00765 * MC

CH Soil

Log Su = 0.55851 - 0.00238 * MC

Log Su = 0.0077 * MC = 0.62
Log Su = 0.0024 * MC = 0.56
Conclusions

- Total of 116 borehole data were analyzed. Based on the analyses of the Houston and Galveston soft soils the following conclusions are advanced:
  - The mean undrained shear strength of CL and CH soils was comparable. The natural moisture content of **over 97% of the clays was lower than the liquid limit**
  - **Statistical Quantifications** of Geotechnical Properties.
  - XRD and TGA analyses with the plasticity index chart confirmed the presence of **illite clay** mineral in the soft soil.
  - **Undrained shear strength** of the soft clay was related to the **moisture content** of the soil.
Soft Clays (Su < 3.5 psi (25 kPa))

(1) Marine Deposits…

(2) Deltaic Deposits
Figure 1. Locations of soft clay soils used for the analyses
OBJECTIVES

Investigate the general trends observed in soft clay behavior from around the world

(a) Marine vs. Deltaic

(b) Property Correlations

(c) Constitutive Models
<table>
<thead>
<tr>
<th>Type of Deposit</th>
<th>W (%)</th>
<th>LL (%)</th>
<th>PL (%)</th>
<th>PI (%)</th>
<th>Su (kPa)</th>
<th>$\sigma_p$ (kPa)</th>
<th>e</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine Clay (Number of data = 51)</td>
<td>30-133</td>
<td>32-121</td>
<td>19-51</td>
<td>12-25</td>
<td>1.8-248</td>
<td>0.8-3.52</td>
<td></td>
<td>Nagaraj &amp; Miura (2001), Chung, Nagaraj &amp; Kwag (2002), Shibuya &amp; Tamrakar (1999), Nash, Sills, Davison, Powell &amp; Lloyd (1992)</td>
</tr>
<tr>
<td>Mean</td>
<td>72.6</td>
<td>64.2</td>
<td>24.3</td>
<td>35.2</td>
<td>17.4</td>
<td>74.5</td>
<td>1.95</td>
<td></td>
</tr>
<tr>
<td>Std. Dev</td>
<td>23.3</td>
<td>22.2</td>
<td>3.4</td>
<td>11.7</td>
<td>6.6</td>
<td>41.8</td>
<td>0.59</td>
<td></td>
</tr>
<tr>
<td>COV (%)</td>
<td>30.3</td>
<td>34.6</td>
<td>13.8</td>
<td>33.2</td>
<td>37.9</td>
<td>56.1</td>
<td>30.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deltaic Clay (Number of data = 97)</td>
<td>13-59</td>
<td>24-93</td>
<td>8-35</td>
<td>8-61</td>
<td>7-25</td>
<td>-</td>
<td>0.34-1.56</td>
<td>Vipulanandan et al. (2007)</td>
</tr>
<tr>
<td>Mean</td>
<td>28.9</td>
<td>53.6</td>
<td>21.8</td>
<td>32.4</td>
<td>19.5</td>
<td>-</td>
<td>0.77</td>
<td></td>
</tr>
<tr>
<td>Std.Dev</td>
<td>9.5</td>
<td>22.7</td>
<td>6.9</td>
<td>16.9</td>
<td>5.1</td>
<td>-</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>COV (%)</td>
<td>32.8</td>
<td>42.4</td>
<td>31.7</td>
<td>52.2</td>
<td>26.2</td>
<td>32.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Rate of sedimentation of different types of clay deposits (Vipulanandan et al. 2007a)
Probability Distribution Function for $Su/e_0$ 

(a) Marine Clay - Beta 

(b) Deltaic Clay - Beta
Figure 4. Liquid limit versus natural water content for the soft clays (a) Marine Clay (b) Deltaic Clay
Expansive Clay Problem?

Borrowed from Kenneth Tand
How to Mitigate Problems?

1. Waffle Slabs

2. Drilled Shaft With Bells?
Medical Similarity?

Expansive Clay Problem is the Hypertension (High Blood Pressure) in the Body

(Na+, Water, Pressure, Kill you (?))
Effect of Climate Conditions on the Cracking of a Highway Retaining Wall Supported in the Active Zone
Distress in a Highway Retaining Wall: Why?

1. Canopy Rotation?

2. Panel Separation?
1. Panel Cracks
2. Separation
What is the Cause of Failure?

Active Zone vs. Consolidation?
SITE VIEW

Wall No. 2E

Clear creek

B3
B2
B1
B4
B5

840 ft

Clear creek relief

N
Clear Creek Relief Bridge Soil Profile

Diagram showing soil profile with layers labeled:
- Soft Clay
- Very Soft Clay
- Stiff Clay

Elevation (ft) scales from -130 to 20.

Sections labeled CCR-1, CCR-3, CCR-4.

WALL #2E

R-1, R-2, R-13.
Cracked panels in the retaining wall

Demec Points

Crack
Dimech Points
Cracked panels in the retaining wall

Bulge (Slope)

Crack

Digital Level
Inclinometer
Active Zone

Failure?

SH3
FIELD INSTRUMENTATION

ACTIVE ZONE

TOTAL SETTLEMENT

INCLINOMETER (Lateral Deformation)

GWL

Soft Soil

1.5 m

Extensometer

Tensiometer

Piezometer

9.1 m
Tensiometer

- Removable Cap
- Vacuum Gauge
- Tube
- Porous Cup
Field Installation of Tensiometer

- Vacuum Gauge
- Removable Cap
- Bench Mark
Measured Rainfall and Temperature (www.weather.gov) (Also HURRICANE IKE Effect?)

Hurricane Ike 90/13/2008

Measured Rainfall and Temperature (www.weather.gov) (Also HURRICANE IKE Effect?)
Change in crack opening with time at Point H
Change in Suction Pressure with Time in the Active Zone

![Graph showing change in suction pressure with time](image-url)
Settlement-Time Relationship in Active Zone

Measured Rainfall and Temperature (www.weather.gov)
Measured Rainfall and Temperature (www.weather.gov)

Variation of Consolidation Settlement
Lateral Deformation along Borehole B2

B2 A axis
Change in Deflection (in)

Depth (ft)

-0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3

6 Days
14 Days
47 Days
161 Days
244 Days
265 Days
357 Days
490 Days

244 265 161 47 357 490
Conclusions

(1) There was swelling and settlement in the active zone due to changes in the ground moisture content.

(2) Largest lateral movement was observed in the active zone.

(3) Consolidation settlement was much smaller than what was observed in the active zone.

(4) Crack opening and closing in the retaining wall panel was directly affected by the active zone movements.
WATERTABLE EFFECT ON THE RETAINING WALLS
General View (Retaining Wall - Leaking)

Retaining Wall

I-59/69
Vertical Joint
Westpark Road

91 ft

Panal 1

Panal 2

Panal 11

Panal 12

Detention Pond

After 4 Panel

Worst

Feeder Road

New Fronts?

West side of the West Park
### 1st visit to the site

<table>
<thead>
<tr>
<th>Location</th>
<th>Flow rate/ (ml/s)</th>
<th>pH</th>
<th>Location</th>
<th>Flow rate/ (ml/s)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.5</td>
<td>8.09</td>
<td>7</td>
<td>4.7</td>
<td>11.55</td>
</tr>
<tr>
<td>2</td>
<td>2.0</td>
<td>8.50</td>
<td>8</td>
<td>4.0</td>
<td>11.45</td>
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<tr>
<td>3</td>
<td>1.2</td>
<td>8.72</td>
<td>9</td>
<td>0.3</td>
<td>8.69</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>8.30</td>
<td>10</td>
<td>0.7</td>
<td>8.31</td>
</tr>
<tr>
<td>5</td>
<td>0.7</td>
<td>8.59</td>
<td>11</td>
<td>1.2</td>
<td>8.25</td>
</tr>
<tr>
<td>6</td>
<td>1.2</td>
<td>8.33</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What To Do?

1. Dewatering – Lowering the Groundwater Table

2. Grouting (Special Technique) the Panel Joints

3. Combination of Both
1. Dewatering

1. Constructability (Network of Highways)
2. Location of Pumps
3. Connecting to Stormwater Systems
4. Effect of Dewatering (Settlement?)
Pumping @ the rate of 50 ft$^3$/day/ft, @ 25 ft depth in both side of the road
2. Grouting – Control Leaks (NEW)

1. Constructability (From Front)

2. No Interference with the Surroundings

3. Should have a Clean Finish
Grout Fill

Soil

Drains (Vertical)

Drilled Shaft

Concrete Wall

Panels

Highway

Low Pressure & Medium Flow

PLAN VIEW

ELEVATION
Oakum (jute/rope) to fill the Space Between Panels

Reinforces and Stiffens the Grout
Inject Polyurethane Resin + Water = Solidified Grout

Oakum + Grout = Flexible & Low Permeability
Comparison of Repair Methods

<table>
<thead>
<tr>
<th>Operations</th>
<th>Dewatering (DW)</th>
<th>Grouting (G)</th>
<th>Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructability</td>
<td>Difficult</td>
<td>Easy</td>
<td>G</td>
</tr>
<tr>
<td>Pumping</td>
<td>Yes</td>
<td>No</td>
<td>G</td>
</tr>
<tr>
<td>Well Point</td>
<td>Yes</td>
<td>No</td>
<td>G</td>
</tr>
<tr>
<td>Settlement</td>
<td>Yes</td>
<td>No</td>
<td>G</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Yes</td>
<td>Yes</td>
<td>DW/G</td>
</tr>
</tbody>
</table>

Grouting was Successful !!!
ASCE Smart Brief (Also ACI)

JANUARY 21, 2011

ASCE SmartBrief

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Industry News

Sponsored by:

ASCE: U.S. water infrastructure nears the breaking point

The nation's water infrastructure is weak with age. Every day in the U.S., an average of 700 water mains burst, while leaking pipes waste an estimated 7 billion gallons of water, according to the American Society of Civil Engineers. The system needs replacing "and we've got to make those investments or we'll suffer the consequences," said Eric Goldstein of the Natural Resources Defense Council. CNN (1/20) Share: 📰 Facebook 🌐 Twitter 🔵 E-MAIL

China to pump $300B into drinking water system

China plans to invest more than $300 billion in upgrading the country's water system, including reinforcing reservoirs and protecting drinking water. The projects will help secure fresh water for some 60 million people in rural areas. Reuters (1/20) Share: 📰 Facebook 🌐 Twitter 🔵 E-MAIL
FIELD STUDY
( Sites Visits)

• Over 100 sites

Field Visits with Soil Sample and/or Pipe Samples
Failures Cases In the Active Zone
COH/CIGMAT SURVEY
( Participated Cities)

• Eight Cities
  Cleveland, Ohio
  Norman, Oklahoma
  Philadelphia, Pennsylvania
  Austin, Texas
  Denver, Colorado
  San Diego, California
  Toronto ON, Canada
  Houston, Texas
Average No. of Breaks per Day in Surveyed Cities

- Cleveland: 3.8
- Norman: 0.68
- Philadelphia: 2
- Austin: 1.3
- Denver: 0.54
- San Diego: 0.33
- Toronto: 3.56
- Houston: 12
Total Length of Pipelines for Various Cities

- Cleveland: 5000 miles
- Norman: 500 miles
- Philadelphia: 3133 miles
- Austin: 4264 miles
- Denver: 2645 miles
- San Diego: 3381.2 miles
- Toronto: 3635 miles
- Houston: 7500 miles
Correlation between Length and Average No. of Breaks per Day

\[ y = 0.2947e^{0.0005x} \]
\[ R^2 = 0.5902 \]
Figure 3.16 Correlation between Annual Average Rainfall and Breaks per Mile

\[ y = 6 \times 10^{-5}e^{0.8705x} \]

\[ R^2 = 0.7983 \]
## Summary of Failures by Soil Types

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Total</th>
<th>Corrosion</th>
<th>Circum.</th>
<th>Joint</th>
<th>CI</th>
<th>AC</th>
<th>PVC</th>
<th>Pipe diameter (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL</td>
<td>59%</td>
<td>75%</td>
<td>62%</td>
<td>40%</td>
<td>50%</td>
<td>53%</td>
<td>80%</td>
<td>50% 0% 44% 63% 71%</td>
</tr>
<tr>
<td>CH</td>
<td>41%</td>
<td>25%</td>
<td>38%</td>
<td>60%</td>
<td>50%</td>
<td>47%</td>
<td>20%</td>
<td>50% 100% 36% 37% 29%</td>
</tr>
</tbody>
</table>

**Figure 10 Soil Tests**

![Graph showing plastic index (PI) vs. liquid limit (LL) for different soil types and pipe diameters.](image-url)
ACTIVE ZONE? (4ft. Vs. 6 ft.)

Moisture Fluctuation....
NEW TECHNOLOGIES AT CIGMAT

1. MONITORING DURING CONSTRUCTION

2. POLYMER TREATMENT FOR EXPANSIVE SOILS

3. SMART CEMENT......
DHP-CIGMAT in the Field

DHP Steel Case

- Spring
- Penetration Piston
- DHP head
- Sliding Ring
- Protector Plate
Slurry Filled Borehole: - 60 “ Dia Drilled ShaftI-10 & BELTWAY 8

Going in

Pulled Out

- DHP

- Kelly Bar Adaptor

- Ring Moved

- DHP Adaptor

- Slurry
DHP- CIGMAT SOIL RESPONSE

![Graph showing soil response](image)
Analysis of CIGMAT Penetrometer Correlations

![Graph showing correlations between su (psi) and CIGMAT 1800 Deflection (inch)]

- **Houston I-10 East**
- **Dallas Trinity Bridge**
- **Dallas I30-Loop12**

Nc = 16.2
Nc = 13
Nc = 26.6
Nc = 62.8
Modifying DHP-CIGMAT to CIGMAT Surface Penetrometer (SP-CIGMAT)

DHP - CIGMAT

How to Get Compacted Soil Strength?
Quality Control Procedure

Modified CIGMAT Penetrometer

Hole created after Shelby tube sample

CIGMAT Penetrometer performing the test

Deflected Spring After Test
Analysis of SP-CIGMAT Correlations

- The relationship between SP-CIGMAT and Shear Strength of Compacted Soil.
- Correlation between SP-CIGMAT and Modulus of Compacted Soil

Graph 1:
- Shear Stress (psi) vs. Penetrometer Deflection (in)
- \( S_u = 59.5 \)
- \( R^2 = 0.85 \)
- \( N = 9 \)

Graph 2:
- Modulus (psi) vs. Penetrometer Deflection (in)
- \( E = 5910 \)
- \( R^2 = 0.63 \)
- \( N = 9 \)
Analysis of SP-CIGMAT Correlations

- Correlation between CBR Value and Ultimate Strength of Soil obtained by SP-CIGMAT

- The relationship between SP-CIGMAT Deflection and CBR Values.

\[ y = 58.33x \]
\[ R^2 = 0.9647 \]

\[ y = 17.27x \]
\[ R^2 = 0.97 \]
Expansive Clay: Polymer Vs. Lime Treatment

Table 5. TGA results on lime and polymer treated CH soils

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature Range and Weight Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(25-120) °C</td>
</tr>
<tr>
<td>Field CH Soil</td>
<td>6.4</td>
</tr>
<tr>
<td>CH soil treated with 6 % lime after 7 days of curing</td>
<td>1.3</td>
</tr>
<tr>
<td>CH soil treated with 10 % polymer solution (1.5 % polymer content)</td>
<td>0.33</td>
</tr>
<tr>
<td>(using mix 3 after 1 day of curing)</td>
<td></td>
</tr>
</tbody>
</table>
Smart Cemented Well at UH

(Highly Sensing Cement)

(Chemo-Thermo-Piezoresistive Cement)

ALL INSTRUMENTATIONS ARE WORKING

ONLY ONE IN THE WORLD?
"Smart" Cement Could Talk to Engineers about Well Conditions ...
www.uh.edu/.../smart-cement-could-talk-to-engineers-about-well-condition.php
Vipulanandan’s smart cement is a new piezoresistive material that can be monitored from an offshore platform thousands of feet above the well or even from ...

a “smart” cement material - University of Houston
Jun 4, 2012 - A University of Houston civil engineering researcher has received a $2.6 million grant to develop a new type of "smart" cement that could make ...

Smart cement revolutionizes well casings | Control Engineering
www.controleng.com/.../smart-cement.../426ecd6af870e87fc0c8d82cf3bd327b.html
Apr 30, 2015 - Figure 1: A test piece of smart cement showing the wires for feedback connectivity. The novel augmentation of cementing the oil-well casing ...

UH Researchers Create 'Smart Cement' - YouTube
https://www.youtube.com/watch?v=ezjxH_b1Hg
Jul 2, 2015 - Uploaded by UHmultimedia
Researchers at the University of Houston are testing a new cement mixture that offshore oil rig operators could ...
Smart Cement Piezoresistivity Characterization with Sodium ... - ASCE
ascelibrary.org/doi/abs/10.1061/(ASCE)MT.1943-5533.0001667
by C Vipulanandan - 2016
"Smart Cement Piezoresistivity Characterization with Sodium Metasilicate under Temperature and Curing Environments for Oil Well–Cementing." J. Mater. Civ.

Development and Characterization of Smart Cement for Real Time ...
https://www.onepetro.org/conference-paper/OTC-25099-MS
by C Vipulanandan - 2014 - Cited by 3 - Related articles
In this study well cement was modified to have better sensing properties, smart cement, so that its behavior can be monitored at various stages of construction ...

Images for smart cement

More images for smart cement

Sensytec | Houston, TX, US Startup - Gust
https://gust.com/companies/Sensytec
There are currently no other technologies that detect the structural integrity of cement in real-time over the operational lifetime of an oil well. With smart cement, it ...

Searches related to smart cement

smart cement vipulanandan internet of things
cumaraswamy vipulanandan iot
smart concrete
Conclusions

(1) Geology Will Help Understand the Ground Movement.

(2) Deltaic Soils (Houston) Show Greater Variation than Marine Soils.

(3) New Technologies Must Be Developed for Monitoring During Constriction and Handle Expansive Clays.
Thank you
GEO-HOUSTON 2017
March 31 at Rice University
Celebrating Houston