TEST METHODS FOR EVALUATING EXISTING FOUNDATIONS

Document no: FPA-SC-02
Developed by: FPA Structural Committee
Committee chairs: Main Committee - Ron Kelm, P.E.
                Subcommittee - Al Bustamante, P.E.
Subcommittee: Gerard Duhon, Denis Hanys, Ron Kelm,
               Gerard Lowe, Bob Newman, Michael Skoller,
               George Wozny, Nicole Wylie
Presented by: Al Bustamante, P.E.,
             Wiss, Janney, Elstner Associates, Inc.
Presented to: Foundation Performance Association
Presented on: August 11, 2010

Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
OUTLINE

• Introduction
• Test Methods
• Foundation Characteristics and Defects
• Summary Table
• Case Study - Slab-on-Ground Cracking
• Key resources
• Conclusions
Introduction

• Scope
  • Document type - general guideline
  • Audience - Engineers
  • Type of foundation - lightly loaded foundations and pavement
  • Material - concrete
  • Geographic boundary – Houston
  • Safety issues – not addressed
Introduction

• General Considerations

• Cost

  - Rental
  - Equipment
  - Professional services

• Calibration

  - Test results
  - Proprietary equipment

• Test methods - not all-inclusive

Al Bustamante, Wiss, Janney, Elstner
Associates, Inc.
Introduction

- Format
  - General description
  - General applications
  - Some considerations
  - Relative cost
  - Additional resources
Test Methods
Test Methods – Carpenter Level

- Confirm elevation survey
- Levelness
- Plumb
Test Methods – Chain Dragging

• Estimate location and extent of delamination
Test Methods – Chloride Content

• Analyze for chlorides at the level of steel reinforcement
Test Methods – Concrete Cores

- Testing - Compressive strength
- Confirm dimensions
- Petrographic analysis
Test Methods – Concrete Screwdriver Test

- Relative hardness and durability
Test Methods – Geotechnical

• Causes and extent of foundation movement
Test Methods – Geotechnical

- Classify soil types
- Measure soil strength
- Report Atterburg limits
- Moisture content
- Ground water level
- Compaction
- Shear strength
- Active zone depth
- Swell potential
- Potential vertical movement (PVM)
Test Methods – Ground Penetrating Radar

- Location, depth, spacing of steel reinforcement
- Presence of utility lines
- Voids underneath a slab
- Delamination
- Slab thickness
- Soil strata
Test Methods – Ground Probing

- Depth of perimeter grade beams
- Soil type and color
- Soil moisture condition
- Relative soil shear strength
Test Methods – Half Cell Potential

- Probability of steel reinforcement corrosion
Test Methods – Hammer Sounding

• Presence of delamination and voids
Test Methods – Impact Echo

- Delamination
- Internal voids
- Honeycombs
- Voids underneath a slab
Test Methods – Inspection Openings and Excavations

Inspection opening

Test pit excavation

Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
Test Methods – Inspection Openings and Excavations

• Inspection opening
  ▪ Size and placement of steel reinforcement
  ▪ Presence of vapor retarder below a slab
  ▪ Slab thickness

• Excavations
  ▪ Grade beam and bell pier dimensions
  ▪ Presence of plumbing lines
  ▪ Free water elevation and condition of fill

Al Bustamante, Wiss, Janney, Elstner
Associates, Inc.
Test Methods – Laser Level

- Floor elevations
Test Methods – Manometer

• Floor elevations

Closed Liquid/Gas

Water

Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
Test Methods – Metal Detector

- Presence and general location of steel reinforcement
Test Methods – Optical Level

- Floor elevation
Test Methods – Petrographic Examinations

- Coarse aggregate segregation
- Air voids
- Poor curing
- Relative water cementitious ratio
- Relative age of cracks
- Type of cracks
- Detrimental chemical reactions – ASR, DEF
Test Methods – Plumbing Leak Detection

- Foundation movement due to below slab water leaks
Test Methods – Post-tension Lift-Off

- Measure effective tendon force in unbonded post-tensioned tendons
Test Methods – Post-tension Screwdriver Penetration

- Evaluate presence of tension in post-tensioned tendons
Test Methods – Rebound Hammer

• Relative hardness of concrete
Test Methods – Reinforcement Locator

• Spacing, size, and depth of steel reinforcement

Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
Test Methods – Resistivity

- Evaluate effects of
  - Location of pre-existing ponds, foundation, lakes, etc
  - Accumulation of ground water
  - Plumbing leaks
  - Poor drainage
  - Location of pipes
  - Soil strata variations
  - Tree root zones
Test Methods – Ultrasonic Pulse Velocity

- Internal cracking
- Voids
- Honeycomb
Test Methods – Vapor Transmission

• Adequacy of slab-on-ground to receive floor finishes
Test Methods – Visual
Test Methods – Visual

- Apparent damages
- Drainage
- Movement of flatwork
- Moisture conditions
- Soil condition
- Trees
- Topography
- Condition of exposed portion of foundations
Foundation Characteristics and Defects
Foundation Characteristics

- Concrete dimensional properties
- Concrete distress
  - Cracking
  - Delamination
  - Detrimental chemical reactions
  - Honeycombing
  - Joint deficiencies
  - Slab curling and warping
  - Spalling
Foundation Characteristics

- Concrete material properties
  - Air entrainment
  - Chloride content
  - Compressive strength
  - Durability
  - Hardness
  - Unit weight
  - Water cementitious ratio
Foundation Characteristics

• Post-tensioned reinforcement characteristics
  • Anchorages
  • Grease
  • Sheathing
  • Strand
  • Tendon
  • Tendon profile
Foundation Characteristics

- Soil characteristics
  - Moisture content
  - Plasticity index
  - Soil shear strength
  - Soil strata location
  - Soil type and color
  - Tree root
  - Water table presence/location
Summary Table
<table>
<thead>
<tr>
<th>Characteristics and Deficiencies</th>
<th>Test Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Carpenter level</td>
<td></td>
</tr>
<tr>
<td>2.2 Chain dragging</td>
<td></td>
</tr>
<tr>
<td>2.3 Chloride ion testing</td>
<td></td>
</tr>
<tr>
<td>2.4 Concrete cores</td>
<td></td>
</tr>
<tr>
<td>2.5 Concrete-screedriver test</td>
<td></td>
</tr>
<tr>
<td>2.6 Geotechnical</td>
<td></td>
</tr>
<tr>
<td>2.7 Ground penetrating radar (GPR)</td>
<td></td>
</tr>
<tr>
<td>2.8 Halide cell potential (HCL)</td>
<td></td>
</tr>
<tr>
<td>2.9 Harman sounding</td>
<td></td>
</tr>
<tr>
<td>2.10 Impact echo</td>
<td></td>
</tr>
<tr>
<td>2.11 Inspection opening/excavation</td>
<td></td>
</tr>
<tr>
<td>2.12 Last level</td>
<td></td>
</tr>
<tr>
<td>2.13 Laser meter</td>
<td></td>
</tr>
<tr>
<td>2.14 Mass spectrometer</td>
<td></td>
</tr>
<tr>
<td>2.15 Meal detector</td>
<td></td>
</tr>
<tr>
<td>2.16 Optical level</td>
<td></td>
</tr>
<tr>
<td>2.17 Radiographic examination</td>
<td></td>
</tr>
<tr>
<td>2.18 Radiographic leak detection</td>
<td></td>
</tr>
<tr>
<td>2.19 Post-tension tendon lift off</td>
<td></td>
</tr>
<tr>
<td>2.20 Post-tension tendons screw driver</td>
<td></td>
</tr>
<tr>
<td>2.21 Resound hammer</td>
<td></td>
</tr>
<tr>
<td>2.22 Reinforcement locator (RD)</td>
<td></td>
</tr>
<tr>
<td>2.23 Reflectometry</td>
<td></td>
</tr>
<tr>
<td>2.24 Ultrasonic pulse velocity</td>
<td></td>
</tr>
<tr>
<td>2.25 Vapour transmission</td>
<td></td>
</tr>
<tr>
<td>2.26 Visual</td>
<td></td>
</tr>
</tbody>
</table>

### Characteristics and Deficiencies

<table>
<thead>
<tr>
<th>Concrete Dimensional Properties</th>
<th>Test Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>---------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Grade beam dimensions</td>
<td></td>
</tr>
<tr>
<td>Pier dimensions</td>
<td></td>
</tr>
<tr>
<td>Slab levelness and flatness</td>
<td></td>
</tr>
<tr>
<td>Slab thickness</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concrete to Defects</th>
<th>Test Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>Coarse aggregate segregation</td>
<td></td>
</tr>
<tr>
<td>Cracking/types of cracking</td>
<td></td>
</tr>
<tr>
<td>Delamination</td>
<td></td>
</tr>
<tr>
<td>Detrimental chemical reactions</td>
<td></td>
</tr>
<tr>
<td>Honeycombing</td>
<td></td>
</tr>
</tbody>
</table>
Case Study
Case Study – Slab-on-Ground Cracking
Case Study

- Warehouse located in Houston, TX
- Reinforced concrete slab-on-ground
  - 6” thick
  - Vapor retarder below slab-on-ground
  - No. 4 bars at 18” o.c. each way
  - Control joint spacing at ~ 21’ o.c.
Case Study – Slab Cracking

View of a typical aisle in the east-west direction.

Crack previously repaired with epoxy injection

*Al Bustamante, Wiss, Janney, Elstner Associates, Inc.*
Case Study – Slab Cracking

- Random crack pattern
- Typical cracks located roughly in the middle of an aisle

Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
Case Study – Slab Cracking

View of a crack pattern thought to be from a crane load stabilization point

Surface crazing cracking

Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
Case Study – Spalling

Surface spall next to a pallet

Spall at edge of new concrete placed at equipment at overhead door (see arrow)

Al Bustamante, Wiss, Janney, Elstner
Associates, Inc.
Case Study – Joint Distress

Spall and cracks at control joint

Missing control joint material (arrow)

Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
Case Study – Crack Mapping

Grid layout for detailed crack mapping area

Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
Case Study – Crack Mapping

Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
Case Study – Concrete Core Extraction
Case Study – Soil Boring
Case Study – Inspection Opening

Rebar located at the bottom of the slab. Note no cracking propagating from bottom of the control joint. (arrow.)
Case Study – GPR Testing

Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
Case Study – GPR Testing

Figure 3. Original GPR Signal: Note variances in rebar and slab depths.
Case Study – GPR Testing

Figure 4. Migrated Data: Data points are shown for top of rebar (pink) and for bottom of the slab (blue).
Case Study – GPR Testing

GPR Data - Run No. 1 (East-West at Grid 3.3)
Refer to Fig. P3 for Location of GPR Runs

Depth from Top of Slab-on-Grade (in.)

Distance (ft)

Al Bustamante, Wiss, Janney, Elstner
Associates, Inc.
### Case Study – Design and Construction Deficiencies

**Control (Contraction) Joints**

<table>
<thead>
<tr>
<th>As Detailed</th>
<th>Industry Standard</th>
<th>As–Built</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical Control Joint</strong>&lt;br&gt;Detail: 6/23.01</td>
<td><strong>Types of Control Joint</strong>&lt;br&gt;ACI 302R.1–96&lt;br&gt;Figure 3.2.5.3.a</td>
<td>![Image of as-built control joint]</td>
</tr>
<tr>
<td><strong>Slab on Grade</strong>&lt;br&gt;TYP CONTROL JOINT&lt;br&gt;Drawing taken from original structural drawings dated 3–19–02</td>
<td></td>
<td>![Image of as-built control joint]</td>
</tr>
<tr>
<td><strong>Control Joint</strong>&lt;br&gt;Saw cuts were made too late&lt;br&gt;Note that there is no crack below control joint&lt;br&gt;Vapor retarder directly below concrete&lt;br&gt;No cut or discontinuous reinforcing bars&lt;br&gt;Reinforcing at slab cut #2 (Approx Grid C, 2.2)</td>
<td></td>
<td>![Image of as-built control joint]</td>
</tr>
</tbody>
</table>

*Al Bustamante, Wiss, Janney, Elstner Associates, Inc.*
## Case Study – Design and Construction Deficiencies

### Isolation Joint

<table>
<thead>
<tr>
<th>As Detailed</th>
<th>Industry Standard</th>
<th>As-Built</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Image of As Detailed Diagram]</td>
<td>![Image of Industry Standard Diagram]</td>
<td>![Image of As-Built Image]</td>
</tr>
</tbody>
</table>

**Notes:**
- **NOT AN ISOLATION JOINT**
- **CONTROL JOINT BETWEEN COLUMN**
- **SLAB ON GRADE CONTROL JOINT AROUND STEEL COLUMN**
- **J OINT AROUND COLUMN (DETAIL 6/S3.01)**
- **Dowels thru joint and into pier cap prevent freedom of slab-on-grade movement**

**Figures:**
- ISOLATION JOINT ACI 302.1R-96
- FIGURE 3.2.5.1.a

**Details:**
- **ABSENCE OF ISOLATION JOINT BETWEEN COLUMN DIAMOND SHAPE BLOCK-OUT AND SLAB-ON-GRADE**
- **DOUBLE COLUMN AT BUILDING EXPANSION JOINT**
- **ABSENCE OF ISOLATION JOINT BETWEEN COLUMN DIAMOND SHAPE BLOCK-OUT AND SLAB-ON-GRADE**
- **BLOCK-OUT CORNER DOES NOT ALIGN WITH MAIN FLOOR JOINT**
- **NOT AN EXPANSION JOINT (SEE FIG. D-4)**

**Reference:**
Al Bustamante, Wiss, Janney, Elstner Associates, Inc.
### Case Study – Design and Construction Deficiencies

#### Expansion Joints

<table>
<thead>
<tr>
<th>As Detailed</th>
<th>Industry Standard</th>
<th>As-Built</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram of As Detailed Expansion Joint" /></td>
<td><img src="image2" alt="Diagram of Industry Standard Expansion Joint" /></td>
<td><img src="image3" alt="Diagram of As-Built Expansion Joint" /></td>
</tr>
</tbody>
</table>

**As Detailed**
- Joint width depends on slab length
- Smooth bar slip sleeve or greased
- Sealant
- Joint to fill material

**Industry Standard**
- Typical control joint (photograph taken at west end of slab cut #1)
- Note that there is no crack below control joint; this indicates saw cuts were made too late
- Vapor retarder directly below concrete

**As-Built**
- Typical control joint (photograph taken at south end of slab cut #1)
- Typical slab section (photograph taken at north end of slab cut #1)
- No cut or discontinuous reinforcing bars

*Al Bustamante, Wiss, Janney, Elstner Associates, Inc.*
Key Resources

- FPA SC-04 Recommended Practice for Geotechnical Explorations and Reports
- ACI 228.2R Nondestructive Test Methods for Evaluation of Concrete in Structures
- ICRI Guideline No. 03736 Guide for the Evaluation of Unbonded Post-tensioned Concrete Structures
Conclusion

Why do we test?

“Ask the Structure”…

Jack Janney

…but ask the right questions

Al Bustamante, Wiss, Janney, Elstner
Associates, Inc.
Questions?

Contact: Al Bustamante - abustamante@wje.com

Al Bustamante, Wiss, Janney, Elstner
Associates, Inc.