advanced **awareness** technology that enables our clients to optimize the design, construction and operation of the nation’s infrastructure.
Introduction (Speakers)
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EDC Background
System Components (Hardware and Software)
EDC Benefits
Roadmap (new Applications)
Cost and EDC Smart Start
Q&A
EDC technology was designed as a dynamic test system with results comparable to the accuracy of static load test, with repeatability, at a lower cost.

Provide the industry with tools and methods to perform 100% testing while accelerating construction productivity.

Enable designers and engineers to utilize higher resistance factors to reduce cost while enhancing confidence and quality assurance.

Enable economies of volume to enable large deployments of low cost wireless sensors in the transportation infrastructure.
EDC Background

- Based on FDOT / University of Florida Research
- Commercialization focused on creating a system with simple, repeatable, and standardized installation, data collection, and reporting
- Established DOT Processes/Specifications
- Organize / Share data through the Internet
- Create the foundation of a wireless sensor system that can be deployed in all concrete structures
3rd Generation Product

Smaller, Lower Cost, More Integrated, Improved Moisture Resistance, Easier to Install …

SP-400

First Generation

SP-401

Smaller, lower profile DataPort for less intrusion into pile core, better sealing connectors, faster and more sensitive electronics, hardware diagnostics, StateStamp Batteries (against corrosion)

SP-402

Combined radio and sensor electronics resulting in fewer connectors, higher reliability and simplified installation, Smaller DataPort with further sealing improvement (against corrosion, moisture), Improved hardware diagnostics, calibration at sensor level to support Field Swaps, More sensor configurations (ie. Dual Strain, Corrosion, etc.)
Lower the cost of Testing (Hardware)

- **Prototype**
  - SP_401, quantity 100, $16.4K tooling

- **Initial Production**
  - SP_400, quantity 100
  - SP_401 Quantity 1000
  - SP_401, vendor/design changes

- **Florida DOT Mandate Period**
  - SP_401, vendor/design changes

- **Approved as Stand Alone Technology**
  - SP_402, re-design

- **SP_402, new accel design target**
- **SP_402, offshore volume target**

Yearly Breakdown:
- 2005: $1800
- 2006: $1020
- 2007: 84%
- 2008: 70%
- 2009: 64%
- 2010: 49%
- 2011: 42%
- 2012: 34%
- 2013: $1800
- 2014: $1020

Other Key Notes:
- Florida DOT Mandate
- Period: $1800 to $1020
- 84% to 34%
- SP_400, vendor/design changes
- SP_401, vendor/design changes
- Approved as Stand Alone Technology
- SP_402, re-design
- SP_402, new accel design target
- SP_402, offshore volume target
A Complete Ecosystem

- Volume Manufacturing
- Casting Yard / Installation Partners
  - Training and Tools
- Testing Partners
  - Training and Tools
  - Certifications
- Performance Driving Specifications
System Components

- Embedded Electronics: Embedded Data Collector
- Acquisition Hardware: COTS, Rugged, Wireless-enabled Laptop
- Acquisition Software: SmartPile® Acquisition
- Processing/Reporting Software: SmartPile® Review, Match, and Simulate
- Internet Portal: Data, Configuration
Embedded Data Collector

- 100% wireless
- Embedded within concrete
- Tip & Top sensing
- Internet Information System
Typical EDC Use Model

- Wireless communication and data transmission from the pile
- Ruggedized Workstation to collect sensor data in *Real Time*
- Software to Analyze, Present, and Report (at the completion of driving)
- Internet information system to organize and share data
Engineered Installation Process
Real-Time Analysis

Configuration: Fixed Jc Damping Coefficient 0.4
Wave Speed: 132000 [KPsf]

- Total Capacity - Fixed Jc: 16 [Kips]
- Total Capacity - UF Method: 12
- Tip Capacity - UF Method: 12'
- Skin Capacity - UF Method: 0
- Stroke: 45.00 [DBRef]
- BPM: 47 [Blow Count]

Damping Factor Calc

- 12546 [Normalized Wave Speed]
- 1.25 [Max. Top Compressive Stress]
- 0.29 [Max. Top Compressive Stress]
- 0.06 [Max. Tension Stress]
- 35.48 [Length to Max. Tension]
- 0.02 [Residual Stresses Top]
- -0.01 [Residual Stresses Tip]
- 98.00 [KPI (%)]

Smart Structures
Sensor Information System

- Internet-based, SaaS model
- Highly advanced analytics
- Simple dashboards for various types of users
- Mobile accessible
- Pile Driving Analysis
- Soil Simulation
- Signal Matching
- Materials asset management
- Jobsite/facility monitoring
- MRO & Condition-based maintenance
- Disaster risk management
- Inspection & rating
Application-Specific Software

Host (Laptop, Desktop, Headless)
Software tightly linked to portal for data and asset management ...
Host (User) Software: Apps

- Tailored specifically to User Requirements
- EDC Data Collection / Configuration
  - Sampling, Triggering
  - Connection Tolerant
  - Work Standalone and Queue Data for next connection
- Advanced Signal Processing to meet the needs of the Application
- Advanced capabilities that leverage electronics embedded into the structure
- Reporting to the meet the QA needs of the Application/Data
For Driven Concrete Pile ...

SmartPile® Review
- Strain and Accel (Top and Tip) →
- Force, Velocity, Displacement
- Dynamic Damping, Tip Unloading
- Max Case Capacity, UF Capacity
- Results reporting in real time: Excel (CSV) and PDF

SmartPile® Acquisition
- EDC Connectivity and Setup
- Drive configuration (User, Project, Location, Pile Properties)
- Radio Diagnostics
- Calibration Data loaded from Radio
Focus of Simplicity

Collect the Data and generate the Final Report on-site
- Tabular Results
- Capacity, Integrity, Energy Stroke
- Blow Distribution
Other comprehensive reports also available
Futures

- Using Tip Data:
  - Conservation of Energy
  - Segmental Skin Friction

- Casting Yard Monitoring
  - Temperature Curing Profile
  - True Pre-stress
  - Wave Speed $\rightarrow$ Modulus

- Long Term Monitoring
  - Static Monitoring using installed gages
Futures: Pile Inspection

- Combine SmartPile Data Collection and Reporting with Pile Inspector reports
- Eliminate the cost of having and EDC Operator and Pile Inspector on Full Dynamic Projects
- Has not yet been approved by FDOT
EDC Benefits

- The Method
- Embedded Wireless Sensors
- Tip Data / Validated Signal Matching
- Advanced Integrity Assessment
- Real Time Capacity
- Simple Software / Deterministic Results
- Direct Measurements - Accuracy
- Configurability / Application Flexibility
The Method

• Perform pile capacity analysis on every hammer blow in real-time

• Damping value computed from top and tip sensor data

• Minimum operator influence on results due to direct measurements (Consistent results)

• Art versus Science
Embedded, Wireless Sensors

- Fast Setup
- Embedded Calibration
- Safety, no climbing leads
- Embedded sensors can be used for long term asset monitoring
- Embedded sensors detect conditions/changes not possible with externally mounted sensors
Top / Tip Instrumentation Benefits

- **Measured Pile Integrity (MPI)**
  - Change in static pre-stress tracking aids in advanced detection of pile damage
  - Ability to assess proper load transfer at pile toe in cases of damage detection
  - Numerous pile extractions have confirmed results
  - Two published papers by authors internationally well known in wave mechanics

- **Measured wave speed**
  - No pile end location assumptions
  - Ability to confirm wave speed used for key calculations at the end of drive – Known sensitivity on total capacity results
  - Able to detect the onset and monitor material fatigue during driving
Pre-Load Delta (microstrain)

Approximately 600 blows before the end...
Extraction Example #2

Pre-Load Delta (microstrain)

~700 blows before the end...

- Preload Delta Top Strain (uStrain)
- Preload Delta Tip Strain (uStrain)
Extraction Example #3

Pre-Load Delta (microstrain)

~2000 blows before the end...
ABSTRACT: In 1979, a paper was published by Rausche and Goble describing a method to determine damage in driven piles using the Beta Method. Over the years this method has become the standard for pile damage assessment in many parts of the world.

Recently developed technologies have begun to shed a different light on the reliability of this method, suggesting that a thorough assessment of the method derivation would be appropriate. Taken together the results of this re-evaluation clearly demonstrate that this widely applied method cannot be considered a reliable indicator and should therefore be used with extreme care.

“The theoretical review of the method showed clearly that the Beta Method cannot be a reliable indicator of pile toe damage... ...the Beta method should not be used to protect against pile toe damage.”

Verbeek, G.E.H. / Goble, G.
Benefits of Early Detection

Collision Avoidance – vs. – Costly Recovery/Replacement

It's not about damage being detected, but real damage going undetected!

Limitations of damage detection measured at pile top only well documented

Ability to assess proper load transfer at pile toe in cases of damage detection – confirm vs. assume performance
No Loss of Pre-stress example
Loss of Pre-stress example
Tip Instrumentation Benefits

- Understanding driving resistance contribution by direct measurement (%tip vs. %skin)
- Measured static tip resistance and end of initial drive (EOID)
- Soil Freeze - understanding true skin contribution (only) during restrike
  - confirming un-mobilized pile tip (total capacity = skin capacity with un-mobilized pile tip)
- Improves quality by preventing potentially damaging and unnecessary overdriving of piles
Comprehending Composite Capacity (EOD/BOR)

Similar tip resistance before and after re-strike.
Tip Data Signal Matching

- Signal match performed at pile top, and results validated using pile tip data
  - Validated solution for given pile top and pile tip boundaries
  - Soil model provides initial conditions
  - Results used to better understand and characterize soil properties and behavior
- Eliminates estimates, assumptions, and subjective interpretation
Simulate - Establish Target Soil Profile
EDC Match – Confirm Soil Model

Capacity versus Depth

- SSI Total Capacity
- Estimated Total Capacity
- SSI Tip Capacity
- Estimated Tip Capacity
- SSI Skin Capacity
- Estimated Skin Capacity
Prepare for Signal Match

* Signal Match only deals with a single point in the Soil Model for the end bearing but includes shaft resistance data for all soil layers above the pile toe*

Penetration \([f(\text{capacity})]\)

Blow # :
Signal Match - Top

**PILE DATA**
- Transferred Energy: 36.386 [Kipsft]
- at level 0.00 [ft]
- at level 0.00 [ft]
- Maximum pile toe displ.: 0.26 [in]
- Penetration pile toe: 75.00 [ft]
- Blow count: 61.7 [bl/ft]
- Set per 10 blows: 1.95 [in]
- Prestress force: 0.000 [Kips]
- Prestress level in pile: 0.000 [ksi]
- Maximum stresses in pile
  - Compression stress: 3.062 [ksi]
    - at level 31.64 [ft]
    - at time 9.926 [ms]
  - Tension stress: 0.302 [ksi]
    - at level 85.36 [ft]
    - at time 19.151 [ms]

**SOIL DATA**
- Total driving resistance: 1638.69 [Kips]
- Max. driving resistance: 1640.42 [Kips]
- Mobilized static resistance: 872.240 [Kips]
- Mob. static resistance toe: 91.752 [Kips]
- Mob. static resist. shaft: 780.488 [Kips]
- Mob. static resistance toe: 0.159 [ksi]

**MATCH QUALITY DATA**
- Signal match quality upward wave:
  - Up to toe: 2.68% (Improve)
  - Toe 1: 3.57% (Fair)
  - Toe 2: 2.84% (Good)
  - After Toe: 1.93% (Good)
  - 4L/c till 6L/c: 6.71% (Good)
  - 6L/c till End: (Not defined)

**Graphs**
- Upward travelling wave as function of Time at level = 0.00

**Penetration**
- 75.00 [ft]

**Date**
- 8/28/2013
Signal Match – Validated Toe

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- Transferred Energy: 36.386 [kips/ft]
  - at level 0.00 [ft]
  - at level 0.00 [ft]
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Drilled Shaft Monitoring

- Leverage EDC in 2 Configurations
  - Static Load Monitoring: Strain Gages
  - Dynamic Impact Testing: Strain / Accel Data

- Dynamic:
  - Supplements CSL data to help mitigate shaft integrity concerns and provides options to shaft coring ($$$)
  - Measure concrete wave speed for material quality testing – Top – Tip (w/o reflection)
  - Look for early reflections coming from voids or other material defects
  - Assess measured load transfer at shaft tip (or at other instrumented locations)
  - Measured set at shaft tip indicates presence of loose or soft material
Monitor Changes in Pile and Cap Strain

Detect changes in Static loading over extended periods

Walk up or Gateway Monitoring

All data send to Portal
Structural Health Remote Monitoring

- Remote Monitoring Gateway To-Go
- Walk-up, drive-by monitoring
- Battery powered
- No user controls or operation

- Remote Monitoring Gateway permanently mounted
- Plug powered
- No user controls or operation
Mainstream Infrastructure Monitoring

- By being part of the construction process …
  - Make monitoring part of the construction process
  - Leave sensors behind and make monitoring an incremental cost
  - Work to minimize labor costs

- Through innovative pricing models
  - Pilot Pricing (FDOT/FHWA)
  - Small Project Pricing
  - Large Scale Full Dynamic Testing
    - Sensors as a Service: SaaS
Roadmap: EDC Technology Applications

Beyond Bridges
- Ports
- Petrochem
- Energy/Industrial

Beyond Testing
- Condition-based Monitoring
- Asset Management
- Situational Awareness

Beyond Piles
- Drilled Shafts
- Machine Foundations
- Pipelines

Structural Health Monitoring (SHM)
DOT Pilot Programs

For DOT’s, State Agencies, Federal Agencies and Municipalities – PILOT PROJECTS

SMARTPILE® FastStart Package $9,995.00
Includes:

EDC
- Ten (10) Embedded Data Collectors (SP_402)
- Installation kit
- Installation at casting yard

SmartStart for DOTs Program
- 90-minute online (web) briefing on System

12-month SmartPile® Workstation lease
- Hardware
- embedded software
- wireless data services
- remote support
- 24-hour hardware break/fix/replace

EDC Plus Software Suite for DOTs
- SmartPile® Review
- Named account access
- Unlimited phone/web technical support during standard business hours
Small Project Pricing

EDC

- Embedded Data Collectors (SP_402)
- Installation kit
- Installation at partner casting yard

$ 899.00/set*

* Large volume reductions apply
## Large Scale Testing Projects

**Standard Embedded Data Collector Data Service**
- SP_402 EDC device with top and tip sensor packs
- Installation kit and all required accessories
- Installation
- EDC data service
- $29.00/month

**EDC Review & Management Software Services**
- Named account on EDC Portal with Project Dashboard
- EDC Review application
- Unlimited online and telephone technical support
- $99.00/month

**Online Project Database Software Services**
- Storage and management of all EDC data and reports
- Automated backup of all project Workstations
- Online Software & Portal User Introductory Training
- $250.00/month

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*On average, cost per instrumented pile for projects is around $550.00. Please note, that there are minimum terms on duration.*
**Remember**
There is a cost to have a person in the field regardless of the type of instrumentation (Collecting Data, part of the Verification process).

**Field Equipment Lease**

<table>
<thead>
<tr>
<th>Work Station</th>
<th>$ 999.00/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Rugged Laptop</td>
<td></td>
</tr>
<tr>
<td>✓ Acquisition software</td>
<td></td>
</tr>
<tr>
<td>✓ Review software</td>
<td></td>
</tr>
<tr>
<td>✓ Discounts for long duration projects</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

• A new approach to dynamic testing enabling all structural elements to be efficiently tested during installation

• Owner Advantages over “Top Only” Dynamic Testing:
  • Final Capacity dependent on wave speed used in key calculations – EDC provides ability to confirm correct wave speed at the end of drive!
  • It’s not about damage being detected, but real damage going undetected!
  • %tip vs. %skin - Need to know in two places? Measure in two places!
  • Signal Matching results validated using pile tip data!
  • Estimates, assumptions, and subjective interpretation replaced with measured data!

• It’s not about more data, but more reliable data, providing for checks and balances, to improve owner confidence, and warrant a higher resistance factor
Thank You!!
To Learn More (Contacts)

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