Development of Rapid, Reliable, and Economical Methods for Inspection and Monitoring of Highway Bridges

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Joint Venture:
University of Texas at Austin
National Instruments
Wiss, Janney, Elstner Associates

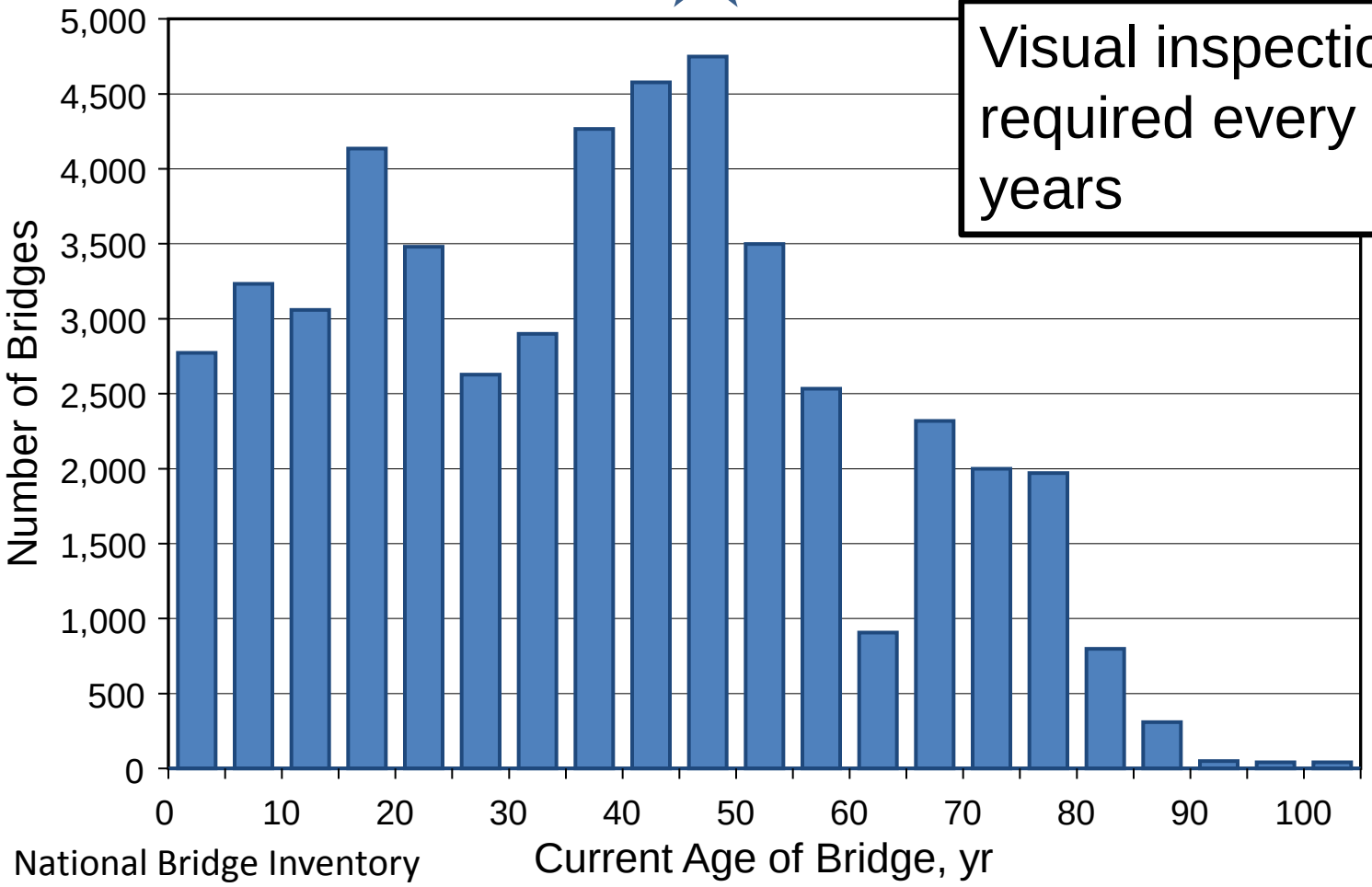
13 March 2014

Project Team

- The University of Texas at Austin
  - Structural engineering
  - Electrical engineering
  - Mechanical engineering
- National Instruments
- Wiss, Janney, Elstner Associates, Inc.

Fracture-Critical Bridges

Aging Infrastructure…



Source: National Bridge Inventory

Quantitative Data Needed

- Transportation officials need methodologies to set priorities among bridges
  - For inspection, retrofit, and/or replacement
- Remaining fatigue life is one metric
  - Determine fatigue damage in current year
  - Estimate accumulation of cycles
  - Calculate fatigue life using deterministic or probabilistic approach

Goals of Research Project

- Develop a monitoring system that will augment visual inspections
  - Always have a need for visual inspections
  - Use monitored data to better allocate resources
  - Focus on fracture-critical bridges due to significant inspections requirements
- Promote more efficient inspection by including quantitative data in the decision-making process

Collect data reliably

analyze data effectively

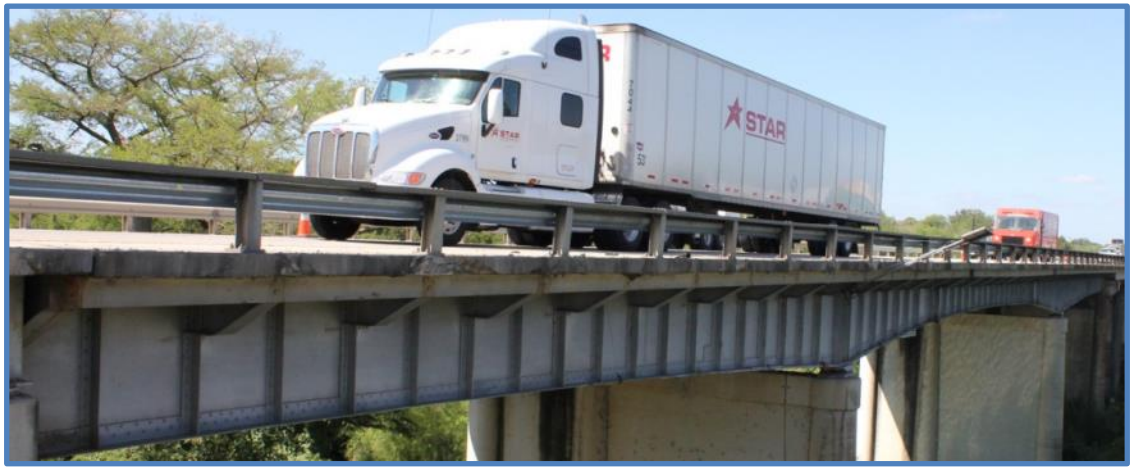
Quantitative Data Needed

- Transportation officials need methodologies to set priorities among bridges
  - For inspection, retrofit, and/or replacement
- Remaining fatigue life is one metric
  - Determine fatigue damage in current year
  - Estimate accumulation of cycles
  - Calculate fatigue life using deterministic or probabilistic approach

Determine Fatigue Damage

- Structural analysis
  - Assume representative fatigue truck
  - Assume live load distribution factor (LLDF)
  - Assume dynamic impact factor (IM)
  - Calculate effective stress range for annual daily truck traffic (ADTT)
- Field monitoring
  - Distribution of fatigue cycles is measured directly

Value of Monitoring



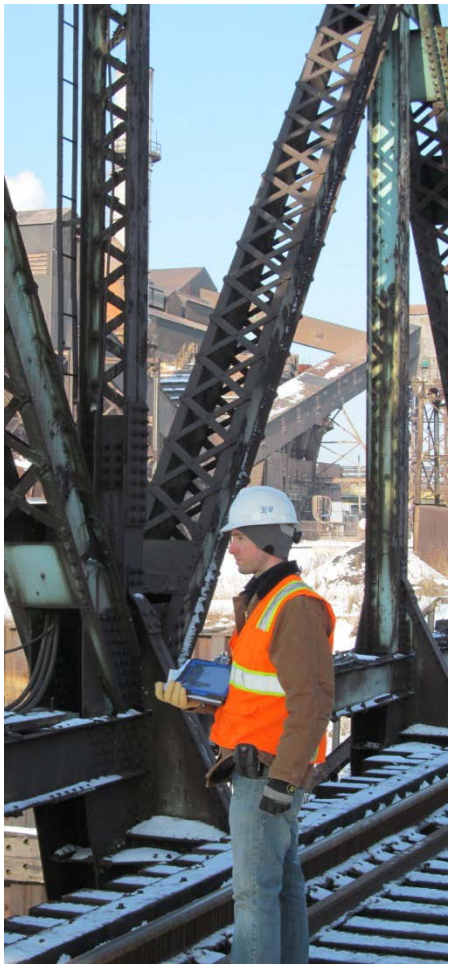
	Structural analysis	Field monitoring
S_{re}	14.4 ksi	5.15 ksi
N_d	4,000 cycles	4,000 cycles
Fatigue life	~ 1 year	~ 10-30 years

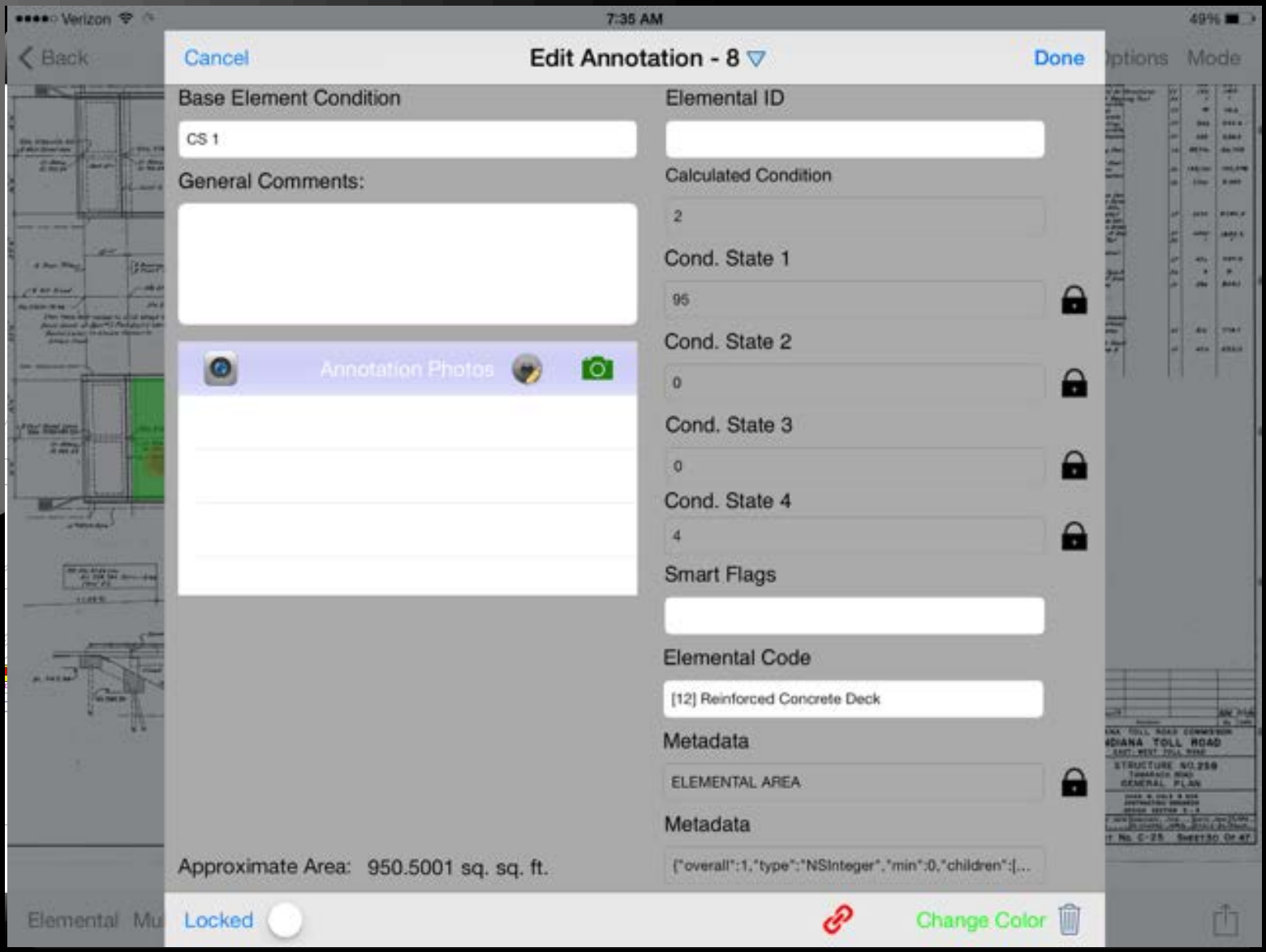
Solutions

- Digital inspection and data gathering app
- Wireless strain and displacement monitor
- Enterprise management software
- Passive corrosion detection system

Digital Inspection - Plannotate

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[12] Reinforced Concrete Deck
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ELEMENTAL AREA
Metadata
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Locked
Change Color
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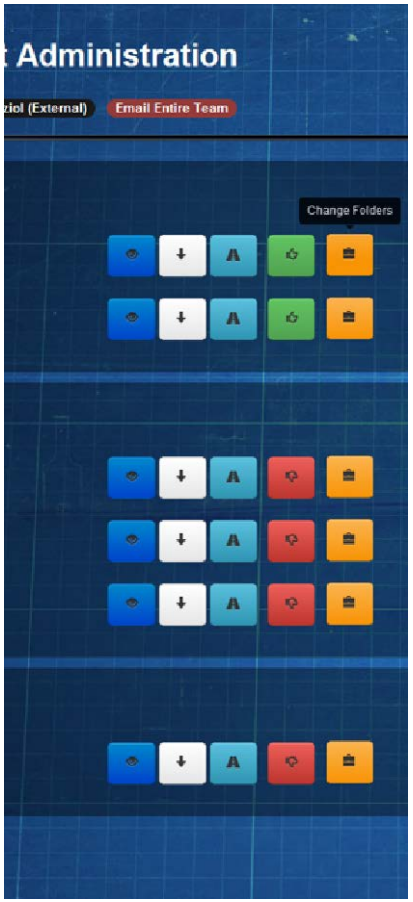
Annotates with Intelligence

PDF Pictures Forms Cloud

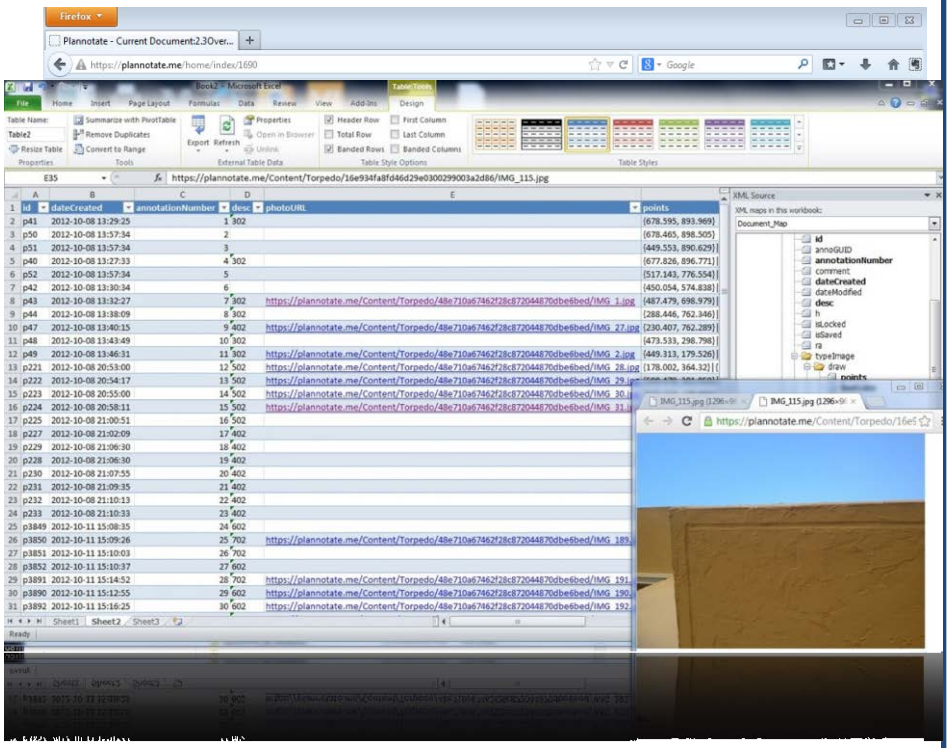


Annotates with Intelligence

- Speed
- Real-time collaboration
  - Other Inspectors
  - Technical Experts
- QA/QC
  - Eliminate transcription
  - Review progress
- Analysis ready data
- Understanding…

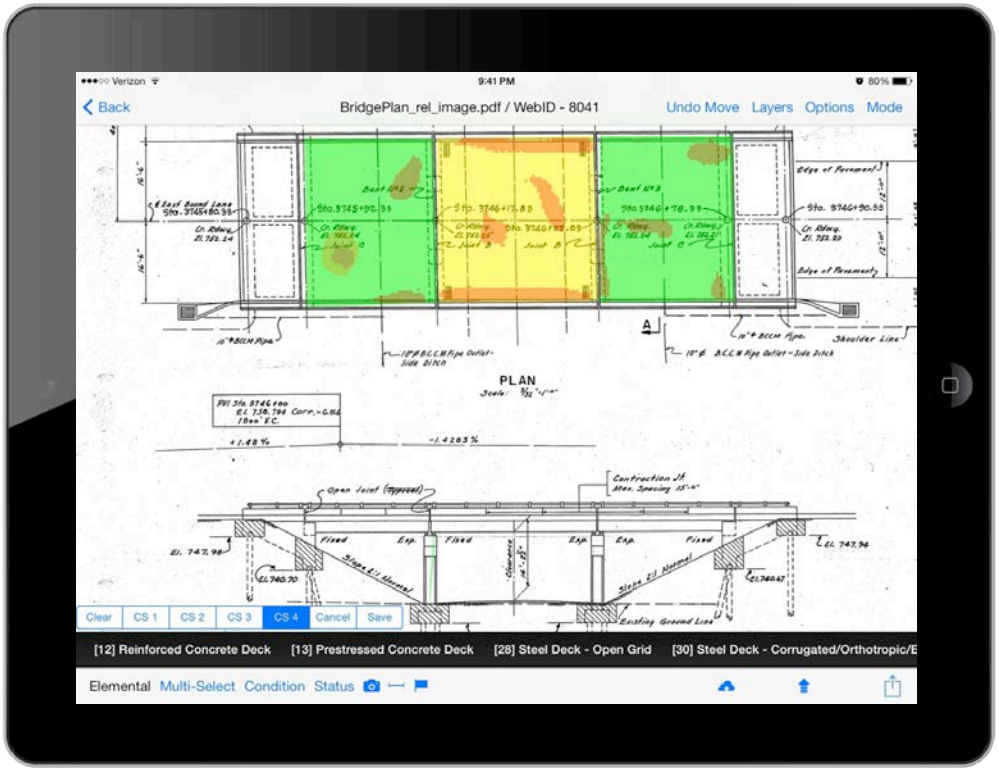
Features

- Dynamic annotations
  - Primitives to freehand
  - Dynamic state
- Viewable anywhere
  - Web interface
- Import into Excel
- Import into AutoCAD
- Automated reporting



PlannotateDOT

- DOT's required to perform elemental inspection
- Plannotate ideal
  - Use existing documents
  - Specialized forms
- Looking to provide to DOT's for free

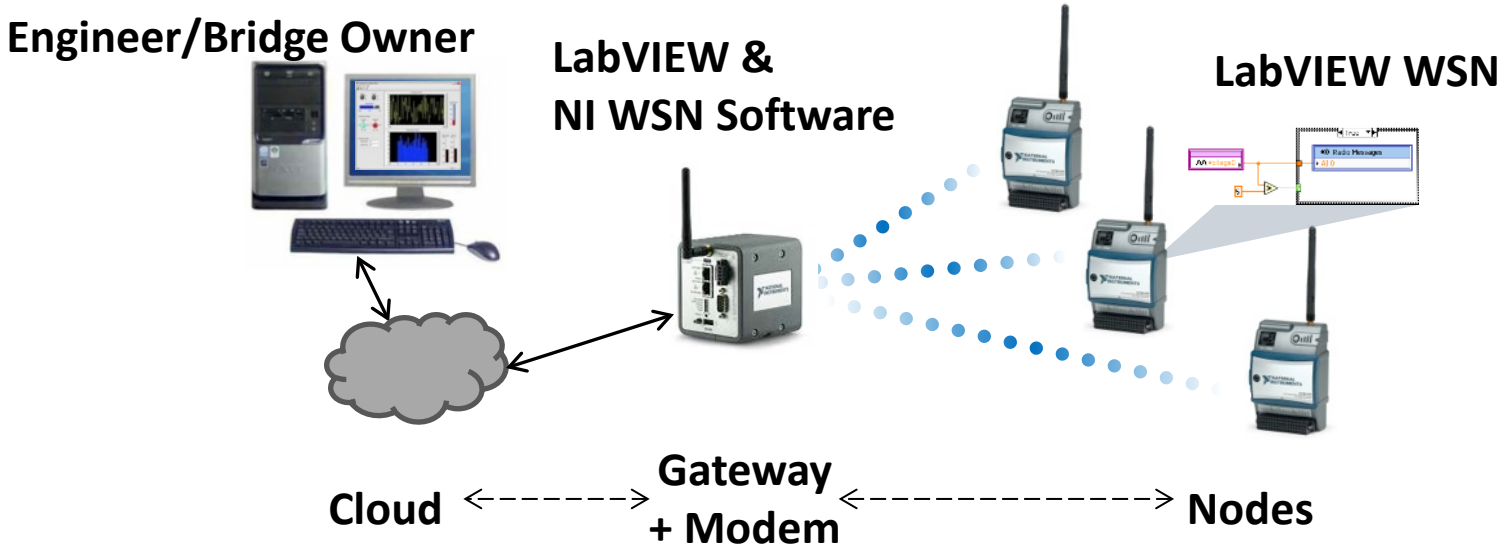


Prime time

- Software actively used
  - Much more than bridges!
- Over 100 users and 300 different projects
- Resulting 8000 annotated documents in 18 months
- Over 135,000 photos managed

NI WSN System

- Rainflow algorithm (WSN Node)
- System automation (Gateway/Controller)
- Data storage/access (Cloud)



Wireless Strain Input Node

- Four input channels
- Full/half/quarter-bridge measurements
- Dynamic data acquisition
  - 1-kHz sampling rate to local buffer
  - 20-bit resolution
  - Configurable noise performance
- Onboard processor for local data processing using LabVIEW WSN

Strain Node Software

- Embedded programs
  - Streaming mode
  - Rainflow mode
  - Trigger (waveform) mode
  - Rainflow+Trigger mode
  - LoadTest mode
  - Can be integrated with camera
- Configurable over the air (string message)

Gateway

- Manages and automates wireless network
- Equipment configured by four text files: *config*, *mode*, *email*, and *channel_info*
- Temporary data storage
- Email notification

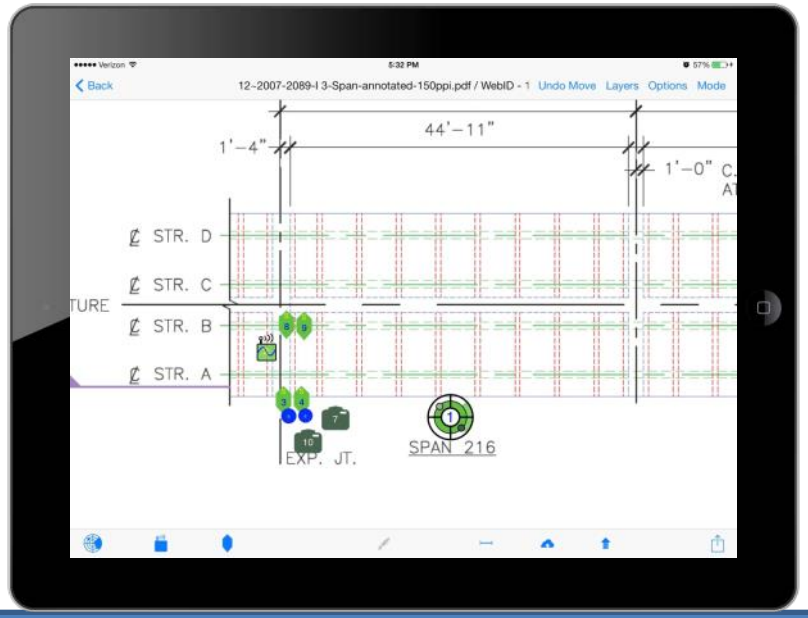
Core Concepts

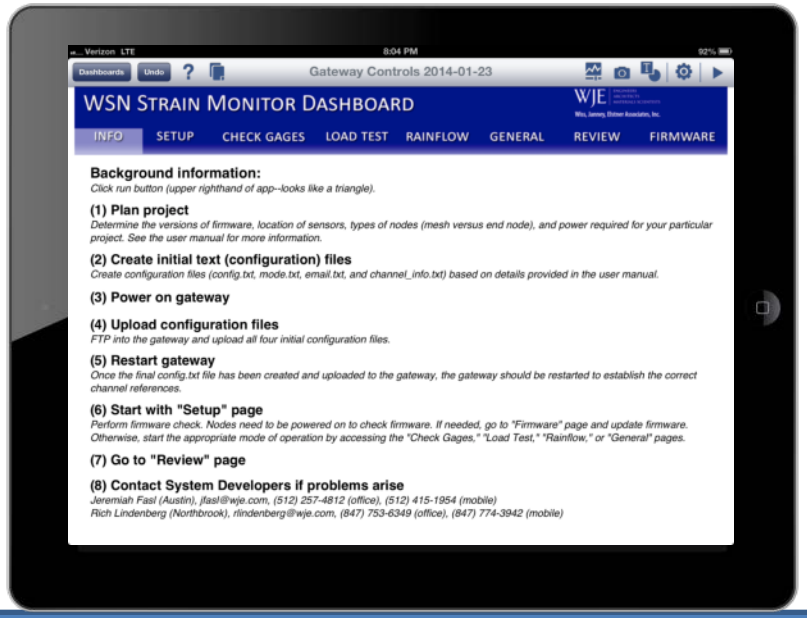
- Waveform response
- Environmental response
- Rainflow with event triggering
- Collect images of triggered events

- Faster/Easier
- Simplify data management and reporting

User Interface

- Two iPad apps are used by WJE
  - Plannotate (documentation)
  - NI Data Dashboard (configuration)





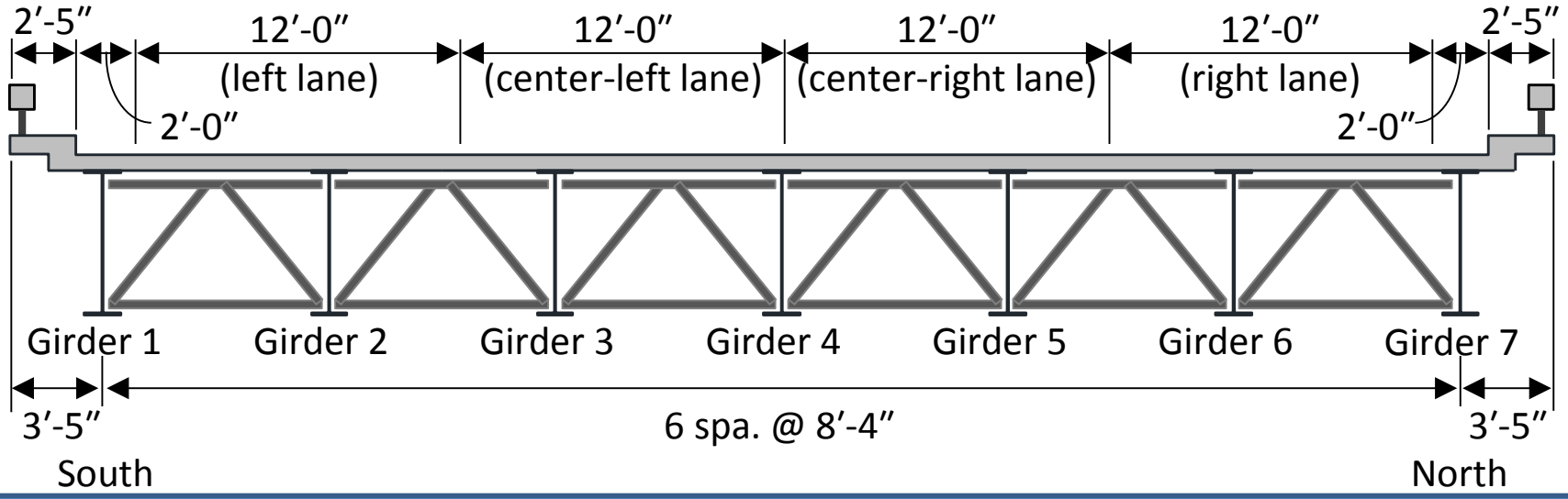
Used on Multiple Bridges

Example Bridge

- I-girder bridge
  - Seven girders
  - Over 40 years old

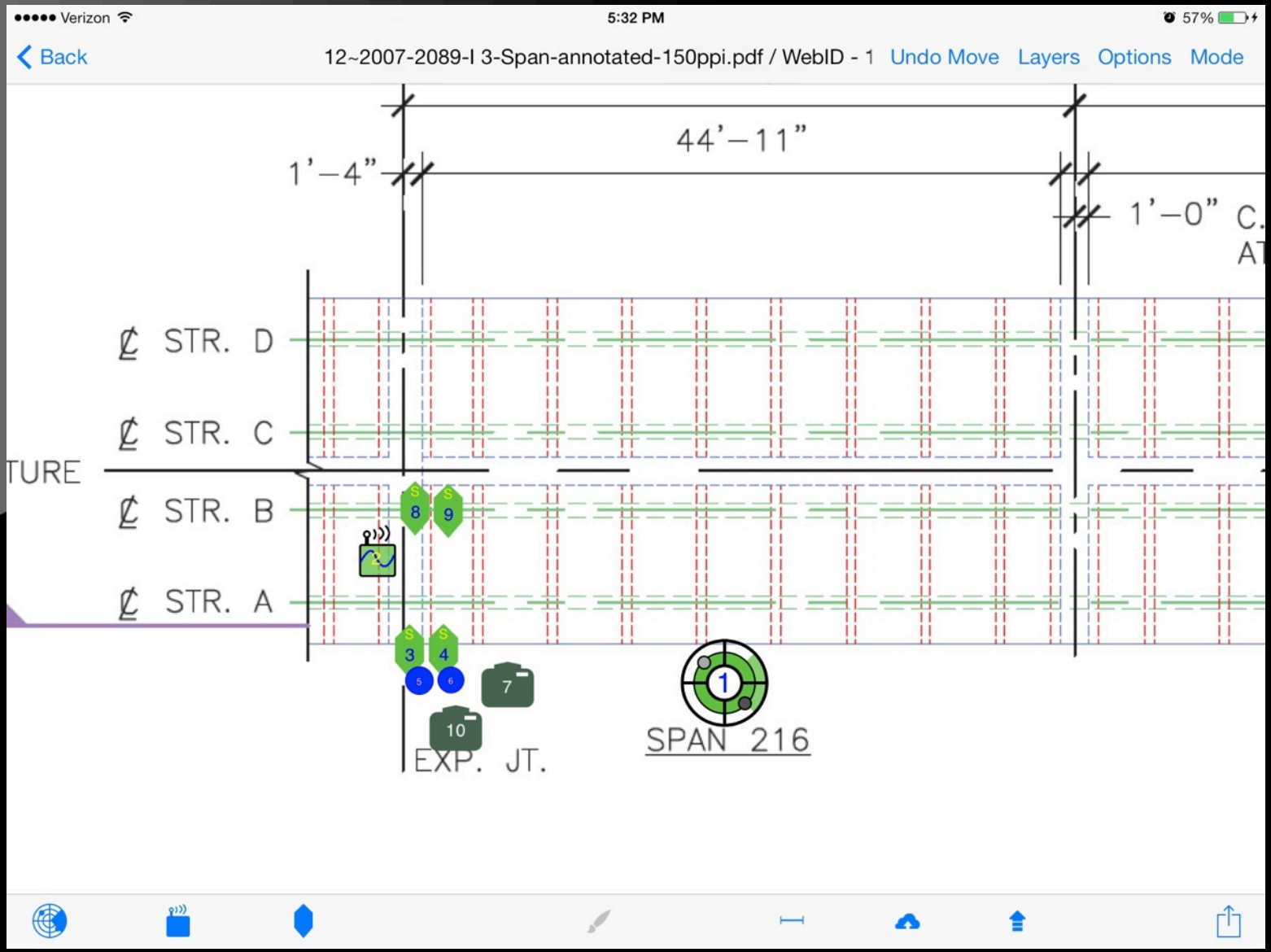
Identify Critical Details

- Flange-to-web welds (Category B)
- Transverse stiffeners (Category C′)
- Ends of cover plates (Category E′)



Access Bridge

Install Instrumentation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1'–4"
1'–0" C.
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SPAN 216

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Cancel

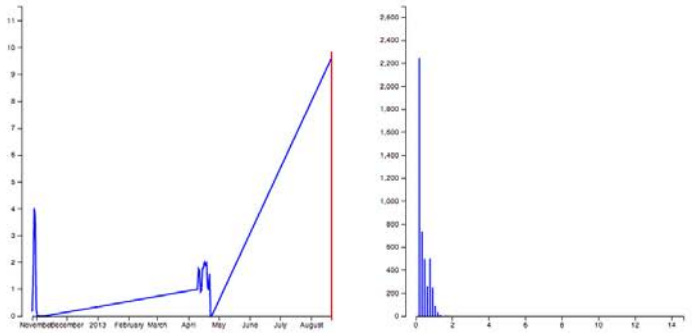
Edit Annotation - 9

Done

Options Mode

Node	16C7967	B. Resistance	350
Channel Id	3	Gage Factor	2.01
Description	S side stringer 2 hanger	S. Alarm H. µE	344
Acquire	True	S. Alarm L. µE	-344
Bridge Config:	Quarter Bridge I	S. Alarm Eval.	True
		T. Trigger	100
		T. Min Amp.	-100
		T. Pre Trigger Pnts.	150
		T. Post Trigger Pnts.	650

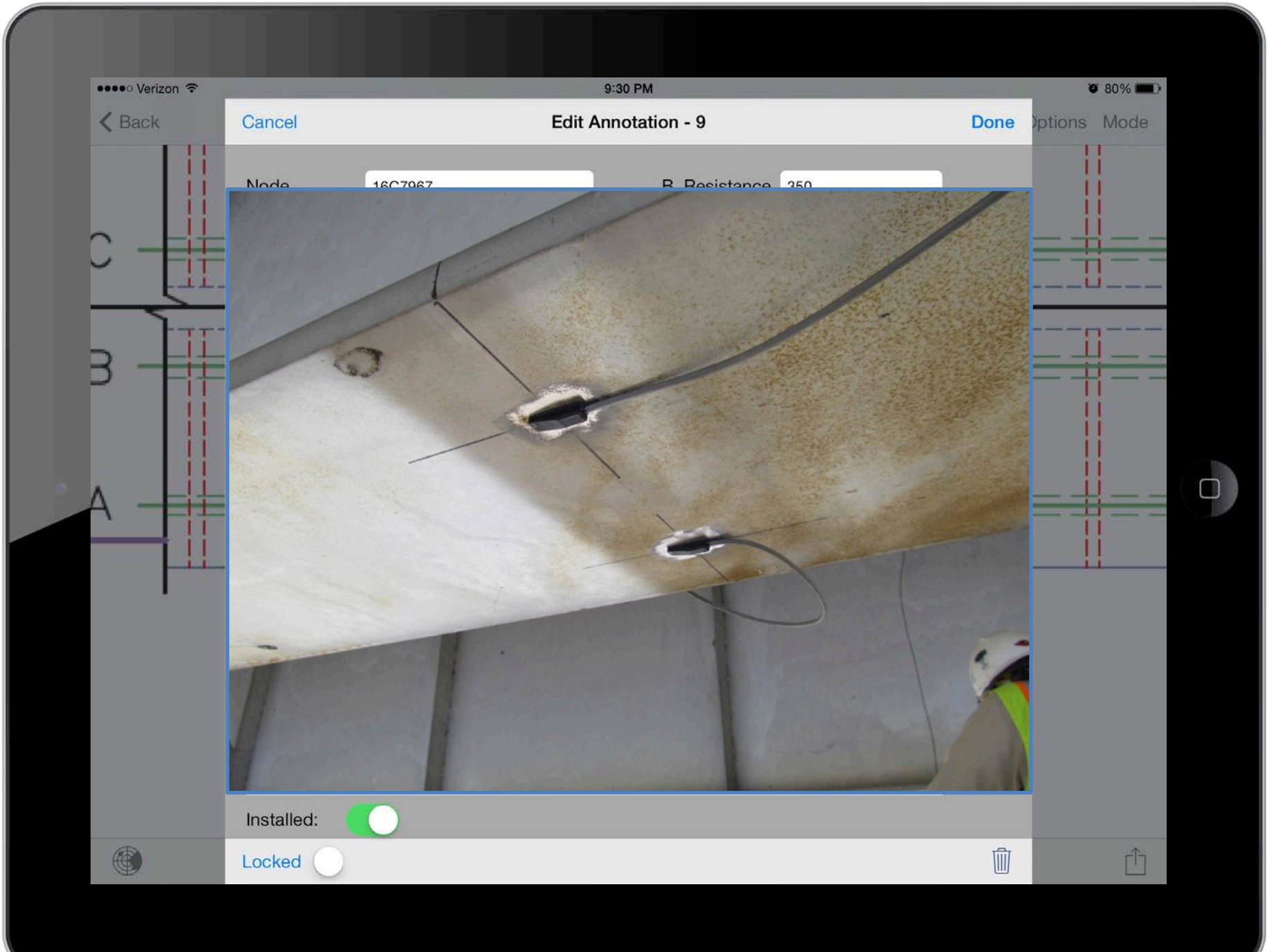
Photos



Expand

Installed:

Locked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Mode
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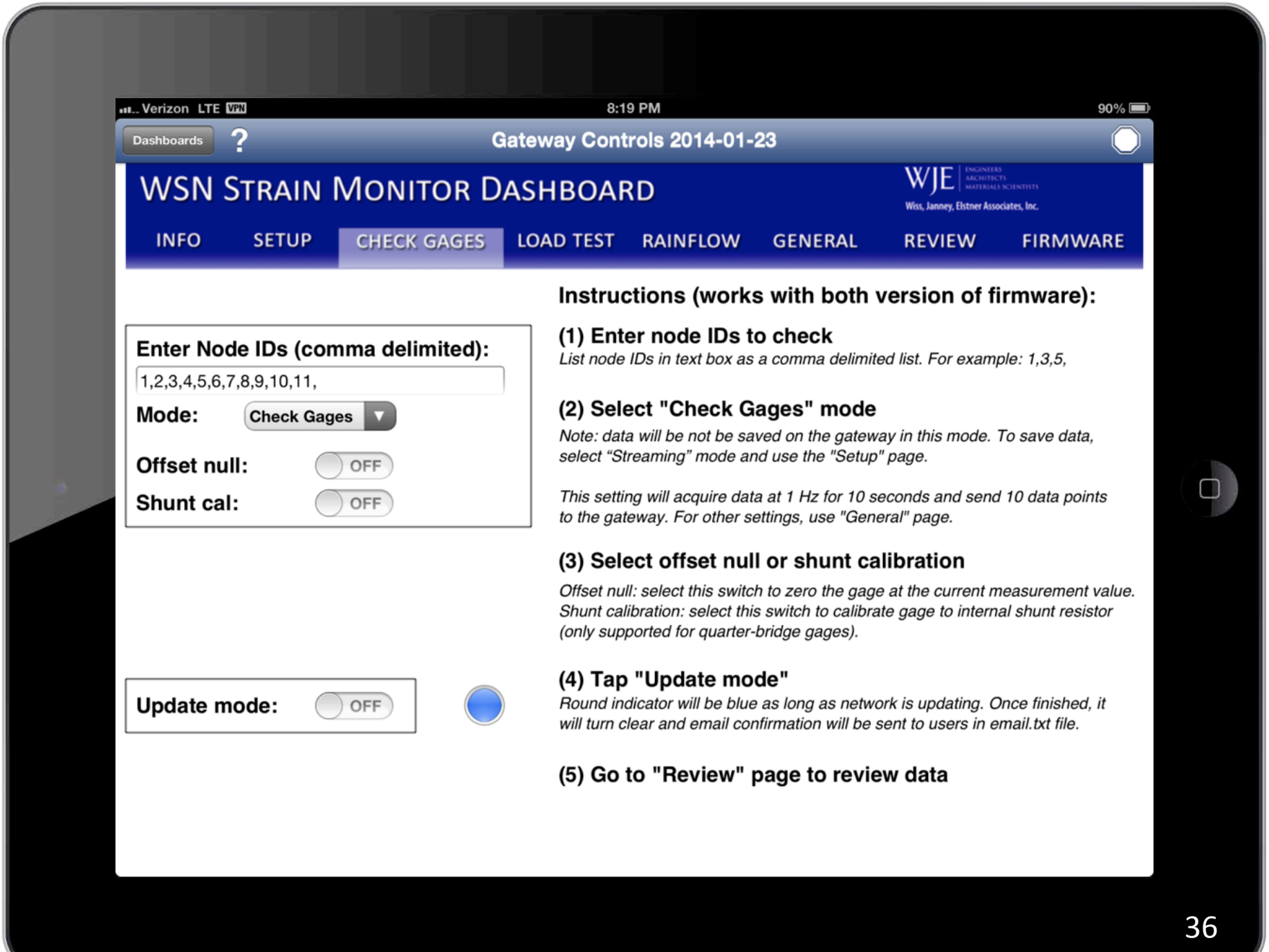
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8:19 PM
90%
Dashboards
?
Gateway Controls 2014-01-23
WSN STRAIN MONITOR DASHBOARD
WJE ENGINEERS ARCHITECTS MATERIALS SCIENTISTS
Wiss, Janney, Elstner Associates, Inc.
INFO
SETUP
CHECK GAGES
LOAD TEST
RAINFLOW
GENERAL
REVIEW
FIRMWARE
Enter Node IDs (comma delimited):
1,2,3,4,5,6,7,8,9,10,11,
Mode:
Check Gages
Offset null:
OFF
Shunt cal:
OFF
Update mode:
OFF
Instructions (works with both version of firmware):
(1) Enter node IDs to check
List node IDs in text box as a comma delimited list. For example: 1,3,5,
(2) Select "Check Gages" mode
Note: data will be not be saved on the gateway in this mode. To save data, select “Streaming” mode and use the "Setup" page.
This setting will acquire data at 1 Hz for 10 seconds and send 10 data points to the gateway. For other settings, use "General" page.
(3) Select offset null or shunt calibration
Offset null: select this switch to zero the gage at the current measurement value.
Shunt calibration: select this switch to calibrate gage to internal shunt resistor (only supported for quarter-bridge gages).
(4) Tap "Update mode"
Round indicator will be blue as long as network is updating. Once finished, it will turn clear and email confirmation will be sent to users in email.txt file.
(5) Go to "Review" page to review data

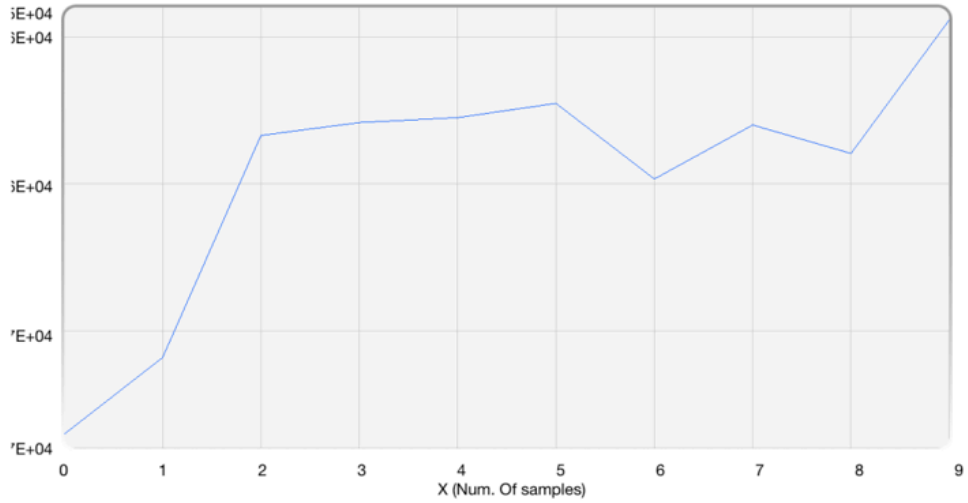
Verizon LTE VPN 8:21 PM 90%

Dashboards ? Gateway Controls 2014-01-23

WSN Strain Monitor Dashboard

WJE Engineers Architects Materials Scientists
Wiss, Janney, Elstner Associates, Inc.

INFO | SETUP | CHECK GAGES | LOAD TEST | RAINFLOW | GENERAL | REVIEW | FIRMWARE



Instructions:

(1) Select channel to graph

Channels are based on unique names entered in channel_info.txt file. If channels are missing, gateway may need to be restarted to establish channel references.

(2) Check LQI

Select the appropriate node ID to check link quality indicator. Minimum LQI of 40 is recommended for each node.

Pick sensor channel for graphing: gage6

Time of last received data: 2014-01-25 20:20:36

Received number of samples (from Load Test): 0

LoadTest data received since start of test:

Link Quality Indicator

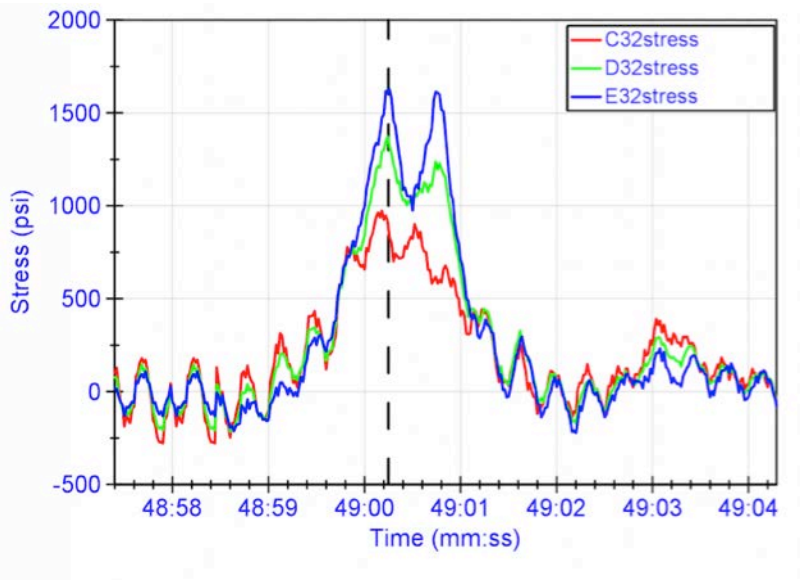
Node: Node1

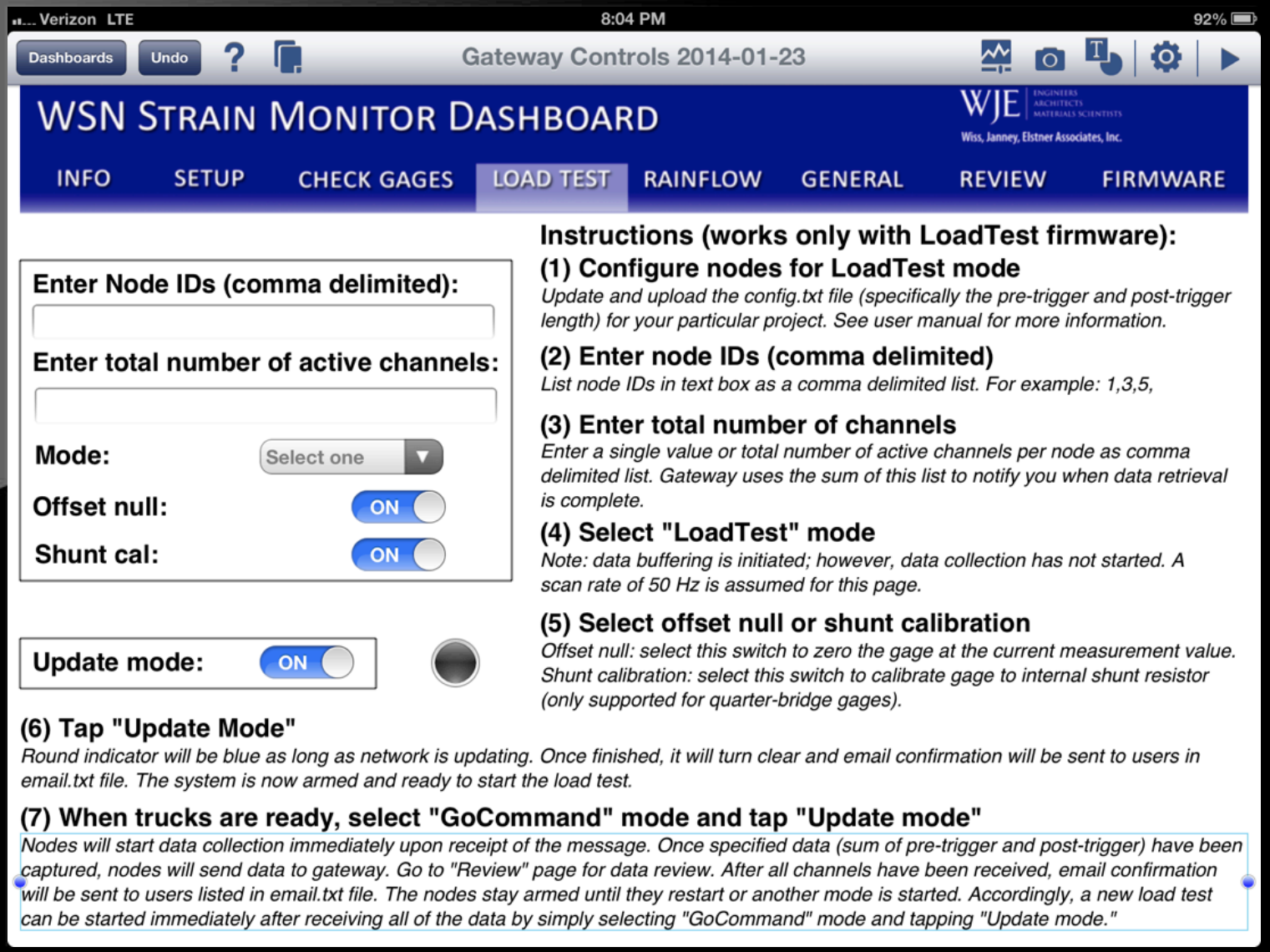
LQI: 82

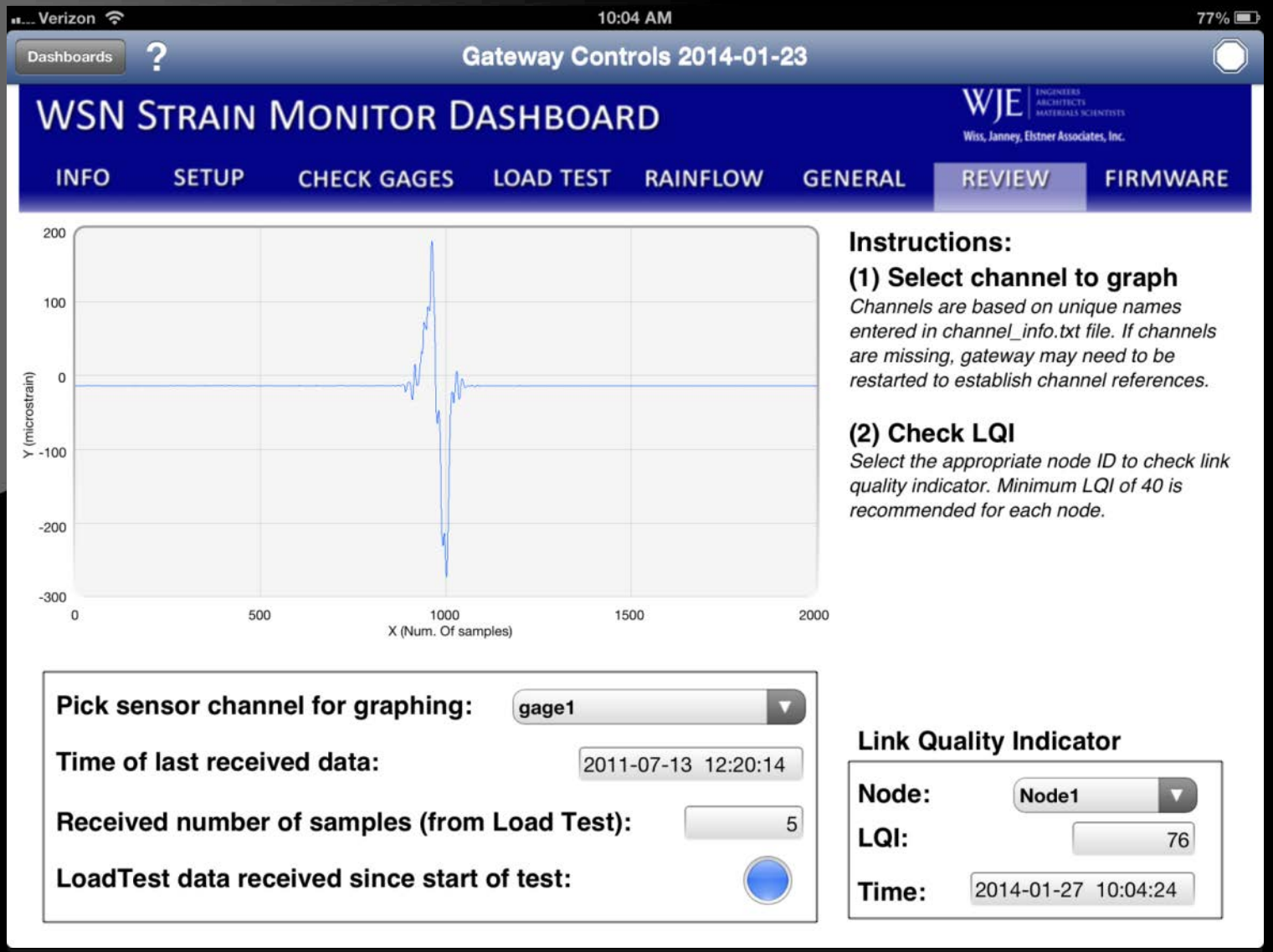
Time: 2014-01-25 20:21:20

Perform Load Test

- Generally performed with known loads
- Establishes baseline behavior of bridge
- Can develop trigger thresholds from results




Verizon LTE
8:04 PM
92%
Dashboards
Undo
Gateway Controls 2014-01-23
WSN STRAIN MONITOR DASHBOARD
WJE
Wiss, Janney, Elstner Associates, Inc.
INFO
SETUP
CHECK GAGES
LOAD TEST
RAINFLOW
GENERAL
REVIEW
FIRMWARE
Enter Node IDs (comma delimited):
Enter total number of active channels:
Mode:
Select one
Offset null:
ON
Shunt cal:
ON
Update mode:
ON
Instructions (works only with LoadTest firmware):
(1) Configure nodes for LoadTest mode
Update and upload the config.txt file (specifically the pre-trigger and post-trigger length) for your particular project. See user manual for more information.
(2) Enter node IDs (comma delimited)
List node IDs in text box as a comma delimited list. For example: 1,3,5,
(3) Enter total number of channels
Enter a single value or total number of active channels per node as comma delimited list. Gateway uses the sum of this list to notify you when data retrieval is complete.
(4) Select "LoadTest" mode
Note: data buffering is initiated; however, data collection has not started. A scan rate of 50 Hz is assumed for this page.
(5) Select offset null or shunt calibration
Offset null: select this switch to zero the gage at the current measurement value.
Shunt calibration: select this switch to calibrate gage to internal shunt resistor (only supported for quarter-bridge gages).
(6) Tap "Update Mode"
Round indicator will be blue as long as network is updating. Once finished, it will turn clear and email confirmation will be sent to users in email.txt file. The system is now armed and ready to start the load test.
(7) When trucks are ready, select "GoCommand" mode and tap "Update mode"
Nodes will start data collection immediately upon receipt of the message. Once specified data (sum of pre-trigger and post-trigger) have been captured, nodes will send data to gateway. Go to "Review" page for data review. After all channels have been received, email confirmation will be sent to users listed in email.txt file. The nodes stay armed until they restart or another mode is started. Accordingly, a new load test can be started immediately after receiving all of the data by simply selecting "GoCommand" mode and tapping "Update mode."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10:04 AM
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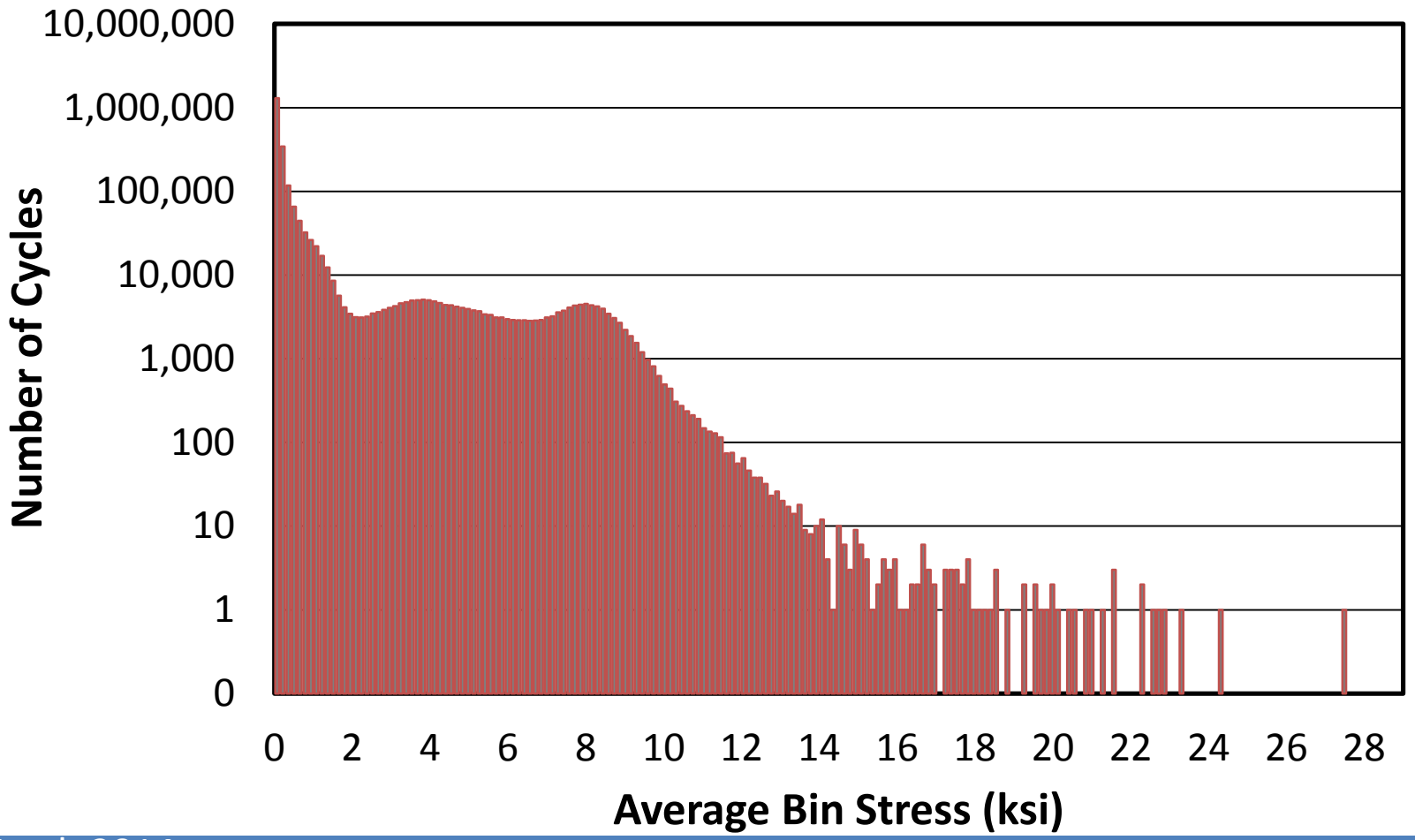
Dashboards
Gateway Controls 2014-01-23
WSN STRAIN MONITOR DASHBOARD
WJE
Wiss, Janney, Elstner Associates, Inc.
INFO
SETUP
CHECK GAGES
LOAD TEST
RAINFLOW
GENERAL
REVIEW
FIRMWARE
200
100
0
-100
-200
-300
Y (microstrain)
0
500
1000
1500
2000
X (Num. Of samples)
Instructions:
(1) Select channel to graph
Channels are based on unique names entered in channel_info.txt file. If channels are missing, gateway may need to be restarted to establish channel references.
(2) Check LQI
Select the appropriate node ID to check link quality indicator. Minimum LQI of 40 is recommended for each node.
Pick sensor channel for graphing:
gage1
Time of last received data:
2011-07-13 12:20:14
Received number of samples (from Load Test):
5
LoadTest data received since start of test:
Link Quality Indicator
Node:
Node1
LQI:
76
Time:
2014-01-27 10:04:24

Fatigue Monitoring

- Measure fatigue damage from daily traffic
- Capture trigger data to confirm large-amplitude cycles

Photo/Video

Rainflow+Trigger Mode



Techniques for Fatigue Analysis

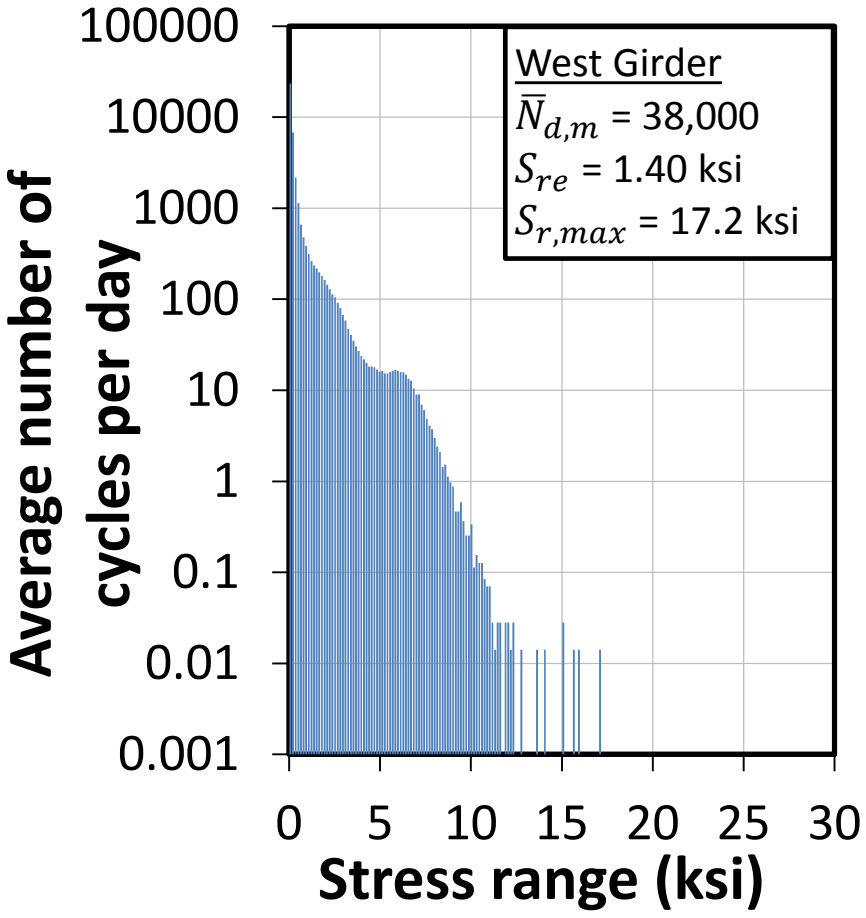
- Count variable-amplitude cycles
  - Simplified rainflow counting
- Determine amount of damage
  - Effective stress range

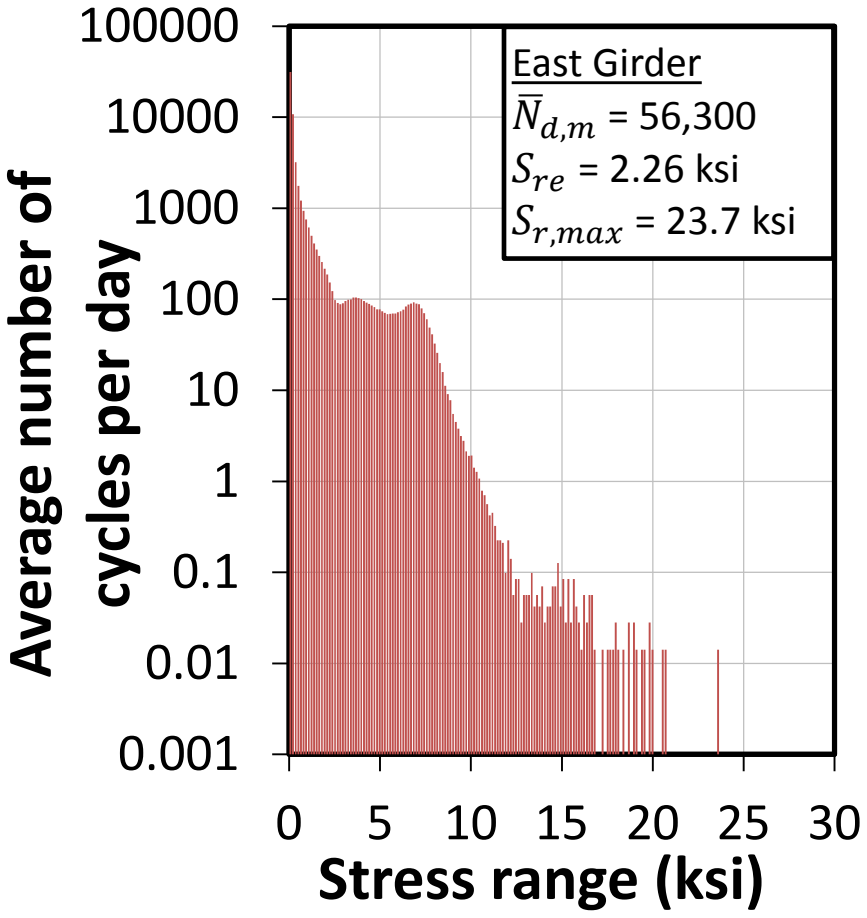
Techniques for Fatigue Analysis

- Count variable-amplitude cycles
  - Simplified rainflow counting
- Determine amount of damage
  - Effective stress range
  - Index stress range
- Characterize fatigue damage
  - Contribution to damage
  - Cumulative damage

New techniques

Rainflow Data

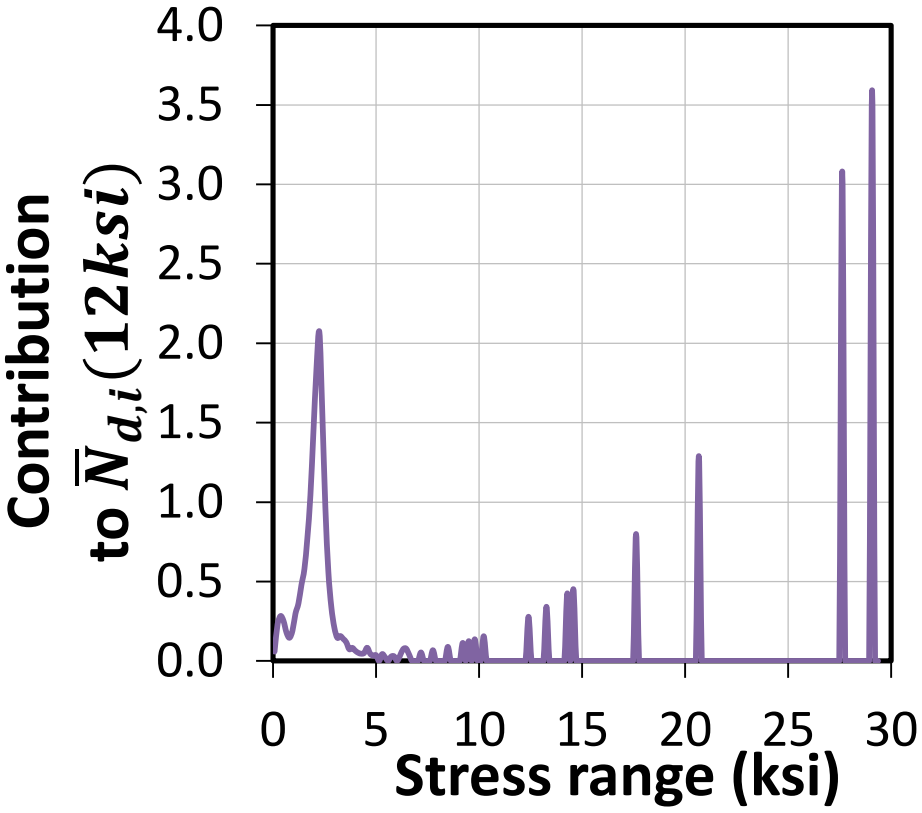


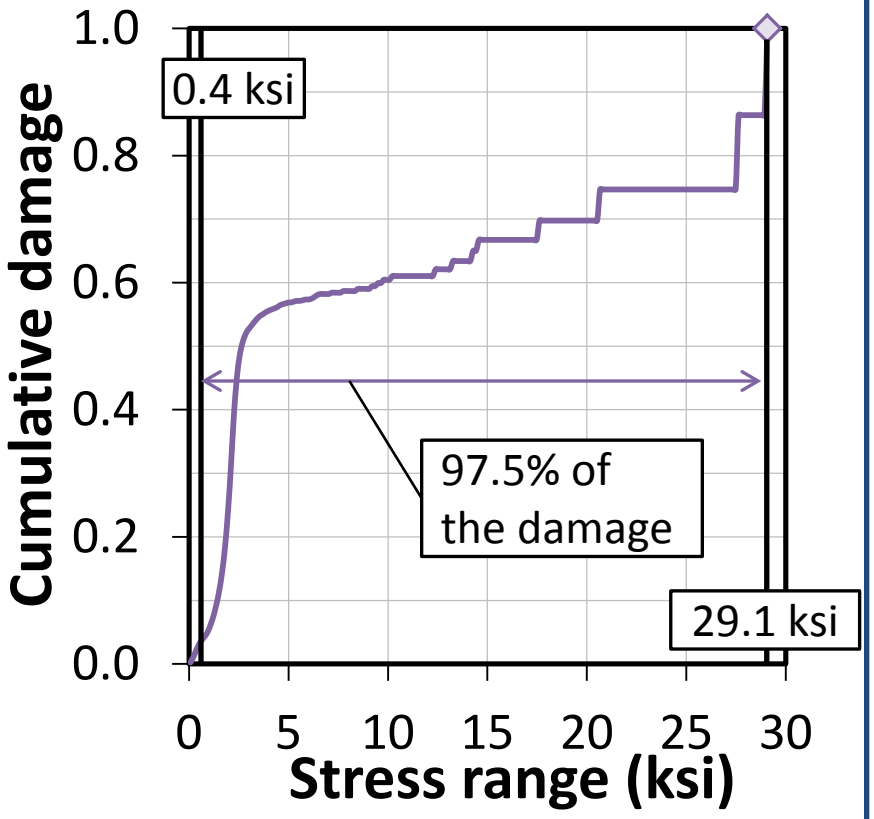


Comparison Between Methods

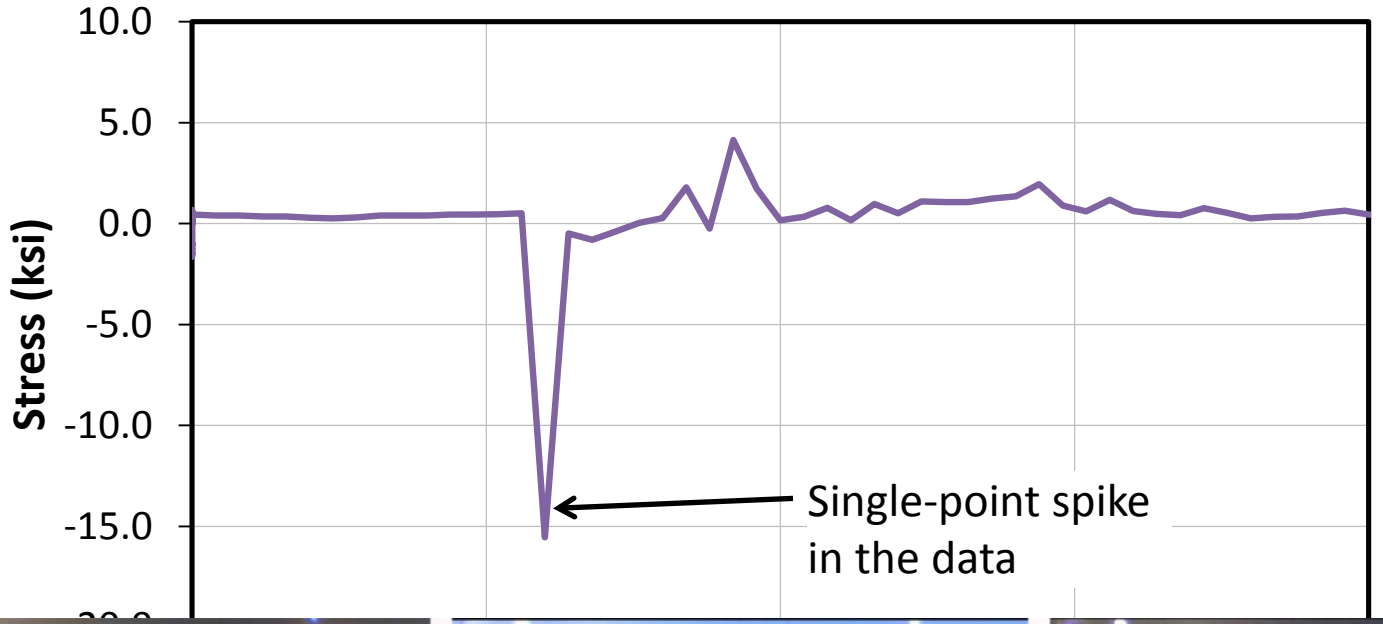
- Effective stress range
  - West girder: 38,000 cycles per day at 1.44 ksi
  - East girder: 56,300 cycles per day at 2.26 ksi
- Index stress range
  - West girder: $\overline{N}_{d,i}(4.5ksi)$ = 1,250 cycles
  - East girder: $\overline{N}_{d,i}(4.5ksi)$ = 7,080 cycles
- Easier to compare with index stress range (5.7 times more damage in East girder)

Characterize Fatigue Damage

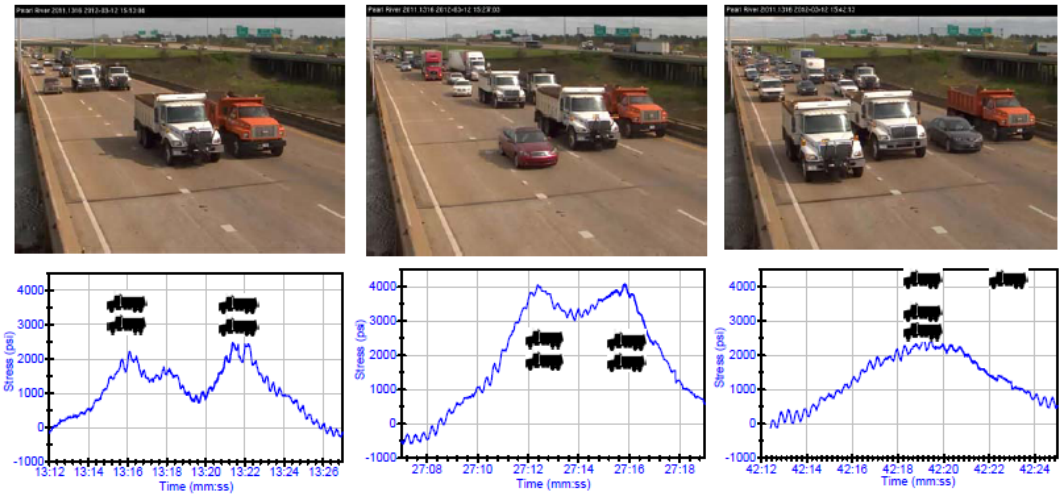




Single-Point Spike in Waveform



Reporting



Gage: E32

WJE ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

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Enterprise Management System

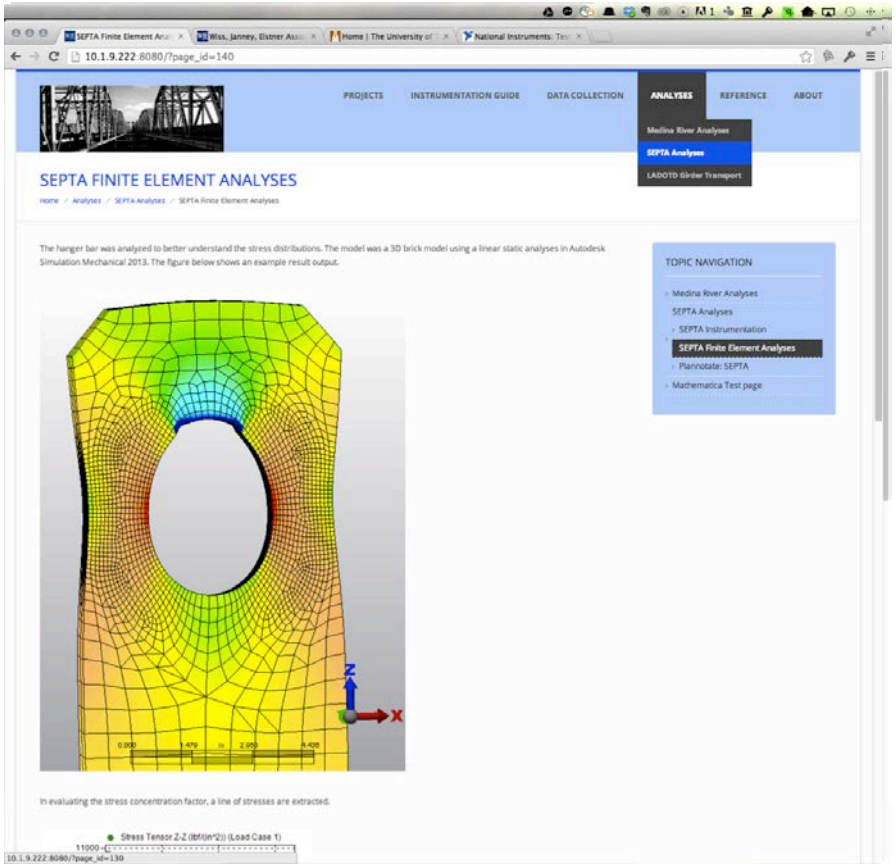
- Database Management System (DBMS)
- Project & System Website
- Tools
  - API's
  - Report tools
  - Canned visualizations

Instrumentation Data Storage

- Apache Cassandra
  - NoSQL Database
  - Developed by Facebook
  - Open source
- Ideal for our data
  - High throughput
- Data architecture
  - Customizable
  - Focus on how you read

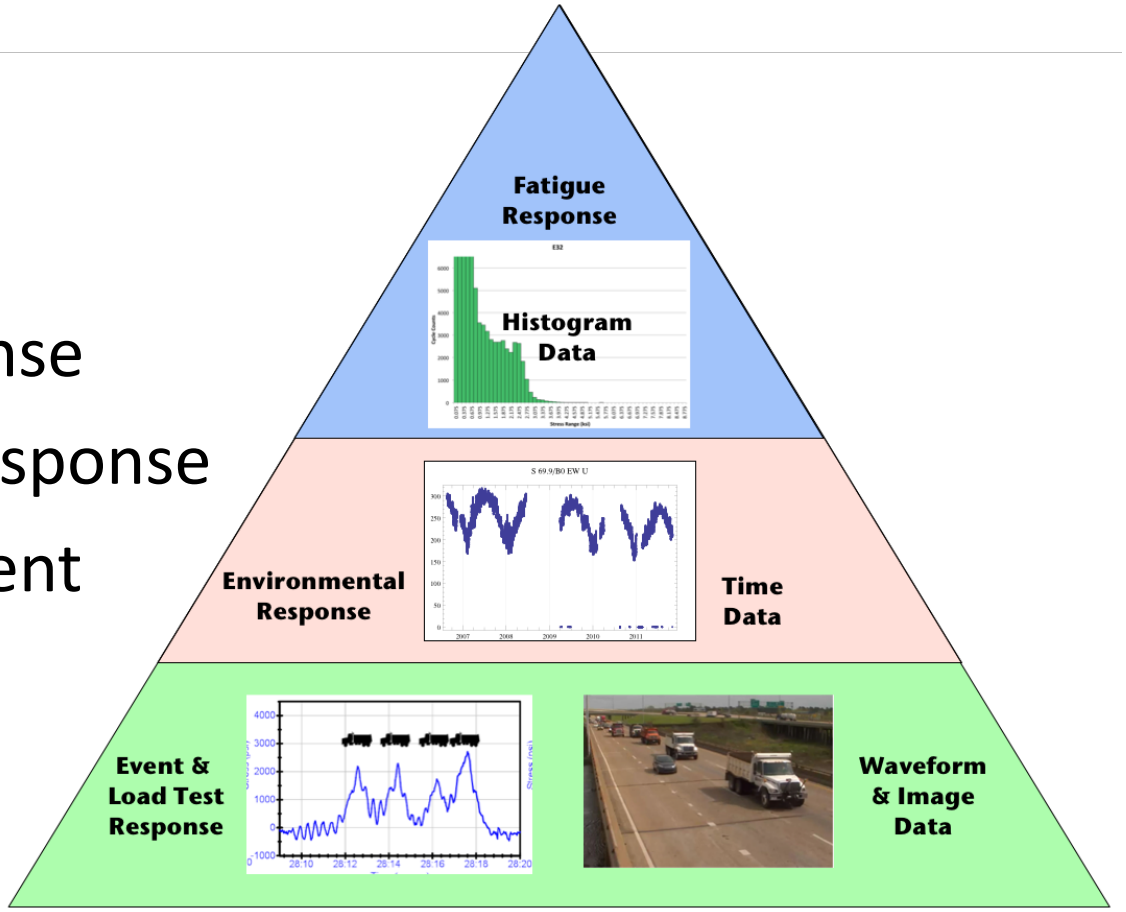
Project & System Website

- Project information
  - Location map, photos
- Instrumentation system manual
- Backend server guide
- Reference information
  - Gage durability, etc.
- User Analysis



Complete Package

- Performs core instrumentation elements
  - Waveform response
  - Environmental response
  - Rainflow with event triggering
  - Collect images of triggered events



Deliverables

- WSN strain node with on-board computational capabilities
- Add-on environmental enclosures for WSN nodes and programmable gateway
- Software developed for acquisition of strain histories and evaluation of data using rainflow counting
- Enterprise management system for cloud-based data archive and decision support

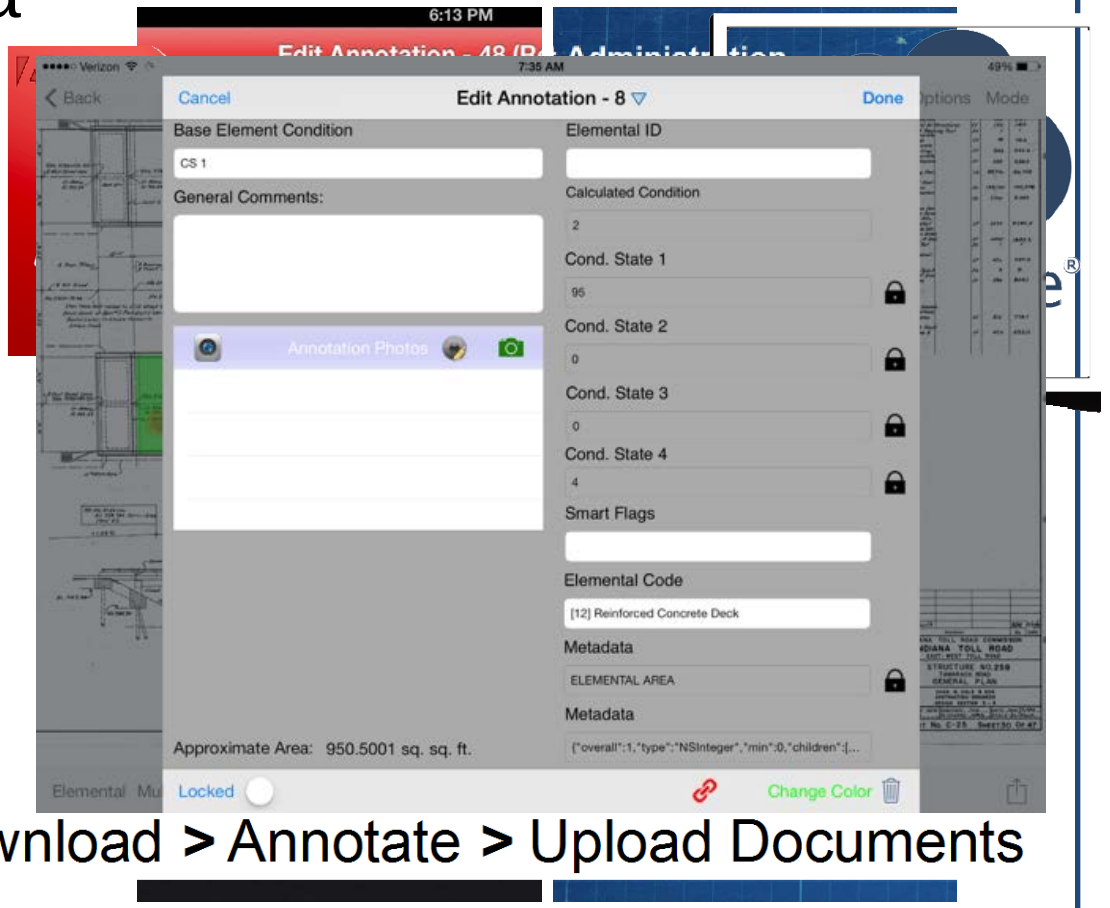
Questions?


2'

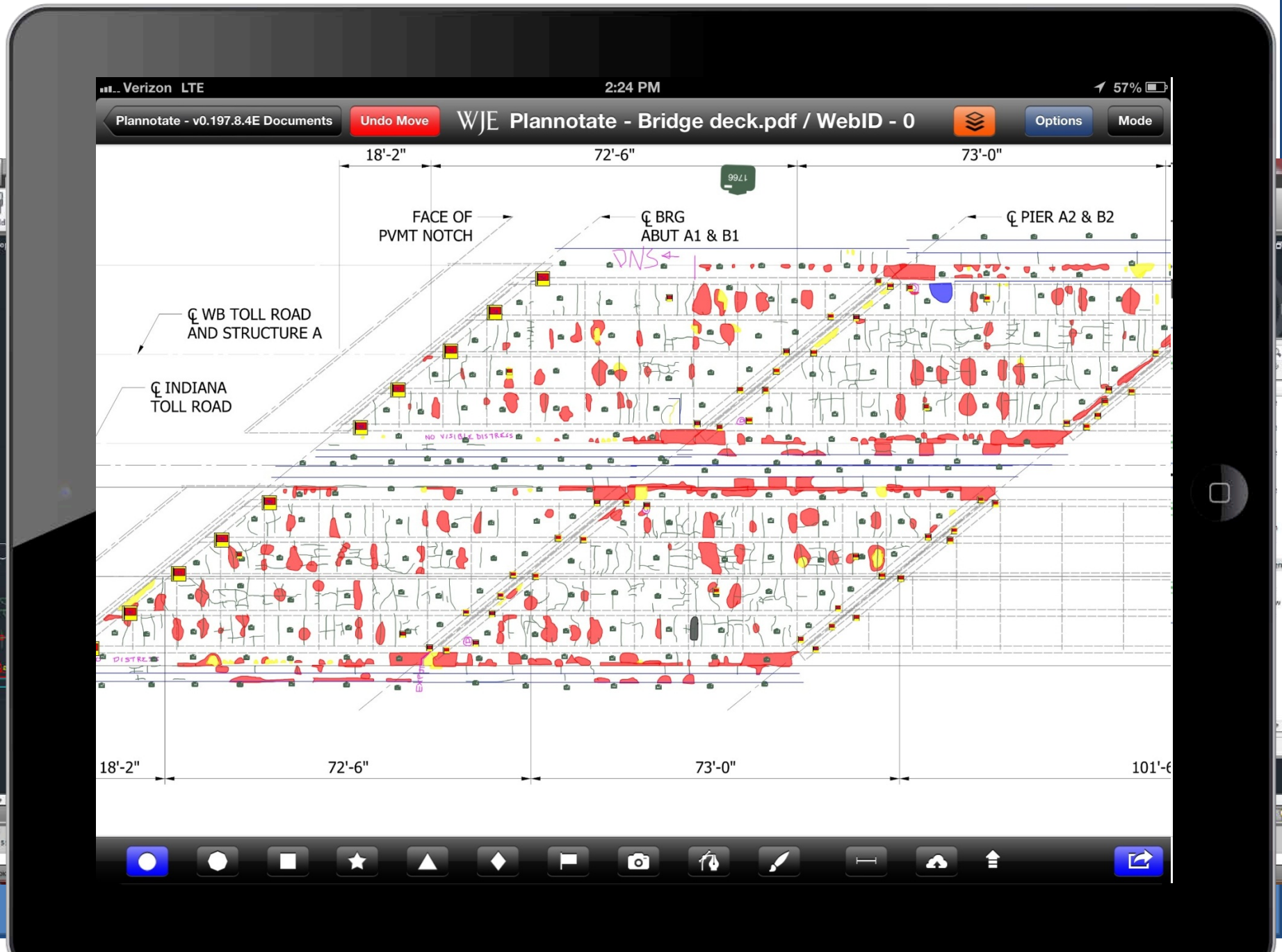
Data and Cloud

- Annotations = Data
  - Spatial
  - Form (customizable)
  - Photographs
  - Instrumentation
  - Object-oriented
- Cloud
  - Backup
  - Synchronization
  - Sharing
  - Administration

Forms Cloud



Download > Annotate > Upload Documents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Plannotate - v0.197.8.4E Documents
Undo Move
WJE Plannotate - Bridge deck.pdf / WebID - 0
Options
Mode
18'-2"
72'-6"
73'-0"
FACE OF
PVMT NOTCH
℄ BRG
ABUT A1 & B1
℄ PIER A2 & B2
℄ WB TOLL ROAD
AND STRUCTURE A
℄ INDIANA
TOLL ROAD
DNS
NO VISIBLE DISTRESS
18'-2"
72'-6"
73'-0"