Revised Procedures for FWD Calibration

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Cornell Local Roads Program

15th FWD User's Group Meeting
Helena, MT
September 18-19, 2006

Pooled fund study - participants

- California
- Colorado*
- FHWA
- Georgia
- Iowa
- Indiana*
- Kansas*
- Minnesota*
- Mississippi
- Montana
- North Dakota
- New Jersey
- New York
- Pennsylvania*
- South Carolina
- South Dakota
- Texas*
- Washington

Thanks for your support !

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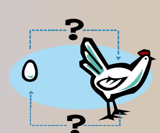
Chickens and eggs



- Hardware improvements
- Software improvements
- Procedural improvements

They are interrelated, and one begets the other …

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Progress to date

- Re-established a working SHRP FWD calibration center at Cornell
- Selected a 16-bit data acquisition board
- Selected a low-noise, durable accelerometer as the reference sensor
  - → Replaces the LVDT in the SHRP procedure
- Conducted proof-of-concept tests for use of accelerometer

⇒October 2005

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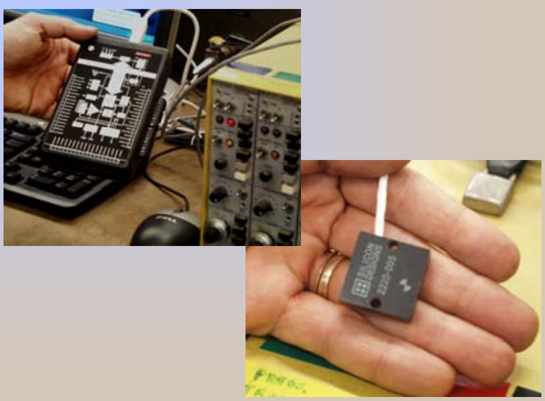

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Progress to date

- Developed a database of calibration results according to the SHRP procedure
  - → A standard of comparison for new procedures
- Converted the old DOS software (FWDREFCL) to Visual Basic 6
- Adapted the VB6 software to the new DAQ and accelerometer (WinFWDCal)
  - → Developed double integration method to convert acceleration to deflection

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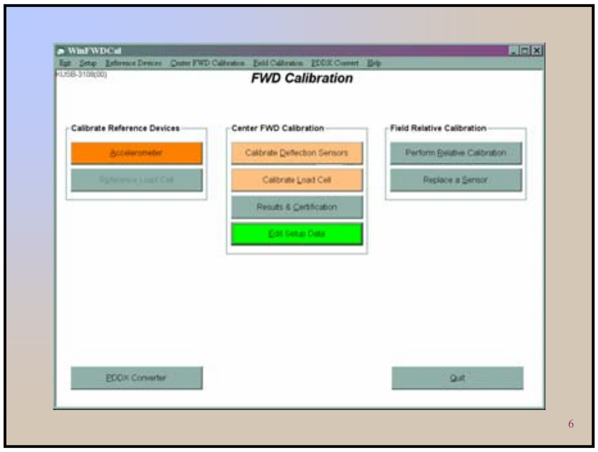
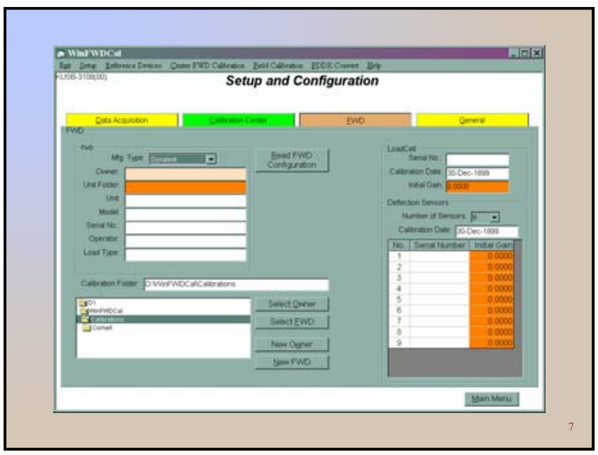
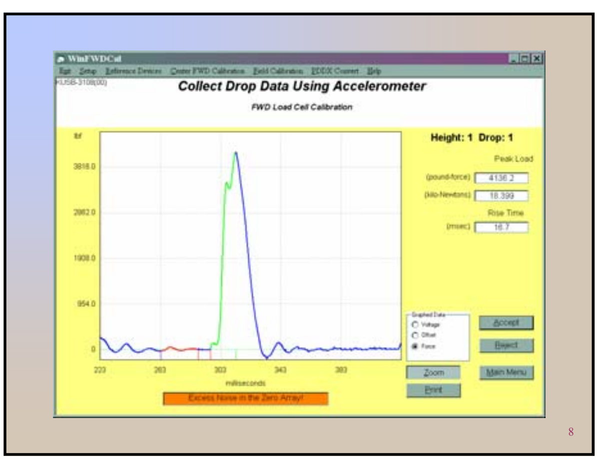

WinFWDCal
FWD Calibration
Calibrate Reference Devices
Center FWD Calibration
Field Relative Calibration
Accelerometer
Reference Load Cell
Calibrate Deflection Sensors
Calibrate Load Cell
Results & Certification
Edit Setup Data
Perform Relative Calibration
Replace a Sensor
PDDX Converter
Quit
6


WinFWDCal
Setup and Configuration
Data Acquisition
Calibration Center
FWD
General
Read FWD Configuration
Select Owner
Select FWD
New Owner
New FWD
Main Menu
7


WinFWDCal
Collect Drop Data Using Accelerometer
FWD Load Cell Calibration
Height: 1 Drop: 1
Peak Load
4136.2
18.399
Rise Time
16.7
Accept
Reject
Zoom
Main Menu
Print
milliseconds
Excess Noise in the Zero Array!
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Progress to date

- Developed a new software tool to convert FWD native output to PDDX file format
  - Reads JILS, KUAB, Carl Bro and Dynatest files
  - Allows data exchange between the FWD computer and the calibration computer
- Designed and evaluated multi-sensor stands to merge reference and relative calibration
  - One for geophones and another for seismometers
  - Goal is to have position in the stand NOT be significant

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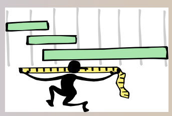
Progress to date



- Evaluated the new procedures, hardware and software with each brand of FWD
  - Dynatest, KUAB, JILS and Carl Bro
  - Conducted tests in Harrisburg, PA (twice), Denver, CO and College Station, TX
  - 3 Dynatest FWDs, 1 JILS FWD and 1 Carl Bro FWD
  - Results were very satisfactory

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Carl Bro FWD
College Station, TX

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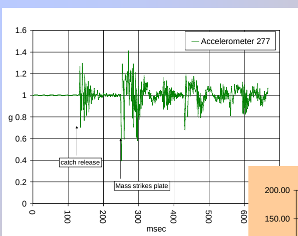
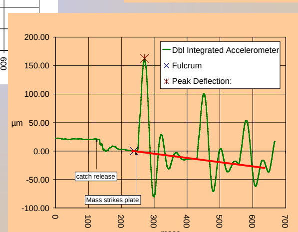


Raw data – JILS FWD acceleration vs time

Processed data – displacement vs time



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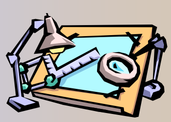
Current activities



- Making final refinements of hardware design
  - Plans/specifications for procurement
- Making final refinements of software
  - WinFWDCal
  - PDDX file converter
- Ordering parts for distribution to the four LTPP Calibration Centers

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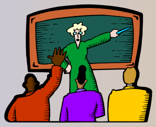
Remaining work



- Secure approval from COTR
- Distribute new equipment and software, and train the center operators

⇒Planned for mid-October

- Submit final report (by early December)

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Three types of measurement errors

- Seating errors
  - Occur only in field usage of the FWD
  - Reduced by doing several unrecorded drops
- Random errors (repeatability)
  - Reduced by averaging several replicate drops
- Systematic error (bias – not random)
  - Reduced by performing "SHRP" calibration
  - This is what we are working on in TPF-5(039)

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Typical FWD specification

"Deflections shall be accurate to ±2 percent or ±2 microns, whichever is larger."

- The ±2 micron error is a random error, independent of the magnitude of the deflection
- The ±2 *percent* error is a systematic (non-random) error
- Whenever the deflection is 100 microns (4 mils) or larger, the systematic error would be larger than the random error

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Project goal: Systematic error < ±0.3%

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Reason

- If the systematic error is ±0.3 percent, and the random error is ±2μ (±0.08 mils), then the random error will be larger than the systematic error for all deflections up to 650μ (26 mils)
  - 2 ÷ 0.003 ≈ 650
  - Pavement deflections are not commonly greater than 26 mils, even at the center deflection

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Observations

- A large pavement deflection is helpful for detecting and correcting the systematic error
- When calibrating deflection sensors we would like to have a deflection around 500 microns (20 mils) on the test pad

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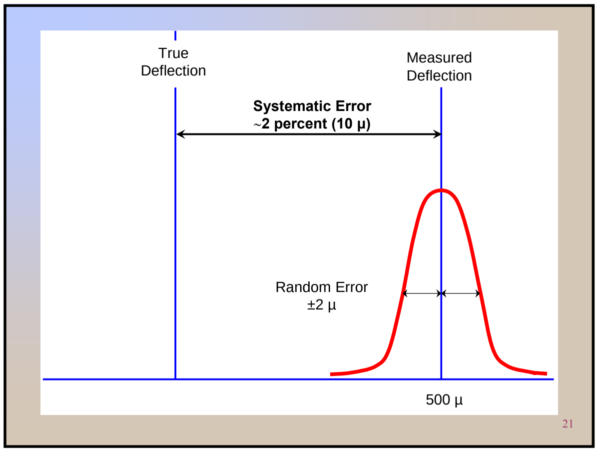

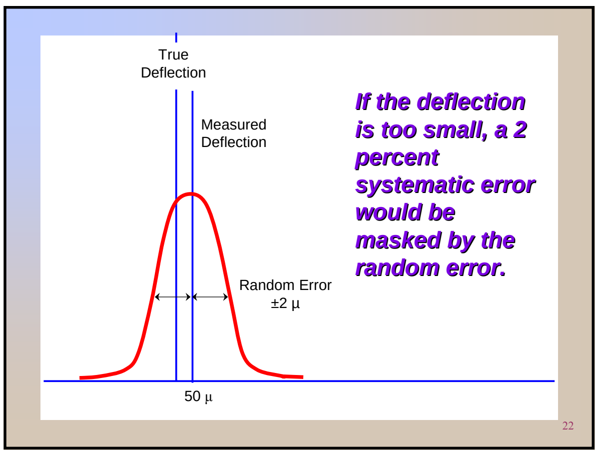

Conclusions

- Continue to use a test pad that yields a 500±100 micron (20±4 mil) deflection at a 16,000 lb load and a 20-inch offset.
- Continue to remove the deflection sensors from their holders.
  - Allows inspection and cleaning of sensors and cables
- Continue to use the custom load cell.

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Recommended test pad:
5" fiber-reinforced concrete
6" crushed stone base
5' CBR 5 subgrade – membrane wrapped

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No major changes planned for load calibration

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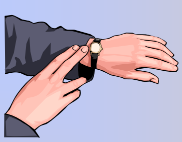

When everything goes well, the current SHRP procedure takes about six hours to complete …

When things do not go well, it usually is due to maintenance problems with the FWD …

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SHRP Reference Calibration – one sensor at a time

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SHRP Relative Calibration – rotation of sensors takes time

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Ways to speed up the process

- Conduct reference calibration on all deflection sensors at the same time
  - Go to multisensor calibration stand
- Eliminate the manual entry of FWD data in the calibration computer
  - Go to electronic transfer of data via PDDX
- Eliminate or reduce rotation of sensors in the relative calibration procedure
  - Position in the stand must not be significant

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Accomplishment - speed

- So far we have got the procedure routinely under three hours
- May be possible to get it close to two hours

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Problems with existing stands

- Position in the stand was highly significant
  - Stand was too flexible
- Similar findings for stands from Dynatest, Carl Bro and KUAB
- Decided to design a stiffer stand
  - To accommodate several types of deflection sensors

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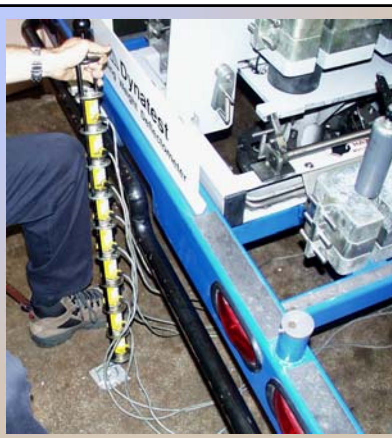

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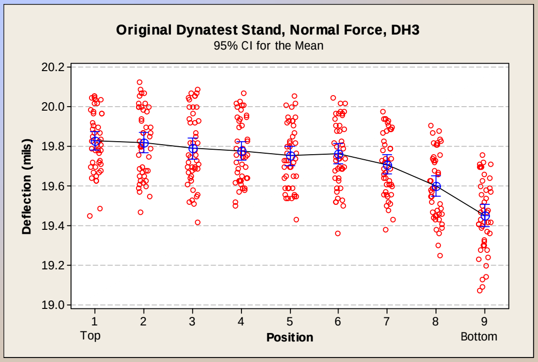

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Prototype Calibration Stands

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Ball Joint Base ***Direct Anchor Base***

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Large Channel Stand

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Ladder Stand

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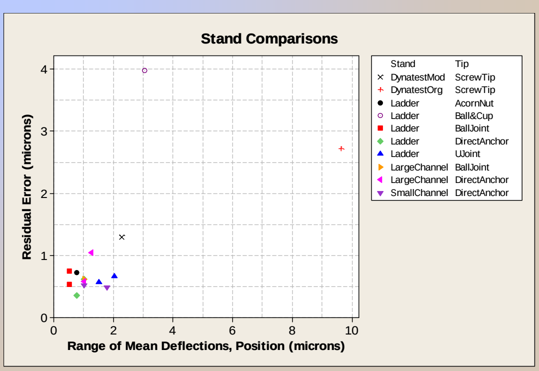

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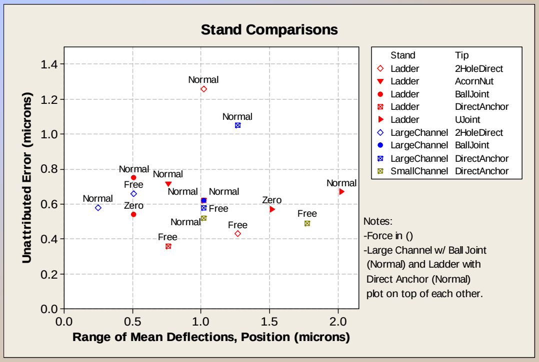

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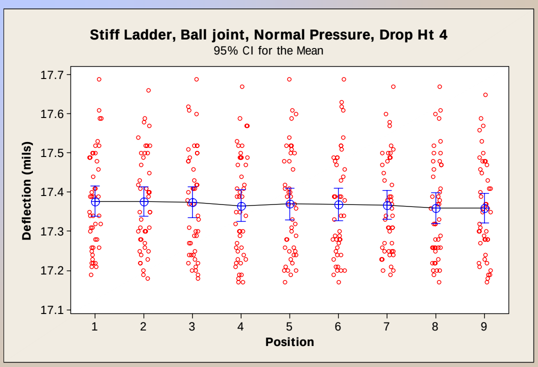

Full rotation of sensors

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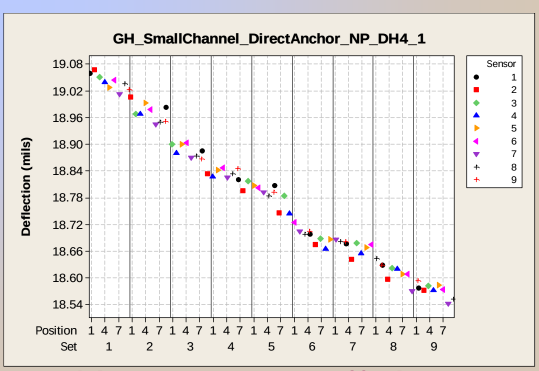

Each data point represents average of five drops per set

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Proof of concept
KUAB stand
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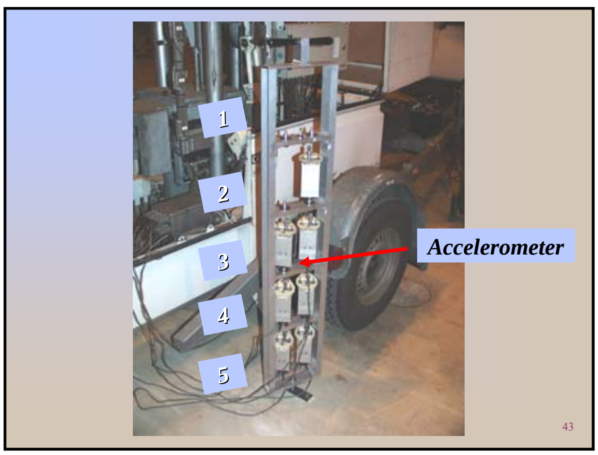
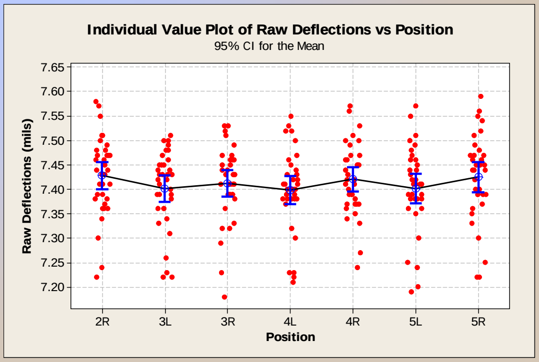

1
2
3
4
5
Accelerometer
43


SILICON DESIGNS
2220-005
00277
44



Full rotation of sensors

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Analysis of Variance (KUAB stand)

Source	N	MSE	F	p*
Shelf	4	.00131	0.25	86.1%
Column	2	.01701	3.24	7.3%
Set	7	.02691	5.12	0.0%
Sensor	7	.00004	0.01	100%
Error	225	.00525		
Total	245			

Unattributed error = 0.072 mils (1.84 microns)

**** p = probability that the observed MSE is random.***

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Conclusions - KUAB stand

- Shelf level did not matter very much
  - 0.92 micron is barely "significant"
  - "flip" sensors top-to-bottom to eliminate
- Column position mattered a lot more
  - Rotate the stand to interchange the columns
- Unattributed error about as expected
  - 1.84 microns

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Lessons learned – from proof of concept tests

- Accelerometer is an unbiased reference sensor, accurate to about 2-3 microns (random error)
  - Same as LVDT (including allowable beam movement)
  - Place at mid-height of stand
- Position in stand adds a small amount of bias (~0.5 micron or less)
  - Dynatest, JILS and Carl Bro – Rotate sensors top-to-bottom to cancel out the bias
  - KUAB – Rotate columns right-to-left and sensors top-to-bottom to cancel out the bias

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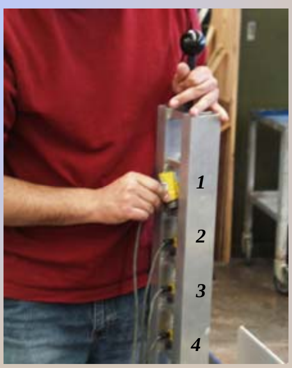

Sensor 1 to Position 9, Sensor 9 to Position 1, etc.

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Lessons learned

- Difficult to get 500µ deflections at present locations on test pad
  - Move test point closer to edge of slab
- Rotation in stand may not be necessary from a practical point of view, but doing so provides a higher level of confidence in the results

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Lessons learned

- Necessary to attach stand to test pad
- Ball-joint swivel preferred to direct anchor

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Tentative calibration protocol

(subject to change)

General …

- Load calibration procedure is unchanged
  - Increase calibration capacity to 24,000 pounds
  - Use about triggering
- Perform reference and relative calibrations
  - Use accelerometer in reference calibration
  - Calibrate accelerometer on day of use by measuring Earth gravity (+1g and -1g)
  - Use multisensor stand(s) for refcal and relcal
  - Transfer data from FWD to calibration computer electronically using thumb drive

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Reference calibration

- Perform 20 to 24 drops, using at least three load levels and an equal number of drops per load, achieving 500 ±100 microns at the highest load level
  - 3x7, 3x8, 4x5, 4x6 qualify
  - Use same sequence in load calibration
- Reverse sensors top to bottom in stand and repeat (KUAB: rotate columns left to right)
- Transfer data and process

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Relative calibration

- Perform 40 replicate drops in stand, achieving 500 ±100 micron deflections
  - Pause after 20 drops to give operator a break
- Reverse sensors top to bottom in stand and repeat (KUAB: rotate columns left to right)
- Transfer data and process

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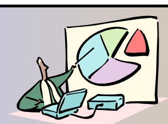
Data analysis



- Transfer data from FWD electronically
  - Use PDDX file format
- Compute interim gain factors from refcal
- Multiply interim gain factors times relcal data (in software – no entry in FWD)
- Compute relcal means ratios and final gain factors
- Transfer final gain factors to FWD computer

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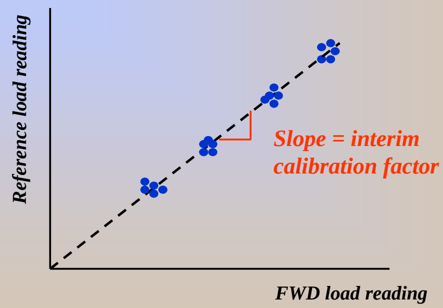
Reference calibration data



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Relative calibration data

$$\text{Means Ratio} = \frac{\text{Overall Average Deflection}}{\text{Individual Sensor Avg. Deflection}}$$

$$\text{Final Gain} = \text{Interim Cal Factor} \times \text{Means Ratio}$$

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Quality assurance

- Do not exceed 4 g's during refcal drops
- Compare final gain factors to previous calibration results for the FWD
  1. Accept results if factors have not changed more than 1 percent since last calibration
  2. Accept results if final gain factors fall between 0.98 and 1.02
  3. Results are acceptable if *either* criterion is met.

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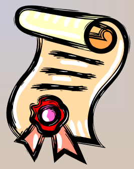
Quality assurance

- Issue certificate of calibration if all load and deflection sensors pass Criterion #1 or Criterion #2



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Calibration frequency

- Full calibration (all sensors) annually
- Relative calibration monthly
  - Assures detection of sensors going bad
  - Use of SLIC transform in field program may reduce the need for monthly relative calibration

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