Pooled Fund Study TPF-5(039)
FWD Calibration Center and Operational Improvements

Lynne H. Irwin
Cornell Local Roads Program

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Topics to be covered

- Objective and goals of this study
- Brief history of FWD calibration
- Project tasks
- Technical approach
- Timeline and status
- Technical issues/problems
- Technical questions for discussion

Project objective

To develop and implement long-term plans for FWD calibration centers, and to minimize the variability in pavement deflection data obtained with falling weight deflectometers

--- TPF-5(039) Website

Goals

1. Modify the existing calibration procedure to be compatible with all FWD equipment on the market and in use by state highway agencies (FWDs able to impart a load of at least 6000#).
   - Evaluate the feasibility of streamlining the calibration process without reducing the accuracy and precision of the results obtained.
   - Evaluate the feasibility of automatic data acquisition triggering and automated reference deflection system movement compensation without reducing the accuracy and precision of the calibration results obtained.

Goals

2. Upgrade calibration hardware and software to be compatible with operating systems and computers that are current at the time of delivery.
   - The new software shall work with both SI and U.S. Customary units.

Goals

3. Produce an upgraded and tested calibration system for use in the existing LTPP FWD Calibration Centers and non-LTPP calibration centers, and provide accompanying documentation and training to calibration center operators.

--- RFP DTFH61-04-R-00020

Development of the current methods

- 1988 – Strategic Highway Research Program initial FWD calibration efforts in Indiana
- 1989 – SHRP decides to establish four calibration centers
- 1991 – 1992 Regional Centers are established
- 1993 – 2005
  - Operational
  - Occasional refinements
  - Periodic meetings of calibration center operators

FWD calibration centers

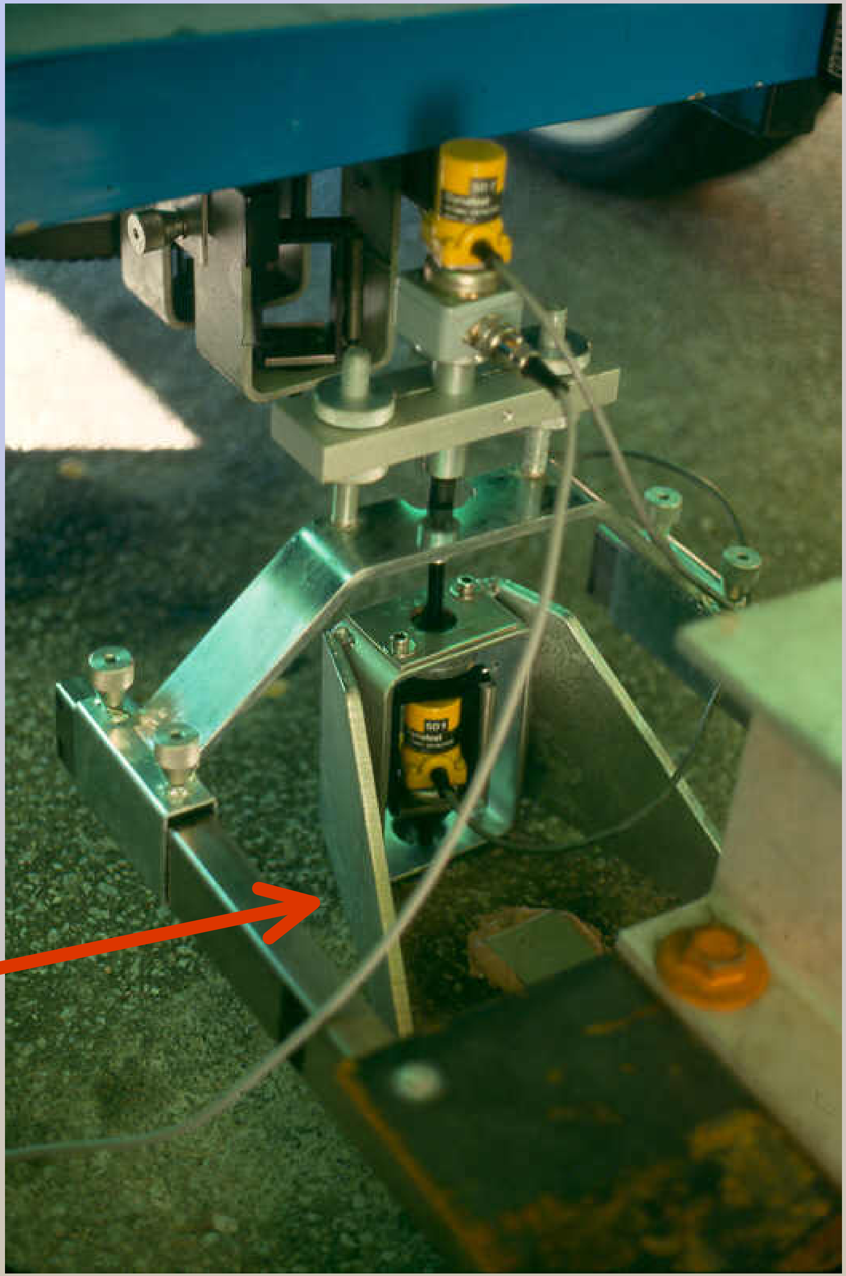
Center	Opened
SHRP North Central Region (Minnesota)	1991
SHRP Western Region (Nevada, now in Colorado)	1991/2003
SHRP Southern Region (Texas)	1992
SHRP North Atlantic Region (Pennsylvania)	1992
Dynatest, Florida	1992
South Africa	1996
ARRB	1996
Kansas	1997
Indiana	1997
Western Australia	2002


Perth, Western Australia 2002

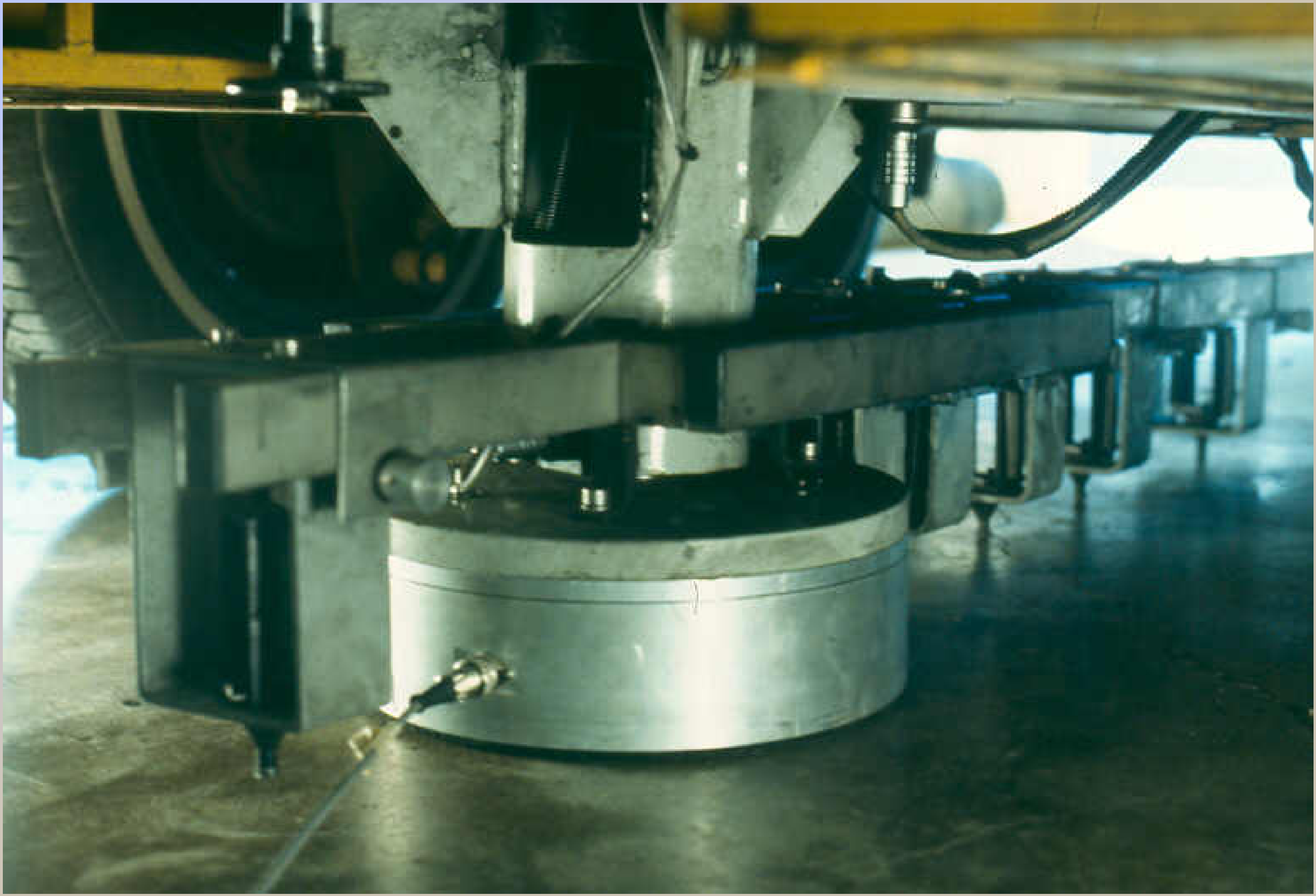
Indiana Department of Highways - 1988

Indiana - November & December 1988


Reference
Calibration
1988



The "snowplow"




Dynatest 8000
60035
Relative Calibration 1988

1988 - SHRP's Four FWDs

Typical FWD specification (1988)

"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 error
- Whenever the deflection is 100 microns (4 mils) or larger, the systematic error would be larger than the random error

SHRP's Objectives

- To assure that comparable measurements would be obtained by SHRP-owned and state-owned FWDs
  - Required knowledge of error sources
  - Intended to work with all types of FWDs
- To try to create an environment during calibration as close as possible to field conditions
  - Use a ground wave from the FWD
  - Improve on the accuracy of the measured deflections beyond the manufacturers' specifications

Carl Bro FWD

Have successfully calibrated all types

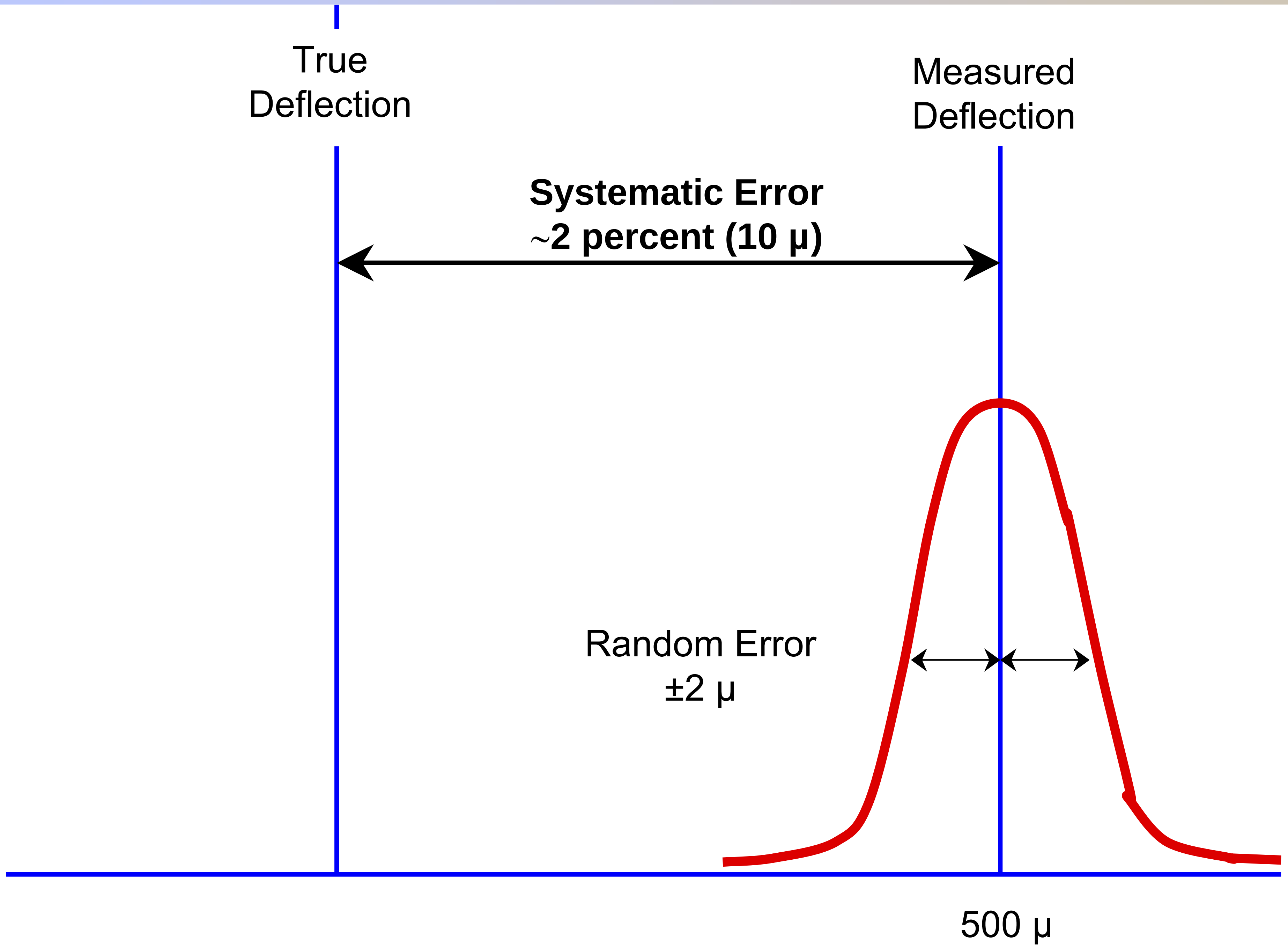
Three types of measurement errors

- Seating errors
  - Reduced by doing several unrecorded drops
- Random errors (repeatability)
  - Reduced by averaging several replicate drops
- Systematic error (bias)
  - Reduced by performing calibration

Corollary objective

- Try to improve on the overall accuracy of the FWD measurements
  - Reduce the 2% systematic error
  - It had been found that deflection errors of only a couple of microns had a profound effect on back-calculated layer moduli

Goal: < 0.3%
Systematic Error

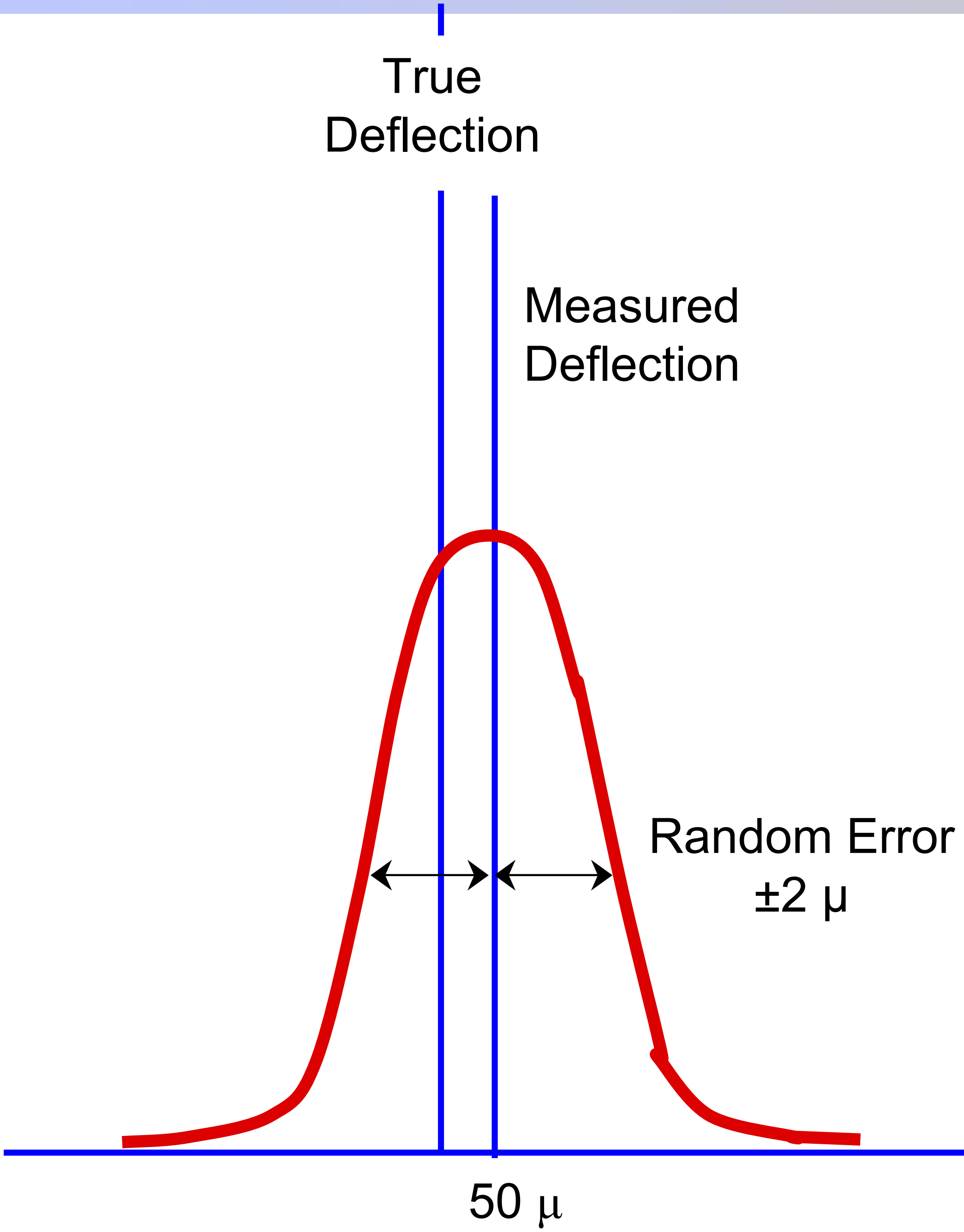

True
Deflection
Measured
Deflection
Systematic Error
~2 percent (10 μ)
Random Error
±2 μ
500 μ

If the systematic error is less than 0.3 percent, and the random error is ±2 μ, then the random error will be larger than the systematic error for all deflections up to 600 μ.

Pavement deflections are not commonly greater than 600 μ.

FWD Deflection Basin

Be concerned about the size of the deflections!



If the deflection is too small, a 2 percent systematic error would be masked by the random error.

- It was necessary to design a test pad that would have a 400 - 600 micron deflection for a 16,000 lb. load at a 20-inch offset from the FWD load plate.
- It is necessary to remove the deflection sensors from their holders.

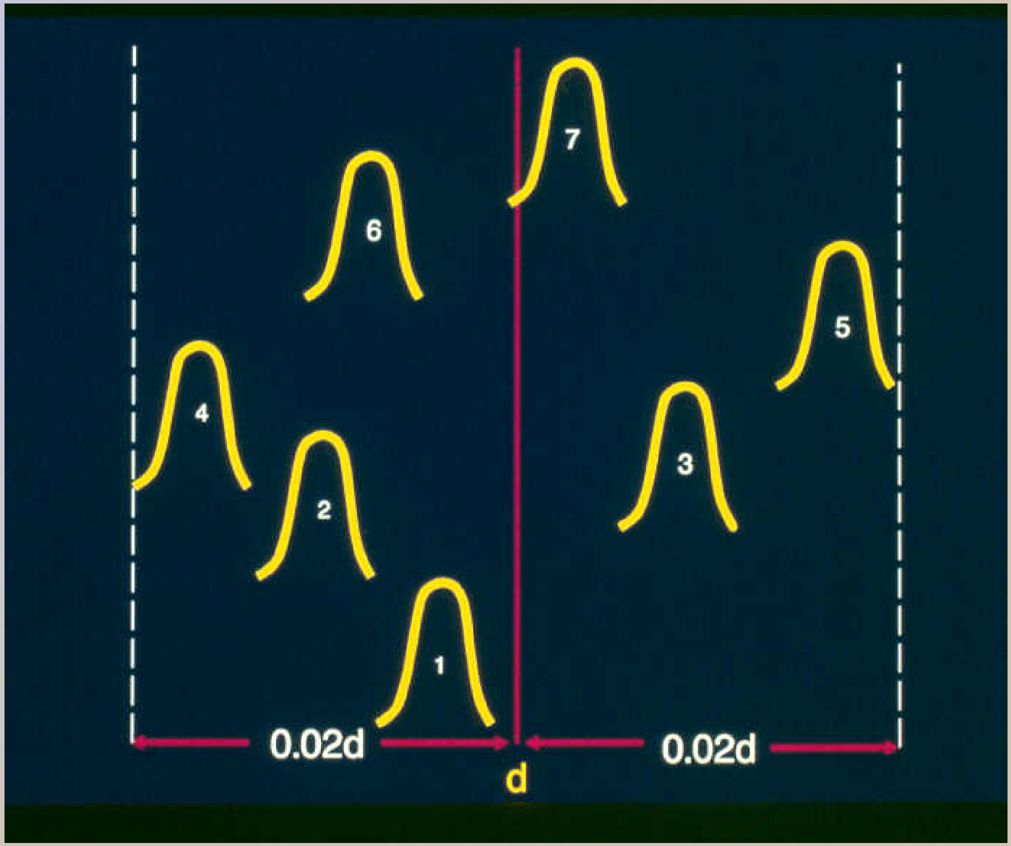

5" fiber-reinforced concrete
6" crushed stone base
5' CBR 5 subgrade

Two step process

1. Reference calibration
   - Compare to a reference load or deflection device
   - Obtain an unbiased set of deflection sensors
2. Relative calibration
   - Compare sensors to each other
   - Only used with deflection sensors
   - Statistical approach

Concept – deflection calibration

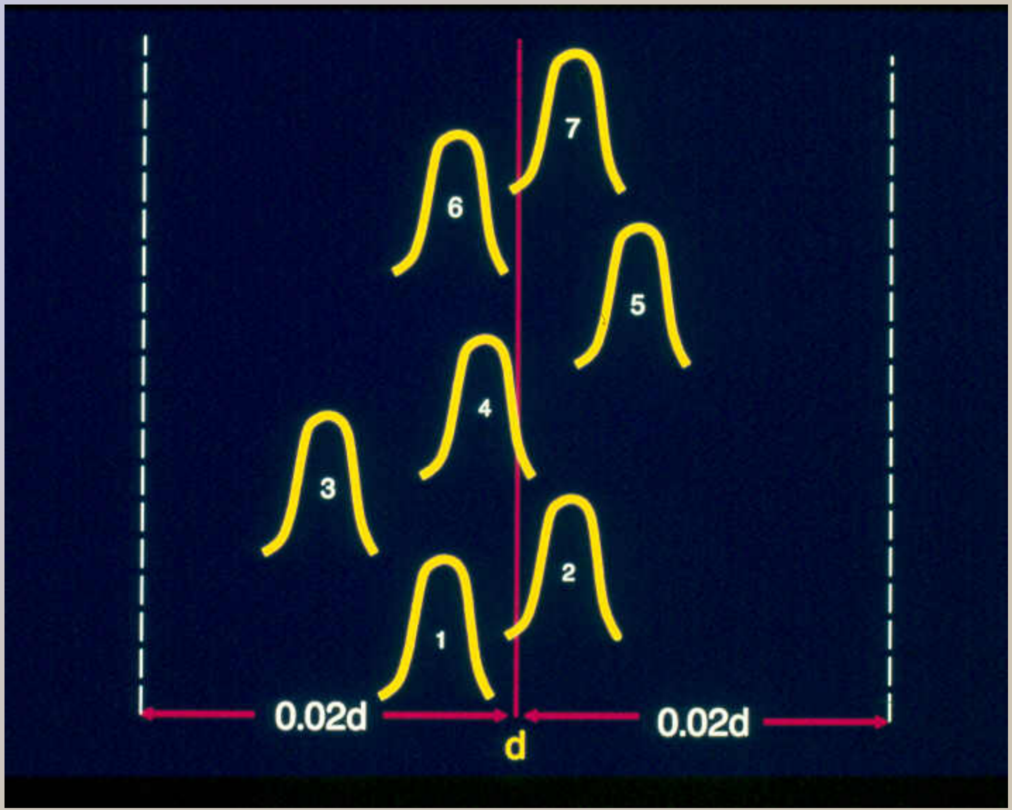
- ***Reference*** calibration assures that each sensor is randomly positioned about the accurate reading (i.e., "truth")
- Method is only intended to make the sensors unbiased



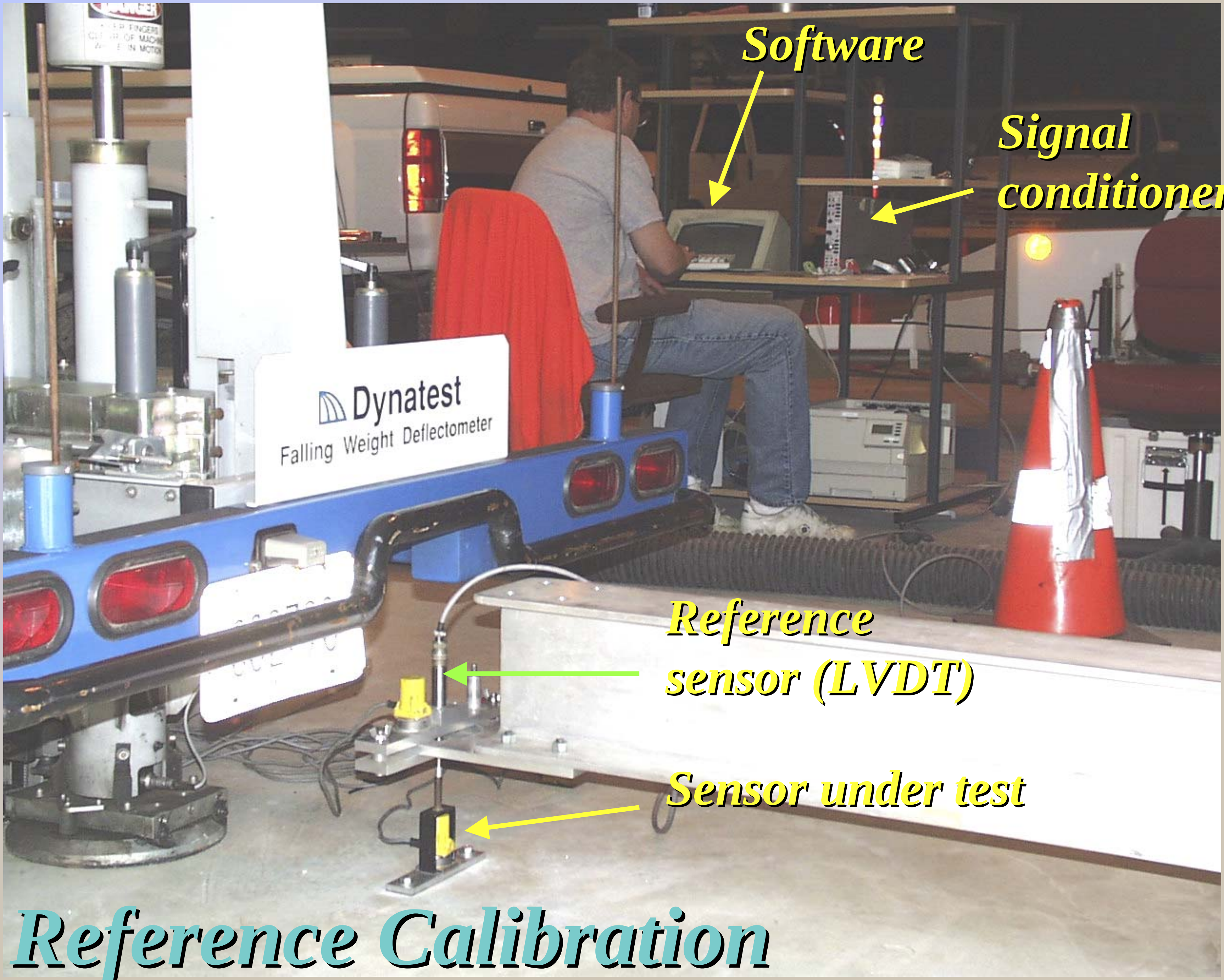
Before reference calibration

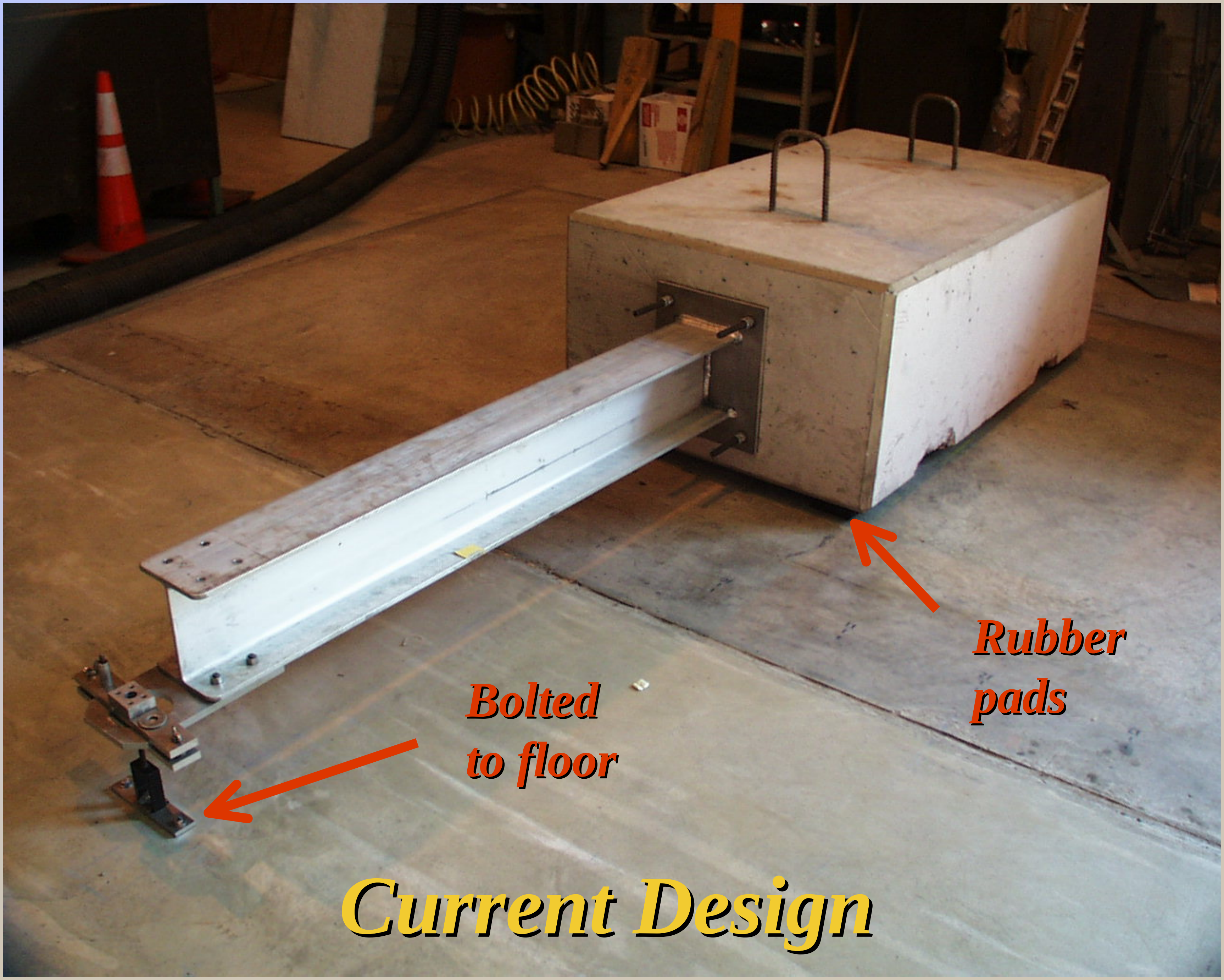
Concept – deflection calibration

- ***Relative*** calibration produces a large set of data that can be evaluated statistically using ANOVA
- Since each individual sensor is random about truth, the overall average is a good estimate of truth



After relative calibration


Software
Signal conditioner
Dynatest
Falling Weight Deflectometer
Reference sensor (LVDT)
Sensor under test
Reference Calibration



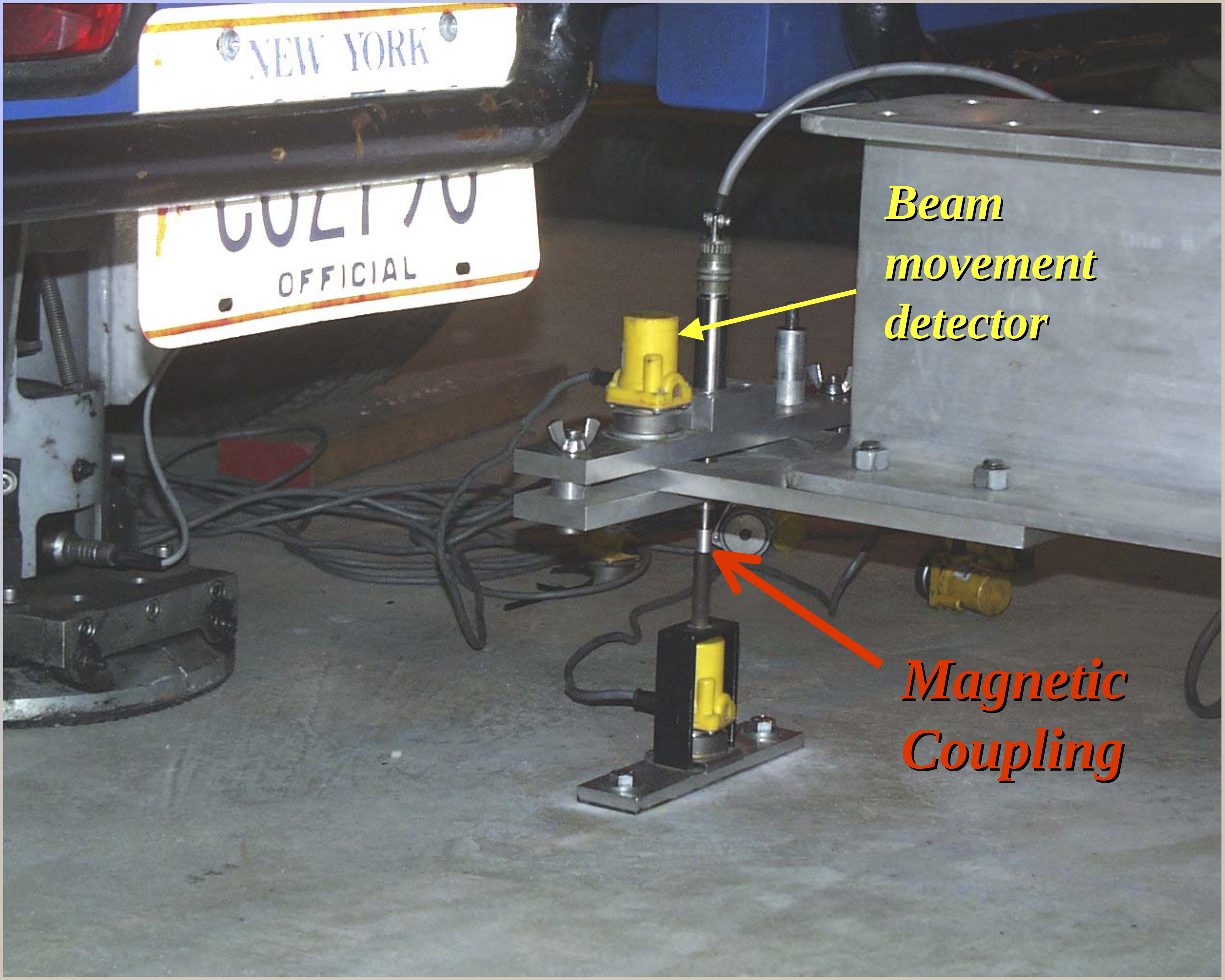
Rubber
pads
Bolted
to floor
Current Design


Sensor holders

Vibration absorbing rubber pads

Calibrating the LVDT

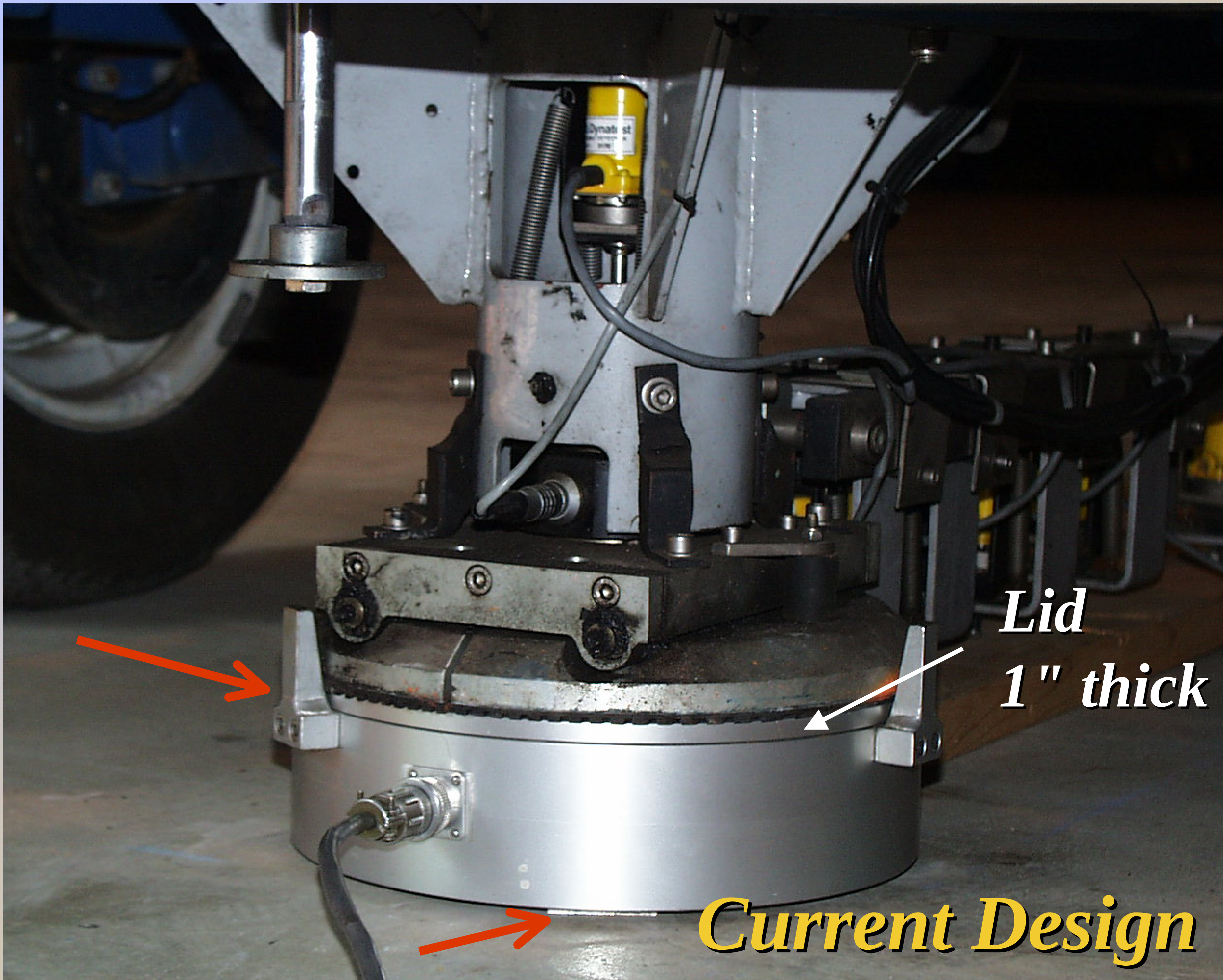
Zeroing the LVDT


NEW YORK
OFFICIAL
Beam movement detector
Magnetic Coupling

Reference calibration factor

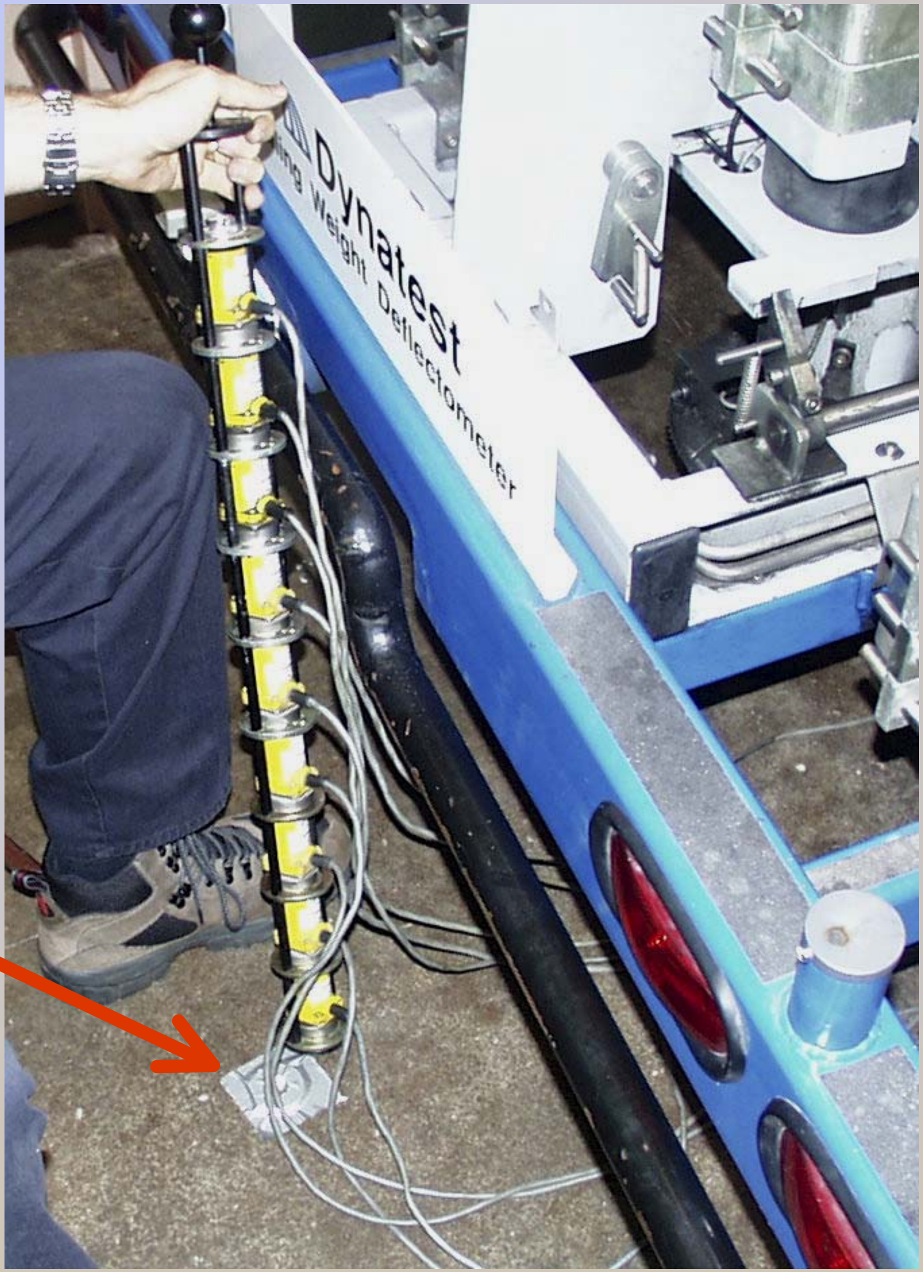
$$\text{Refcal Factor} = \frac{\text{Reference Deflection}}{\text{FWD Sensor Deflection}}$$


Load
Calibration


Lid
1" thick
Current Design

Relative Calibration

Current Design



Washer on floor

Relative calibration factor

$$\text{Relcal Factor} = \frac{\text{Overall Average Deflection}}{\text{Individual Sensor Avg. Deflection}}$$

Proof of concept

- Comparative testing with multiple, calibrated FWDs (*"**thump-offs**"*)
- Replicate calibrations of the same FWD
- Round-robin testing


Indiana Thump-Off 1988

Thump-Off results

- Three thump-offs, conducted with the four SHRP FWDs in 1988 and 1991, were not definitive when ANOVA was used to analyze the data
- Apparent reason: repeated FWD testing on the same point changes the stiffness
- *Cannot distinguish a* ***difference between FWDs*** *from a* ***change in materials stiffness with repeated loading***

Thump-Off practicality

- Today there are about 225 FWDs in the United States
- It would be extremely cumbersome to conduct comparative testing of all our FWDs at the same location by means of a thump-off

Replicate testing results

- Multiple calibrations carried out on the same sensor indicated a repeatability (of the calibration factor) of better than 0.3 percent
- This was so for both load and deflection calibrations

Round-robin test results 1992

Data for #1 Geophone

	FWD #058 Northeast	FWD #059 Southern	FWD #060 North Central	FWD #061 Western
Texas Jan. 1992	1.014	1.012	1.016	1.009
Nevada Jan. 1992	1.013	1.012	1.019	1.009
Penna. April 1992	1.012	1.016	0.999*	---
Minnesota May 1992	1.012	1.013	1.013	1.005

* Reference calibration only.   No relative calibration.

Conclusions

- Goal of ±0.3 percent accuracy after calibration was achieved
- Goal of applicability to all types of FWDs was met
- It has not been possible to ***prove*** that you get comparable results at the same site from several different FWDs by using thump-offs
- Procedure is very easy to use …

Dynatest Calibration Center 1998

Back to the present

- FWDREFCL is a DOS program
- Computers no longer have ISA bus
- DAS-16 data acquisition card no longer manufactured
- Many improvements in technology have occurred since 1992
- Hardware and software require updating to continue to calibrate FWDs

Pooled-fund study tasks

TASK 1 - Communication, coordination and reference resources

a. Gather software source code and FWD calibration protocol.
b. Gather equipment specifications and suggestions from the FWD manufacturers.
   Seek input from the calibration center operators.

Pooled-fund study tasks

TASK 2 – Modify calibration process

a. Streamline the process. Expedite.
b. Improve detection of the release of the mass (triggering).
c. Measure or compensate for movement of the inertial mass in reference calibration (beam movement).

TASK 2 requirements *(from RFP)*

- Concurrent reference calibration of up to 12 FWD deflection sensors
- Simultaneous reference and relative calibration of up to 12 FWD deflection sensors (to eliminate the need for relative calibration as a separate step)
- Automatic data acquisition triggering

TASK 2 requirements

- The ability to conduct concurrent, or separate reference calibration of the FWD deflection sensors and FWD load cell
- Automatic compensation for movement in the reference deflection system, or replacement of the reference deflection system

TASK 2 requirements

- Confirm and demonstrate to the COTR that the streamlined calibration procedure meets or exceeds the accuracy precision requirements of the current protocol and repeatability achieved with the current calibration procedure

Pooled-fund study tasks

TASK 3 – Hardware and software upgrades and/or development

a. Rewrite source code to be compatible with a Windows environment.

   Revise source code to accommodate process modifications from Task 2.

b. Purchase and configure hardware to equip four regional FWD calibration centers.

   Demonstrate to COTR that upgrades meet the project requirements.

TASK 3 requirements *(from RFP)*

- a graphical user interface (GUI)
- ability to document pre-calibration maintenance and troubleshooting activities
- ability to detect, notify and monitor any movement of the reference-deflection-sensor-system in real time
- ability to record and display history of calibration factors for sensors from FWD units

TASK 3 requirements

- ability to automatically compensate for the effects of this movement to peak deflections as described by the process modification in task 2, if applicable
- the calibration output file shall serve as a calibration report; and be readable by spreadsheet applications
- wireless data transfer capability

Pooled-fund study tasks

TASK 4 – Calibration System Testing, Installation, Operator Materials/Training

a. Test the modified process and equipment to demonstrate that it expedites the procedure and maintains accuracy.

b. Document the revised process and prepare a manual for calibration center operators.

c. Install equipment and train operators.

Pooled-fund study tasks

TASK 5 – Presentation and Reporting

- Coordinate travel and arrangements for TAC meetings.
- Make a presentation at the Annual FWD Users Group Meeting

Pooled-fund study tasks

TASK 6 – Miscellaneous Support

Perform work under Task Orders on an as needed basis.

Work to be carried out during Option Years 3, 4, and 5.

Possible TASK 6 Options ***(from RFP)***

1. Coordinate travel and meeting arrangements for the Technical Advisory Panel (TAP)
2. Technical Support for calibration centers
3. Design and modification of equipment, software, facility or calibration process
4. Equipment and software purchase and installation

Possible TASK 6 Options

5. Training and training materials for calibration center personnel
6. Preparation of guidelines and protocols related to equipment calibration
7. Data processing and analysis
8. Produce marketing materials

Possible TASK 6 Options

9. Investigate/make recommendations/implement a mechanism to make certifications of calibration center reference equipment traceable to the National Institute of Standards and Technology (NIST), or similar entity

Technical Approach

- Communicate with all FWD manufacturers
- Communicate with all calibration centers
- Outreach to European FWD calibration agencies
- Observe the calibration of a JILS FWD
- Observe the calibration of a Carl Bro FWD
- Obtain a complete set of manufacturer's specifications for all types of FWDs

Technical Approach

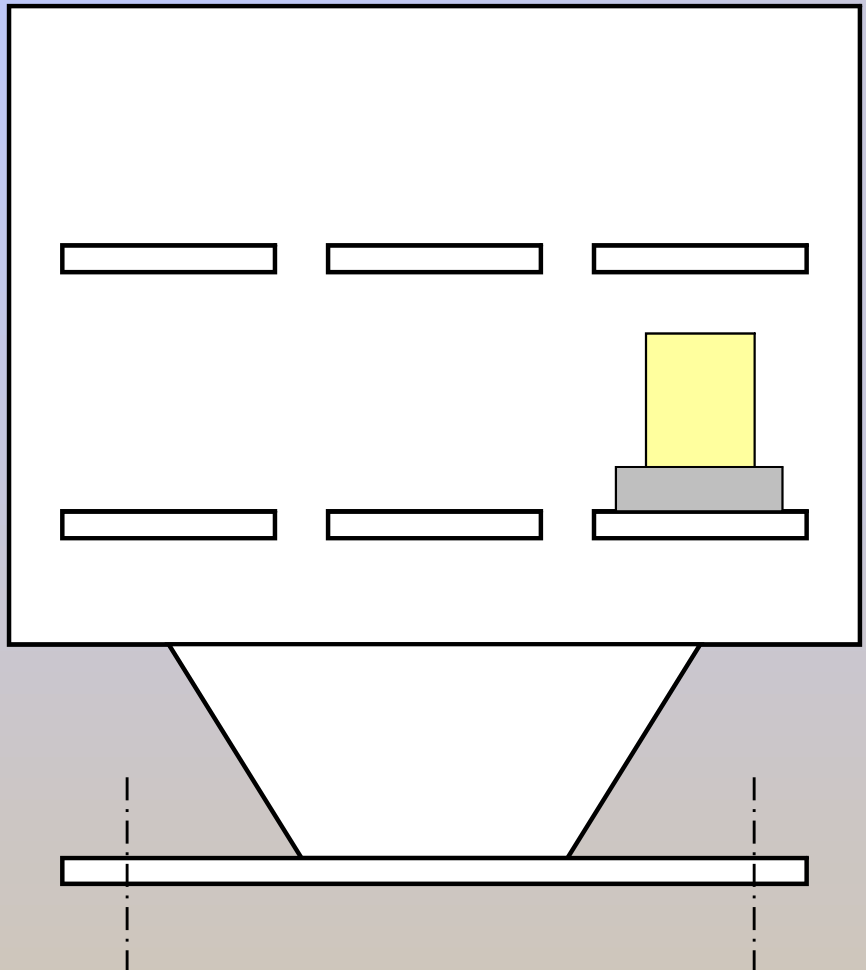
- Combine TASK 2 & TASK 3 and pursue them simultaneously
- Re-establish the SHRP calibration center in our laboratory at Cornell
- Select a data acquisition board and programming language
- Convert existing FWDREFCL program to Windows environment

Technical Approach

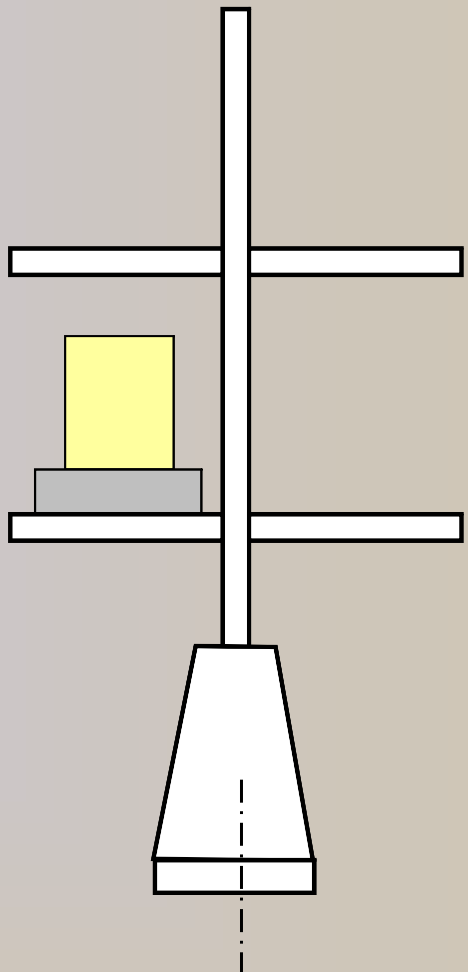
- Seriously explore the possible use of an accelerometer to replace the LVDT as the reference deflection device
  - Could eliminate need for the concrete block and beam
  - Highly portable approach
  - May be difficult to achieve accuracy as good as we have now

Technical Approach

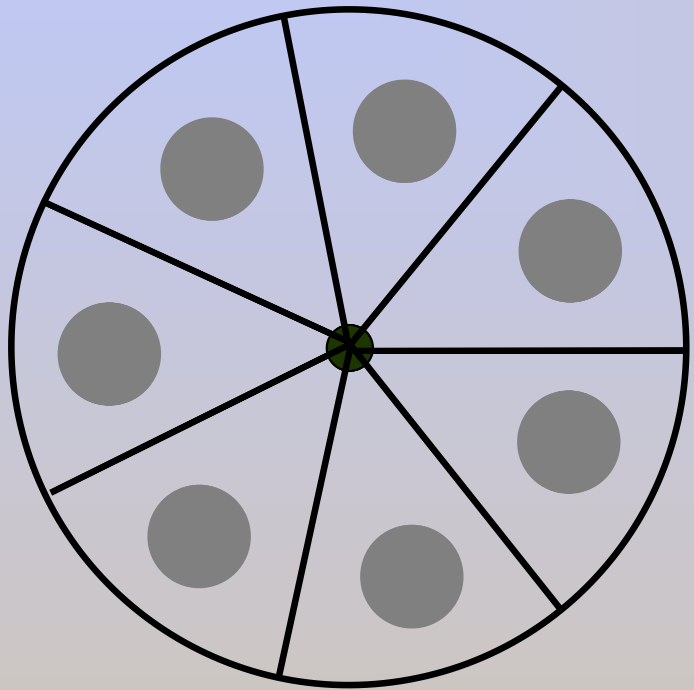
- Develop procedure that will allow simultaneous calibration of up to 12 deflection sensors
- Correct for beam movement (if needed)
- Investigate whether reference calibration and relative calibration can be combined into one procedure
- Investigate whether load calibration can be done at the same time



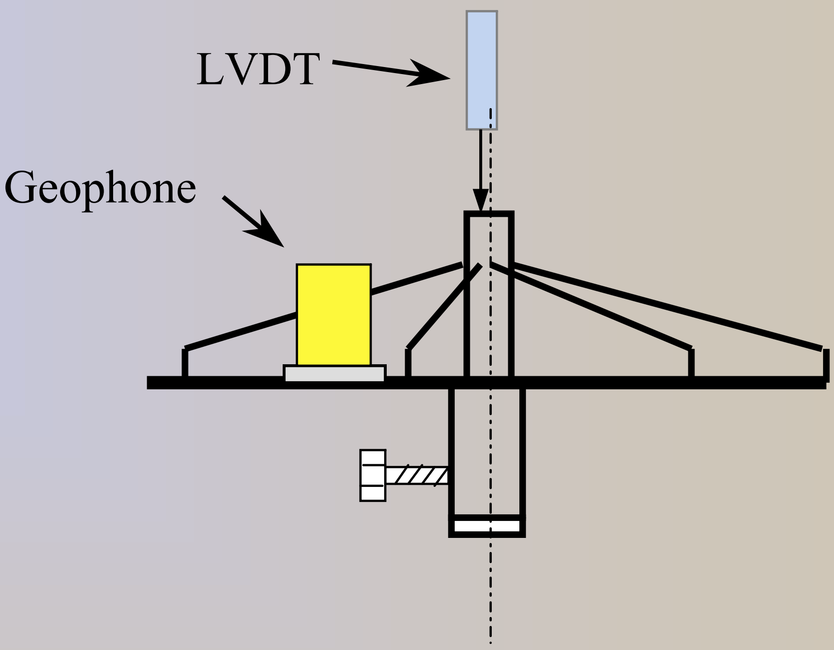
Front View



Side View



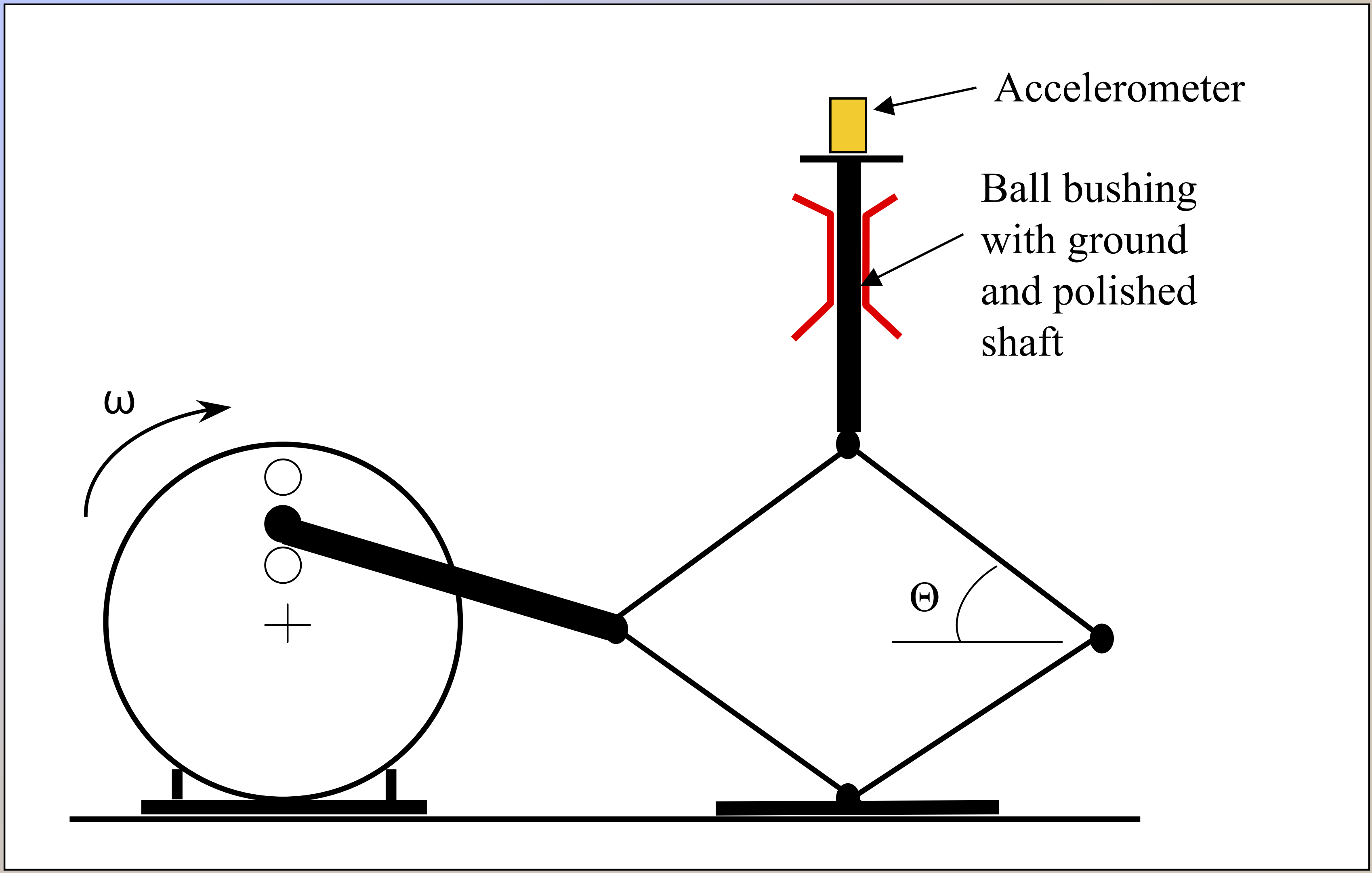
Top View



Side View

Technical Approach

- Investigate whether to use a sensor to detect the release of the mass or use a software buffer to sense the release
- Develop an accelerometer calibrator and supporting software (if needed)



Accelerometer Calibrator

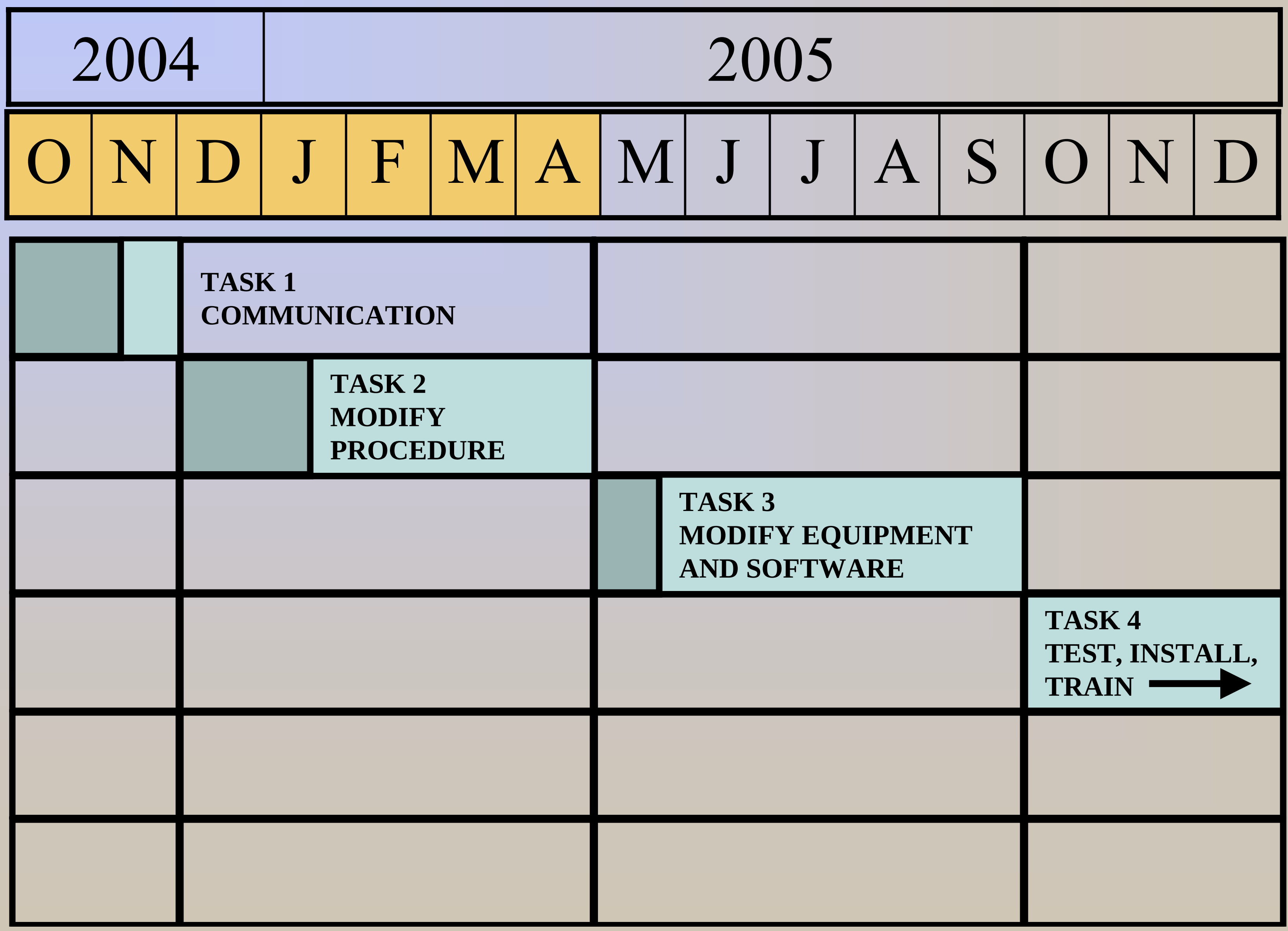
Technical Approach

- Engineer first, then experiment
- Conduct all investigations using valid statistically-based experimental design
- Demonstrate revised procedures and equipment by calibrating all four major types of FWDs

Project status ***(April 1, 2005)***

Task	Percent Complete
1	70
2	30
3	15
4	0
5	0
6	Not in contract

Schedule *(from RFP)*



Schedule

2006									07	08	09
J	F	M	A	M	J	J	A	S			
TASK 4											
	TASK 5 PRESENTATIONS AND REPORT			Draft Report	TASK 5			Final Report			
									TASK 6 TASK ORDERS		

Problems – so far

- Getting FWDREFCL to run
  - Bought old Gateway
- Floor too stiff in new lab
  - Replaced floor slab
- Some FWD manufacturers slow to respond
  - Interactions are good, just take a while

Questions for discussion

- Should we develop a 450 mm diameter load cell?
  - Apparently there is only one FWD in the United States with that size plate
- Should we develop a special high capacity load cell for HWDs?
  - We currently use a very stringent criterion on linearity

Questions for discussion

- Are there any special provisions that should be made to accommodate truck-mounted FWDs?
- How can we meet our own specifications when calibrating KUAB FWDs?
  - → Difficult to get sufficiently large deflections

Questions for discussion

- Can we modify our standard procedure to accommodate the JILS FWD?
  - Large mass with small drop height does not allow enough time after mass is released
  - Excess noise is a problem for the 6,000 lb. drop height
  - Company asks to use 9,000, 12,000, 15,000 and 18,000 pound load levels.

Questions for discussion

- Is noise at low drop height a common problem for all types of FWDs?
- How often do sensors fail to pass the linearity check (0.0020 std. error)?
  - More common with some types of FWDs?
- What types of FWD calibration problems are NOT addressed by the approach discussed today?