Quarterly Progress Report

TPF-5(039)	**Falling Weight Deflectometer (FWD) Calibration Center and Operational Improvements**

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Reporting Period:	**April 1, 2006 through June 30, 2006**
Project Status: **(Tasks 1-5)**	Work completed through end of period: 81.3% Project funds expended (pct. of total budget): 81.0% Expected completion date: September 6, 2006

Status of the Project

Activity during the seventh quarter focused mainly on proof-of-concept. The project team traveled to three LTPP Calibration Centers in Harrisburg, PA, Denver, CO, and College Station, TX to evaluate the new hardware and software by calibrating all types of FWDs including Dynatest, KUAB, JILS and Carl Bro. Results of those tests are discussed below.

The fourth meeting of the TPF-5(039) Technical Advisory Committee (TAC) took place on 27-28 April 2006 in Denver, CO, hosted by Colorado DOT. Minutes of that meeting have been posted at the TPF-5(039) Web site

In accordance with the terms of the contract, the COTR must approve the new hardware and software before we can order equipment sets and train the four LTPP Calibration Center. A meeting in Harrisburg, PA has been scheduled in mid-July for that purpose. Depending on the outcome of the meeting, we may still be able to complete the contract by September 6, but that is looking doubtful. It is envisioned that a brief, no-cost time extension may be needed.

Activity during the reporting period

Software development continued throughout the seventh quarter. Hardware development was nearly complete by the end of the previous quarter. The main activity during the reporting period involved trying out the new hardware and the new calibration procedures with various FWDs. To accomplish this we traveled to three LTPP Calibration Centers, as noted above.

The calibration tests were performed as part of Task 4a on the following FWDs.

- A Dynatest FWD owned by Cornell University.
- A Dynatest FWD owned by the Texas Department of Transportation.
- A KUAB FWD owned by the Pennsylvania Department of Transportation.
- A JILS FWD owned by the Colorado Department of Transportation.
- A Carl Bro FWD owned by Fugro/BRE, Inc. (Austin, Texas)

Generally speaking all of the calibrations were successful. We had some difficulty achieving the desired maximum deflections in several of the locations, but that did not hinder the work. We had a problem with load cell calibration on the Carl Bro FWD, but it was later established that the new calibration procedures gave correct and accurate results that were in agreement with the original factory calibration.

Harrisburg, PA - April 10–11, 2006

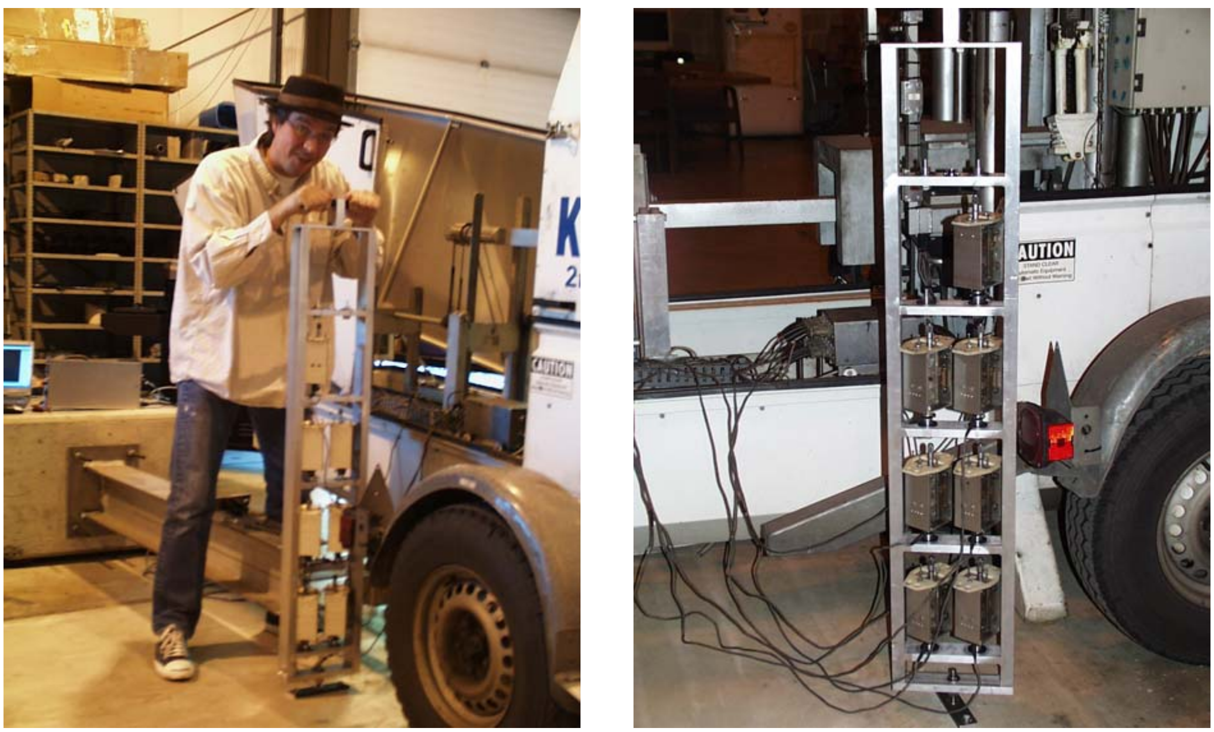


Figure 1. Calibration of KUAB FWD in Harrisburg, PA. The KUAB seismometers were stacked two to a shelf (right).

Both the PennDOT KUAB FWD and the Cornell Dynatest FWD were calibrated at the Pennsylvania DOT calibration facility on April 10-11. Of primary interest was whether the KUAB stand, which had been designed to hold two KUAB seismometers on each shelf, showed any statistical sensitivity to orientation (position) in the stand. The variables were the left and right column positions, and the shelf numbers (shelf 1 through 5, numbered from top to bottom).

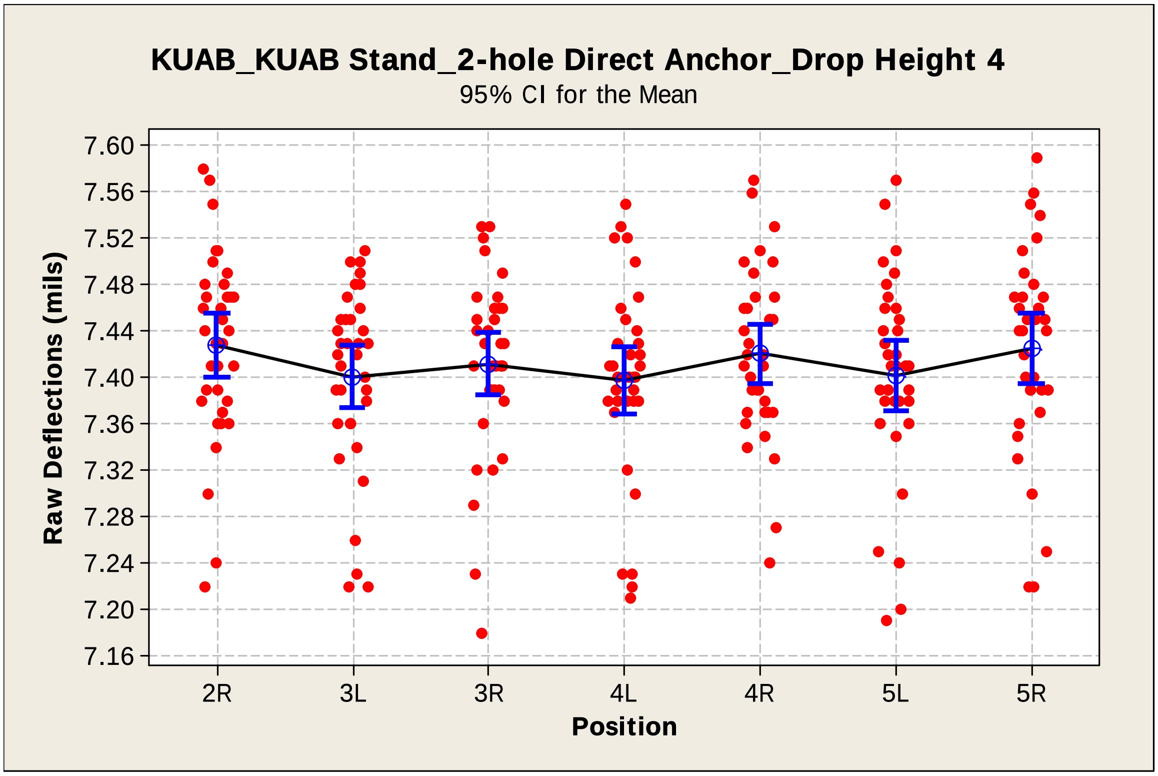


Figure 2. Relative calibration of KUAB seismometers. All seven sensors were rotated to all positions in the stand. R and L refer to the right and left columns in the stand. Shelf number 2 was near the top of the stand. The red dots depict the 35 drops; the blue circles are the mean deflections for each position. The 95 percent confidence intervals for the means are shown by the vertical blue bars. Neither column nor shelf number was statistically significant. (Note: 1 micron = 0.04 mils)

Ten calibration trials were carried out. The results of one relative calibration test are shown in Figure 2. Even though the highest force level was used, the mean deflection was only 7.4 mils, which is a lot less than the desired 20-mil deflection. It was difficult to get the seismometer stand close to the FWD load plate. Also, the hold down position for the stand was several feet from the edge of the test pad, which reduced the deflections.

The mean deflections shown in Figure 2 ranged from 7.40 to 7.43 mils, an interval of 0.03 mils or 0.76 microns. From an analysis of variance (ANOVA) the unattributed error in the relative calibration was found to be 1.92 microns. The latter, in our experience, is relatively large. A typical value for unattributed error is one micron or less.

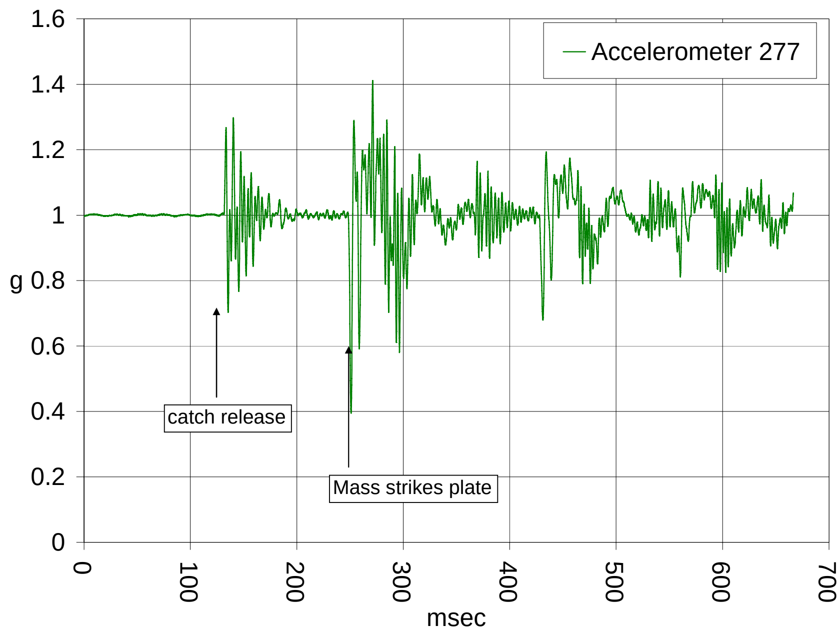
We found that the reference sensor (accelerometer) response was much noisier with the KUAB than we had previously experienced with the Dynatest FWD. This caused us to modify the strategy we use to trigger the data acquisition system. We also modified the software procedure for integration of the accelerometer signal to obtain the deflection-time history. We also found that the seismometers were a bit loose on the mounting pegs in the stand, which may partially explain the large unattributed error.

The trials also showed that it is not necessary to move the sensors to every position in the stand during relative calibration with the KUAB FWD. A simple top-to-bottom swap, perhaps along with a left to right swap, did not increase the statistical significance of position when compared to full rotation. This would reduce the overall time to perform relative calibration.

Denver, CO - April 25–26, 2006

Figure 3. Calibration of the JILS FWD in Denver, CO. Prototype geophone stand on the left, with accelerometer in place (red arrow) for a reference calibration. The same stand is also used for relative calibration. On the right, JILS geophones are stacked in the factory relative calibration stand for comparison of results to the new stand.

The same stiff, prototype geophone stand that was used with the Dynatest FWD in Harrisburg, PA was also used with the JILS FWD in Denver. Similar to our experience in Harrisburg, the mean deflections at the highest load level were only about 9.3 mils, substantially less than the desired 20 mils. The large distance from the FWD load plate to the calibration stand (3¼ feet) contributed to the small deflections.



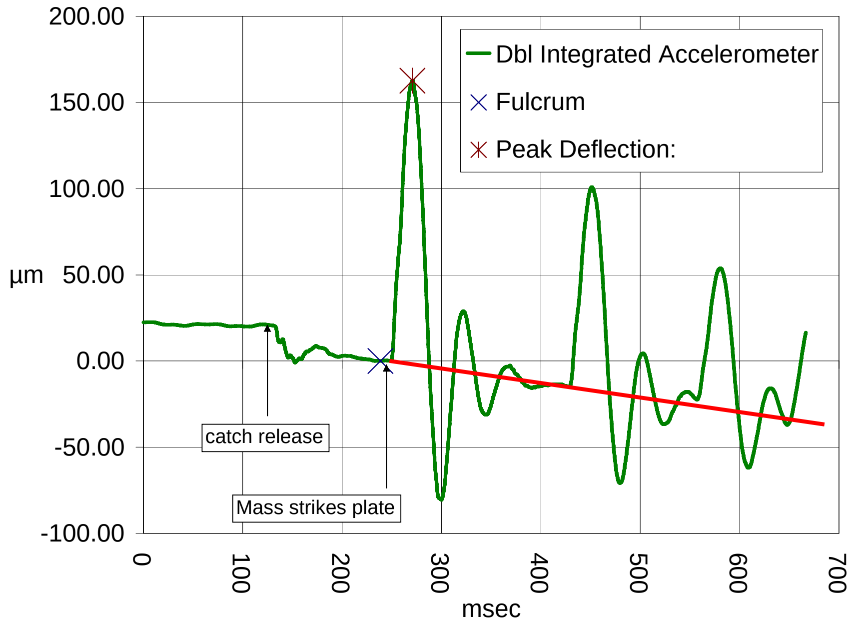


Figure 4. Accelerometer response when the JILS mass is released. Upper: data in terms of acceleration units; Lower: double integrated data in microns. Note the baseline drift in the integrated data (red line). The integration procedure used in the software has been modified to correct this effect.

Several problems with the JILS FWD were experienced. Deflection sensor number 6 was found to be unresponsive, and it had to be replaced. Triggering was also a problem. The acceleration when the FWD mass was released was about the same as when the mass struck the load plate (see Figure 4). We did not see that phenomenon with the Dynatest FWD. This required careful adjustment of the triggering level for the about trigger. Several new strategies for triggering the data collection were tried, and improvements were accomplished.

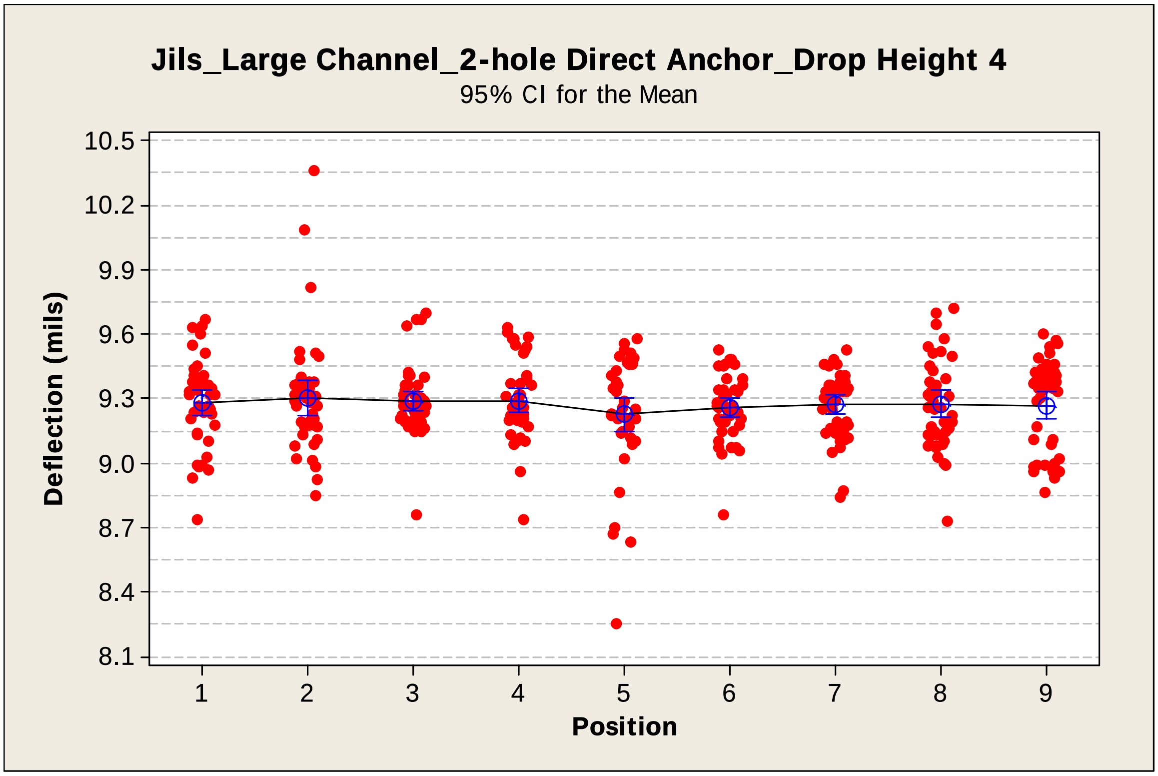


Figure 5. Relative calibration of JILS geophones. Although the mean deflection was less than desired, position in the stand was not statistically significant.

The stiff geophone stand performed well, although outliers in the data caused the statistics to be not so favorable. The range of the mean deflections was about 2 microns, and from an ANOVA the unattributed error was 3.4 microns, which we considered to be very large and mainly due to the outliers. However, position in the stand was not statistically significant.

A design improvement was suggested by the CDOT hosts to provide a *slotted* hole for the hardware on each shelf. This would make it more convenient and faster to move the sensors from one position to another.

We reconfirmed the finding from Harrisburg that it is not necessary to move the sensors into every position during relative calibration with the JILS FWD. A simple top-to-bottom swap, moving sensor 1 from stand position 1 to position 9, sensor 9 to position 1, sensor 2 to position 8, sensor 8 to position 2, etc., reduces the number of data sets from 9 to 2, and it gave equally reliable results.

College Station, TX - May 23–25, 2006

Figure 6. Calibration of the Carl Bro FWD in College Station, TX. Left: Reference calibration of geophones using modified prototype stand. Right: Load cell calibration.

Before taking the geophone stand to Texas it was modified to provide a slotted hole in each shelf for inserting the geophones. This allowed quicker rotation of the sensors in the stand. The software triggering and the acceleration integration procedures were also modified to achieve better results, based on the data collected in Denver.

The Carl Bro FWD was calibrated using the old SHRP procedure as well as the new procedure. Detecting the release of the mass was a large problem for the old procedure. The cal center operator had to visually detect the release, and manually trigger the computer. This was not always successful. Triggering was no problem at all for the new procedure.

Results of a relative calibration of the Carl Bro are shown in Figure 7. The means ratios ranged from 20.17 to 20.19 mils (0.02 mil or 0.5 micron). From the ANOVA, the unattributed error was 0.8 microns. Both of these values are quite small, and very acceptable.

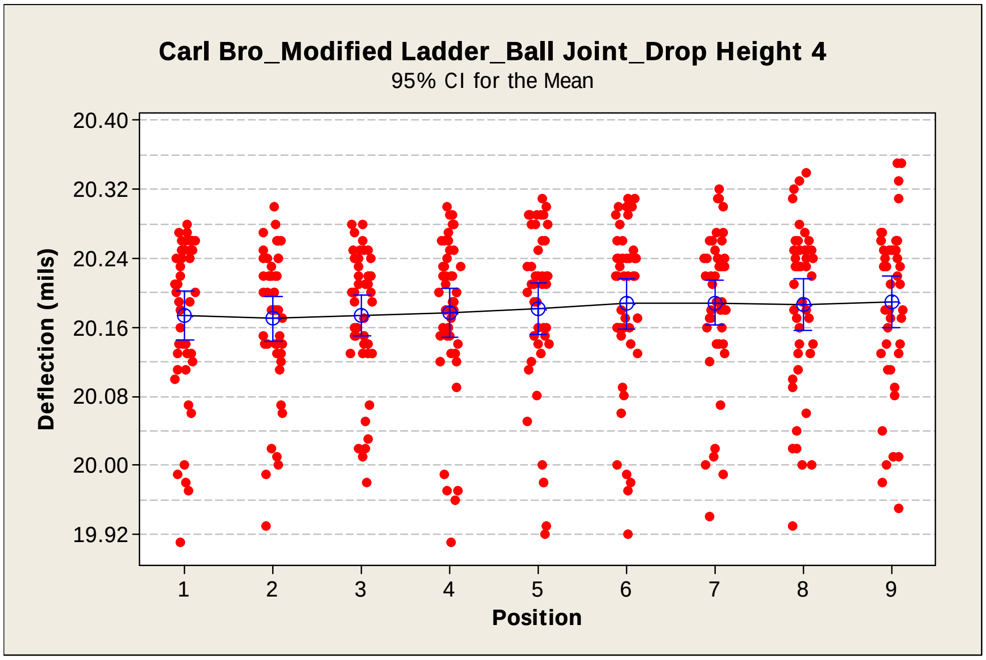


Figure 7. Relative calibration of Carl Bro geophones. The mean deflection, at 20 mils, was exactly what was desired. Position in the stand was very slightly significant, but since the range of the mean deflections was only 0.5 micron, from a practical point of view, it has no importance.

Figure 8. Calibration of Dynatest s/n 047 FWD in Texas using the modified geophone stand with slotted holes.

There was some concern following the load cell calibration of the Carl Bro. Results from the old SHRP procedure and the new procedure did not agree with each other. After some investigation, it was found that the difference was due to the manual triggering problems with the old SHRP procedure. The SHRP method was capturing the second bounce of the mass, not the first one. The load cell calibration factor obtained with the new procedure matched the two-year-old original factory calibration factor quite closely.

A Dynatest FWD s/n 047 owned by Texas DOT was also calibrated during the same visit (Figure 8). It gave good results with both the old SHRP procedure and the new procedure. The difference in the gain factors for sensors 1 to 7 according to the two procedures is shown in Table 1.

Table 1. Calibration factors for TexDOT Dynatest #047 using the old SHRP procedure versus the new calibration procedure.

	Old SHRP Procedure 19 May 2006	New Calibration Procedure 23 May 2006	Difference Old vs New
Load Cell	0.987	0.984	0.003
Geophone 1	1.007	1.004	0.003
Geophone 2	1.008	1.003	0.005
Geophone 3	1.006	1.001	0.005
Geophone 4	1.012	1.011	0.001
Geophone 5	1.004	0.997	0.007
Geophone 6	1.008	1.004	0.004
Geophone 7	1.015	1.011	0.004
Average (Geophones only)	1.0086	1.0044	0.0041

From past research we know that the repeatability of the calibration factor for a single sensor is ±0.003. To compare the two calibrations a paired t-test was made. The null hypothesis was that the difference was equal to 0.003. The alternate hypothesis was that the difference was not equal to 0.003. The t-value for the test was 1.62, and the null hypothesis was rejected. Thus it can be concluded that there is no statistical difference in the calibration results using the two procedures (Figure 9).

Ideas for several software refinements were obtained during the Texas trials. The slotted holes in the geophone stand worked quite well. John Ragsdale suggested going to a large diameter

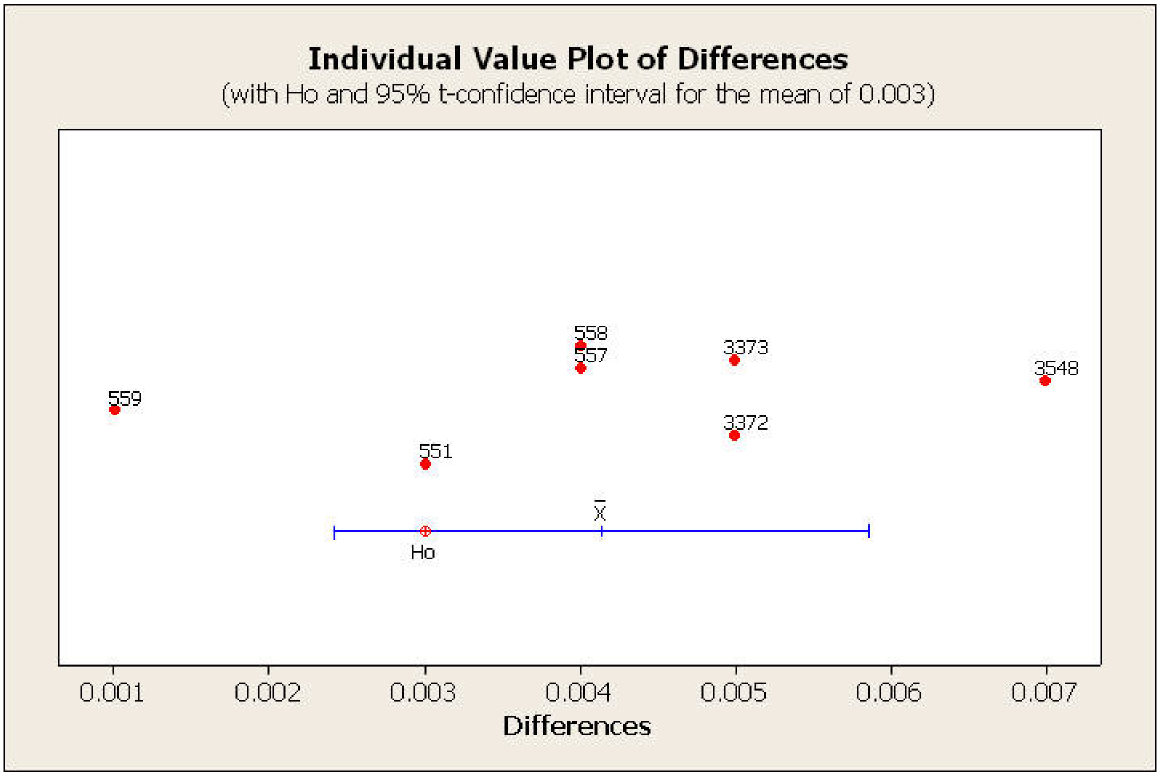


Figure 9. Comparison of old (SHRP) versus new calibration procedures for TexDOT Dynatest FWD # 047. The data points represent the difference in the calibration factor for each sensor (Table 1). The two procedures were found to not be statistically different.

knurled nut to make it easier to tighten the Carl Bro sensors into position. This has been adopted.

In relative calibration, both the Carl Bro FWD and the Dynatest FWD showed that a simple top-to-bottom rotation of geophones gave good results. The full rotation of geophones that is used in the SHRP calibration procedure is no longer necessary.

Conclusions from the Field Trials

The field trials represented time well invested. Three of the Calibration Center Operators, Dave Wassel (PennDOT), Ed Trujillo (Colorado DOT), and John Ragsdale (TAMU) each offered useful feedback which has been incorporated in the calibration procedure. Randy Beck (TexDOT) and Eric Prieve (CDOT) also provided suggestions for improvements that have been adopted. The visits were a learning experience, and both the new software and hardware were improved as a result of the collaboration with the center operators. We also learned that the new procedure will work effectively with all four types of FWDs.

The software has been extensively revised as a result of the suggestions. The geophone calibration stand was redesigned twice. The net result of the feedback will be a better, more user friendly calibration procedure.

Work completed by task

The six tasks referred to below are described in detail in the Statement of Work on the TPF-5(039) pooled-fund web site. Progress was made on all tasks during this quarter.

Task 1. Communication, Coordination and Reference Resources

Task 1a is complete. All protocols, software, and drawings of the currently used FWD equipment that are available are in hand. One set of this information will be transmitted to the COTR.

Task 1b will continue throughout the project. This task provides for a dialog with the FWD manufacturers and the Calibration Center operators. We feel this dialog should continue for the duration of the project.

The Task 1 report is essentially finished. All it requires is a bit of reorganization of the tables and a final edit. It has been difficult to find time for this project due to all of the other time demands during the quarter.

Task 2. Modify Calibration Process

Task 2a is nearly complete. Our revised calibration procedure combines reference calibration and relative calibration into a single procedure, with electronic data transfer from the FWD computer to the Calibration Center computer. We have developed a PDDX file conversion tool to accomplish the electronic data exchange.

We need an unbiased reference sensor and an unbiased stand for the calibration procedure. The accelerometer fulfills the need for a reference sensor. We have developed a nearly unbiased sensor stand, and the small bias error can be cancelled out by simply inverting the sensors in the stand. The full rotation of sensors through all position in the stand will not be necessary.

A goal for streamlining the calibration procedure was established at the April 2005 meeting of the Technical Advisory Committee (TAC). The Committee asked that we expedite the procedure so it can be completed within three hours. We have been able to complete the new procedure in less than three hours for all types of FWDs, so we feel that goal has been achieved.

While the new software has the ability to read the FWD data from a PDDX file format, we have found there are problems with the AASHTO standard for PDDX files. We are working with the COTR and the AASHTO committee in an effort to reconcile the problems.

Task 2b will not be necessary. In WinFWDCal (the new software) we have been successful with developing "about triggering" for the Keithley KUSB-3108 DAQ board. This means that an event such as the falling mass striking the load plate can be used to detect the release of the falling mass. We have found that this technique will work with both load and deflection sensor calibration. Thus it will not be necessary to develop an automated mechanism to trigger data acquisition at the release of the mass.

Task 2c will not be necessary. The LVDT/beam/block assembly will be eliminated through use of the accelerometer as the reference deflection sensor. Thus it will not be necessary to develop an automated mechanism to correct for movement of the beam.

Task 3. Hardware and Software Upgrades and/or Development

Task 3a is nearly complete. All aspects of the conversion of the software to a Windows environment have been completed. Cosmetic refinements are still being made. The new software, WinFWDCal, is able to collect and report data from the accelerometer, and convert it to displacement units. The new software can read data from all types of FWDs in a PDDX format.

Task 3b awaits approval of the COTR. We do not plan to purchase hardware for distribution to the Calibration Centers until the COTR has accepted the modified procedures. We plan to demonstrate the new procedures, hardware and software to the COTR during the coming quarter. Then we will request approval to purchase hardware for distribution to four centers during the last quarter of this contract.

Task 4. Calibration System Testing, Installation and Operator Materials/Training

Task 4a is continuing. Collection of a database of calibration test results is complete. This will be used to verify that the new procedures equal or exceed the previous calibration procedures.

Three Calibration Center Operators have been involved in testing the new procedures and equipment. Useful feedback has been received.

We have achieved the goal of developing a new procedure that can be completed within three hours.

Task 4b is continuing. We are documenting the WinFWDCal software, and developing flow charts keyed to the software. As various activities are concluded we prepare brief internal reports for the file, which help to organize the data and will expedite the writing of the software and hardware documentation.

Task 4c awaits approval of the COTR. Formal installation of the new equipment and training for its use will not proceed until the COTR has accepted the new procedures.

Task 5. Presentation and Reporting

There were several activities during the reporting period.

- Technical Advisory Committee meeting was held in Denver, CO on April 27-28.
- A presentation on the progress of the project was given at the meeting. The presentation can be downloaded from Irwin Presentation
- A demonstration of the new hardware and procedures was given to the TAC during the Denver meeting.

Task 6. Miscellaneous Support for TPF-5(039)

This task is not included in the current contract. Effort on this task is not anticipated before fall 2006. It will require separate task orders.

Work planned during the coming quarter

Under Task 1 we will continue to maintain a dialog with the FWD manufacturers and Calibration Center operators.

Under Task 2 we will finalize the calibration protocol.

Under Task 3 we will finalize the hardware and software development.

Under Task 4 we will meet with the COTR in Harrisburg in July to demonstrate the hardware and software for final approval. Near the end of the quarter we expect to begin drafting the final report.

No activity is planned for Task 5.

Task 6 – Not included in the current contract.

Table 2. Work Schedule and Completed Work

WORK COMPLETED

Year	2004			2005											
Month	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December
Task															
1 Communication and Coordination	**TASK 1**														
2 Modify Calibration Processes					**TASK 2**										
3 Hardware and Software Upgrades									**TASK 3**						
4 Testing, Installation, and Training															
5 Presentation and Reporting															
6 Miscellaneous Support															

Year	2006									2007	2008	2009	**Percent of Task Completed**
Month	January	February	March	April	May	June	July	August	September	FY	FY	FY	
Task													
1 Communication and Coordination													**98**
2 Modify Calibration Processes													**99**
3 Hardware and Software Upgrades													**98**
4 Testing, Installation, and Training	**TASK 4 cont'd**												**70**
5 Presentation and Reporting					**TASK 5**				**Final Report**				**55**
6 Miscellaneous Support (not in this contract)											**TASK 6**		**Not in contract**