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Final Report

ESTABLISHMENT OF A FALLING WEIGHT DEFLECTOMETER CALIBRATION FACILITY

Mustaque Hossain

Kansas State University
Manhattan, Kansas

December 1998

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KANSAS DEPARTMENT OF TRANSPORTATION
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16 Abstract
The Strategic Highway Research Program (SHRP) developed a protocol for calibration of Falling Weight Deflectometers (FWD) which is now being administered by the Long Term Pavement Performance (LTPP) Division of the Federal Highway Administration (FHWA). The calibration procedure for FWD's recommended by SHRP consists of two parts: (a) Reference Calibration, and (b) Relative Calibration. Reference calibration requires permanent facilities similar to those established by LTPP in Reno, Nev., Harrisburg, Penn., Minneapolis, Minn., and College Station, Tex. Relative calibration can be performed almost anywhere, using equipment provided by the FWD manufacturer. Since the center closest to Kansas is in Minneapolis, and considerable time is required for travel and calibration (usually a week), a local facility was considered to be very beneficial by the Kansas Department of Transportation.

The FWD Reference Calibration facility, for the Dynatest model FWD, has been developed at Kansas State University and is available for calibration of FWD's in the surrounding area. The facility was established in accordance with the SHRP/LTPP FWD calibration protocol. The calibration center became operational in the spring of 1998. An independent quality assurance visit by PCS/LAW Engineering of Beltsville, Maryland has confirmed that the equipment and setup are working correctly.

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Final Report
K-TRAN Research Project KSU-95-7

ESTABLISHMENT OF A FALLING WEIGHT DEFLECTOMETER CALIBRATION FACILITY

Prepared for

Kansas Department of Transportation

by

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December 1998

PREFACE

This research project was funded by the Kansas Department of Transportation K-TRAN research program. The Kansas Transportation Research and New-Developments (K-TRAN) Research Program is an ongoing, cooperative and comprehensive research program addressing transportation needs of the State of Kansas utilizing academic and research resources from the Kansas Department of Transportation, Kansas State University and the University of Kansas. The projects included in the research program are jointly developed by transportation professionals in KDOT and the universities.

NOTICE

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The financial support for this study was provided by the Kansas Department of Transportation (KDOT). The author wishes to thank Todd M. LaTorella, P.E., Project Monitor of KDOT for his patience, cooperation and advice during this study. The study may have not been possible without the valuable work and supervision by Mr. Russell Gillespie, Research Technologist of the Civil Engineering Department at Kansas State University. Participation of Mr. Donald Bruns of KSU and Mr. Affan Habib, formerly with KSU, is also acknowledged. Finally, Dr. Lynn Irwin of Cornell University provided valuable assistance in fabrication and calibration of the load cell. The author would like to acknowledge his contribution with deep gratitude.

EXECUTIVE SUMMARY

The Strategic Highway Research Program (SHRP) developed a protocol for calibration of falling weight deflectometers (FWD) which is now being administered by the Long-Term Pavement Performance (LTPP) Division in the Federal Highway Administration. The calibration procedure of FWD's recommended by SHRP consists of two parts: (a) reference calibration, and (b) relative calibration. Reference calibration requires permanent facilities similar to those established by LTPP in Reno, Nev., Harrisburg, Penn., Minneapolis, Minn. and College Station, Tex. Relative calibration can be performed almost anywhere, using equipment provided by the FWD manufacturer. Since the closest center to Kansas is in Minneapolis, and considerable time is required for travel and calibration (usually a week), it was considered to be very beneficial for the Kansas Department of Transportation (KDOT) to have a facility in the state. A ***calibration facility*** for the FWD's (Dynatest model) has been developed at Kansas State University. The facility was established as per the SHRP/LTPP FWD calibration protocol. The total budgeted cost of the project was approximately $42,000 which include the cost of the dedicated computer, component materials, strain gage services, and labor. It does not include the cost of the building which is a new facility.

The calibration center is operational as of Spring, 1998. An independent quality assurance visit by PCS/LAW Engineering of Beltsville, Maryland has confirmed that the equipment and setup are working correctly. KSU, from now on, will provide KDOT with continued FWD reference and relative calibration services till year 2002.

INTRODUCTION

Non-destructive testing (NDT) is now widely recognized as an important tool for structural evaluation of pavements. State-of-the-art NDT evaluation measures a pavement's deflection response to a known load. The load generated by a NDT device may be static (Benkelman Beam), steady-state vibratory (Dynaflect and Road Rater) or impulse (Falling Weight Deflectometers) type. The new AASHTO Guide for Design of Pavement Structures (*1*) recommends the use of "dynamic" NDT deflection measuring devices for surface deflection measurements. Non-destructive testing for measuring surface deflection is accepted by most highway agencies as a standard practice and falling weight deflectometers (FWDs) are currently the most popular NDT devices. KDOT owns two Dynatest model falling weight deflectometers and needs to calibrate these every year.

BACKGROUND

In the SHRP calibration procedure, the deflection and load transducers from the FWD are first calibrated individually against independently-calibrated reference devices. This is called "reference calibration", and it is performed at a LTPP Regional Calibration Center, or any other properly equipped location *(2)*. The calibration of the FWD deflection sensors is further refined by comparing them to each other in a process referred to a "relative calibration". Relative calibration is done as a final step that accompanies reference calibration, and it can also be carried out alone, at any suitable location. There is no corresponding relative calibration procedure for the load measurement system *(2)*.

The procedure results in calibration factors that are entered into the FWD Software as multipliers. When the FWD measurements are multiplied by the calibration factors the result is a measurement which has been corrected to agree with the calibration instrumentation. It is necessary that there be a place in the FWD software to enter the calibration factors. That is the responsibility of the FWD manufacturer.

KANSAS FWD CALIBRATION CENTER

The Kansas FWD Calibration Center is an indoor facility and is a part of the new building that houses the Kansas Accelerated Testing Laboratory (K-ATL) for Civil and Highway Infrastructure Research. Figure 1 shows the floor plan of K-ATL with the FWD Calibration Laboratory area shaded. K-ATL is located at 924 Carlson St. just off McCall Road in Manhattan, Kansas. The calibration laboratory floor space is approx. 1,000 sq ft. (32 ft x 32 ft) and has a height clearance of 12 ft. It is accessible by a 10 ft x 10 ft retractable door. This indoor space provides easy access for FWD and towing vehicle, large level floor, controlled temperature and humidity, heating, and good security for the calibration equipment.

The floor slab is 15 feet by 15 feet, with an 8-foot wide clear zone around the perimeter (for maneuvering FWDs and the reference data acquisition system), and was built as a smooth, crack-free Portland cement concrete surface. The slab consists of a 5-inch-thick Portland cement concrete slab resting on an 8-inch open-graded crushed stone base. This slab thickness was intended to achieve slab deflection of at least 16 mils under a 16,000 lb load at the position of the deflection sensor holder when the FWD is in the specified position for calibration. To increase the fatigue life, fiber-reinforced concrete was used in the slab. A layer of filter fabric was placed below the base to protect it from intrusion of subgrade fines. The slab, when tested upon completion, showed a deflection

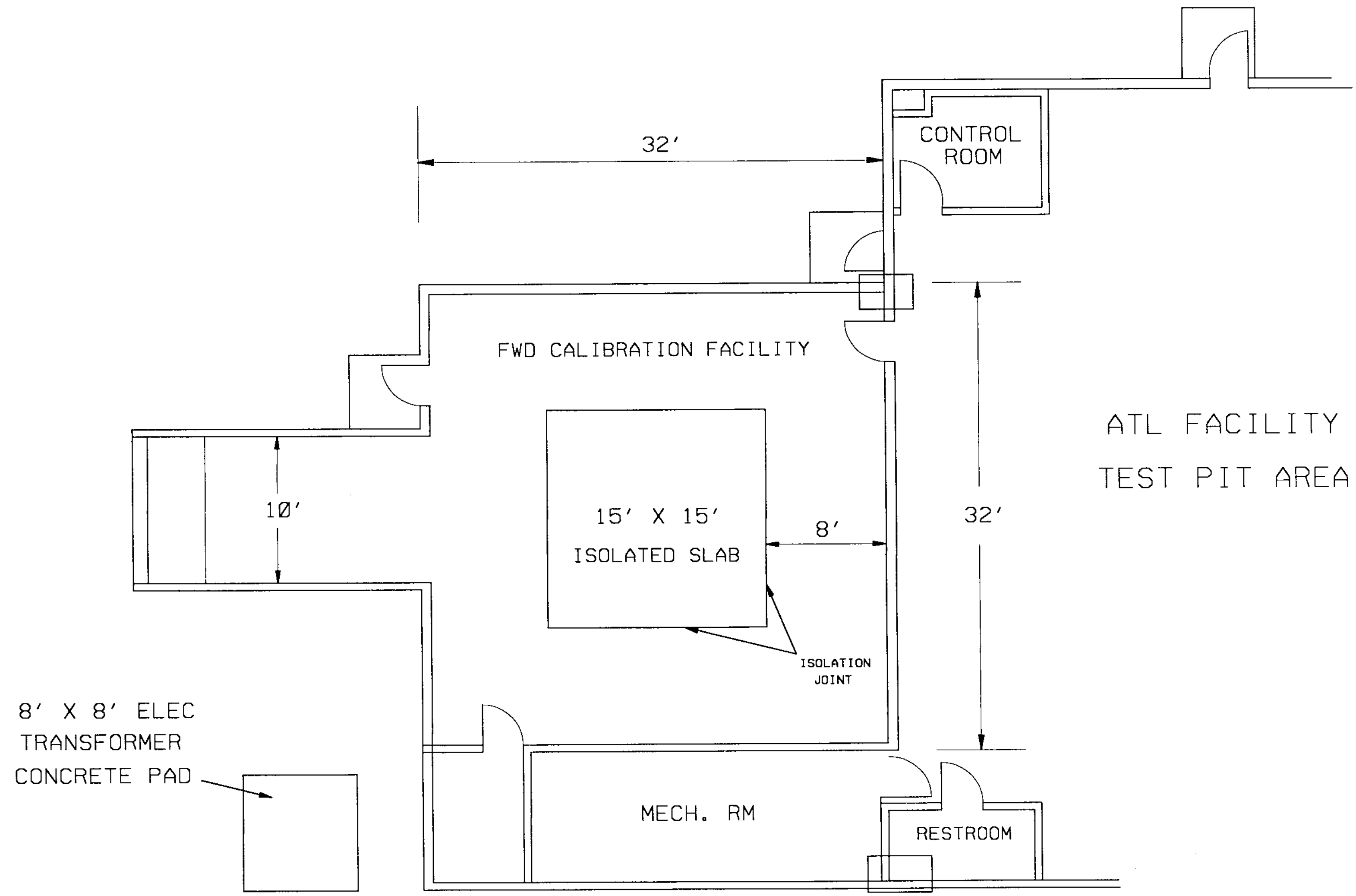

Figure 1 Floor Plan of FWD Calibration Facility and K-ATL

of more than 17 mils under a 16,000 lb load at the location of the sensor holder. The sensor holder was located not closer than two feet from the edge of the test pad.

REFERENCE CALIBRATION EQUIPMENT

The following items were fabricated at the Civil Engineering Department shop for the Kansas FWD calibration laboratory. The items were constructed using blueprints supplied by the SHRP/LTPP program.

- A 3' wide x 22" high x 5' long concrete inertial block weighing approximately 4,000 lbs was cast. The block was lightly reinforced with No. 3 and No. 5 rebars and rests on 4" x 4" Air Cel low frequency rubber isolation pads. The block is equipped with four trailer jacks for easy and precise vertical positioning. Photo #1 shows the concrete inertial block for the Kansas FWD calibration center.
- A 5-foot long, wide flange aluminum reference beam was attached to the concrete block through a base plate as shown in Photo #2. On the other end of the beam, the LVDT mounting hardware was fabricated which consists of the deflection sensor holder assembly (LVDT Clamp, Top Plate, Bottom Plate, Spacer, KUAB Seismometer Mount, Washer, Stainless Steel Bolts, Hex Head Cap Screws and Magnetic Tip for LVDT) as shown in Photo #3. A fisheye bubble has been placed to ensure that the top plate is level after the sensor is in place in the holder.
- A Schaevitz Model GCD-121-125 DC Linear Variable Differential Transformer (LVDT) with 0.125-inch stoke and Cannon connector was used. A Schaevitz metric LVDT calibrator, C-41M (micrometer), was used in an in-house assembly for calibrating the LVDT as shown in Photo #4. A magnetic tip is used on the top of the LVDT while in

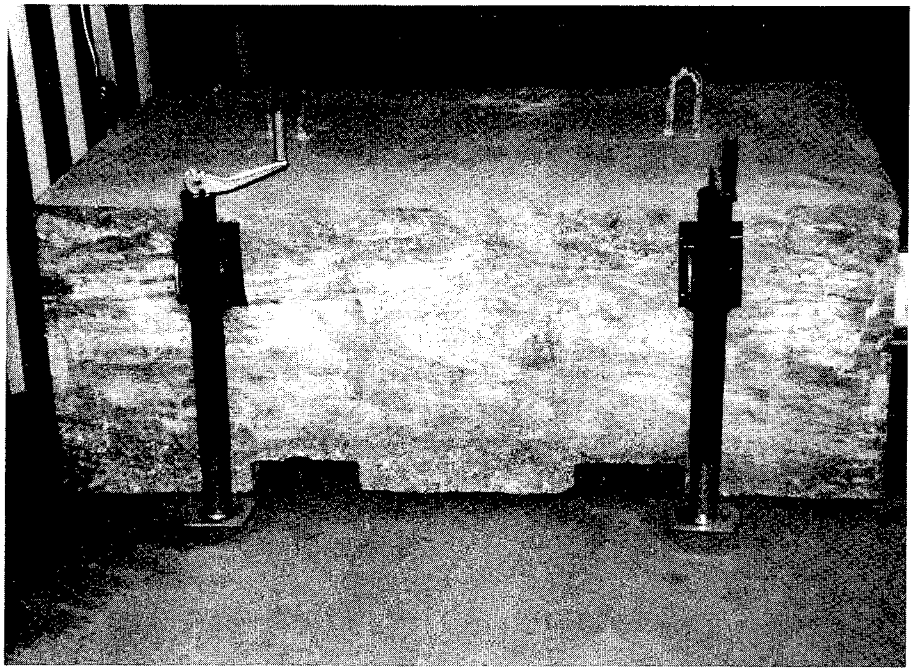

Photo # 1 Concrete inertial block for the Kansas FWD calibration laboratory.

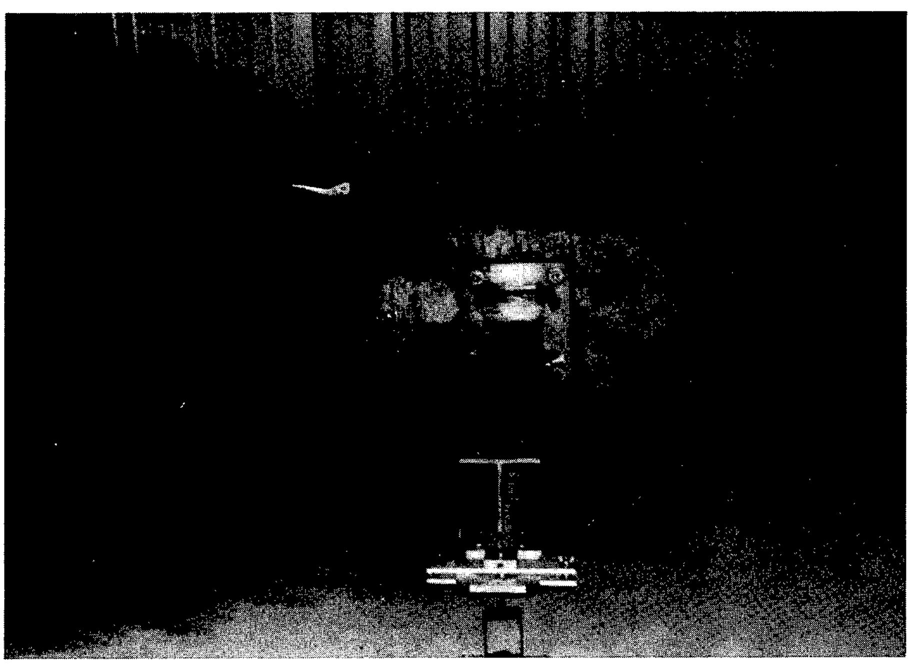

Photo #2 Wide flange aluminum reference beam

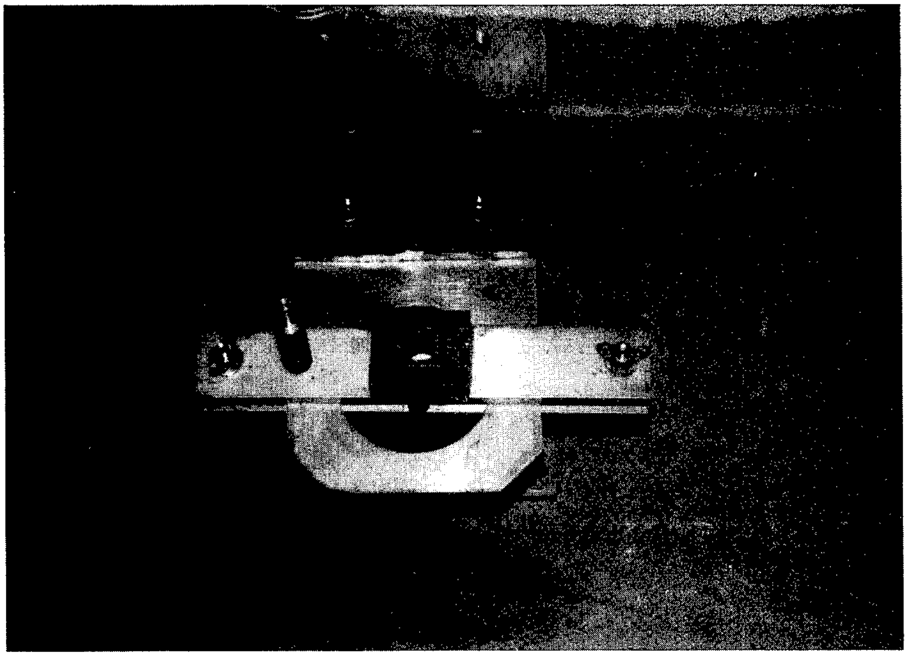

Photo #3 Deflection sensor holder assembly

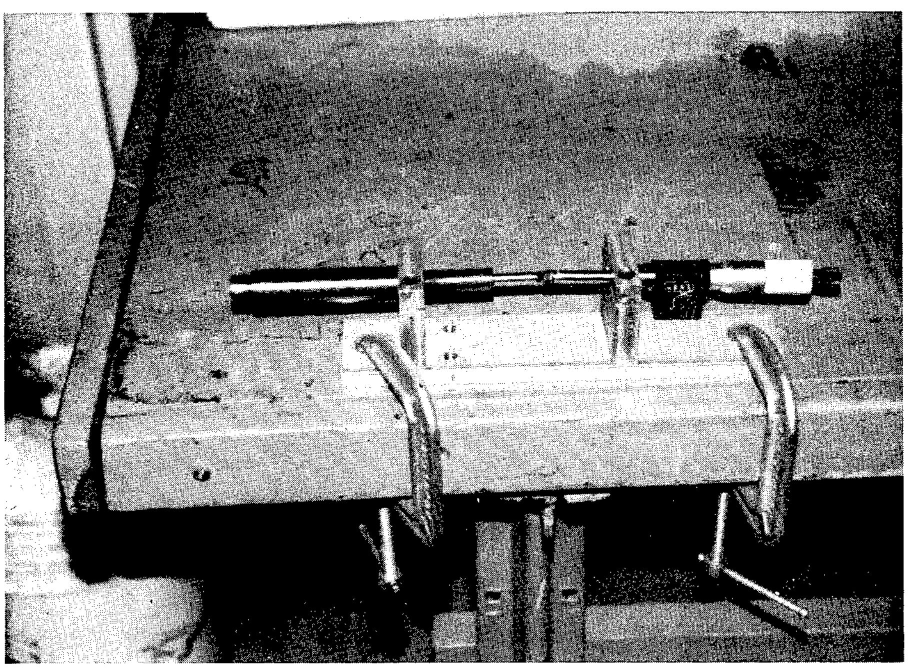

Photo #4 Micrometer assembly for calibrating the LVDT the calibration assembly.

- A KUAB Seismometer holder assembly consisting of KUAB Seismometer holder frame, KUAB Seismometer mount, base plate, steel rod and machined screws, was also fabricated.
- The fabricated Dynatest Geophone holder consists of aluminum frame, steel clip, circular base plate, aluminum base, steel rods, and machined screws.
- A Measurements Group, Inc. Vishay Model 2310 signal conditioner, shown in Photo #5, with modification for + 15 V DC and - 15 V DC excitation, was installed with line cord and stabilizer, and extra am phenol plug with options V & Y.
- A Keithly-MetraByte Model DAS-16 G2 data acquisition board, with STA-16 screw terminal board and C-1800 ribbon cable was installed in the dedicated computer which is an IBM-compatible microcomputer with 80486 processor with 40 MHZ processor speed, 1.6 megabyte RAM and 400 megabyte hard drive. An 8-bit expansion slot was used for the MetraByte board. The computer has a VGA color monitor, and a good quality ink jet printer is used for printing. The complete data acquisition and output assembly is shown in Photo #6.
- Connecting cables, Vishay to LVDT and Vishay to MetraByte, were purchased from a local Radio Shack (RS) store.
- A reference load cell (300 mm diameter, 40,000 lbs. capacity) was fabricated following the structural and cabling diagrams furnished by the LTPP program. The following

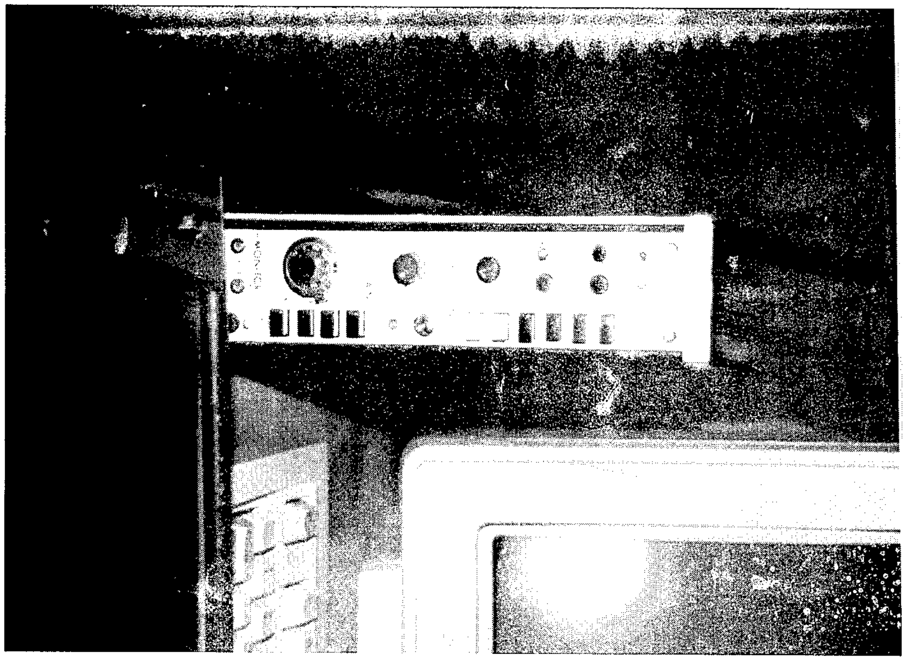

Photo #5 Vishay model 2310 signal conditioner

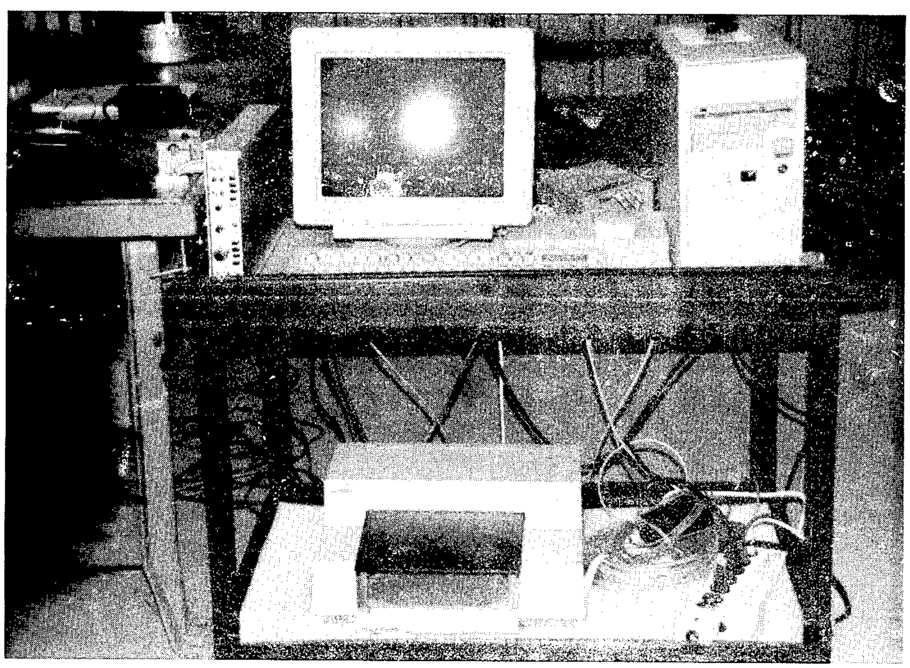

Photo #6 Data acquisition and output assembly are the components of the load cell: aluminum body and lid, box (RS #270-230), cable (3 conductor, shielded), 2 kohm resistor (RS #271-1321), push button switch (RS #275-609), cable strain relief (RS #278-1636), 3 lug strip (RS #274-688), strain gages, Am phenol receptacle, Am phenol plug, cable, cable clamp, ribbed rubber sheet, and guide posts. For signal light, the following components were used: box (RS #270-230), cable (RS #278-513), LED (RS #276-022), LED holder (RS #276-079), and cable strain relief (RS #278-1636). The strain gages were installed in the load cell by the B & Q Technical Services in Philadelphia, Penn. Photos #7 and 8 show the complete load cell. Connecting cables were also needed for connection from Vishay Signal Conditioner to the load cell. Circular wooden blocks (Photo #9) matching diameter of the load cell were also assembled in the shop. The initial calibration of the load cell was performed at Cornell University in Ithaca, New York.

- FWD reference calibration software **(FWDREFCL)** and documentation were obtained from the LTPP program with some difficulty.

REFERENCE CALIBRATION

The calibration procedure is done following the SHRP/LTPP FWD Calibration Protocol of March 1994 *(2)*. To do reference calibration, the Dynatest FWD's must have Version 10 or higher software. Earlier versions do not have the pause feature and do not allow programming the required number of drops in the test sequence. Furthermore, it is not possible to leave the load plate down, as is called for in this procedure. Thus, Dynatest FWD's must be upgraded to Version 10 or higher software *before* calibration. Both KDOT FWDs currently have the latest version, Version 25, of the software, although DARWin cannot read Version 25.

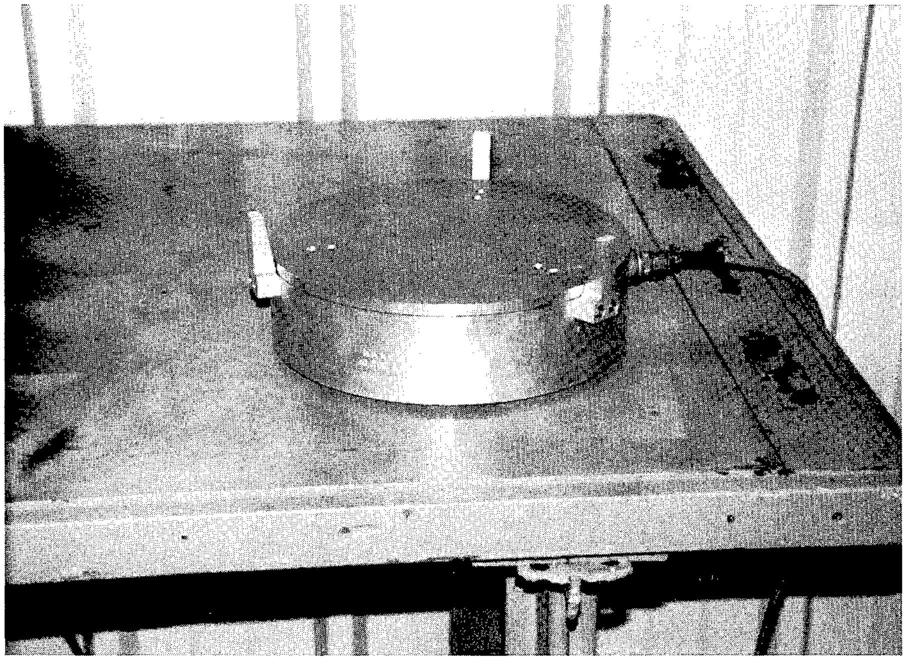

Photo #7 Kansas FWD calibration center reference load cell

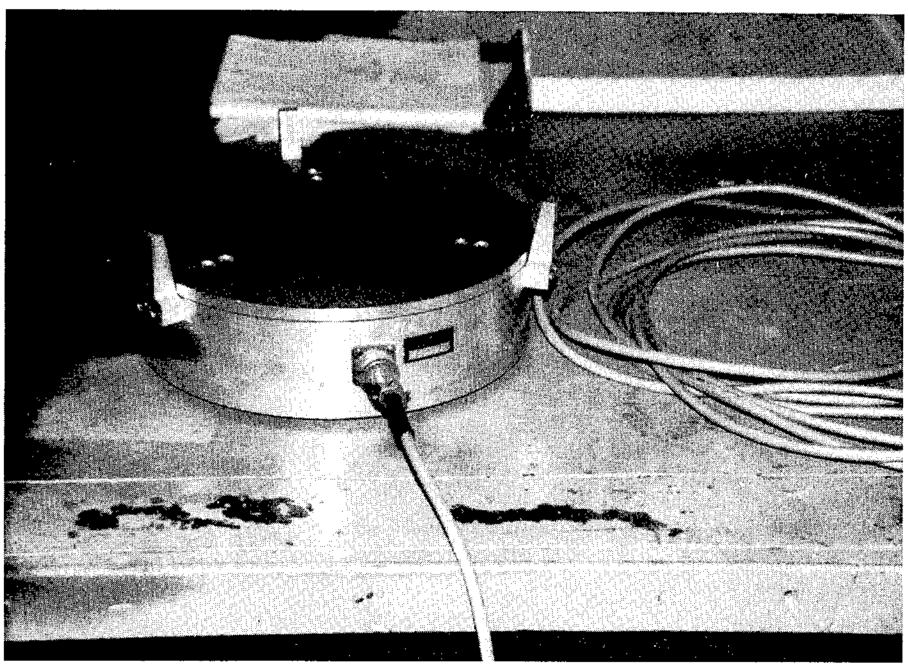

Photo #8 Complete reference load cell

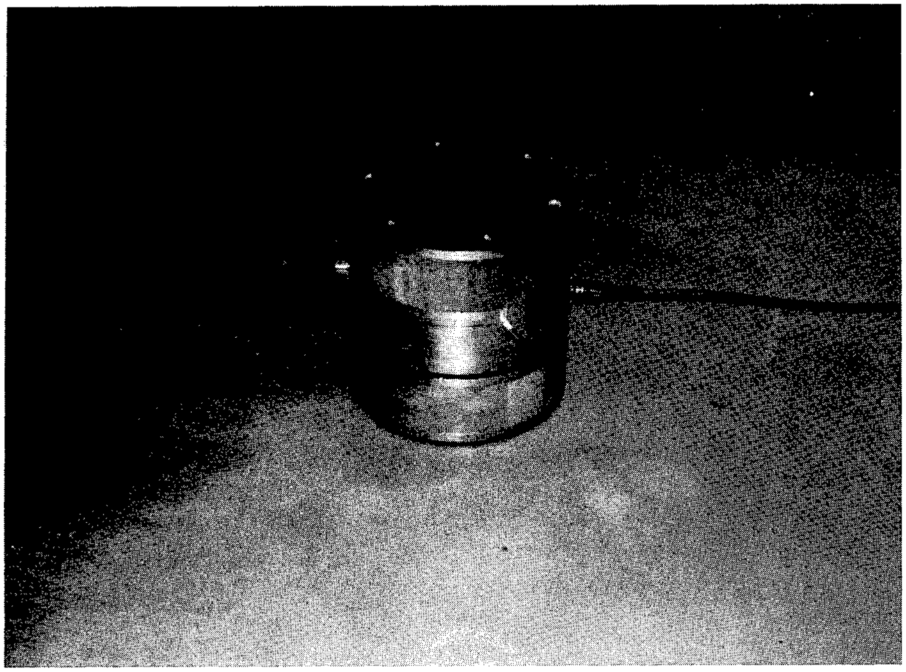

Photo #9 Circular Wooden Blocks for Load Cell Calibration

Frequency of Calibration

Reference calibration should be performed at least once per year, or as soon as possible after a sensor has been replaced on the FWD.

Relative calibration should be performed on the deflection sensors at least once per month. It should also be performed immediately after a deflection sensor is replaced.

Personnel Required for FWD Calibration

The calibration procedure is expected to be a two-man operation: (i) FWD System Operator and (ii) Calibration System Operator.

User Preparation

LTPP has prepared guidelines for users of the FWD calibration centers *(4)*. The guidelines outline what and what not to expect from the FWD calibration centers, specific FWD equipment requirements for calibration, general FWD equipment requirements, calibration center procedures and a users pre-trip checklist for FWD calibration centers. A checklist for the user is attached as Appendix A to this report.

Equipment Preparation

The FWD should be in good operating condition prior to performing reference calibration. Particular attention should be paid to cleaning the magnetic deflection sensor bases to insure that they seat properly. Also, the FWD load plate needs to be firmly attached to the load cell. In the event that the load plate is loose, the lower bolts should be tightened to a torque of 7.5 lb-ft and set with Locktite before proceeding. (This torque requirement is applicable to the Dynatest FWD's. For non-Dynatest FWDs, the manufacturer should be consulted). All electrical connectors should be inspected and, if necessary, cleaned and firmly seated.

The FWD should be at room temperature. If the FWD has been outdoors at a very low or a very high temperature, sufficient time should be allowed for it to equilibrate to room temperature. It is recommended that a series of warm-up drops be performed immediately prior to beginning calibration, to assure that the rubber buffers have been thoroughly warmed up.

The FWD mass and drop heights were set to produce loads within $\pm$ 10 percent of 6, 9, 12, and 16 kips (27, 40, 53, and 71 kN). For the Dynatest FWD, it is possible to be within this tolerance for the highest load, and yet to have the drop height set too high. *Before placing the reference load cell under the load plate, and with the mass positioned* *at drop height four (the highest position), verify that there is at least a four inch clearance between the highest point on the mass subassembly and the underside of the brace between the two columns that surround the cylinders that raise and lower the load plate.* If the clearance is too small, reposition the target for the fourth drop height to achieve the required clearance. This should assure that there will be adequate clearance when the reference load cell is in position under the load plate.

Before beginning any calibration work, and throughout the entire calibration period, it is necessary that *there be no data filters in operation in the FWD. It should be verified that the "peak smoothing" processor has been turned off.* This feature is accessed from the Dynatest Main Menu by selecting "Road Options" (item #3, followed by item #12), where "Peak Readings" should show "direct" and not "smooth".

General Procedure

The FWD load cell should be calibrated at least twice. Multiple calibration tests are performed on the load cell, and the results are averaged, since it is not possible to perform relative calibration on the load cell. Acceptance criteria based upon the repeatability of the calibration factor are identified in the load cell calibration. If the results persist in failing the acceptance criteria, then the cause of the erratic results should be identified and corrected.

Each deflection sensor shall be calibrated once. Spare deflection sensors do not have to be calibrated until they are in active use. After all load and deflection sensors have been calibrated, the interim calibration factors shall be entered into the FWD computer before proceeding with relative calibration.

A sample reference calibration setup screen for the Dynatest FWD with version 10 or version 20 software is given in Figure 2. The information in Figure 2 can also be used as the basis for setup of Dynatest FWDs running version 25 and higher software.

A complete summary of the data to be recorded is given in Table 1. *Before beginning to perform the calibrations, FWD-specific information should be recorded via printouts from the FWD data acquisition program screens (e.g., showing the deflection sensor serial numbers and calibration factors, load cell serial number, calibration factor, and sensitivity, and voltage screens from the Dynatest software), which have been annotated with the date and FWD identification information (i.e., FWD model and serial number).*

The calibration data acquisition system should be as close as possible to the FWD computer so that the two systems operators will be able to converse easily. The communication at the Kansas FWD Calibration Center is accomplished by using Two-way radios. The reference calibration software **FWDREFCL** should be loaded into the reference system computer. Tables 2, 3, 4 and 5 show the checklists for the facilities, equipment preparation, FWD load cell calibration and deflection sensor calibration, respectively.

Directions for performing reference calibration using this software are provided in the **FWDREFCL** User's Guide *(4)*. The following are the brief steps in the **FWD Deflection Sensor Reference Calibration**:

1. Initialize the computer data acquisition program.
2. Two important checks need to be done:
   - *the **AC-IN** labeled push-button switch on the front panel of the 2310 signal conditioner, should be in the **OFF** position (i.e., fully extended) at all times.*

```
   Relative Calibration
 1. Test UNITS...: lbf.mil.inch    (kPa.mu.mm)
 2. Temperature..: Fahrenheit      (Centigrade)
 3. Stn.Request..: OFF             (ON)
 4. Test Checks..: NONE            (Decreasing defls. Roll-Off. RollOFF+Decr)
 5. Reject prompt: OFF             (ON)
 6. Stationing...: [doesn't matter]
 7. Temp.Request.: OFF             (ON)
 8. Cond.Request.: OFF             (ON)
 9. Variation : Load NOT Checked !  Deflections NOT Checked !
10. Diameter of Plate: 11.8
11. Deflector distances: [doesn't matter - keep what you have]
                                 1          2          3          4
12. Drop No.  : 1234567P8901234P5678901P2345678P9012345P6789012P3456789S.......
13. Heights*  : CC44444PCC44444PCC44444PCC44444PCC44444PCC44444PCC44444S1111111
14. Test Plots: ...............................................................
15. Save Peaks: ..*****...*****...*****...*****...*****...*****...*****........
16. Load His. : ...............................................................
17. Whole His.: ...............................................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.

*Note:  Drop height should be adjusted to attain deflections within the specified
range.
```

Figure 2   A Sample Reference Calibration Setup Screen for the Dynatest FWD

Table 1 Summary of Data Items to be Recorded During Reference Calibration Procedure

Data Item	Mode of Entry	Source[1]
FWD Operator Name	Manual	Operator
Calibration System Operator Name	Manual	Operator
Date and Time of Calibration	Automatic	Computer Clock
FWD Serial/ID Number	Manual	Operator
FWD Manufacturer	Manual	Operator
FWD Owner	Manual	Operator
FWD Load Cell Serial Number	Manual	Transducer Setup and Gain Printout
FWD Deflection Sensor Serial Numbers	Manual	Transducer Setup and Gain Printout
Reference Load Cell Serial Number	Automatic	Configuration File[2]
Reference LVDT Serial Number	Automatic	Configuration File[2]
FWD Calibration Center Location	Automatic	Configuration File[2]
Current Calibration Factor for FWD Load Cell	Manual	Transducer Setup and Gain Printout
Current Cal. Factors for FWD Deflection Sensors	Manual	Transducer Setup and Gain Printout
Ref. Load Cell Calibration Constants	Automatic	Configuration File[2]
Ref. Load Cell Calibration Date	Automatic	Configuration File[2]
Ref. LVDT Calibration Constants	Computed	**FWDREFCL** Software
Ref. LVDT Calibration Date	Automatic	**FWDREFCL** Software
FWD Load Cell Readings (20 total)	Manual	FWD Computer
Ref. Load Cell Readings (20 total)	Automatic	Calibration Data Acquisition System
FWD Deflection Readings (20 per sensor)	Manual	FWD Computer
Ref. LVDT Readings (20 per sensor)	Automatic	Calibration Data Acquisition System
Interim Cal. Factors from Reference Calibration	Computed	**FWDREFCL** Software
FWD Relative Calibration Data	Automatic	Relative Calibration Data Files
Calibration Factors from Relative Calibration	Computed	**FWDCAL2** Software
Final Calibration Factors	Manual	Final Gain Worksheet

[1]For SHRP FWDs. Source may be different for FWDs from other manufacturers.

[2]Reference calibration configuration file (**FWDREFCL.CNF**).

Table 2 Checklist for Facilities

Question	Yes	No	Comments
1. Is calibration test pad clean of any debris so nothing will be under load plate when it is lowered? (p.18)			
2. Is data acquisition system close enough to FWD computer so that two system operators can converse easily? (p.3)			
3. Is calibration test pad isolated, uncracked, and are joints well sealed? (p.18)			
4 Is there easy access for FWD and towing vehicle? (p.18)			
5. Does FWD and towing vehicle sit level inside facility while testing? (p.18)			
6. Does it appear that facility is kept at a constant temperature between 10 and 30°C and humidity between 40 and 80%? (p.18)			
7. Does it appear that adequate security has been provided for calibration equipment? (p.18)			
8. Is concrete inertial block uncracked? (p.18)			
9. Is there any deformation of isolation pads? (p.18)			
10. Is aluminum reference beam tightly connected to concrete inertial block? (p.18)			
11. Does calibration center have a copy of most current Protocol?			
12. Is calibration center using most current version of the FWDREFCL?			

Table 3 Checklist for Equipment Preparation

Question	Yes	No	Comments
1. Have all electrical connectors been inspected to make sure they are clean and firmly seated? (p.2)			
2. Has all wiring been inspected to make sure it is in good shape with no nicks, exposed wire or crimps? (p.2)			
3. Are signal conditioner and data acquisition board those specified in the Protocol?			
4. Did Calibration System Operator ask FWD Operator for pre-calibration checklist and calibration diskette?			
5. Has enough time been allowed for FWD to cool down or warm up to room temperature? (p.2)			
6. Have warm-up drops been performed immediately prior to calibration to stabilize loads obtained during calibration? (P.2)			
7. Have all data filters been turned off in FWD before and during any calibration work? (p.3)			
8. Has signal conditioner been warmed up for at least 60 minutes prior to testing?			
9. Does reference system computer show correct date and time? (p.3)			
10.Is green LED signal light in use and working properly?			

Table 4 Checklist for FWD Load Cell Calibration

Question	Yes	No	Comments
1. Has load cell been calibrated within last 12 months? (p.4)			
2. Has FWD computer data acquisition program been initialized and printouts of current gains obtained prior to calibration? (p.3)			
3. Are signal conditioner excitation and gain factor set exactly to levels at which reference load cell was calibrated? (p.6)			
4. Is there a 4-inch clearance between highest point on mass assembly (at drop height 4) and underside of brace prior to placing reference load cell under load plate? *Note: adjust if clearance is less than 4-inch.*			
5. Has reference load cell been zeroed with FWD load plate in raised position? (p.6)			
6. Is reference load cell properly and accurately aligned with FWD load plate? (p.6)			
7. Has a sixth drop been used and saved to assure a spare drop, in case a drop is missed by reference system instrumentation? (p.6)			
8. Have correct five drops of information been entered from FWD if sixth drop was used?			
9. Has the FWD load plate been raised at any time during the calibration sequence? It should never be raised after the seating drops. (p.6)			
10. Has load cell reference calibration been performed at least twice? (p.6)			

Table 5 **Checklist for Deflection Sensor Calibration**

Question	Yes	No	Comments
1. Has FWD computer data acquisition program been initialized and printouts of current gains obtained prior to calibration? (Note: printout must be clearly marked as "BEFORE CALIBRATION") (p.7)			
2. Has LVDT been cleaned with a non-lubricating cleaner prior to calibration of sensors? (p.7)			
3. Is standard error for calibration of LVDT less than 0.001?			
4. With FWD in position close to geophone holder, is a 16 mil or greater deflection achieved at 16,000 pound drop?			
5. Is holding assembly for sensors clean and free of debris?			
6. Are sensors' magnetic surface clean and free of debris? (p.2)			
7. Is LVDT vertical in its holder and is whole system vertical to FDW sensor holder? This must be verified by means of a spirit level. (p.8)			
8. Has anyone walked around FWD or testing area while calibration process was being performed? This may introduce noise, false triggering and beam movement into tests.			
9. Have correct five drops of information been entered from FWD if sixth drop was used?			
10. Has FWD loading plate been raised at any time during calibration sequence? It should never be raised after seating drops. (p.9)			
11. Have FWD history plots been viewed to assure that movement of calibration beam at time of peak reading of sensor under test is small (p.9)			
12. Has each sensor been calibrated at least once?			

- *The slide switch marked **PLAYBACK** on the rear panel of the 2310 signal conditioner should be in the **NORM** position.*

2. Clean the spring-loaded tip of the LVDT.

3. Use the micrometer to calibrate the LVDT *(the Metrabyte board should read ± 30 bits of 2,000 bits).*

4. Check that the LVDT calibration results are in the computer.

5. Secure the LVDT in its holder on the Reference system aluminum beam *so that it reads near zero. The FWD plate should be on the pad, **and the Auto Balance Switch on the signal conditioner should be in the OFF position.***

6. Position the FWD trailer *so that the load plate is as close as possible to the deflection sensor holder.*

7. Remove the deflection sensors from their holders on the FWD beam, *and verify that they are free of dirt and grime.*

8. Place one deflection sensor in the sensor holder, and position the LVDT holder *so that the LVDT and the FWD sensor holders are aligned concentrically. Once the LVDT is satisfactorily close to zero (e.g., within ± 50 bits), the screw may be tightened to prevent the LVDT from slipping during the testing.*

9. Place a second deflection sensor on top of the LVDT, *so that it will measure the movement of the end of the beam.*

10. Zero the signal conditioner *(the Metrabyte board should read ± 30 bits of 2,000 bits).*

11. Complete the FWD drops as sequenced *(3 seating drops at height 3, 5 drops at heights 1, 2, 3 and 4 with a pause after completion of drops at each height). Check one complete FWD time history plot for the fifth drop at each height, to verify that the calibration beam does not move prior to the recorded peak deflection.*

The data recording sheet and FWD deflection sensor calibration check criteria are attached in Appendix B.

The **FWD Load Cell Calibration Procedure** can be summarized in the following steps:

1. Check that *the reference load cell has been calibrated within the last 12 months.*

2. Attach the cable *from the signal conditioner to the reference load cell, turn on the signal conditioner, and allow the system to warm up for at least 60 minutes.*

3. *Initialize the computer data acquisition program.*

4. Position the FWD so that the load plate is near the center of the calibration test pad. *Verify that there is no sand or other loose debris under the reference load cell.*

5. Position the reference load cell beneath the FWD load plate, *making sure that the three guides are aligned around the plate.* ***Zero the signal conditioner with the load plate high.***

6. Complete the FWD drops as sequenced *(3 seating drops at height 3, 5 drops at heights 1, 2, 3 and 4 with a pause after completion of drops at each height. Stop after the last drop with the load plate continued to be down). During each drop make sure that the FWD Operator is recording the peaks for exactly the same drops that the reference system is recording.*

7. Perform the load cell reference load calibration twice.

The data recording sheet and FWD deflection sensor calibration check criteria are attached to the Appendix B.

RELATIVE CALIBRATION PROCEDURE

Relative calibration of the FWD deflection sensors is used to ensure that all sensors on a given FWD are in calibration with respect to each other. As such, it serves as the final step in the overall FWD calibration process, and as a quick means to periodically verify that the sensors are functioning properly and consistently. Relative calibration uses the relative calibration stand supplied by the FWD manufacturer. The sensors are stacked vertically in the stand, one above another, so that all sensors are subjected to the same pavement deflection. Relative calibration assumes that the overall mean deflection, as determined from simultaneous measurements by the full set of deflection sensors, yields an accurate estimate of the true deflection. This assumption requires that the deflection sensors must have first been subjected to the reference calibration procedure. Table 6 shows the checklist for the relative calibration procedure.

Equipment

A FWD relative calibration stand with as many positions as the number of active deflection sensors. For the purpose of illustration, a seven-position stand is assumed herein. FWD relative calibration software **(FWDCAL2)** and documentation are also necessary to perform relative calibration.

General Procedure

The process involves rotation of each deflection sensor through every positions in the calibration stand. Each combination of sensors and levels is considered a "set," and the number of sets of data will be equal to the number of sensors. The test point is "conditioned" before beginning the calibration procedure to reduce the possibility that set will be significant in the data analysis. The required order of movement of the sensors is shown in Table 7. In order for the data processing with **FDWCAL2** to be done correctly it is very important that the sensor rotation from the set to set be done correctly. Spare deflection sensors do not have to be calibrated until they are in active use.

When done in conjunction with reference calibration, the relative calibration procedure shall be repeated twice. Acceptance criteria based upon the repeatability of the calibration factor are identified in the relative calibration procedure. If the results persist in failing the acceptance criteria, then the cause of the erratic results should be identified and corrected.

Table 6 **Checklist for Relative Calibration**

Question	Yes	No	Comments
1. Has interim calibration factor from reference calibration been entered into FWD computer prior to proceeding with relative calibration (p.3)			
2. Have all filters been turned off in FWD? (p.3)			
3. Have rubber buffers been warmed up and test point conditioned by a sequence of ten drops repeated two to three times? (p.14)			
4. Have deflections in a sequence of ten drops been checked to assure they are not steadily decreasing or increasing? (p.14)			
5. Have deflections between 16 and 24 mils been achieved? (p.14)			
6. Are sensors properly labeled with respect to their normal position? (p.13)			
7. Are levels of stand marked correctly? (p.13)			
8. Are two seating drops followed by five replicate drops being applied for each set while holding stand in a vertical position?			
9. Is sensor holder being held firmly in place?			
10. Is sensor holder being held in a vertical position and precisely on same spot? (p.14)			
11. Has loading plate been raised or moved during the relative calibration? (p.14)			
12. Is latest version of the FWD relative calibration software being used?			
13. Has acceptance criteria been used to determine whether calibration must be performed a third time?			
14. Have final calibration factors been entered into FWD field program and printouts of final gains obtained? (Note: printout must be marked as "AFTER CALIBRATION") (p.2)			

Table 7 Relative Calibration Sensor Positions by Set

Level in Sensor Stand	Set:	1	2	3	4	5	6	7
		Defection Sensor Number in the Stand						
(Top)								
A		1	2	3	4	5	6	7
B		2	3	4	5	6	7	1
C		3	4	5	6	7	1	2
D		4	5	6	7	1	2	3
E		5	6	7	1	2	3	4
F		6	7	1	2	3	4	5
G		7	1	2	3	4	5	6
(Bottom)								

Note: The rotation must be done as prescribed above in order for the software (FWDCAL2) to work properly. For instance, for Set 2, move Sensor 2 to the position formerly occupied by Sensor 1, etc.

After the relative calibration is completed, the final calibration factors shall be entered into the FWD computer. A sample relative calibration setup screen for the Dynatest FWD with version 10 or version 20 software is given in Figure 3. The information in Figure 3 can also be used as the basis for setup of Dynatest FWD's running version 25 and higher software.

```
   Relative Calibration
 1. Test UNITS...: lbf.mil.inch     (kPa.mu.mm)
 2. Temperature..: Fahrenheit       (Centigrade)
 3. Stn.Request..: OFF              (ON)
 4. Test Checks..: NONE             (Decreasing defls, Roll-Off, RollOFF+Decr)
 5. Reject prompt: OFF              (ON)
 6. Stationing...: [doesn't matter]
 7. Temp.Request.: OFF              (ON)
 8. Cond.Request.: OFF              (ON)
 9. Variation : Load NOT Checked !  Deflections NOT Checked !
10. Diameter of Plate: 11.8
11. Deflector distances: [doesn't matter - keep what you have]
                          1          2          3          4
12. Drop No.   : 1234567P8901234P5678901P2345678P9012345P6789012P3456789S.......
13. Heights*   : CC44444PCC44444PCC44444PCC44444PCC44444PCC44444PCC44444S1111111
14. Test Plots: .................................................................
15. Save Peaks: ..*****...*****...*****...*****...*****...*****...*****........
16. Load His. : .................................................................
17. Whole His.: .................................................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.

*Note: Drop height should be adjusted to attain deflections within the specified
range.
```

Figure 3 Relative Calibration Test Setup for the Dynatest FWD

Steps in Relative Calibration of the Deflection Sensors

1. Remove all deflection sensors from their holders on the FWD. Make sure that the sensors are labeled (e.g., from 1 to 7, or 0 to 6) with respect to the their normal position on the FWD. The center sensor is position number "1" on the Dynatest FWD and is position number "0" on the KUAB FWD.
2. Label the seven levels on the sensor stand from "A" to "G". The top level is usually labeled "A".
3. Position the seven deflection sensors in the stand for the first of the seven sets according to Table 7.
4. Support the sensor stand in a vertical position. Mark the location where the stand rests so that it can be relocated precisely on the same spot. This may be done by gluing a washer to the pavement, or by making a small divot in the pavement with a chisel.
5. Select the FWD drop height and the distance from the loading plate to the sensor stand to yield deflection on the order of 400 to 600 microns (16 to 24 mils). If deflections in this range cannot be achieved, then it may be necessary to relocate the FWD to a different pavement. In general, a concrete pavement on a relatively weak subgrade will yield the required deflection. In most cases the reference calibration test pad should be usable for relative calibration.
6. Warm up the FWD rubber buffers and condition the test point by repeating a sequence of ten drops until the loads and deflections that are registered are nearly uniform. The deflections in a sequence of ten drops should not be showing a steadily increasing or decreasing trend. If liquefaction or compaction is indicated by the warm-up data,

relocate the FWD to another pavement.

7. Lower the FWD loading plate. **DO NOT** raise the loading plate or remove the FWD during the relative calibration testing. This will assure a constant distance between the center of the load plate and the base of the sensor stand.
8. For each set make two seating drops (no data recorded) followed by five replicate drops (for which data is recorded) while holding the stand in a vertical position. With seven sets and five replicate drops, data for a total of 35 drops is required (see Figure 3).

Relative Calibration Data Analysis

A three-way analysis of variance (ANOVA) technique is used by **FWDCAL2** to evaluate the data. The data analysis results in a set of adjustment factors to determine the final calibration factors.

Relative Calibration Acceptance Criteria

When relative calibration is conducted in conjunction with reference calibration, the procedure is repeated two times. *If the two sets of calibration factors agree within 0.003 for each deflection sensor, then the results of the two tests shall be averaged.* If they are outside the limit, then a third relative calibration shall be performed. If the standard deviation of the three results (based on n-1 degrees of freedom) is less than 0.0030, then the three results shall be averaged. If the standard deviation exceeds 0.0030, then relative calibration procedure should be repeated. A data sheet for the calculations following this procedure is shown in the Appendix B. The average final calibration factors should be computed, and the factor for each deflection sensor should be entered into the FWD computer software (e.g., the "FWD Field Program").

When relative calibration is done alone, typically on a monthly basis, then adjustments of the calibration factors in the FWD Field Program should be made only when those changes are both significant and verified to be necessary. The following guidelines are to be used to evaluate the need for adjustment to the calibration factors:

1. Computed sensor adjustment ratios, R_i, between 0.997 and 1.003 inclusive are considered to be equivalent to a ratio of 1.000. In other words, the required adjustments are trivial and need <u>not</u> be made.
2. Where the adjustment ratios for one or more sensors fall outside of the range 0.997 to 1.003, the relative calibration process should be repeated. If both sets of data agree within 0.003, the gains should be adjusted for all sensors.
3. According to the recommendations of the FWD manufactures, a final calibration factor less than 0.98 or greater than 1.02 is possibly indicative of a damaged sensor, which should be repaired by the manufacturer, or replaced. Final calibration factors that are within this range should be entered into the FWD data collection software.
4. If any calibration factors are changed, the relative calibration process must be repeated to verify the accuracy of all the final values. *The resulting adjustment ratios should be within the range 0.997 to 1.003 for all sensors*. If they are not, the test procedure should be repeated.

CALIBRATION REPORT

The full FWD calibration report will consist of the following:

- Printouts of the following Dynatest FWD Field Program screens (or equivalent for non-Dynatest FWDs).

- Transducer Setup and Calibration factors
- Voltages
- Load Cell Calibration

Each of the above printouts will be annotated with the FWD unit identification (e.g., manufacturer's serial number or agency ID), and the calibration date.

- All printouts from the FWDREFCL software.
- The final printouts from the FWDCAL2 software for all relative calibration trials.
- The Final Calibration Computation worksheet (see Appendix B)

The diskettes on which the reference and relative calibration data are stored will be kept in the FWD. It is recommended that the labeled backup copies be kept on file with the calibration report at the office out of which the FWD is operated. When relative calibration is done alone (e.g., as a monthly calibration check), the relative calibration report will consist of all printouts from the FWDCAL2 software, annotated as necessary to explain any problems which might have been encountered.

COST

The total budgeted cost of the project was approximately $42,000 which include the cost of the dedicated computer, materials, strain gage services, and labor. The total expenditure to date is approximately $40,000. The figure does not include the cost of the building which is a new facility. Appendix C shows the break down of the costs of equipment fabrication done at Kansas State University.

USE AND MAINTENANCE OF THE KANSAS FWD CALIBRATION CENTER

The calibration center is operational as of Spring, 1998. An independent quality assurance visit by PCS/LAW Inc. of Beltsville, Maryland has confirmed that the equipment and setup are working correctly. KSU, from now on, will provide KDOT with continued FWD reference and relative calibration services as per a Memorandum of Understanding (MOU) between KDOT and KSU till year 2002. The MOU defines the mechanics of cooperation between the Secretary of the Kansas Department of Transportation and KSU regarding the use and maintenance of the proposed facility.

REFERENCES

1. AASHTO. *AASHTO Guide for Design of Pavement Structures.* AASHTO, Washington, D.C., 1993
2. SHRP/LTPP. *FWD Calibration Protocol.* Federal Highway Administration, Washington, D.C., March 1994.
3. LTPP/FHWA. Guidelines for the Users of the SHRP FWD Calibration Centers. Report No. FHWA-SA-95-038, November 1994.
3. SHRP/LTPP. *Reference Calibration of Falling Weight Deflectometer: Software User's Guide and Instrumental Manual.* Ver 3.72, March 1994.
4. Law/PCS Engineering & Environmental Services. *FWD Calibration Center Quality Assurance Review Report.* Beltsville, Maryland, May 1998.

APPENDIX A Precalibration Checklist

KANSAS FWD CALIBRATION CENTER

USERS PRE-TRIP CHECKLIST

FWD Operator: ______________________________

Agency: ______________________________

FWD Mfg and Model No.: ______________________________

Serial Nos.: ______________________________

Calibration Date (dd/mm/yyyy): __ /__ /____

Place ✓ Here	
	Repair or replace any damaged connections, fittings, or cables. Damaged cables and bad connections might affect deflection data.
	Properly lubricate, if applicable, the load cell swivel and the bolts torqued to specification. Assure that 12-in (300-mm) diameter load plate is installed.
	Remove the rear extension bar removed on Dynatest FWD, if currently installed.
	Clean the sensor bases. (*Note*: Deflection sensors will be removed from holders for calibration.
	Ensure that the printer is in working order with an adequate supply of printer paper, ink cartridges, etc.
	Format a 3 ½ in" diskette for the calibration data. If your FWD was previously calibrated, bring the diskette that has the last set of calibration results.
	Place your FWD manuals and typical spare parts in the tow vehicle as you may need them in case of unforeseen problems.
	Test all batteries with a hydrometer or load tester. Check battery terminals for corrosion and clean if necessary.
	Bring a relative calibration stand that accommodates the maximum number of sensors used on your FWD.
	Properly maintain the hydraulic system; check for leaks.
	Program the proper test setups into the FWD software (reference and relative calibration).
	Attain target loads of 6,000, 9,000, 12,000, and 16,000 pounds (± 10%) at drop heights 1, 2, 3, and 4. (*Note*: If 6,000 lbs. Load cannot be achieved, use lowest practical drop height.)

Note: **Complete this checklist and present it to the calibration center operator prior to calibration.**

Comments: ______________________________

____

Prepared by: ____________________ Date (dd/mm/yyyy): __/__/____

APPENDIX B: Data Sheets and Criteria Checklists

KANSAS FWD CALIBRATION CENTER

DEFLECTION SENSOR CALIBRATION

Sensor ID: **Date:**
Prev. Calib. Factor:

Sensor No.	Drop Height	Drop No.	Comment
	1	1	
		2	
		3	
		4	
		5	
		6	
	2	1	
		2	
		3	
		4	
		5	
		6	
	3	1	
		2	
		3	
		4	
		5	
		6	
	4	1	
		2	
		3	
		4	
		5	
		6	

Operator:

KANSAS FWD CALIBRATION CENTER

Sensor Calibration Acceptance Criteria:

Sensor ID: ______ **Date:** ______

1. Movement of Beam (during any height): **Yes/No** ______

2. Excessive Noise Message for Heights #2, 3 or 4: **Yes/No** ______

3. Standard Deviations:

Height #	Reference	FWD	Differ by a Factor of 3	Yes/No
1				
2				
3				
4				

4. Standard Error of the Adjustment Factor:

Reference	Criteria (at most 0.0020)	Yes/No

5. Peak Deflections (for the high drop height or 16,000 lb level):

Drop #	(less than 16 mils?)		Yes/No
1			
2			
3			
4			
5			

FINAL: ACCEPT/REJECT ______

Operator ______

KANSAS FWD CALIBRATION CENTER

FWD LOAD REFERENCE CALIBRATION

Reference Calibration Pass Number:

Load Cell ID:	
Prev. Cal. Factor:	

Date:	
Operator:	

Test No.	Height No.	Drop No.	Comment
	1	1	
		2	
		3	
		4	
		5	
		6	
	2	1	
		2	
		3	
		4	
		5	
		6	
	3	1	
		2	
		3	
		4	
		5	
		6	
	4	1	
		2	
		3	
		4	
		5	
		6	

KANSAS FWD CALIBRATION CENTER

FWD Load Cell Reference Calibration Acceptance Criteria Check:

		Pass No. No. 1	No. 2	Comment
1. Excessive Noise Messages For Drop Heights 2, 3 or 4:				Differ by a Factor of 3 From the Ref. System?
2. Standard Deviation of Five (5) Readings for Height No:				
	1			
	2			
	3			
	4			
3. Standard Error of Adjustment: *(should be less than 0.002)*				
4. Repeatibility Criteria: (*factors from two passes should be Within 0.003 or see Protocol p.7 March 1994*)				
FINAL: ACCEPT/REJECT		CHECKED BY:		DATE:

KANSAS FWD CALIBRATION CENTER

COMPUTATION SHEET FOR THE FINAL CALIBRATION FACTORS

FWD No. **Date:**

Sensor	Final Calibration Factors from Relative Calibration					Avg. Final Calibration Factors	Standard Deviation /(less than 0.003 ?)	Comment
	Trial 1	Trial 2	Abs. Diff.	Comment	Trial 3			
1								
2								
3								
4								
5								
6								
7								

Operator:

Supervisor:

APPENDIX C: Cost Break Down for Equipment Fabrication

KSU/KDOT

FWD CALIBRATION CENTER

HARDWARE COSTS (MATERIAL AND LABOR)

				Labor - $39 p.h.	
			UNIT COST		TOTAL
ASSEMBLY	ITEM	QTY	MATERIAL	LABOR/HRS	COST
	concrete		$346.50		
Concrete Block	4'X8'X3/4" plywood				
	4'x8'x1/2" plywood				
	5/8" threaded rod, 72" long				
	3/8" re-bar				
	5/8" re-bar				
	1/2" x 14 1/2" x 12" steel plate				
	2"x4"x8' lumber				
	4"x4" rubber pads				
	stud bolts				
	Labor			24 hrs.	**$ 936.00**
I-Beam	Wide Flange Aluminum Beam		$600.28	2 hrs	$ 78.00
	Base Plate			1/2 hrs	$ 19.50
	LVDT Mounting Plate			5 hrs	$ 195.00
	Welding				
	Labor			5 1/2 hrs	**$ 214.50**
LVDT Clamp	LVDT Clamp			3 hrs	$ 117.00
	Top Plate			4 hrs	$ 156.00
	Bottom Plate			1 hr	$ 39.00
	Spacer			1 hr	$ 39.00
	KUAB Seismometer Mount			2 1/2 hrs	$ 97.50
	Washer				$ 39.00
	Stainless Steel Bolts with washers				$ 78.00
	Hex Head cap screws				$ 156.00
	Labor			11 1/2 hrs	**$ 448.50**
LVDT	DC-LVDT (Schavitz 6CD-121-125)				
	LVDT Calibrator				
	in house			4 hrs	$ 156.00
	LVDT Connector Plug				
	LVDT Cable				
	Cable Clamp				
	Assemble cable			4 hrs	$ 156.00
	Labor			8 hrs	**$ 312.00**

KSU/KDOT

FWD CALIBRATION CENTER

HARDWARE COSTS (MATERIAL AND LABOR) CONT.

			UNIT COST		TOTAL
ASSEMBLY	ITEM	QTY	MATERIAL	LABOR/HRS	COST
LVDT Tip	Magnet Aluminum Rod Threaded Rod Labor			2.5 hrs	$ 97.50 **$ 97.50**
KUAB Seismometer Holder	KUAB Seis. Holder Frame KUAB Seis. Mount Base Plate Steel Rod Machine Screws Labor-shop Labor- technician			2.5 hrs	$ 97.50 **$ 97.50**
lvdt holder, tall Misc. parts	frame Stem allum. Etc. Labor			6 hrs	$ 234.00 **$ 234.00**
Dynatest Geophone Holder	Aluminum Frame Steel clip Circluar Base Plate Aluminum Base Machine Screws Steel Rod Labor			4 hrs	$ 156.00 **$ 156.00**
Metrabyte Board installation	DAS-16G2 Board STA-16 Screw Terminal C-1800 Ribbon Cable			2 hrs	**$ 78.00**
Vishay Signal Conditioner	Vishay Model 3210 modified for +/- 15v output Line Cord and Stabilizer Extra Amphenol Plug Option V Option Y Modify Vishay for +/- 15v DC installation			2 hrs	**$ 78.00**

FWD CALIBRATION CENTER
HARDWARE COSTS (MATERIAL AND LABOR) CONT.

			UNIT COST		TOTAL
ASSEMBLY	ITEM	QTY	MATERIAL	LABOR/HRS	COST
Reference Load Cell Calib. Equipment	Aluminum Plate		$314.00		
	Wood Block				
	Labor			24 hrs	$ 936.00
Load Cell Calibration Push Button	Box, Radio Shack #270-230				
	Cable, 3-conductor, shielded				
	2 kOhm Resistor Radio Shack # 271-1321				
	Push Button Switch, Radio Shack # 275-609				
	Cable Strain relief, Radio Shack #278-1636				
	3-lug strip, Radio Shack #274-688 (see note below)				
	Labor			3 hrs	$ 117.00
					$ 1,053.00
Load Cell	Body and Lid				
	welding/ mach. Work		$ 65.00		
	Strain gages				
	Mount Strain gages		$ 1,627.75		
	Amphenol Recepticle				
	Amphenol Plug				
	Cable				
	Cable Clamp				
	Ribbed Rubber sheet				
	Guide posts			16 hrs	$ 624.00
	Labor, assemble cable			3 hrs	$ 114.00
	Load Cell Feet Labor - shop			3 hrs	$ 114.00
	Misc. tools & supplies		$ 468.08		**$ 852.00**
Signal Light	Box, Radio Shack #270-230				
Misc. parts	Cable, Radio Shack #278-513				
	LED holder Radio Shack #276-079				
	LED, Radio Shack #276-022				
	Cable Strain Relief Radio Shack #278-1636				
Note:	(Radio Shack total parts)		$ 43.41		
	Build FWD Lab/Building		$ 1,279.65	60 hrs	$ 2,340.00
	Misc. tools and supplies		$ 817.58		
	Metal, alum. plate, etc...		$ 1,185.68		
	Battery chargers, Sears		$ 369.95		
	10X14 building		$ 429.95		
					$ 39.00
					$ 2,379.00
			$ 7,547.83		$ 6,936.00