UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1055-89

PROCEDURE FOR

CALIBRATING DIFFERENTIAL PRESSURE TRANSDUCERS

INTRODUCTION

This procedure is under the jurisdiction of the Geotechnical Services Branch, code D-3760, Research and Laboratory Services Division, Denver Office, Denver, Colorado. The procedure is issued under the fixed designation USBR 1055. The number immediately following the designation indicates the year of acceptance or the year of last revision.

1. Scope

1.1 This designation outlines the procedure for calibrating differential pressure transducers by establishing a relationship between transducer output and change in height of a water column (volume tube). From this relationship the linearity, hysteresis, and repeatability of the differential pressure transducer are determined.

1.2 A lateral pressure correction factor which is defined as the slope of a line relating the difference between observed volume tube readings and differential pressure transducer output to applied lateral pressure is also determined [1].[1]

NOTE 1.–This procedure was prepared for calibrating differential pressure transducers used to measure volume change of soil specimens associated with laboratory triaxial shear testing as shown on figure 1. With some modifications it may also be used to calibrate differential pressure transducers used in other laboratory testing.

2. Auxiliary Tests

2.1 The pressure gauge and volume tube used in this procedure must be calibrated in accordance with USBR 1040 and 1455 respectively prior to performing this calibration procedure.

3. Applicable Documents

3.1 *USBR Procedures*:
USBR 1040 Calibrating Pressure Gauges
USBR 1455 Calibrating Volume and Drain Tubes
USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics

4. Summary of Method

4.1 A differential pressure transducer is attached to a testing apparatus in which the height of a column of water in a volume tube can be measured both electronically and visually. The volume tube is filled with de-aired water and drained or filled as appropriate to change the height of water column. The change in height of water column is compared to the output from the differential pressure transducer at selected intervals over the range to be calibrated. The linearity, hysteresis, and repeatability of the differential pressure transducer are determined.

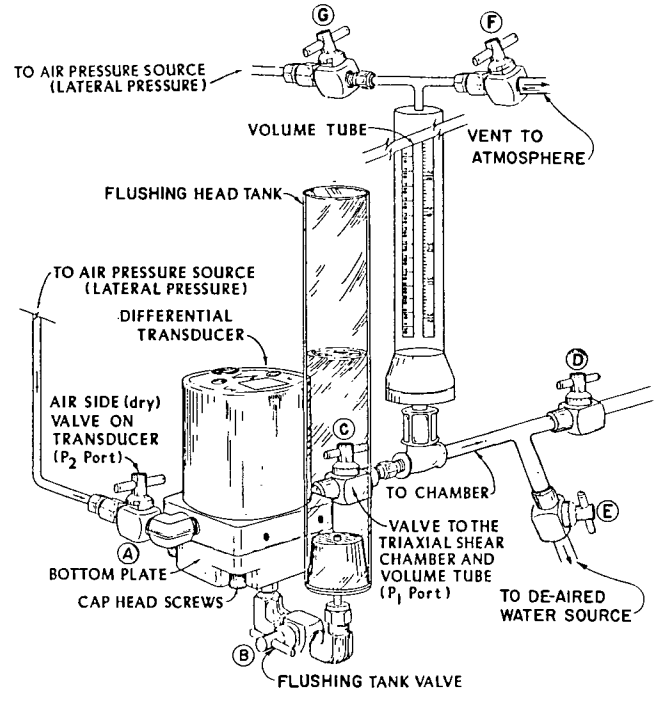

Figure 1. – Differential pressure transducer mounted on a triaxial shear machine.

5. Significance and Use

5.1 Calibrated differential pressure transducers may be used in the laboratory to obtain data electronically which allows the calculation of volume change or flow rate.

5.2 This calibration procedure is to be performed when the differential pressure transducer is put into service and verified before each test.

6. Terminology

6.1 Definitions are in accordance with USBR 3900.

6.2 Terms not included in USBR 3900 specific to this designation are:

[1] Number in brackets refers to reference.

6.2.1 *Linearity.*-The variation of transducer output from a straight line. In this procedure, measurements are obtained using a series of reference pressures (water column heights) applied over the total rated capacity of the differential pressure transducer.

6.2.2 *Repeatability.*-The maximum difference between transducer outputs for repeated pressures (water column heights) under identical loading and environmental conditions.

6.2.3 *Hysteresis.*-The maximum difference between transducer output for the same applied pressure; one reading obtained by decreasing the pressure from the upper calibration limit (not to exceed the transducer rated capacity) to zero, and the other by increasing the pressure from zero to the upper calibration limit.

6.2.4 *Rated Capacity.*-The maximum differential pressure the transducer is designed to measure.

7. Apparatus

7.1 *Differential Pressure Transducer.*-A differential pressure transducer, as shown on figure 2, of sufficient range and accuracy for its intended laboratory testing application.

7.2 *Pressure Gauge.*-A bourdon tube air pressure gauge having a range equal to or greater than that of the differential pressure transducer to be calibrated. The gauge must have a current calibration accompanied with a certificate of traceability.

7.3 *Pressure Source.*-An air pressure source capable of delivering and maintaining pressure up to the maximum rated pressure of the transducer.

7.4 *Digital Voltmeter.*-A voltmeter having a digital display of the electrical signal being sent from the signal conditioner which can be read accurately to the nearest 1 millivolt.

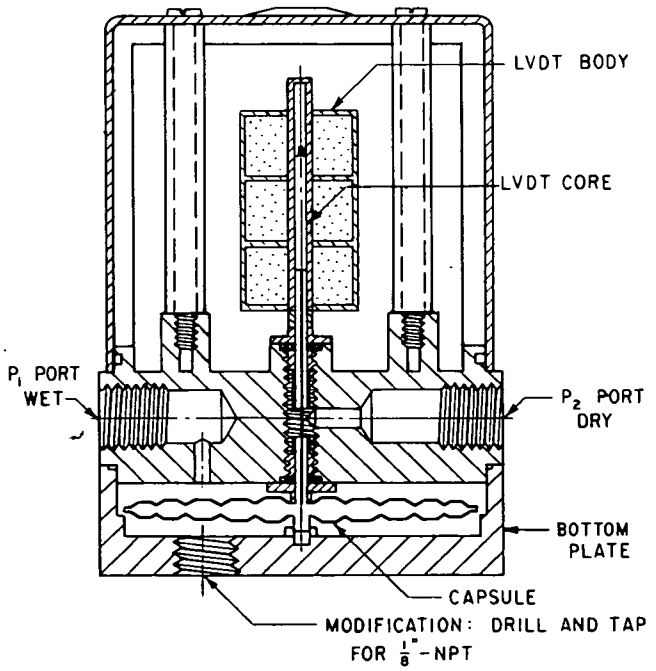

Figure 2. - Cutaway view of differential pressure transducer.

7.5 *Head Tank and Volume Tube.*-A head tank and volume tube as shown on figure 1. The volume tube should be graduated to be read to the nearest 0.01 inch over the range of typical use.

7.6 *De-aired Water.*-De-aired water, as described in subparagraph 8.1, is used for performing the calibration of the differential pressure transducer.

7.7 *Vacuum Pump.*-A hand-held vacuum pump used to remove entrapped air from the system.

7.8 *Signal Conditioner.*-A signal conditioner must be used to make the differential pressure transducer output compatible with the readout system.

7.9 *Miscellaneous Equipment.*-Appropriate size valves and pipe fittings used to attach the differential pressure transducer to the testing apparatus.

8. Reagents and Materials

8.1 De-aired water that is free of acids, alkalies, or oils, and is suitable for drinking should be used for calibrating the differential pressure transducer.

9. Precautions

9.1 *Safety Precautions*:

9.1.1 Ensure that all electrical wiring is properly connected.

9.1.2 Examine the differential pressure transducer body for burrs and sharp edges.

9.1.3 This procedure involves the use of compressed air. Appropriate precautions must be taken.

9.2 *Technical Precautions*:

9.2.1 Modifications to the procedure (outlined in par. 12) are required for calibration of differential pressure transducers used in applications other than on the triaxial shear assembly shown on figure 1. (See note 2.)

9.2.2 Use the same electrical cables for calibrating the transducer and for performing a test. A different cable length will change the resistance of the circuit and will result in a change in calibration.

9.2.3 It is recommended that the serial number be used for identification. If the transducer must be marked, use extreme care. Use an indelible marking pencil rather than a scribe to mark on the transducer body.

9.2.4 The transducer must be stored in a suitable box or case when not in use.

10. Calibration and Standardization

10.1 Verify that the pressure gauge and the volume tube used are currently calibrated in accordance with USBR 1040 and 1455 respectively. If the calibration is not current, perform the calibration before using the equipment for this procedure.

10.2 Verify that the readout system is currently calibrated. If the calibration is not current, it is to be calibrated in accordance with the manufacturer's guidelines. A voltmeter may be used as the readout system for this

calibration procedure. At the Bureau's Denver Office, a computer is used to accept the output signal from the signal conditioner and convert it into a transducer measurement.

11. Conditioning

11.1 Perform this calibration procedure in an area isolated from wide temperature variations and electrical power surges.

11.2 To ensure stability allow all electronic equipment to warm up a minimum 30 minutes before use.

11.3 Place the differential pressure transducer, pressure gauge, volume tube, and electronic equipment in the environment in which they are to be calibrated at least 24 hours prior to time of calibration.

12. Procedure

NOTE 2.–The following procedure is for calibration of a differential pressure transducer mounted on a triaxial shear assembly as shown on figure 1. Generally, the calibration procedure outlined in this designation can be used for calibrating differential pressure transducers used for other applications; however, modifications to the procedure presented here may be necessary.

12.1 All data are to be recorded on the "Differential Pressure Transducer Calibration Sheet" as shown on figure 3.

12.2 Locate and record the rated capacity, serial number and manufacturer of the differential pressure transducer.

12.3 Record the water column height differential for which the differential pressure transducer is to be calibrated as the *CR* (*Calibration range*). (For the example used in this procedure the value is 30.00 inches.)

12.4 Close the valve between the differential pressure transducer and the volume tube. Open the valve on the "dry" side to the differential pressure transducer so that the "dry" side is open to atmospheric pressure.

12.5 Close the valve from the volume tube to the triaxial shear chamber (valve D on fig. 1) and fill the volume tube with de-aired water by opening valve E to the de-aired water source. (At least fill to the 10-inch (254-mm) level for a 32-inch (813-mm) volume tube.)

12.6 Close the valve from the flushing tank to the differential pressure transducer (valve B on fig. 1) and fill the flushing tank about one-half full with de-aired water.

12.7 Remove the bottom plate on the differential pressure transducer by unscrewing the cap head screws that hold the bottom plate to the body of the transducer.

12.8 Open valve B to the flushing tank and allow water to cover the exposed capsule.

12.9 Leave the flushing tank valve slightly open. If the flushing tank valve is not left slightly open, while the bottom plate is being placed, damage may occur to the capsule.

12.10 Fill the cavity in the bottom plate with deaired water. Securely place the bottom plate back onto the differential pressure transducer while being careful not to entrap air.

12.11 Open the valves that connect the flushing tank and volume tube to the differential pressure transducer.

12.12 Secure the rubber stopper attached to the hand held vacuum/pressure pump to the top of the flushing tank and pump de-aired water from the flushing tank through the transducer into the volume tube and back into the flushing tank.

12.13 Close both the flushing tank and volume tube valves.

NOTE 3.–Use extreme caution when flushing the system. A flushing pressure greater than 10 lbf/in^2 (70 kPa) can damage the measuring capsule inside the differential pressure transducer.

12.14 Using appropriate cables, connect a voltmeter and signal conditioner to the pressure transducer.

12.15 Activate the voltmeter and select a range capable of measuring at least 5-volts d.c.

12.16 Disconnect the lateral pressure air hose which runs from the triaxial shear assembly control panel to the top of the volume tube. Open the valve at the top of the volume tube (valve F on fig. 1) so the top of the volume tube is open to atmospheric pressure.

NOTE 4.–If the lateral pressure hose is not disconnected from the control panel, the regulator often allows a small amount of air to leak through it, and the differential pressure transducer will function erratically. The transducer output will not stabilize because the applied pressure is unsteady.

12.17 Open the valves from the transducer to the flushing tank and volume tube and slowly drain water in the volume tube to the 30.00-inch mark on the volume tube. Close the flushing tank valve.

12.18 Read and record the voltmeter output as the *Voltage output at minimum volume tube height.* The voltmeter should register 1.000±0.004 volts. If it does not, adjust the zero screw on the differential pressure transducer until the correct reading is obtained. The zero screw on the differential pressure transducer adjusts the gain on the amplifier.

12.19 Open the valve to the de-aired water supply (valve E on fig. 1) to fill the volume tube with de-aired water to the 0.00-inch mark on the scale; close the valve and read and record the voltmeter output as the *Voltage output at maximum volume tube height.* The voltmeter should read 4.000±0.004 volts. If it does not, adjust the span screw on the differential pressure transducer.

12.20 Repeat subparagraphs 12.17 through 12.19 until the desired values are obtained.

12.21 If more than five trials are necessary to obtain the desired values, the unit should be examined for leaks or entrapped air and this portion of the procedure repeated.

12.22 Determine the linearity, hysteresis, and repeatability.

12.22.1 Fill the volume tube to the 0.00-inch marking on the scale by opening the valve to the de-aired water supply (valve E).

12.22.2 Close valve E and record the volume tube reading and the differential pressure transducer output as the *Volume tube water column height, in* and *Pressure transducer output, V,* under the "Decreasing head" section as shown on figure 3.

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Bureau of Reclamation

DIFFERENTIAL PRESSURE TRANSDUCER
CALIBRATION SHEET

Designation USBR 1055-89

MANUFACTURER	SERIAL NO.
Example	1

RATED CAPACITY	CR (Calibration range)
50.0	30.0 inch of H_2O

CALIBRATION PERFORMED BY	DATE	COMPUTED BY	DATE	CHECKED BY	DATE

(a)	VOLTAGE OUTPUT AT MINIMUM VOLUME TUBE HEIGHT	1.000 V
(b)	VOLTAGE OUTPUT AT MAXIMUM VOLUME TUBE HEIGHT	4.000 V
(c)	DIFFERENCE IN VOLTAGE OUTPUT (a)-(b)	-3.000 V
(d)	SLOPE OF CALIBRATION LINE = (CR)/(c)	-10.00 in/V
(e)	(CR) - (d)(a)	40.00 in

DECREASING HEAD			INCREASING HEAD		
VOLUME TUBE WATER COLUMN HEIGHT (in) (1)	PRESSURE TRANSDUCER OUTPUT (V) (2)	PRESSURE TRANSDUCER OUTPUT (Inch of H_2O) = (d)(2) + (e) (3)	VOLUME TUBE WATER COLUMN HEIGHT (in) (4)	PRESSURE TRANSDUCER OUTPUT (V) (5)	PRESSURE TRANSDUCER OUTPUT (Inch of H_2O) = (d)(5) + (e) (6)
Trial No. 1					
0.00	3.999	0.01	0.00	4.003	-0.03
5.00	3.499	5.01	5.00	3.502	4.98
10.00	2.998	10.02	10.00	3.001	9.99
15.00	2.499	15.01	15.00	2.501	14.99
20.00	1.998	20.02	20.00	1.999	20.01
25.00	1.501	24.99	25.00	1.501	24.99
30.00	0.999	30.01	30.00	0.999	30.01
Trial No. 2					
0.00	4.003	-0.03	0.00	3.999	0.01
5.00	3.500	5.00	5.00	3.500	5.00
10.00	2.999	10.01	10.00	3.001	9.99
15.00	2.499	15.01	15.00	2.502	14.98
20.00	2.003	19.97	20.00	2.001	19.99
25.00	1.501	24.99	25.00	1.499	25.01
30.00	0.999	30.01	30.00	0.999	30.01

LINEARITY % ERROR	HYSTERESIS % ERROR	REPEATABILITY % ERROR
$\left\lvert\frac{(1)-(3)}{(CR)}\right\rvert \times 100$	$\left\lvert\frac{(3)-(6)}{(CR)}\right\rvert \times 100$	$\left\lvert\frac{(3)1st-(3)2nd}{(CR)}\right\rvert \times 100$
Trial No. 1		
0.03	0.13	0.13
0.03	0.10	0.03
0.07	0.10	0.03
0.03	0.07	0.00
0.07	0.03	0.17
0.03	0.00	0.00
0.03	0.00	0.00
Trial No. 2		
0.10	0.13	
0.00	0.00	
0.03	0.07	
0.03	0.10	
0.10	0.07	
0.03	0.07	
0.03	0.00	

ACCEPT [X]
REJECT [ ]

REMARKS: _____

Figure 3. - Differential pressure transducer calibration sheet — example.

12.22.3 Open the valve to the flushing tank and allow water in the volume tube to drain 5.00 inches (127 mm) and close the valve.

12.22.4 Repeat subparagraphs 12.22.2 and 12.22.3 for the full range to be calibrated.

12.22.5 Open the valve to the water source (valve E) and allow the water level to rise in the volume tube 5.00 inches.

12.22.6 Record the volume tube reading and the differential pressure transducer output as the *Volume tube water column height, in*, and *Pressure transducer output, V*, under the "Increasing head" section as shown on figure 3.

12.22.7 Repeat subparagraphs 12.22.5 and 12.22.6 until the water level in the volume tube is elevated to the 0.00-inch mark on the scale.

12.22.8 Repeat subparagraphs 12.22.1 through 12.22.7 to obtain a second set of readings.

12.22.9 Calculate and record the *Pressure transducer output, Inch of H_2O*, for each pressure (volume tube water column height, in) increment as shown on figure 3.

12.22.10 Calculate the differential pressure transducer linearity, hysteresis, and repeatability for each pressure (volume tube water column height, in) increment.

12.22.11 Evaluate the values of error obtained. If the percent error for linearity, hysteresis, or repeatability does not fall within the tolerances specified by the manufacturer, the calibration procedure is to be repeated. If the differential pressure transducer still does not meet specified requirements, it is to be rejected for laboratory use.

12.23 Determine the lateral pressure correction factor.

NOTE 5.–Specimen volume change during laboratory testing of soil, e.g., triaxial shear or back pressure permeability, can be measured by determining the amount of water entering or leaving a confining pressure cell. Research performed in the Bureau's Geotechnical Services Branch, Research and Laboratory Services Division, Denver Office, Denver, Colorado, demonstrated the feasibility of using a differential pressure transducer for soil specimen volume change measurement [1]. To accurately measure specimen volume change using a differential pressure transducer, the response of the differential pressure transducer to varying applied lateral pressures must be determined. This relationship is used to determine a lateral pressure correction factor.

12.23.1 All data are to be recorded on the "Lateral Pressure Correction Factor" form as shown on figure 4.

12.23.2 De-air and flush the volume tube and differential pressure transducer as outlined in subparagraphs 12.4 through 12.17.

12.23.3 Set the water level in the volume tube at about the 10-inch (254-mm) mark on the scale and record the value as the *Volume tube water column height, in.*

12.23.4 Ensure that the lateral pressure gauge reading is 0.0 lbf/in^2 and record the value as the *Applied lateral pressure.*

12.23.5 Connect one end of the lateral pressure line to the valve at the top of the volume tube and the other end to the lateral pressure gauge on the control panel.

12.23.6 Close the valves located at the top of the volume tube (valves F and G on fig. 1).

12.23.7 Raise the lateral pressure approximately one-eighth the differential pressure transducer rated capacity and record the value of lateral pressure applied as indicated by the lateral pressure gauge. Slowly open the valve G located at the top of the volume tube.

12.23.8 Allow the system to stabilize a minimum of 5 minutes at each lateral pressure increment. Read and record the *Volume tube water column height, in* and the *Pressure transducer output, V*, as shown on figure 4.

12.23.9 Raise the lateral pressure in increments of approximately one-eighth the differential pressure transducer rated capacity and repeat subparagraph 12.23.8 for the full range to be calibrated.

12.23.10 Calculate and record the *Pressure transducer output, Inch of H_2O* as shown on figure 4.

12.23.11 Calculate the difference between the *Volume tube water column height, in* and the *Pressure transducer output, Inch of H_2O* for each lateral pressure increment.

12.23.12 Plot the data obtained as shown on figure 5.

12.23.13 Calculate the equation of the calibration line. The slope of the line is equal to the lateral pressure correction factor.

13. Calculations

13.1 The calculations of linearity, hysteresis, and repeatability are as shown on figure 3.

13.2 Calculations required to determine the lateral pressure correction factor are as shown on figure 4 and 5.

14. Report

14.1 The report is to consist of the following completed and checked forms and plot:

"Differential Pressure Transducer Calibration Sheet" (fig. 3).

"Lateral Pressure Correction Factor" (fig. 4).

A plot of the obtained data (fig. 5).

14.2 All calculations are to show a checkmark and all plotting must be checked.

15. Reference

[1] Benavidez, Abel A., *Utilization of Differential Pressure Transducers to Measure Volume Change of Soil Specimens During Triaxial Shear Testing*, Bureau of Reclamation Report No. REC-ERC-84-10, 22 pp., Denver, Colo., April 1984.

LATERAL PRESSURE CORRECTION FACTOR

Designation USBR 1055-89

(1) APPLIED LATERAL PRESSURE psi [X] kPa [ ]	(2) VOLUME TUBE WATER COLUMN HEIGHT (in)	(3) PRESSURE TRANSDUCER OUTPUT (V)	(4) = (d*)(3) + (e*) PRESSURE TRANSDUCER OUTPUT (inch of H_2O)	(5) |(2)-(4)|	(6) ORDERED PAIRS	
					(1)	(5)
0.0	10.00	2.999	10.01	0.01	0.0	0.01
25.0	10.00	2.994	10.06	0.06	25.0	0.06
50.0	10.01	2.987	10.13	0.12	50.0	0.12
75.0	10.03	2.980	10.20	0.17	75.0	0.17
100.0	10.04	2.973	10.27	0.23	100.0	0.23
125.0	10.05	2.967	10.33	0.28	125.0	0.28
150.0	10.07	2.959	10.41	0.34	150.0	0.34
175.0	10.09	2.952	10.48	0.39	175.0	0.39
200.0	10.11	2.945	10.55	0.44	200.0	0.44

*Values obtained from differential pressure transducer calibration.

(d) = -10.00

(e) = 40.00

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Figure 4. – Lateral pressure correction factor — example.

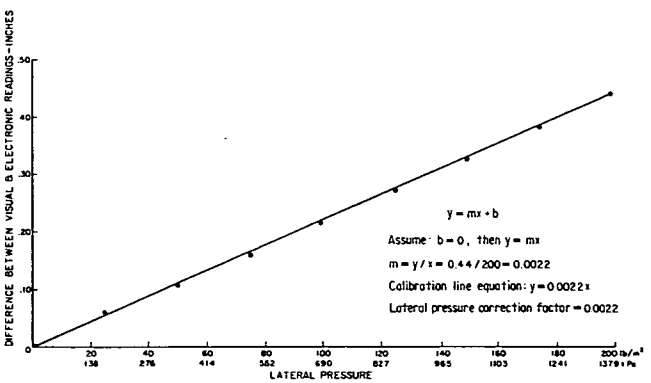

Figure 5. – Plot of lateral pressure correction factor — example.