UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

USBR 1045-89

PROCEDURE FOR

CALIBRATING FORCE TRANSDUCERS (LOAD CELLS)

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 1045. 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 force transducers (load cells) for laboratory use. Two calibration methods are described. Method A outlines a calibration procedure using a platform scale load frame and a set of calibration masses for applying compressive forces or hanging a set of calibration masses to apply tensile forces. Method B describes a calibration procedure using a universal testing machine. Force transducers (load cells) can be calibrated in tension or compression using either method.

2. Auxiliary Tests

2.1 The universal testing machine used in this procedure must be calibrated in accordance with ASTM E 4. The platform scale load frame used in this procedure must be calibrated in accordance with USBR 1012 prior to performing this calibration procedure.

3. Applicable Documents

3.1 *USBR Procedure*:
USBR 1012 Calibrating Balances or Scales
3.2 *ASTM Standard*:
E 4 Load Verification of Testing Machines

4. Summary of Method

4.1 A force transducer (load cell) is loaded in either tension or compression using either a platform scale load frame and mass standards (method A, compression) and hanging standard masses (method A, tension), or a universal testing machine (method B). Forces are applied to the force transducer in increments over its rated capacity. The electrical output of the force transducer is compared to the known force applied at each force increment; and the linearity, hysteresis, repeatability, and creep of the force transducer are determined.

5. Significance and Use

5.1 A calibrated force transducer (load cell) must be used in the laboratory to ensure reliable test results.

5.2 This calibration procedure is to be performed upon receipt of the force transducer and annually thereafter.

6. Terminology

6.1 Definitions are in accordance with USBR 3900.

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

6.2.1 *Creep.*–Time-dependent strain or deformation; for example, continuing strain with sustained stress (ASTM definition).

6.2.2 *Hermetically sealed.*–Sealed and guaranteed to be airtight.

6.2.3 *Universal.*–In the text of this procedure, the term universal implies that the device can apply either compression or tension loads.

6.2.4 *Linearity.*–The variation of force transducer output values from a straight line. The measurements are obtained using a series of standard loads applied over the total rated capacity of the force transducer.

6.2.5 *Repeatability.*–The maximum difference between force transducer output readings for repeated loadings under identical loading and environmental conditions.

6.2.6 *Hysteresis.*–The maximum difference between force transducer output for the same applied load; one reading obtained by increasing the load from zero to the force transducer rated capacity, and the other by decreasing the load from the force transducer rated capacity to zero.

6.2.7 *Rated Capacity* (maximum capacity).–The maximum axial load the force transducer is designed to measure within its specifications.

7. Apparatus

7.1 *Force Transducer* (load cell).–A transducer (fig. 1) which converts changes in force into an electrical output.

7.1.1 Components of the force transducer should possess the following characteristics:

7.1.1.1 The force transducer should be hermetically sealed to prevent damage to the internal electrical components in the event of exposure to moisture.

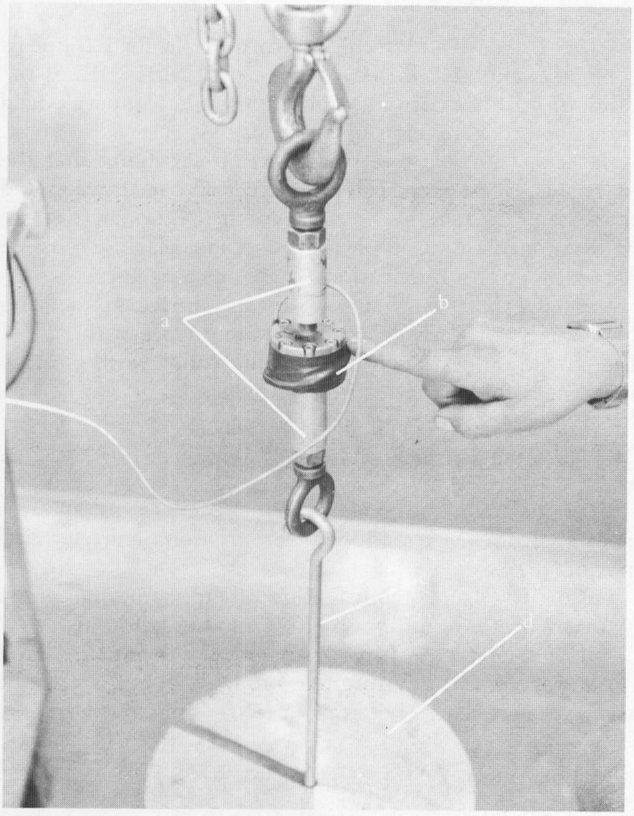

Figure 1. - Force transducer (load cell) and hanger. a) load cell couplers, b) load cell, c) hook, and d) hanger assembly with mass.

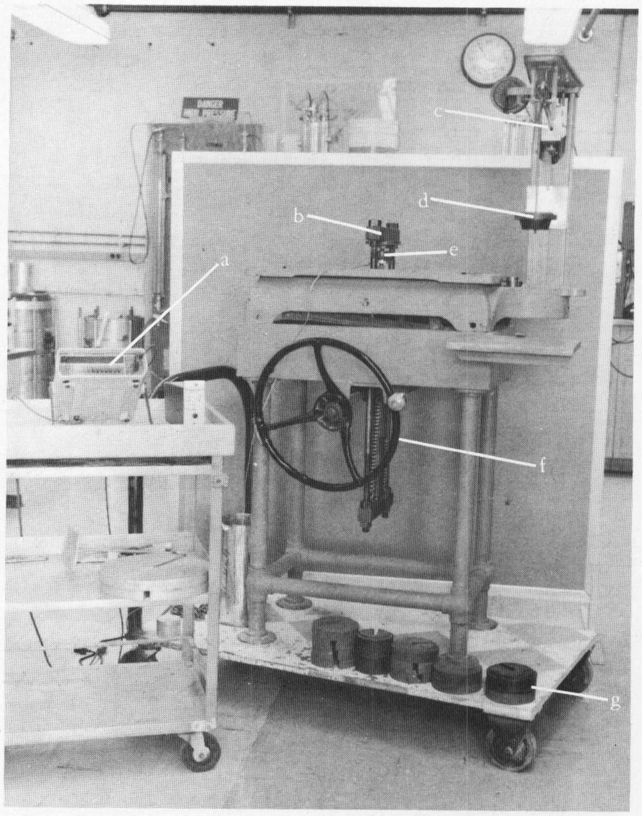

Figure 2. - Platform scale load frame. a) digital voltmeter, b) loading yoke, c) scale beam, d) scale beam hanger, e) load cell, f) wheel, and g) calibration masses.

7.1.1.2 The force transducer should be threaded with appropriate size threaded fittings to attach the load cell to the test frame.

7.1.1.3 The cable and cable gland connections should be securely fastened to the body of the load cell.

7.2 *Signal Conditioner.*-A device necessary to make the electrical output from the transducer compatible with the readout system.

7.3 *Readout System.*-A device (voltmeter or computer) that accepts the output signal from the signal conditioner and converts it into a visual display.

7.4 *Method A Equipment Requirements.*-Platform scale load frame (fig.2):

7.4.1 *Loading Apparatus.*-A mechanical loading device used to apply a known compression load to the force transducer by way of a system of knife edges and beams. A unit having the capacity to apply 2,000 pounds-force (8.896 kN) in compression is sufficient for most calibration tasks in a geotechnical laboratory.

7.4.2 *Calibration Masses.*-A set of precision calibration masses used to apply loads to the force transducer in increments of approximately 20, 40, 60, 80, and 100 percent of the rated capacity of the force transducer.

7.4.3 *Hanger.*-A hanger assembly, yoke, or hook from which to hang calibration masses from the force transducer as shown on figures 1 and 3.

7.5 *Method B Equipment Requirements.*-A Universal testing machine (fig. 4) capable of applying tension or compression loads in excess of 25,000 pounds-force (111 kN). Universal testing machines are used when force transducer calibrations require loads in tension or compression beyond the practical range of calibration masses or other mechanical loading devices. Verify that the universal testing machine was calibrated within the past year in accordance with ASTM E 4.

8. Precautions

8.1 *Safety Precautions*:

8.1.1 This designation may involve hazardous materials, operations, and equipment.

8.1.2 Examine the load cell body for burrs and sharp edges.

8.1.3 Verify that all electrical wiring is properly connected.

8.1.4 Safety shoes are to be worn when handling calibration masses.

8.2 *Technical Precautions*:

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

8.2.2 It is recommended that the serial number be noted for control purposes. Use a marking pencil rather

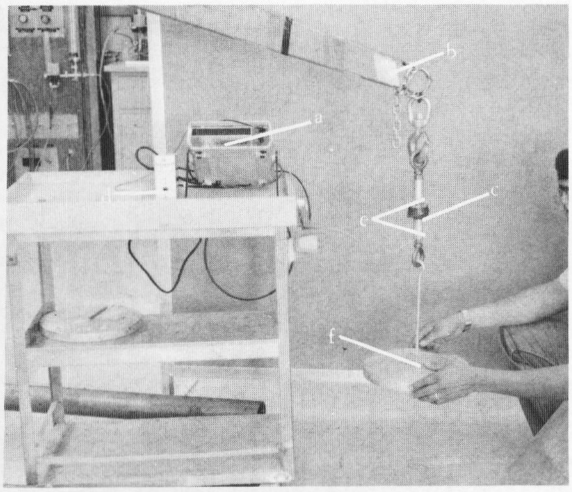

Figure 3. - Force transducer hanger assembly for tension calibration using mass standards. a) digital voltmeter, b) hoist, c) load cell, d) signal conditioner, e) load cell couplers, and f) hanger assembly.

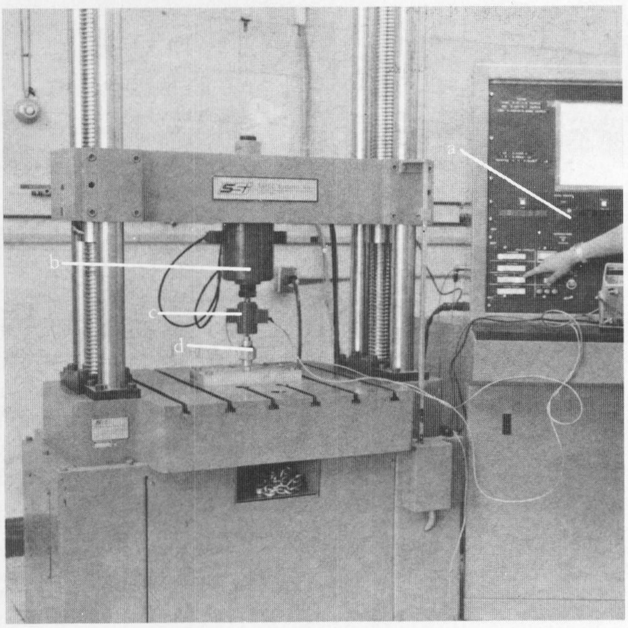

Figure 4. - Universal testing machine. a) control panel, b) universal testing machine force transducer, c) force transducer being calibrated, and d) coupler.

than a scribe to mark on the transducer body. If the force transducer must be marked, use extreme care.

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

9. Calibration and Standardization

9.1 Verify that the readout system used is currently calibrated. If calibration is not current, it is to be calibrated in accordance with manufacturer's guidelines.

9.2 *Method A*:

9.2.1 Verify that the platform scale load frame is currently calibrated in accordance with USBR 1012. If the calibration is not current, calibrate the platform scale load frame before using for this procedure.

9.2.2 A certificate of inspection certifying that the mass calibration standards meet Federal specification and that their accuracy is traceable to the National Institute of Standards and Technology (National Bureau of Standards) or an International standard is required.

9.3 *Method B*.-Verify that the universal testing machine is currently calibrated in accordance with ASTM E 4. If the calibration is not current, calibrate the testing machine before using for this procedure.

10. Conditioning

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

10.2 To ensure stability, allow all electronic equipment to warm up for a minimum of 30 minutes before use.

10.3 Place the force transducer and calibration standards in the environment in which they are to be calibrated at least 24 hours prior to the time of calibration.

11. Procedure

11.1 All data are to be recorded on the "Force Transducer (Load Cell) Calibration" form as shown on figure 5.

11.2 Connect all electronic components to an appropriate power supply and allow the equipment to warm up a minimum of 30 minutes before use.

11.3 *Method A — Calibration Using a Platform Scale Load Frame and Mass Standards* (compression, fig. 2):

11.3.1 Connect the force transducer to the signal conditioner using appropriate connecting hardware.

11.3.2 Adjust the signal conditioner so the output of the force transducer is 0.000 volt d-c with zero mass on the force transducer.

11.3.3 Place the force transducer on the platform scale, and tare its mass so that the scale beam of the platform scale is balanced.

11.3.4 Position the force transducer directly beneath the loading yoke and plate of the platform scale load frame. Ensure that the force transducer loading pins are in the vertical position. (For some force transducers, it may be necessary to turn a nut onto each loading pin to hold the load cell vertical, level, and in compliance with the requirements for axial alignment as specified by the manufacturer.)

11.3.5 With the scale beam pin in place beneath the scale beam of the platform scale load frame, place sufficient mass on the scale beam to equal 100 percent of the rated capacity of the force transducer. Record the mass as the RC (*Rated capacity*) as shown on figure 5.

11.3.6 Slowly turn the wheel of the platform scale load frame until the scale beam lifts off of the pin on which the beam rests.

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FORCE TRANSDUCER (LOAD CELL) CALIBRATION

Designation USBR 1045-89

MANUFACTURER Example MODEL NO. 176 SERIAL NO. 2001

CALIBRATION METHOD: ☐ A - PLATFORM SCALE ☒ B - UNIVERSAL MACHINE

RC (RATED CAPACITY) (a) 200 lbf ____ N FORCE TRANSDUCER FACTOR (c)=(a)/(b) 20.000 ☒ lbf/V ☐ N/V

VOLTAGE OUTPUT (b) +10.000 V

CALIBRATION PERFORMED BY ____ DATE ____ CALIBRATION CHECKED BY ____ DATE ____

CALIBRATION MASS REQUIREMENTS

FORCE INCREMENTS	MASS REQUIRED lbm*	MASS REQUIRED N	ACTUAL MASS USED lbm*	ACTUAL MASS USED N
.2 x (RC) = 40.0	40.0		40.0	
.4 x (RC) = 80.0	80.0		80.0	
.6 x (RC) = 120.0	120.0		120.0	
.8 x (RC) = 160.0	160.0		160.0	
1.0 x (RC) = 200.0	200.0		200.0	

*IMPLIES lbm = lbf

FORCE TRANSDUCER CALIBRATION: ☒ COMPRESSION ☐ TENSION

INCREASING: FORCE INCREMENT ☒ lbm* ☐ N (1)	INCREASING: FORCE TRANSDUCER VOLTAGE OUTPUT (V) (2)	INCREASING: FORCE TRANSDUCER OUTPUT (2)x(c) ☒ lbf ☐ N (3)	DECREASING: FORCE INCREMENT ☒ lbm* ☐ N (4)	DECREASING: FORCE TRANSDUCER VOLTAGE OUTPUT (V) (5)	DECREASING: FORCE TRANSDUCER OUTPUT (5)x(c) ☒ lbf ☐ N (6)
Trial No. 1					
0	0.001	0.02	0	0.005	0.10
40.0	1.986	39.72	40.0	2.000	40.00
80.0	3.978	79.56	80.0	3.994	79.88
120.0	6.000	120.00	120.0	5.994	119.88
160.0	7.987	159.74	160.0	7.993	159.86
200.0	10.000	200.00	200.0	10.000	200.00
Trial No. 2					
0	0.001	0.02	0.0	0.004	0.08
40.0	1.989	39.78	40.0	2.000	40.00
80.0	3.986	79.72	80.0	4.002	80.04
120.0	5.993	119.86	120.0	6.002	120.04
160.0	8.001	160.02	160.0	8.006	160.12
200.0	10.009	200.18	200.0	10.009	200.18

PERCENT ERROR CALCULATIONS

LINEARITY % ERROR $\left\|\frac{(1)-(3)}{(RC)}\right\| \times 100$	HYSTERESIS % ERROR $\left\|\frac{(3)-(6)}{(RC)}\right\| \times 100$	REPEATABILITY % ERROR $\left\|\frac{(3)1st-(3)2nd}{(RC)}\right\| \times 100$
Trial No.1		
0.01	0.04	0.00
0.14	0.14	0.03
0.22	0.16	0.08
0.00	0.06	0.07
0.13	0.06	0.14
0.00	0.00	0.09
Trial No.2		
0.01	0.03	
0.11	0.11	
0.14	0.16	
0.07	0.09	
0.01	0.05	
0.09	0.00	

CREEP % ERROR

FORCE APPLIED ☒ lbf ☐ N

TRANSDUCER OUTPUT AT ZERO MINUTES (a) 200.0 ☒ lbf ☐ N

TRANSDUCER OUTPUT AT 35 MINUTE (b) 200.3 ☒ lbf ☐ N

% ERROR = $\left|\frac{(a)-(b)}{(RC)}\right| \times 100 =$ 0.15

ACCEPT ☒
REJECT ☐

REMARKS: ____

Figure 5. - Force transducer (load cell) calibration — example.

11.3.7 Carefully remove the scale beam pin; and, if necessary, turn the wheel of the platform scale load frame to level the scale beam.

11.3.8 The output of the signal conditioner should read ±10.000 volts d-c. If the output is not ±10.000 volts d-c, adjust the gain control on the signal conditioner to obtain ±10.000 volts d-c. Polarity of the output signal depends on the wiring of the force transducer and the desire of the user. Record the *Voltage output* (fig. 5).

11.3.9 Place the scale beam pin under the scale beam and lower the beam onto the scale beam pin by turning the wheel of the platform scale load frame until the force transducer is completely unloaded. Calculate and record the "Force transducer factor" (fig. 5).

11.3.10 If necessary, readjust the signal conditioner so the output is equal to 0.000 volt d-c. If it is necessary to again zero the signal conditioner, repeat subparagraphs 11.3.5 through 11.3.9.

CAUTION.-Once the appropriate gain has been set do not readjust. If it is readjusted, the calibration values are incorrect and the readings are unreliable.

11.3.11 Remove all the mass from the scale beam and calculate calibration mass requirements as shown on figure 5.

11.3.12 Place sufficient mass on the scale beam so a force equal to 20 percent of the rated capacity of the force transducer is applied.

11.3.13 Lift the scale beam off of the pin by turning the wheel and carefully remove the scale beam pin. If necessary, turn the wheel of the platform scale load frame to level the scale beam. Read and record the *Force increment* applied and the *Force transducer voltage output* as shown in the Increasing Force Increments section of figure 5.

11.3.14 Repeat subparagraphs 11.3.12 through 11.3.13 for force increments of 40, 60, 80, and 100 percent of the rated capacity of the force transducer.

11.3.15 Unload the force transducer by removing mass from the scale beam to correspond to 80, 60, 40, 20, and 0 percent of the rated capacity of the force transducer. Level the scale beam after each decrement of mass is removed. Read and record the *Force increment* applied and *Force transducer voltage output* for each force as shown in the Decreasing Force Increments section of figure 5.

11.3.16 Repeat subparagraphs 11.3.12 through 11.3.15 to obtain two sets of readings.

11.3.17 Using the "Force transducer factor," calculate and record the *Force transducer output* (fig. 5).

11.4 *Method A — Calibration Using Mass Standards* (tension, fig. 3):

11.4.1 Hang the force transducer using appropriate adaptors.

11.4.2 Adjust the signal conditioner so the output of the force transducer is 0.000 volt d-c.

11.4.3 Attach the hanger to the bottom of the force transducer using appropriate adapters. Place sufficient mass on the hanger so the force transducer is loaded in tension to 100 percent of its rated capacity. Record the force applied as the RC (*Rated capacity*) (fig. 5).

11.4.4 The output of the signal conditioner should read ±10.000 volts d-c. If the output is not ±10.000 volts d-c, adjust the gain control on the signal conditioner to obtain ±10.000 volts d-c. Polarity of the output signal depends on the wiring of the force transducer and the desire of the user. Record the *Voltage output*, and calculate and record the "Force transducer factor" (fig. 5).

11.4.5 Remove the hanger and all the mass from the force transducer so the force transducer is completely unloaded and calculate *Calibration mass requirements* as shown on figure 5.

11.4.6 If necessary, readjust the signal conditioner so the output is equal to 0.000 volt d-c. If it is necessary to again zero the signal conditioner, repeat subparagraphs 11.4.3 through 11.4.5.

CAUTION.-Once the appropriate gain has been set, do not readjust. If it is readjusted, the calibration values are incorrect and the readings are unreliable.

11.4.7 Reattach the hanger to the force transducer and place sufficient mass on the hanger to produce tensile forces equal to 20, 40, 60, 80, and 100 percent of the rated capacity of the force transducer.

11.4.8 Record the *Force increment* applied and the *Force transducer voltage output* for each load increment.

11.4.9 Unload the force transducer by removing mass from the hanger attached to the force transducer to correspond to 80, 60, 40, 20, and 0 percent of the rated capacity of the force transducer. Read and record the *Force increment* applied and the *Force transducer voltage output* for each force increment as shown in the Decreasing Force Increments section of figure 5.

11.4.10 Repeat subparagraphs 11.4.7 through 11.4.9 to obtain two sets of readings.

11.4.11 Using the "Force transducer factor," calculate and record the *Force transducer output* (fig. 5).

11.5 *Method B — Calibration Using a Universal Testing Machine* (compression, fig. 6a):

11.5.1 Adjust the signal conditioner so the output of the force transducer is 0.000 volt d-c with zero force on the force transducer.

11.5.2 Adjust all ranges on the universal testing machine to zero.

11.5.3 Position the force transducer directly beneath the loading plate of the testing machine; ensure that the force transducer loading pins are in the vertical position. (For some force transducers, it may be necessary to turn a nut onto each loading pin to hold the load cell vertical, level, and in compliance with the requirements for axial alinement as specified by the manufacturer.)

11.5.4 Carefully adjust the controls on the universal testing machine until the top load plate just makes contact with the force transducer.

11.5.5 Compute the force required for 20, 40, 60, 80, and 100 percent of the rated capacity of the force transducer; select the appropriate load range on the testing machine to ensure that readings are obtained in its most sensitive range. Record the RC (*Rated capacity*) of the force transducer as shown on figure 5.

11.5.6 Slowly load the force transducer until a force equal to 100 percent of the rated capacity of the force transducer has been applied to the transducer.

11.5.7 Adjust the output of the signal conditioner so it registers ±10.000 volt d-c. The polarity of the signal depends on the wiring of the transducer and the desire of the user. Record the *Voltage output* (fig. 5).

11.5.8 Remove the force from the force transducer by adjusting the controls on the testing machine so the total force on the force transducer is equal to 0.00 lbf (0.00 N). Calculate and record the "Force Transducer Factor" (fig. 5).

11.5.9 If necessary, readjust the signal conditioner so the output is equal to 0.000 volt d-c. If it is necessary to again zero the signal conditioner, repeat subparagraphs 11.5.4 through 11.5.8.

CAUTION.-Once the appropriate gain has been set do not readjust. If it is readjusted, the calibration values are incorrect and the readings are unreliable.

11.5.10 Carefully adjust the controls on the testing machine to produce forces equal to 20, 40, 60, 80, and 100 percent of the rated capacity of the force transducer.

11.5.11 Read and record the *Force increment* applied and the *Force transducer voltage output* for each force increment.

11.5.12 Remove the force from the force transducer to correspond to 80, 60, 40, 20, and 0 percent of the rated capacity of the force transducer. Read and record the *Force increment* applied and *Force transducer voltage output* for each force as shown in the Decreasing Force Increments section of figure 5.

11.5.13 Repeat subparagraphs 11.5.10 through 11.5.12 to obtain two sets of reading.

11.5.14 Using the "Force transducer factor," calculate and record the *Force transducer output* (fig. 5).

11.6 *Method B—Calibration Using a Universal Testing Machine* (tension, fig. 6b):

11.6.1 Adjust the signal conditioner so the output of the force transducer is 0.000 volt d-c with zero tensile force on the force transducer.

11.6.2 Adjust all ranges on the universal testing machine to zero.

11.6.3 Attach a ball joint coupler to each side of the force transducer as shown on figure 6b.

11.6.4 Attach the bottom ball joint coupler to the table of the testing machine.

11.6.5 Carefully adjust the controls on the testing machine until the top load plate is low enough so the top ball joint can be attached to it.

11.6.6 Carefully adjust the controls on the testing machine to slowly apply a tension force on the force transducer equal to 100 percent of the rated capacity of the force transducer. Ensure that readings on the testing machine are obtained in its most sensitive range for the force being applied.

11.6.7 Adjust the output of the signal conditioner so it registers ±10.000 volt d-c. The polarity of the signal depends on the wiring of the transducer and the desire of the user. Record the *Voltage output* as shown on figure 5.

11.6.8 Remove the tension force from the force transducer by adjusting the controls on the testing machine so the total force on the force transducer is equal to 0.00 lbf (0.00 N).

11.6.9 If necessary, readjust the signal conditioner so the output is equal 0.000 volt d-c. If it is necessary to again zero the signal conditioner, repeat subparagraphs 11.6.6 through 11.6.8.

CAUTION.-Once the appropriate gain has been set, do not readjust. If it is readjusted, the calibration values are incorrect and the readings are unreliable.

11.6.10 Compute the force required for 20, 40, 60, 80, and 100 percent of the rated capacity of the force transducer. Select the appropriate load range on the testing machine to ensure that readings are obtained in its most sensitive range for the force being applied. Record the RC (*Rated capacity*) of the force transducer and calculate and record the "Force transducer factor" (fig. 5).

11.6.11 Carefully adjust the controls on the testing machine to produce tensile forces equal to 20, 40, 60, 80, and 100 percent of the rated capacity of the force transducer.

11.6.12 Read and record the *Force increment* applied and the *Force transducer voltage output* for each force increment.

11.6.13 Unload the force transducer by carefully adjusting the controls on the testing machine to produce forces corresponding to 80, 60, 40, 20, and 0 percent of the rated capacity of the force transducer.

11.6.14 Read and record the *Force increment* applied and *Force transducer voltage output* for each force increment as shown in the Decreasing Force Increments section of figure 5.

11.6.15 Repeat subparagraphs 11.6.11 through 11.6.14 to obtain two sets of readings.

11.6.16 Using the "Force transducer factor," calculate and record the *Force transducer output* (fig. 5).

11.7 *Creep Test*:

11.7.1 Regardless of the method used to load the force transducer, the procedure is the same for determining creep of the force transducer.

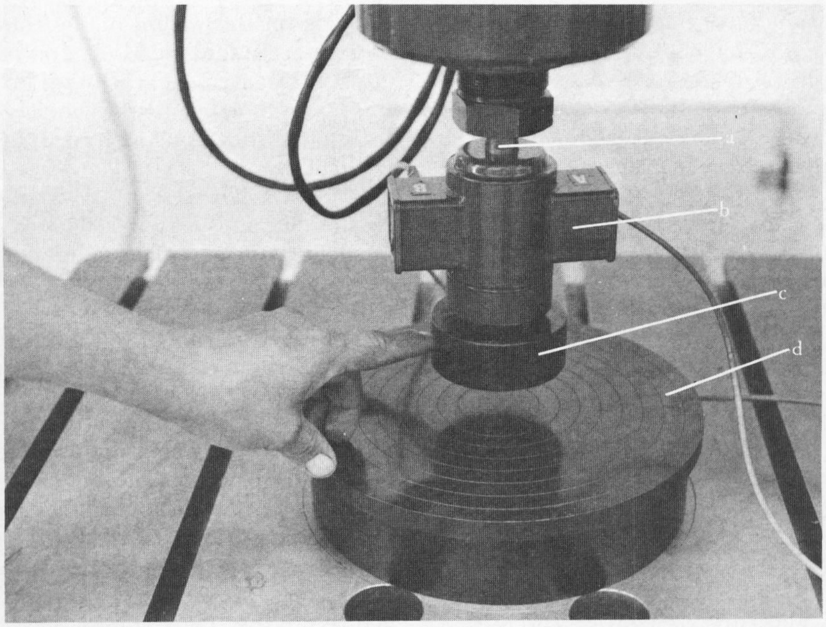
11.7.2 Apply either a tension or compression force on the force transducer equal to 100 percent of rated capacity and read and record the *Force transducer output* as the "Transducer output at zero minutes" (fig. 5).

11.7.3 Maintain the force on the force transducer for a minimum of 30 minutes, and read the *Force transducer voltage output* any time after 30 minutes. Record the time and the force transducer output as "Transducer output at ______ minute" (fig. 5).

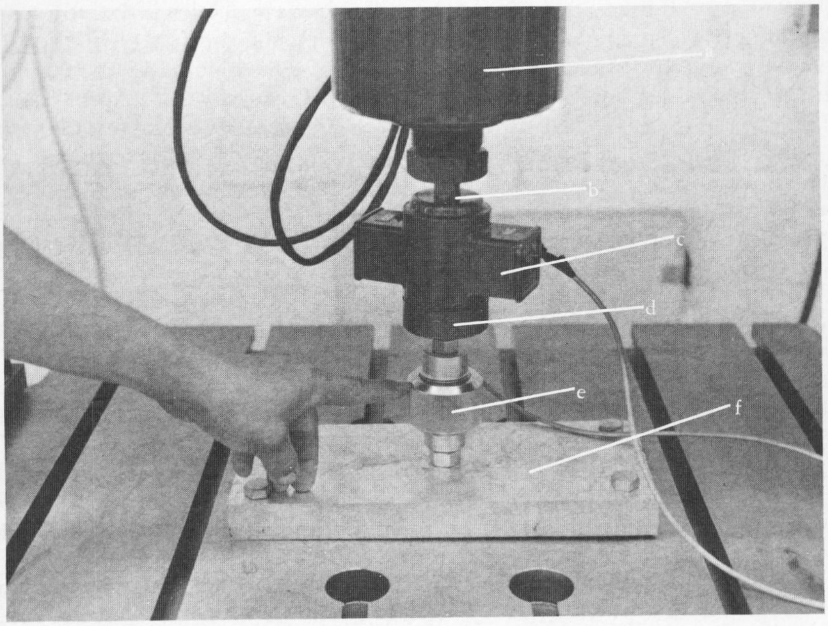
11.7.4 Calculate the *Creep % error* (fig. 5).

11.8 Calculate the linearity, hysteresis, and repeatability of the force transducer at each force increment of 0, 20, 40, 60, 80, 100 percent of rated capacity.

11.9 Evaluate the values of error obtained. If the percent error for linearity, hysteresis, repeatability, or creep



(a) Force transducer calibration using universal testing machine (compression). a) coupler, b) force transducer being calibrated, c) force transducer loading platen, and d) universal testing machine platform base.



(b) Force transducer calibration using universal testing machine (tension). a) universal testing machine force transducer, b) coupler, c) force transducer being calibrated, d) coupler, e) swivel coupler, and f) platform adaptor.

Figure 6. – Force transducer calibration using universal testing machine.

does not fall within tolerances specified by the manufacturer, the appropriate subparagraphs of the calibration procedure are to be repeated. If the force transducer still does not meet specified requirements, it is rejected for laboratory use.

12. Calculations

12.1 Calculations required for determining linearity, hysteresis, repeatability, and creep of the force transducer are as shown on figure 5.

13. Report

13.1 The report is to consist of a completed and checked "Force Transducer (Load Cell) Calibration" form (fig. 5).

13.2 All calculations are to show a checkmark.

14. Background Reference

14.1 "Handbook of Measurement and Control," *Handbook HB-76*, copyright 1976 by Schaevitz Engineering, Pennsauken, NJ, Library of Congress Catalog No. 76-24971.