NBSIR 75-738

A Method and Means of Calibration an Air-Bearing Force Plate for Use With a Towed Pavement Friction Test Trailer

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CONTENTS

ILLUSTRATIONS

In view of present accepted practice in this technological area, U. S. customary units of measurement have been used throughout this paper. It should be noted that the U. S. A. is a signatory to the General Conference on Weights and Measures which gave official status to the metric SI system of units in 1960. Readers interested in making use of the coherent system of SI units will find conversion factors in ASTM Standard Metric Practice Guide, ASTM Designation E 380-70 (available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania 19103).

Length	1 in = 0.0254* meter
Area	1 in^2 = 6.4516* x 10^{-4} $meter^2$
Force	1 lbf = 4.448 newton

*Exact value

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The equations for the variation of the external forces acting at the tire-pavement interface of a symmetrical two-wheeled towed trailer are given. Estimates, derived from experimental results, have been made for the displacement of the tire-plate interface with respect to the ground of an unrestrained locked test tire on the trailer. A description of the force plate calibration test frame, instrumentation and test method is given. The means of applying simultaneous vertical (normal) and horizontal (longitudinal) forces at the contact surface of the air-bearing plate in accordance with the equations are discussed. The change in force plate output with changes in the dimensions of the trailer calibrated in-turn with the force plate are given. A method of locating the coordinate axes of the internal force sensors with respect to level is given. Consistent application of these methods to both the force plate and trailer tranducer calibrations results in reduced vertical-to-horizontal cross-axis differences.

Key Words: Calibration procedures; force plate; pavement skid resistance; skid accident reduction; tire-pavement interface forces.

1. INTRODUCTION

The measurement of the skid resistance of highways under wet weather conditions is part of the Federal Highway Administration's (FHWA) skid accident reduction program. Such measurements are being made by highway departments of the various states in accordance with ASTM Method E-274 [1].* The methods and means to systematically relate the skid resistance quantities to the National Measurement System are being developed at the National Bureau of Standards (NBS). NBS maintains and operates for FHWA an Interim Reference System (IRS) which is used for evaluating and calibrating other skid-resistance-measuring systems maintained by FHWA to which the state systems relate [2].

*Figures in brackets indicate the literature references at the end of this report.

The ASTM E 274 method of skid-resistance testing utilizes the measurement of the frictional force occurring at the tire-pavement interface on a locked test wheel as it is dragged over a wetted pavement at a constant speed.

Wheel transducers are usually instrumented to measure force at the tire-pavement interface or torque about the wheel axle. Because of the effects of the flexible suspension system and tires on the trailer making the measurement, there is a need to calibrate the wheel transducer in situ. A force plate is a loading platform on which a locked test wheel of the trailer is placed during the calibration of the trailer instrumentation. Transducers associated with the force plate act in series with the force components occurring at the tire-pavement interface. During wheel transducer calibration, signals from the plate transducers are compared with signals from the wheel transducers for a variety of longitudinal forces applied to the tire through the plate.

The force plate used with the IRS is shown in Figure 1. Since the plate is mounted on an air-bearing platform a lateral force is not developed in the plate during use. Any lateral force required for equilibrium of the trailer occurs at the other trailer tire. This report discusses the development of the equipment and method used to calibrate the force plate for the in situ calibration of the IRS force type wheel transducer.

1.1 Background

During preliminary investigations with force plates a Stevens Institute of Technology force plate, which had been modified by personnel of the Maryland State Highway Administration, was calibrated in accordance with a proposed method of calibration being considered by an ASTM committee. The force standard was an external load cell. In a calibration test frame a screw mechanism was turned to vary the magnitude of the force applied to the force plate and standard in series. The result of the calibration was quite linear. The force plate was then used to calibrate the IRS wheel transducer. Figure 2 illustrates the unacceptable result of the test. In the investigation of possible causes for the nonlinearity, the force plate was temporarily placed on an air-bearing platform and the test was repeated with the result shown in Figure 3. In the latter test the force plate mechanism remained stationary with respect to the loading point, as it was during calibration, while in the initial transducer test the mechanism of the force plate was moved through nominally one inch of displacement.

Inspection of the mechanism revealed that a machining error occurred during the modification of the force plate. The error was corrected and the calibration results returned to their normal values. The procedure by which this plate had been calibrated had failed to reveal the problem because the procedure did not require movement of the force plate mechanism commensurate with that occurring during use.

1.2 Other Preliminary Investigations

An experiment was conducted to quantify the effect of application of the normal force eccentric to the friction surface of the plate. The force plate was mounted in a deadweight calibration machine with vertical force being applied at the locations shown in Figure 4. Using the reading at the center of the plate (position 1) as a reference, the deviation in reading for loads applied at the other positions is shown in Table 1. The forces were applied through a ball and distributed on the plate through a rubber footprint corresponding to the tire-pavement area of an ASTM E 249 tire loaded with 1085 lbf. With the center of the footprint located within two inches of the center of the force plate the variation is less than one-half percent of applied load.

The area of the tire-pavement interface varies with load. For measurement, a tire was placed in a testing machine. The tread was covered with ink. Paper was then placed between the tire tread and a flat surface. The load was increased to a desired value and then reduced to zero leaving an imprint of the tire-surface area on the paper. A series of such impressions were made to develop the variation in area with load. The impressions obtained with the ASTM E 249 tire are summarized in Figure 5. The impressions obtained with the ASTM E 501 tire are summarized in Figure 6.

1.3 Variations in Traction Induced Forces and Displacements

When a traction force is applied at the tire-pavement interface of the locked test wheel of a symmetrical two-wheeled trailer, the normal and the lateral forces change in accordance with the following equations:

$$F_{WL_z} = F_{WL_{z_o}} - F_{WL_x}\left(\frac{H}{L}\right) \quad (1)$$

$$F_{WL_y} + F_{WR_y} = \left(\frac{T}{2L}\right) F_{WL_x} \quad (2)$$

where x = the longitudinal axis, positive direction rearward
y = the lateral axis, positive direction to the left when viewed in the positive direction of the x axis
z = the normal axis, positive direction downward
F_{WL_x} = the longitudinal traction force on the left wheel
F_{WL_z} = the total normal force on the left wheel acting at the tire-pavement interface.

$F_{WL_{z_o}}$ = the normal force on the left wheel acting at the tire-pavement interface when the applied traction is zero.

F_{WR_y} = the lateral force on the right wheel

F_{WL_y} = the lateral force on the left wheel

$\frac{H}{L}$ = the effective normal force unloading constant where H is the hitch height and L is the length from the center line of the trailer wheel to the hitch

$\frac{T}{2L}$ = the effective lateral force constant where T is the track width or distance between the centerlines of the two trailer tires and L is the length from the center line of the trailer wheel to the hitch

Equation (1) shows that the normal load on the test wheel decreases as the traction force increases where the amount of reduction is a function of the dimensions of the trailer. Equation (2) shows that the lateral force increases with an increase in traction where, again, the amount depends upon the dimensions of the trailer. In highway use Equation (2) indicates that the lateral force is shared by both wheels.

The force plate supplied with the IRS is instrumented to measure the longitudinal and vertical components of an applied force, but not the lateral component. This is consistent with the use of an air-bearing force plate. It should be pointed out that use of the force plate without applying the share of the lateral force acting at the test wheel tire-pavement interface fails to apply the effects of this force component to the transducer during its calibration.

Because the trailer suspension system and tires are flexible the tire-pavement interface shifts as the friction force increases and decreases. The measured displacement of the tire-pavement interface of the IRS, while supported on an air-bearing platform, along the longitudinal axis is given in Figure 7 and along the lateral axis in Figure 8, as a function of applied friction force. These figures indicate a movement of approximately up to 1.1 inches in the longitudinal direction and up to approximately 0.4 inches in the lateral direction with a traction force applied of 800 pounds-force.

The force plate outputs are also sensitive to variations in the friction surface orientation with respect to level. Freedom of movement about level is introduced by the air-bearing platform. Variations in plate pitch angle orientation, or rotation about the lateral axis, result in a transformation of coordinates as shown in Figure 9.

The variations in output of the sensitive axes as a function of pitch angle θ are:

$$E_T = K_T(F_{WL_z} \sin\theta + F_{WL_x} \cos\theta) \qquad (3)$$

$$E_L = K_L(F_{WL_z} \cos\theta - F_{WL_x} \sin\theta)$$

where E_T = traction output signal (4)

E_L = normal load signal

E_T = traction constant

K_L = load constant

The variations in plate roll angle orientation or rotation about the longitudinal axis have only a second order effect on the plate traction axis.

2. CALIBRATION APPARATUS

The two-axis loading fixture (Figure 10) provides the means of applying known forces simultaneously to the two sensitive axes of the force plate. The fixture utilizes the air-bearing platform used with the plate during trailer wheel transducer calibration. The traction force is generated by the horizontal hydraulic jack (detail 11) and measured by the horizontal load cell (detail 2). A change in vertical force is generated by the vertical hydraulic jack (detail 19) and measured by the vertical load cell (detail 18). Friction between the force plate and the support surface (detail 9) is negligible due to the air-bearing. Forces are transmitted through ball joints for freedom of alinement. The fixture contains adjustable members to allow calibration in a controlled orientation.

The vertical force is applied to the surface of the force plate through a rubber footprint simulating the footprint of an ASTM test tire at a normal load of 1085 lbf (Figure 5 or Figure 6). In calibration, the horizontal force is applied to the surface of the force plate by means of friction through the footprint, up to the point of slippage. In order to provide a calibration range which exceeds the horizontal force which results in slippage, the excess horizontal force is applied to the plate through a lip (Figure 10, detail 5). The horizontal force is transmitted through a spring (detail 20) connecting the horizontal hydraulic jack (detail 11) to the jack beam (detail 12). This spring allows the footprint to creep without changing the position of the hydraulic jack piston and helps the force to remain constant under this condition.

The footprint is located in the center of the force plate friction surface. The drawbar and force plate index marks are alined. The height of the traction load cell anchor pin (detail 1) is adjusted so the load cell axis is level and alined with the drawbar when the friction surface is maintained at a pitch angle. The vertical tie rods (detail 14) are maintained vertical. The vertical load cell axis is parallel to the vertical tie rods.

When the footprint is centrally located, the force plate will not yaw with changes in traction force.

Scale drawings of the fixture assembly and components are shown in Appendix A.

The applied loads are measured by load cells and readout indicators. These instruments were calibrated by the calibration service of the National Bureau of Standards using deadweights which have been systematically related to the National Measurement System [3]. Typical load cell calibration results are given in Appendix B.

The level of the force plate can be adjusted by means of valves in the lines supplying air to each of three air-bearings. The plate orientation is measured with three dial gages and maintained in a preferred position throughout the test by use of the air valves. The dial gages are located as shown in Figure 11.

The instrumentation includes readout indicators for the horizontal and vertical load cells, signal conditioners for the force plate, an analog-to-digital converter and a pointer. The desired values of force are entered into the load cell indicators, which display null indications when the loads are reached. The force plate signals are conditioned, amplified, and converted to digital values. The printer records the digitized force plate outputs automatically when a button is depressed. The force plate bridge excitation is supplied by the converter.

As discussed in the introduction, the loading fixture should allow any force plate motions to occur during plate calibration which occur during trailer wheel transducer calibration. In the case of a force plate supported by an air-bearing platform, the force plate moves with the tire footprint during wheel transducer calibration. No components of the force plate move with respect to the footprint, except the slight deformation of the internal strain gaged beams. During the calibration of the force plate in this fixture, the slight deformation of the strain gaged beams occurs, and no components move with respect to the footprint. An external shift of about 0.3 inch of the normal force away from the drawbar occurs due to the motion of the tire footprint with respect to the wheel hub. The center of pressure moves less than this amount. The test results of Table 1 indicate a movement of this magnitude would introduce a difference of less than one-third percent of force plate full scale output.

A calibration box is provided with each force plate so the calibration results are independent of the analog-to-digital converter used during calibration. This also enables the force plate to be used with a variety of readout displays.

When a force is applied to the force plate, an internal Wheatstone bridge strain gage circuit becomes unbalanced. With no force applied to the force plate, the bridge can be unbalanced with a resistor shunting one leg of the bridge. The resistors contained in the calibration box are trimmed such that the bridge unbalance that each produces is equivalent to the bridge unbalance which would have occurred by the forces stated on the box and/or in the calibration table results, in accordance with the calibration equation loading conditions. A schematic diagram of the calibration box is given in Appendix C.

The calibration box is located in the cabling which connects the force plate to the readout instrumentation. The strain gage bridge is completed within the force plate. The cabling resistance is in series with the readout instrumentation and the power supply as shown in Figure C-1 when the switch is in the N position. In this case, the effect of the cable resistance is to change the output impedance of the signal supplying the differential amplifier and to decrease the current from the power supply. The effect is to de-sensitize the bridge [4]. The force plate is calibrated using the cabling assigned to the plate. With the use of a regulated power supply and high input impedance amplifier the effect becomes negligible even for moderate temperature changes.

When a calibration resistor is connected into the circuit, the amount of bridge unbalance is affected by the value of the resistance of cable 1. However, the calibration resistor is trimmed with the cable connected to minimize this effect. When the unit is used at a temperature other than that at which it was calibrated, the change in the cable resistance and calibration resistance needs to be considered. The temperature coefficient of the fixed resistors used in the IRS system is less than 5 ppm/°C. The temperature coefficient of the trim potentiometers is less than 25 ppm/°C. The cable resistance has a temperature coefficient of 4,000 ppm/°C. However, since the ratio of the cable resistance to the calibration resistance is 1 to 50,000 and the trimpot value is small compared to the calibration resistance value, the total variation is less than a quarter pound-force within the temperature range from 10°C to 40°C.

The vertical load channel resistors are trimmed to equivalent force values of 250, 500, 750, 1,000, 1,500 and 1,750 pounds. The traction channel resistors are trimmed, in the presence of the stated vertical load, to equivalent force values of 200, 300, 400, 500, 600, 700, 800, 900, 1,000 and 1,500 pounds.

A block diagram of the calibration system is shown in Figure 12.

3. CALIBRATION

The operator is provided with a complete step-by-step procedure. For the purpose of this report, the procedure will be briefly summarized.

The force plate and air-bearing platform are inserted in the loading fixture and with the air-bearing in operation all parts are carefully aligned to ensure proper position. Electrical connections are made and electronic instrumentation warmed up. Ambient temperature is monitored and recorded throughout the procedure.

To establish the force plate friction surface pitch angle at which the coordinate axes of the internal force sensors correspond to the axes of the applied forces, the force plate traction output is electronically adjusted to zero with no load applied to the force plate. With no traction forces on the plate a vertical load is then applied to the center of the plate simulating the static wheel load of a trailer. The air-bearing valves are adjusted such that the force plate is level in the lateral direction and pitched as necessary to return the traction output to zero. The pitch angle is measured using dial indicators referenced to zero by a sensitive bubble level. This orientation is recorded and maintained during the remainder of the test.

Calibration of the vertical load axis of the force plate is done with the horizontal traction axis unloaded. Data is recorded for both increasing and decreasing vertical loads.

Calibration of the traction axis is done with the vertical load varied to simulate the unloading effect of the trailer as shown by Equation 1. The effective normal force unloading constant of the trailer to be calibrated by the force plate is measured and the trailer vertical load corresponding to the traction force is computed. Traction data is recorded for both increasing and decreasing traction loads. Sets of traction calibration data are recorded for different H/L ratios covering the range of geometries of skid measurement trailers, and for a range of initial vertical static loads.

Linear calibration curves are fitted to the data for the vertical and traction axis calibration by the method of least squares with equal weighting. Hysteresis and linearity are expressed as percentages of full scale outputs. For each calibration where independent runs have been obtained, data is pooled and a linear calibration equation is fitted to all points.

The reference resistors in the calibration box are trimmed to match the calibration curves as calculated for one H/L value. The vertical load channel resistors are trimmed with no external loads applied to the force plate and the electronics set to zero. The traction channel resistors are trimmed with

1) the traction channel electronics set to zero when no external loads are applied to the plate, and

2) the vertical static load applied to the plate with the friction surface orientated at the previously determined pitch angle and with no vertical load calibration resistors connected.

The least squares equation may indicate that a calibration resistor should be trimmed for the no load case. Since extremely large resistor values would then be required, perhaps as much as 300 megohms, the trimming of the output to zero is impractical. Instead, the expected offset under no load conditions is calculated and recorded in the table of equivalent calibration forces.

A table of equivalent calibration forces is calculated for each selectable resistor corresponding to all sets of traction calibration data recorded using other H/L ratios.

4. REPORT

The following calibration test information is reported:

1) Date

2) Force plate identification

3) Calibration box identification

4) Traction force indicator and load cell identification

5) Vertical load indicator and load cell identification

6) Ambient temperature range during calibration

7) Friction surface pitch angle

8) Linearity and hysteresis expressed as a percent of full scale. When the least squares linear fit is based on pooled data, the average linearity and hysteresis are reported.

9) Equivalent calibration forces for each selectable resistor corresponding to all sets of traction calibration data recorded using H/L ratios and/or static vertical loads. The expected offset values under no load conditions are included.

A summary report sheet is shown in Figure 13.

5. USE OF THE FORCE PLATE

When using the force plate to establish known forces at the tire-pavement interface of a two-wheeled towed trailer:

5.1 Connect the force plate and calibration box to a suitable readout unit and source of strain gage excitation. Place the force plate on a smooth level floor.

5.2 Scale the normal load readout instrumentation:

a. With no external force applied, set the gain and offset of the normal load readout electronics. Use the values of any two normal load reference points other than N as given in the calibration summary (Figure 13) to obtain readout in engineering units. If the readout is linear, a linear force scale will result.

b. Place the normal load reference resistor switch in the N (no resistor) position for force measurement.

c. Activate the air-bearing platform. Set the friction surface roll angle to zero. Set the friction surface pitch angle to the value specified in the calibration summary and maintain the angles during force measurement.

5.3 Scale the traction readout instrumentation:

a. Center the vertical load provided by the test wheel of the trailer on the force plate. Activate the air-bearing platform. Set the friction surface roll angle to zero. Set the surface pitch angle to the value specified in the calibration summary.

b. From the summary, select the traction resistor equivalent force value column applicable to the H/L ratio and static wheel load of the trailer.

c. With no external traction force applied, set the gain and offset of the traction force readout electronics. Use the values of any two of the traction reference points to obtain readout in engineering units. If the readout system is linear, a linear force scale will result.

d. Place the traction reference resistor switch in the N position for force measurement. Maintain the friction surface at the specified angles during force measurement.

5.4 Measure the force.

a. Apply the force through the force plate.

b. Re-adjust, as necessary, the friction surface orientation to the specified angles.

c. When the readout instrumentation matches the recorded value for a calibration resistance, the force has the value given in the report of calibration.

6. DISCUSSION AND CONCLUSIONS

A calibration method and the apparatus needed to calibrate a two-axis air bearing force plate have been developed. The fixture developed can reproduce the loading conditions found during the in situ calibration of the wheel force transducer of a symmetrical two-wheeled skid measurement trailer.

The apparatus can easily be duplicated by other laboratories. Calibration service for load cells with their indicators is available from several sources, including the NBS. The simplicity of the apparatus calls for more operator skill and time than would be the case if the loads were developed by servomechanisms. The operator must simultaneously null two force indicators by adjustments of two hydraulic jacks while maintaining the force plate in position with three air-bearing valves. The choice of the null indicators for loading and a printing readout help make it possible for the calibration to be performed by one man.

The fixture must be in good mechanical alinement to minimize angular errors. Preliminary results with the equipment indicate that the measurement errors do not exceed one percent of full scale.

7. RECOMMENDATIONS FOR FUTURE WORK

A method of calibrating the plate which is consistent with the calibration of a torque-type transducer needs to be developed. Beyond that, a method of calibrating a wheel transducer, in situ, which includes the lateral force component acting at the tire-pavement interface is needed.

8. REFERENCES

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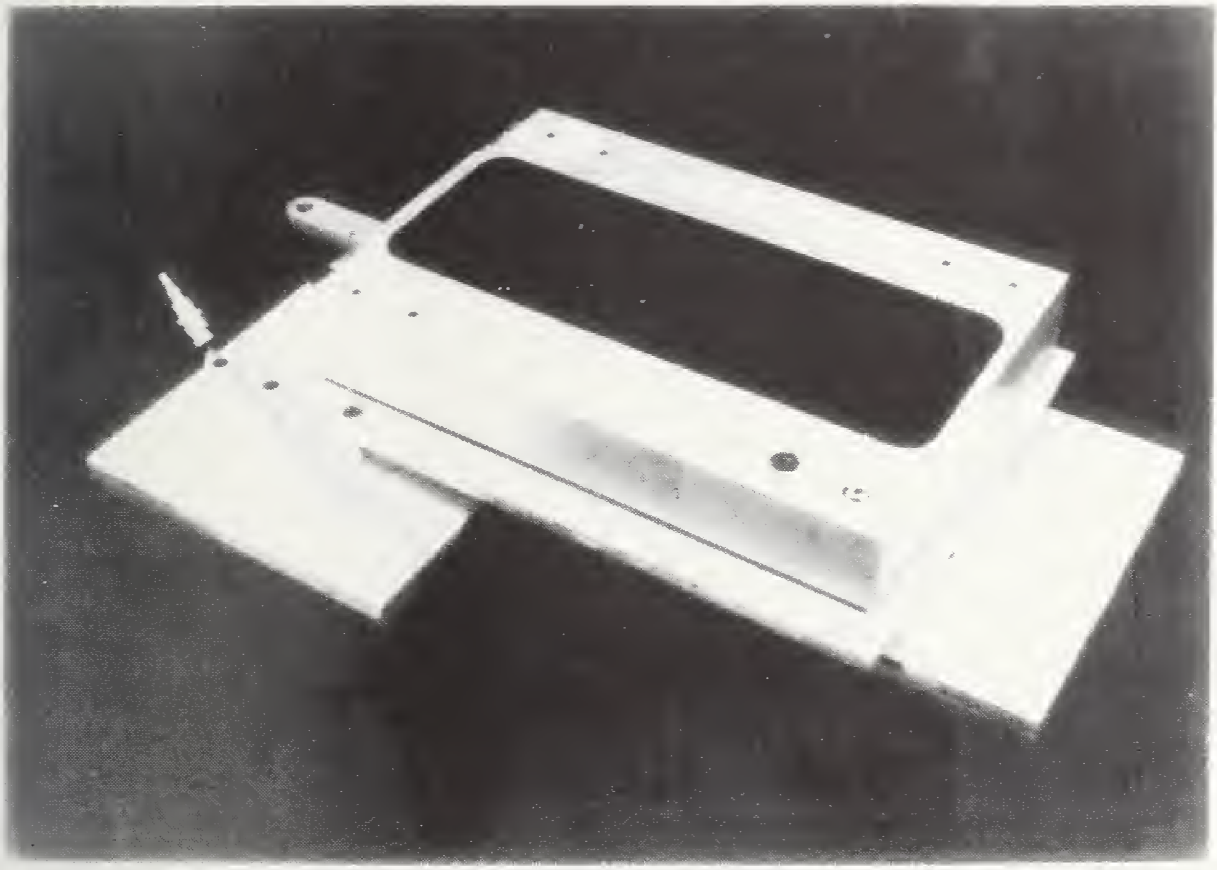


FIGURE 1. INTERIM REFERENCE SYSTEM (IRS) FORCE PLATE MOUNTED ON AIR-BEARING PLATFORM.

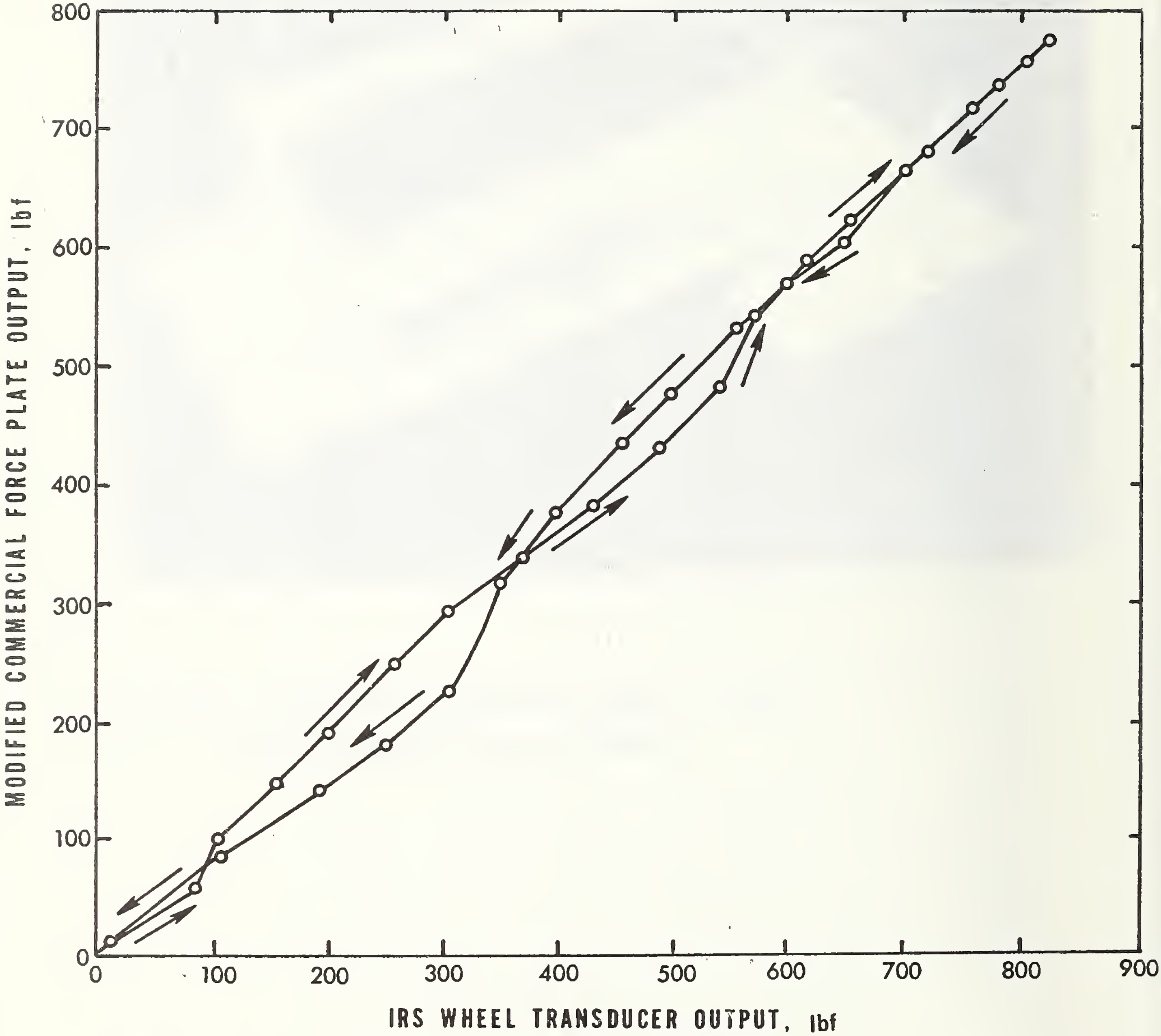


FIGURE 2. INITIAL RESULTS OF CALIBRATING THE IRS WHEEL TRANSDUCER WITH A MODIFIED COMMERCIAL FORCE PLATE.

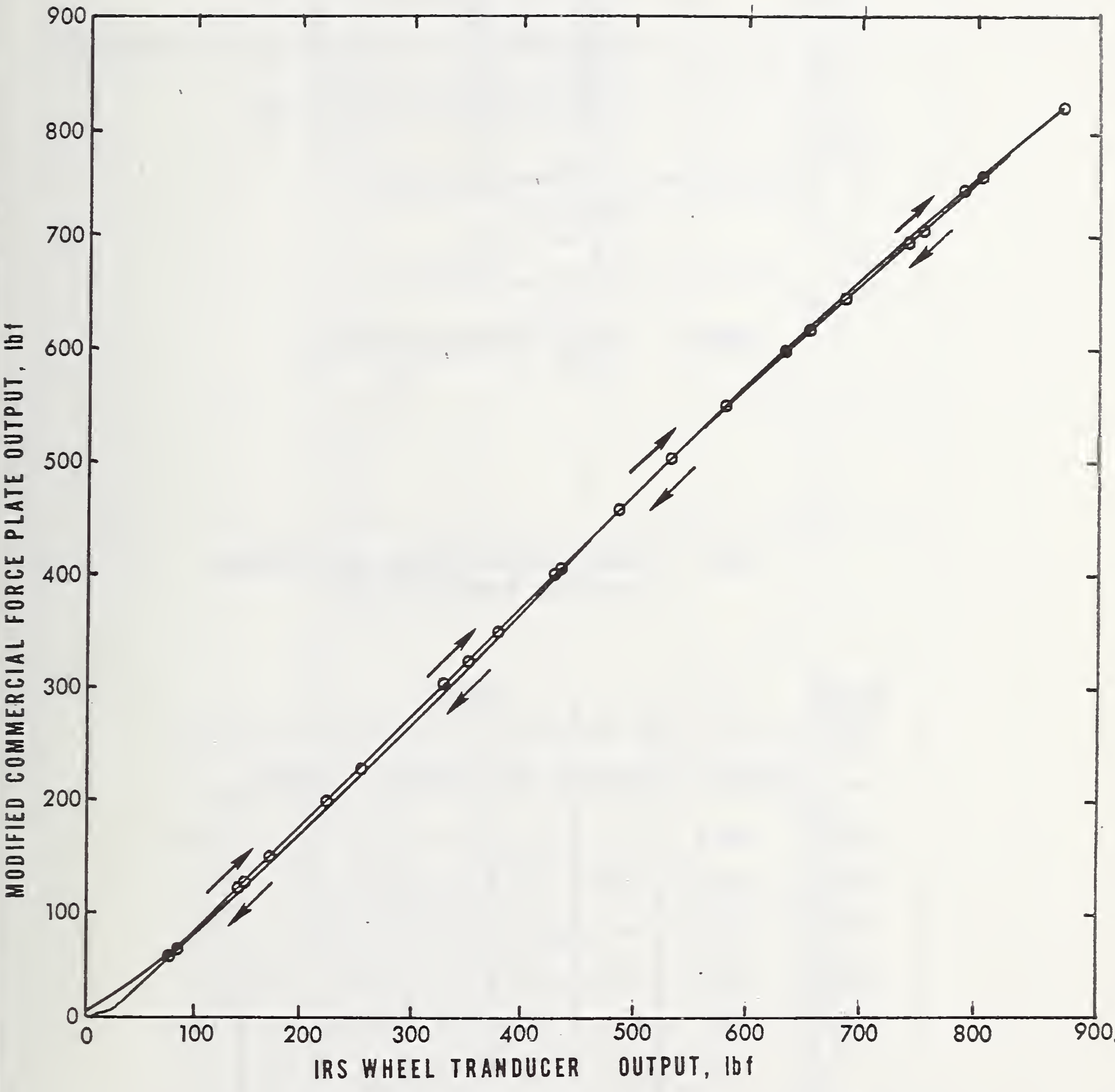


FIGURE 3. INITIAL RESULTS OF CALIBRATING THE IRS WHEEL TRANSDUCER WITH A MODIFIED COMMERCIAL FORCE PLATE SUPPORTED ON AN AIR BEARING PLATFORM.

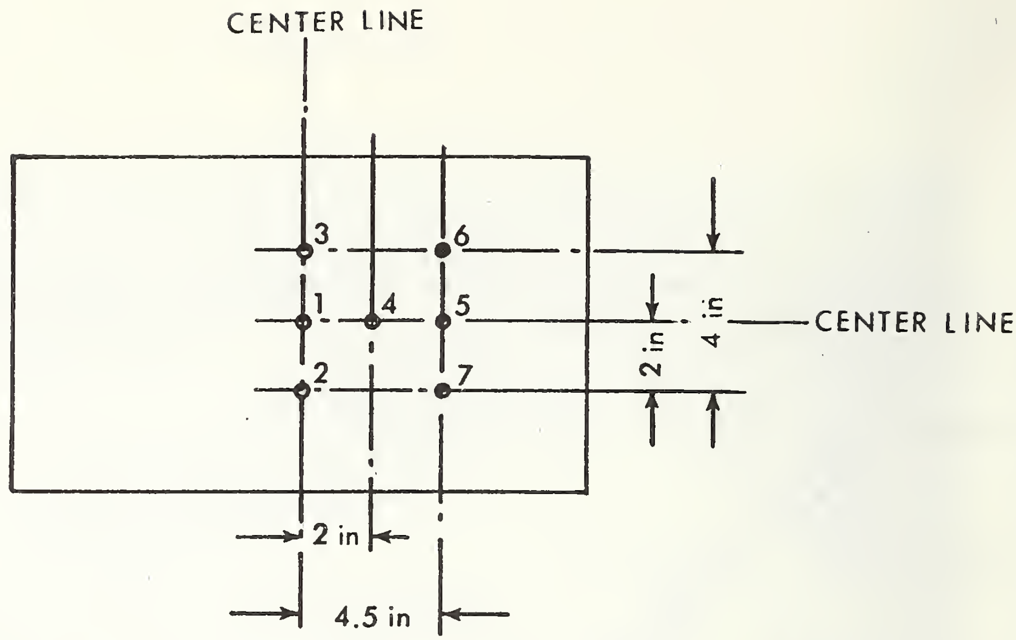


FIGURE 4. ECCENTRIC LOAD POSITIONS.

TABLE 1. FORCE PLATE VERTICAL LOAD OUTPUT VARIATION WITH LOCATION

Vertical load lbf	Position 1	2	3	4	5	6	7
	Reading *	Deviation From Position 1 Reading					
1500	1173	−4	+1	+1	+1	−1	+3
1200	939	−3	0	−1	+1	−1	+2
900	703	−1	+1	+1	+2	0	+3
600	468	0	+1	+1	+2	0	+3
300	234	−1	+1	+1	+1	0	+2
0	0	0	0	0	0	0	0

*Arbitrary scale

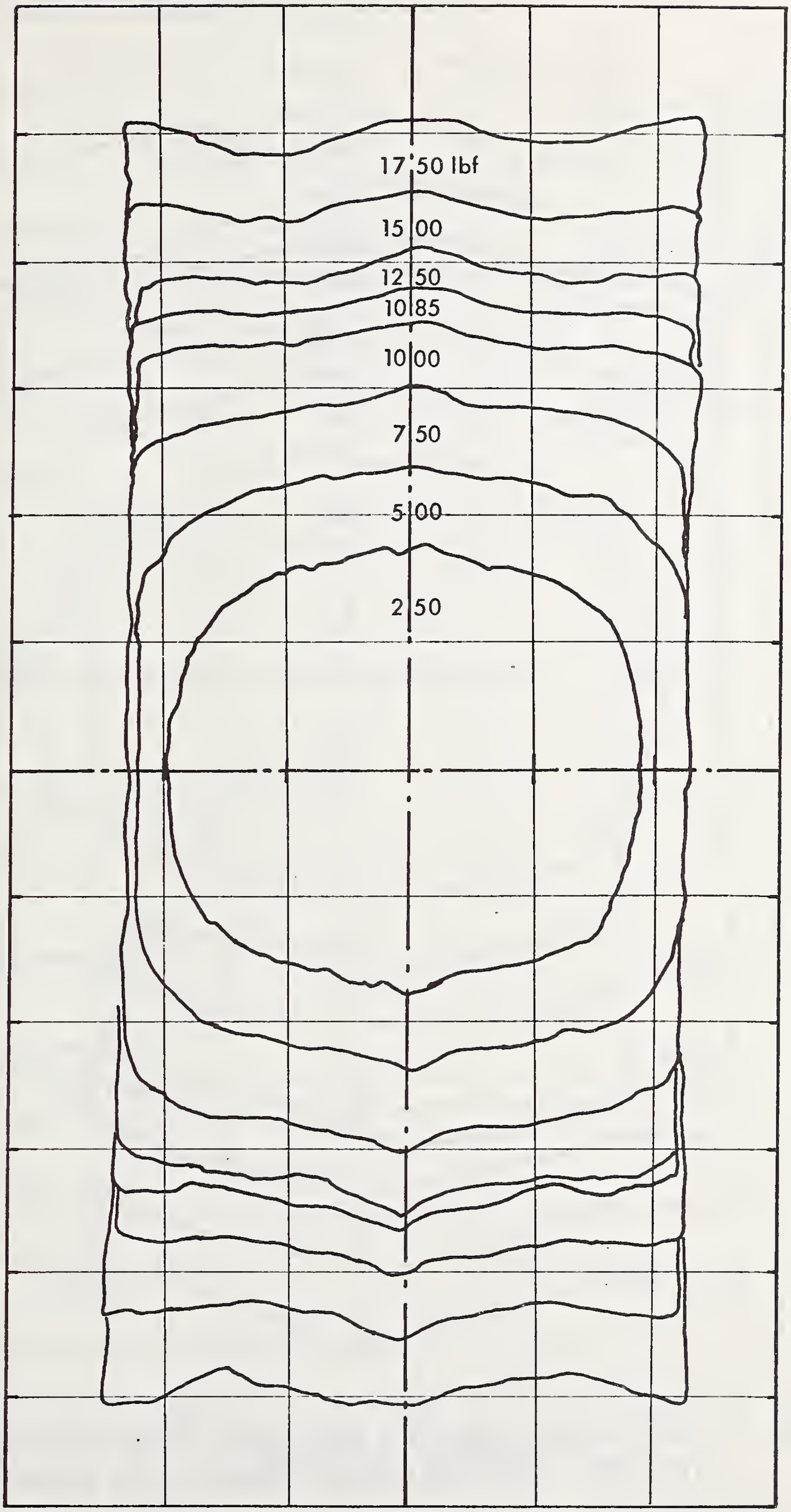


FIGURE 5. TIRE—SURFACE INTERFACE AREA VERSUS LOAD FOR ASTM E249 TEST TIRE. EACH BACKGROUND SQUARE IS ONE SQUARE INCH.

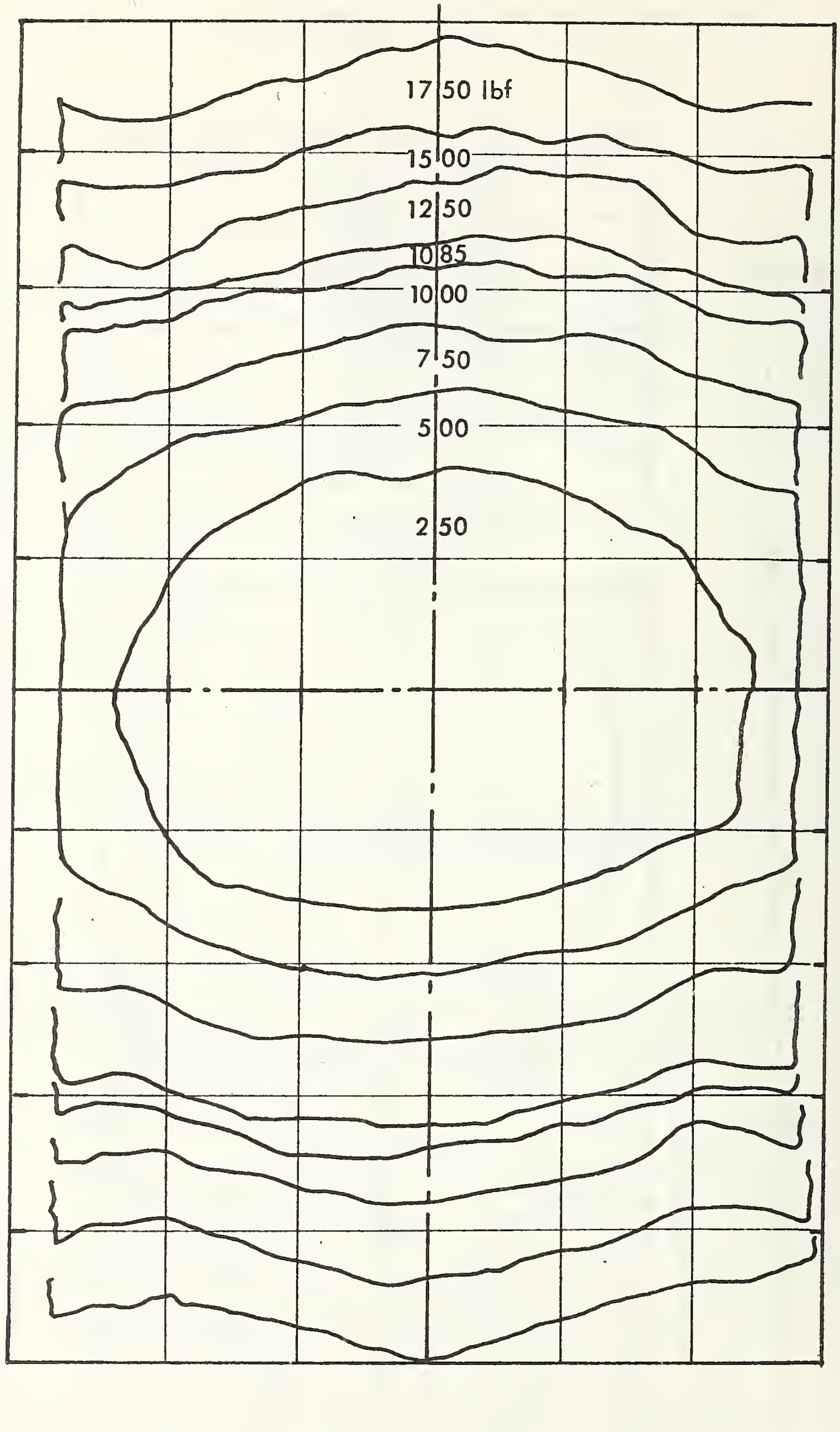


FIGURE 6. TIRE–SURFACE INTERFACE AREA VERSUS LOAD FOR ASTM E501 TEST TIRE. EACH BACKGROUND SQUARE IS ONE SQUARE INCH.

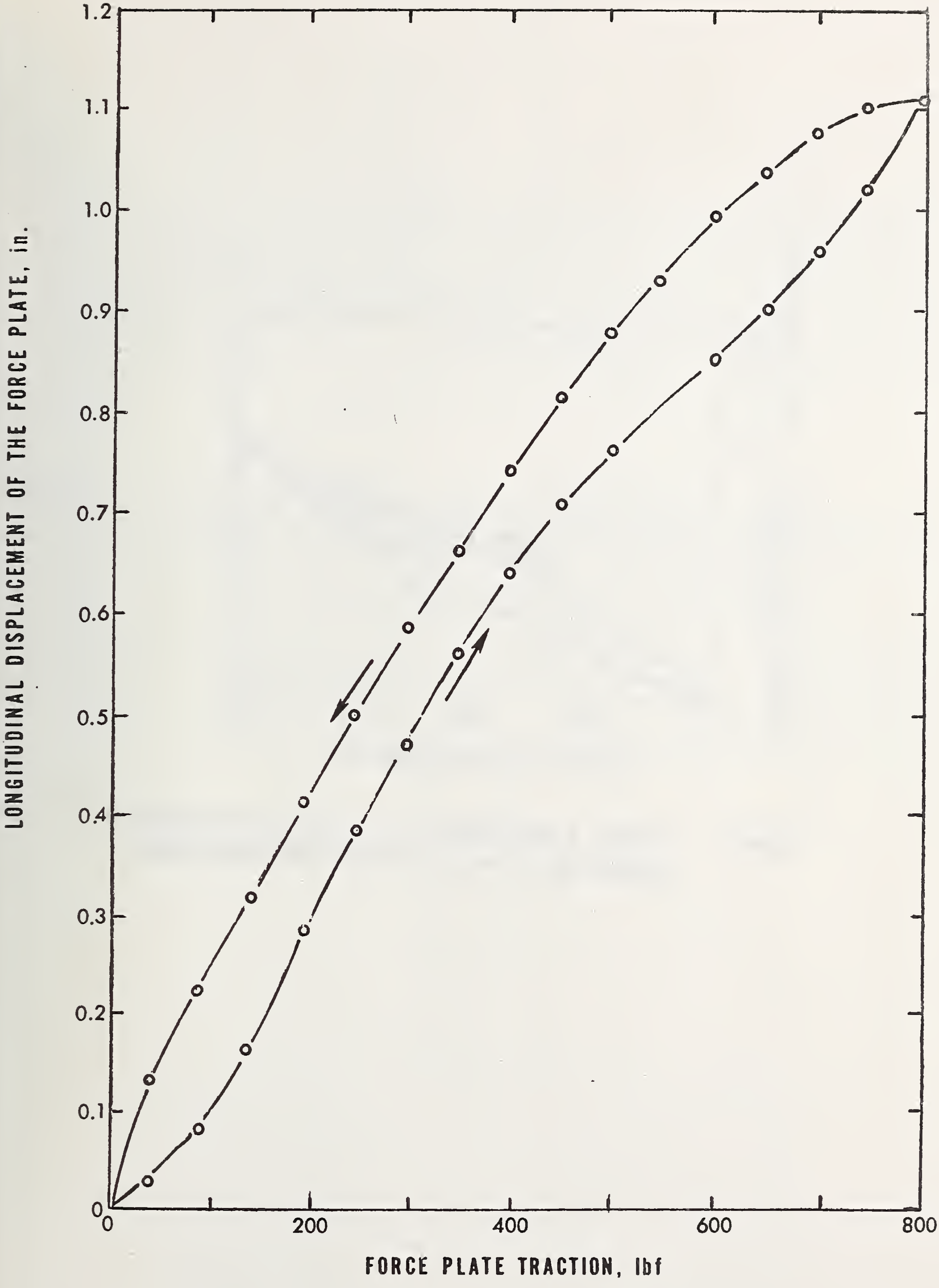


FIGURE 7. LONGITUDINAL DISPLACEMENT OF THE FORCE PLATE DURING THE CALIBRATION OF THE IRS WHEEL LOAD TRANSDUCER

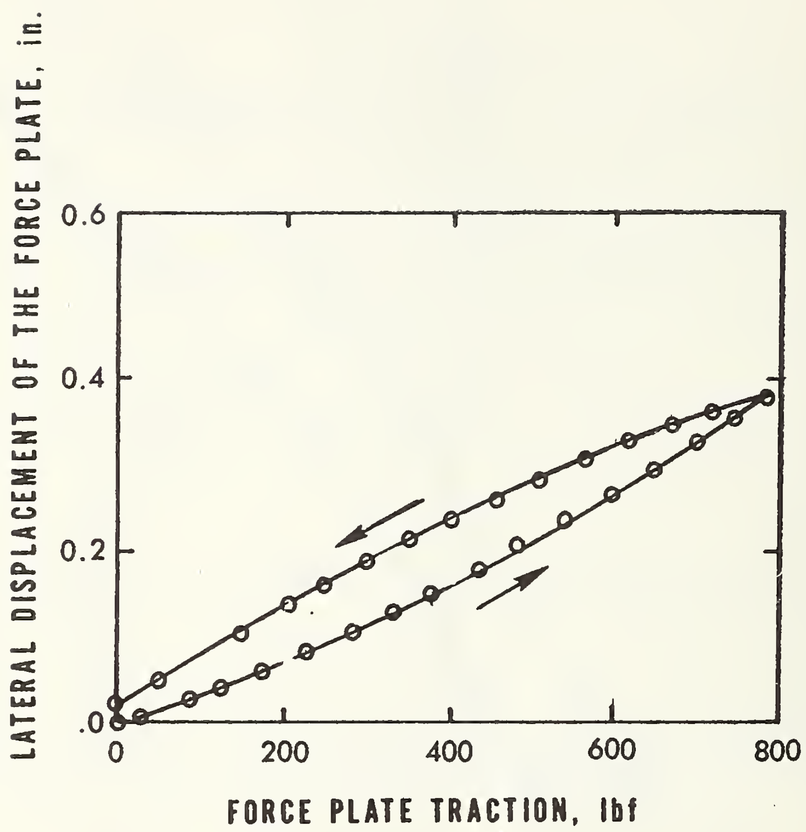


FIGURE 8. LATERAL DISPLACEMENT OF THE FORCE PLATE DURING CALIBRATION OF THE IRS WHEEL LOAD TRANSDUCER.

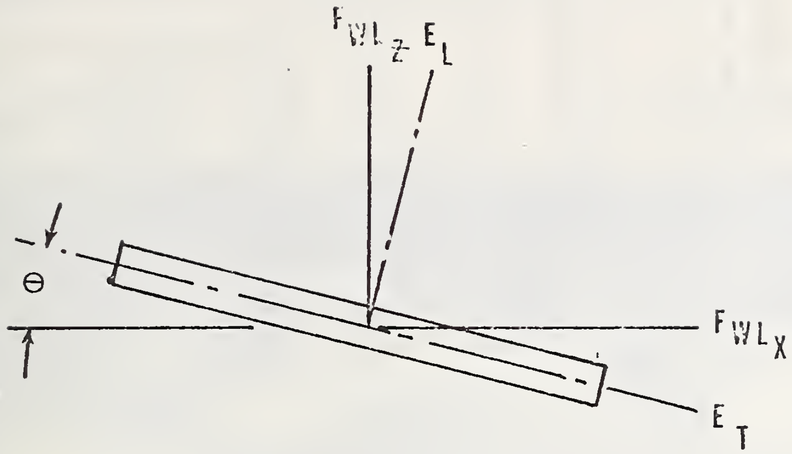


FIGURE 9. ROTATION OF COORDINATE AXES ACCOMPANYING PITCHING OF THE FORCE PLATE FRICTION SURFACE FROM LEVEL.

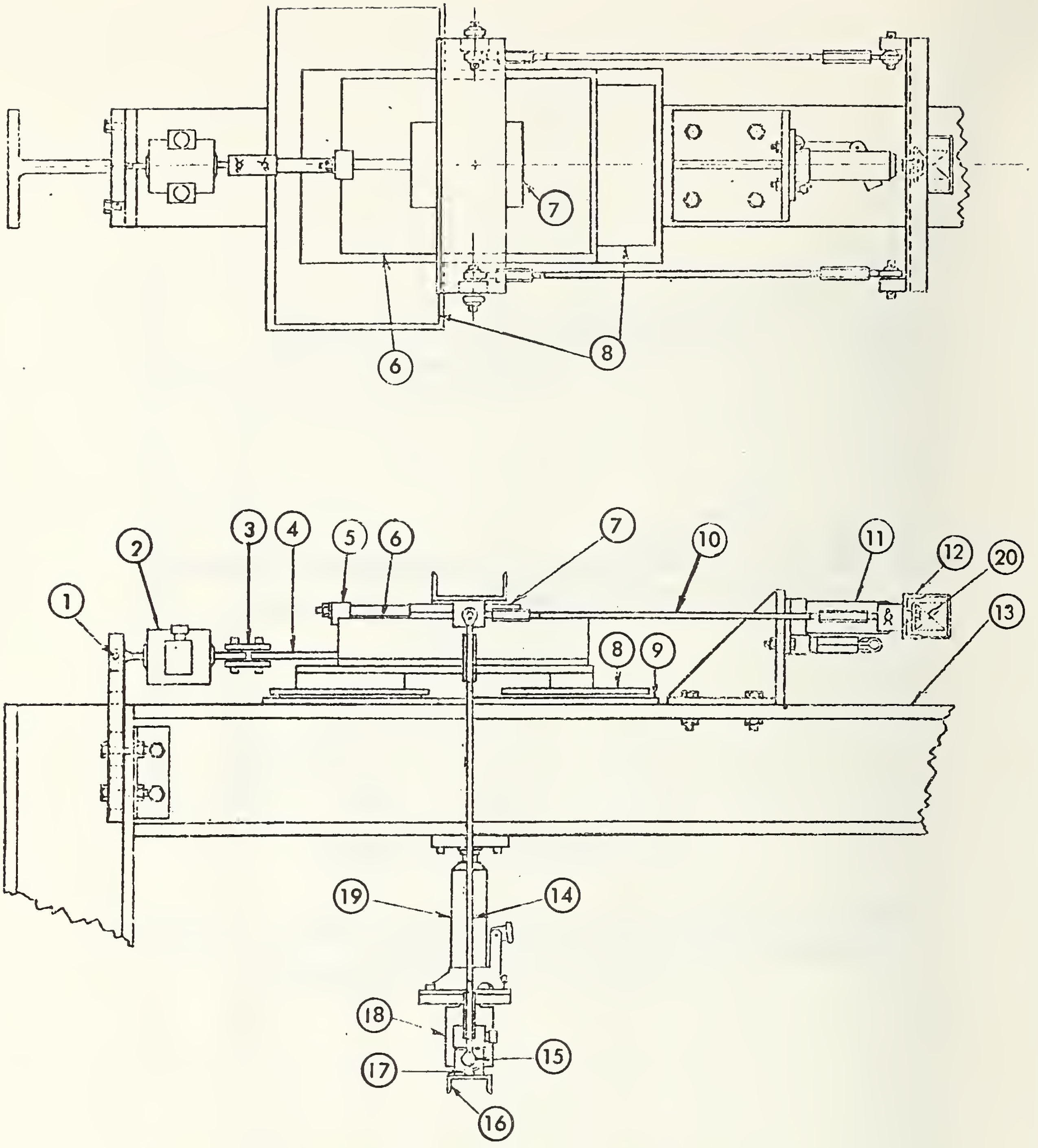
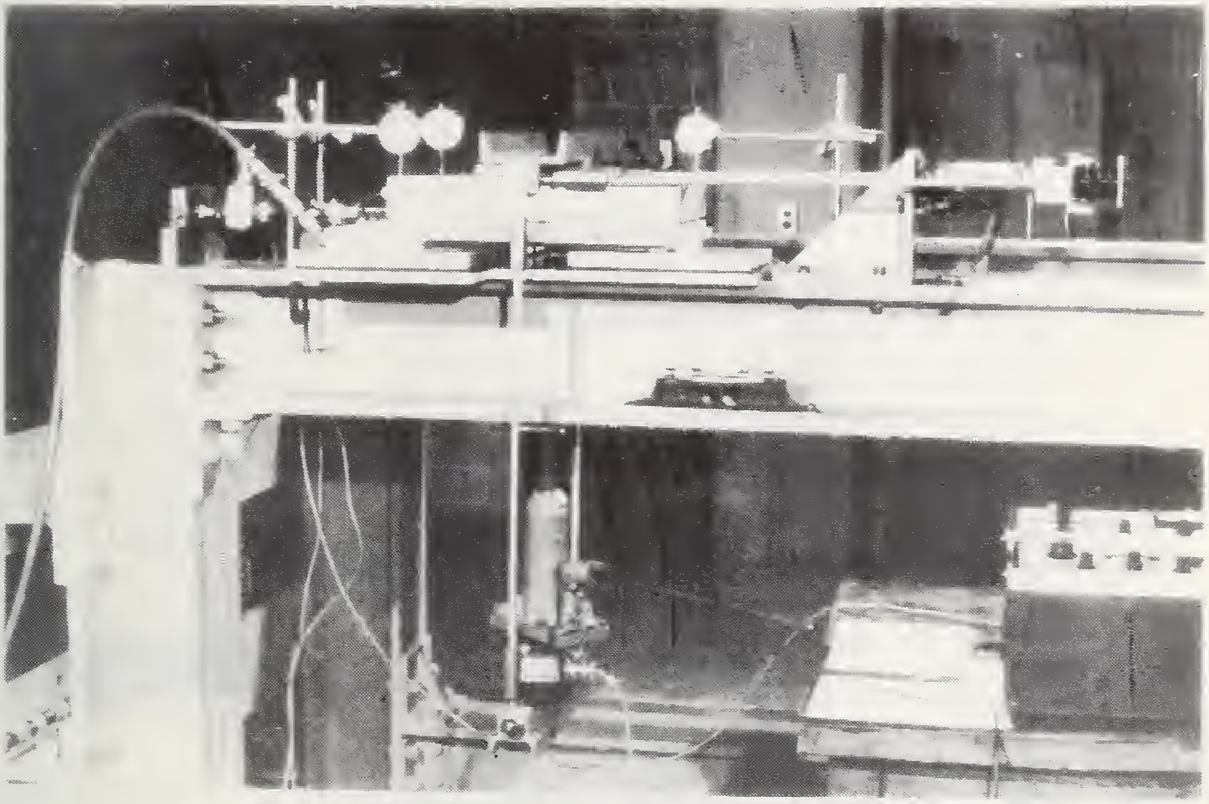


FIGURE 10. NOMENCLATURE OF THE LOADING FIXTURE.

1. HORIZONTAL LOAD CELL ANCHOR PIN
2. HORIZONTAL LOAD CELL
3. LINK
4. FORCE PLATE DRAWBAR
5. LIP
6. FORCE PLATE
7. FOOTPRINT
8. AIR-BEARING BASE
9. AIR-BEARING SUPPORT SURFACE
10. HORIZONTAL TIE RODS
11. HORIZONTAL JACK
12. HORIZONTAL JACK BEAM
13. H-BEAM FRAMEWORK
14. VERTICAL TIE RODS
15. TYPICAL BALL JOINT TIE ROD END
16. VERTICAL JACK BEAM
17. LOADING BALL
18. VERTICAL LOAD CELL
19. VERTICAL JACK
20. SPRING



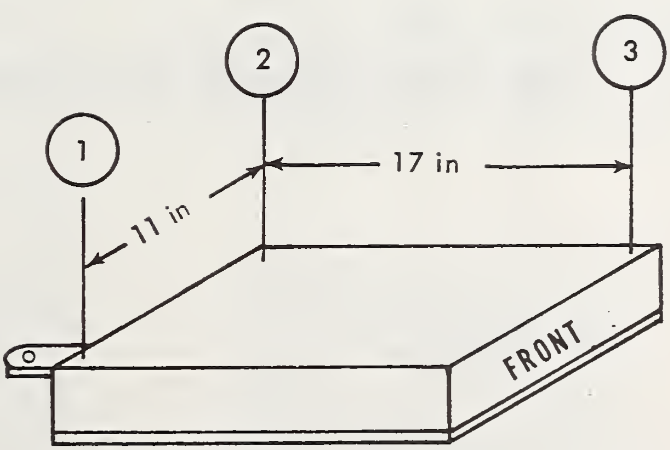


FIGURE 11. DIAL GAGE LOCATIONS.

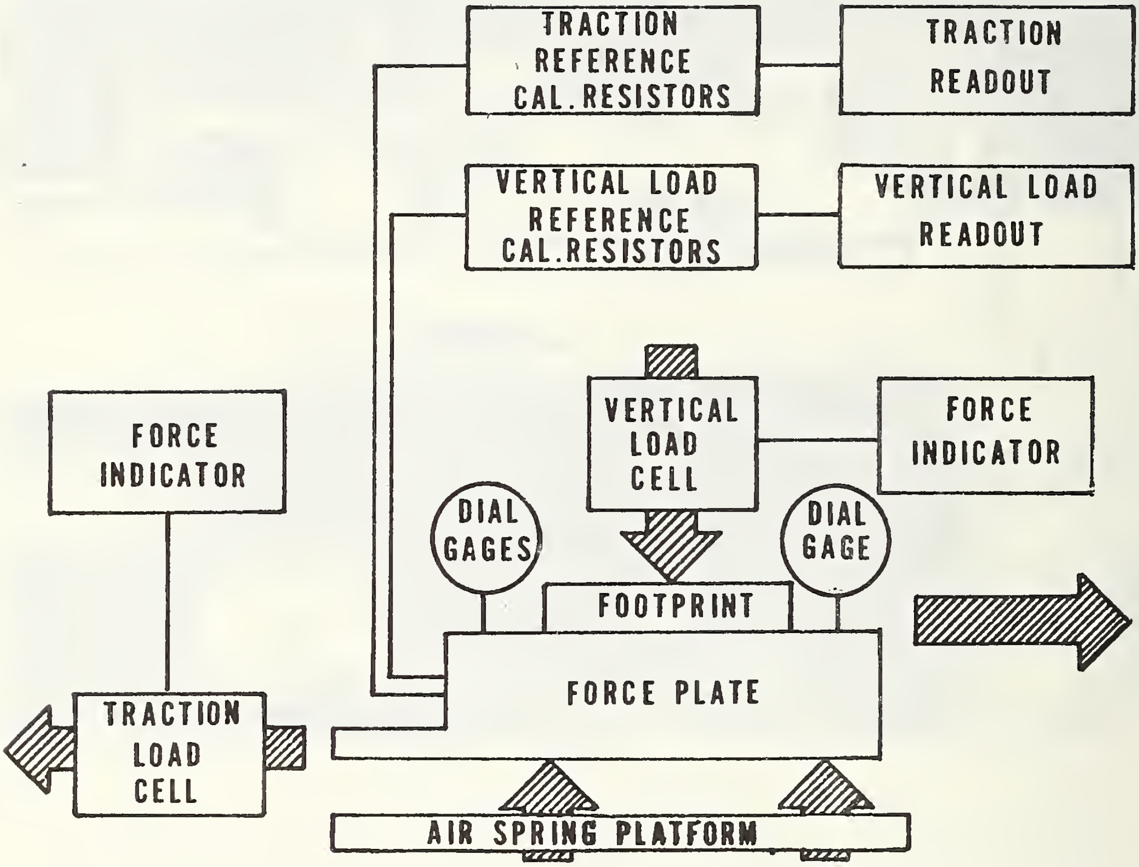


FIGURE 12. FORCE PLATE CALIBRATION BLOCK DIAGRAM

Force Plate System Calibrated:
Force Plate Type K.J. Law Model M1275A Serial 003
Calibration Box Type with Cables NBS Serial 003

Date completed January 31, 1975
Temperature range during calibration 22.6°C to 23.6°C

Force Plate Orientation during Calibration:
The force plate friction surface pitch angle corresponding to a minimum change in the traction channel output for a large change in vertical load was determined to be: Drawbar up 1.7 x 10^{-4} Radian
The force plate friction surface roll angle was zero.

Calibration System:

	Type	Serial
Loading Fixture	NBS	001
Horizontal Load Cell	BLH T3P2B	85420-A
Horizontal Indicator	BLH 615C	2006
Vertical Load Cell	BLH T3P2B	89731-A
Vertical Indicator	BLH L-15-C	150108
Force Plate Readout	BLH SY256	NBS 178454

Normal Load Ref. Resistor Designation	Trimmed to Equiv. Force Value (lbf)
N(No Resistor)	0*
250	250
500	500
750	750
1000	1000
1250	1250
1500	1500
1750	1750
Hysteresis	0.1 %FS
Non-Linearity	±0.1 %FS

Test Conditions	Static Load = 1085 lbf H/L = 0.12	Static Load = 1285 lbf H/L = 0.09	Static Load = 1285 lbf H/L = 0.15	Static Load = 885 lbf H/L = 0.09	Static Load = 885 lbf H/L = 0.15
Traction Ref. Resistor Designation	Trimmed to Equiv. Force Value (lbf)	Calculated Equiv. Force Value (lbf)	Calculated Equiv. Force Value (lbf)	Calculated Equiv. Force Value (lbf)	Calculated Equiv. Force Value (lbf)
N(No Resistor)	+1*	-1*	-2*	-4*	-4*
200	200	198	197	195	190
300	300	298	297	295	295
400	400	398	397	395	395
500	500	498	497	495	495
600	600	597	597	595	595
700	700	697	697	695	694
800	800	797	797	795	794
900	900	897	897	895	895
1000	1000	997	997	995	995
1500	1500	1497	1497	1495	1494
Hysteresis	0.6 %FS	0.7 %FS	0.6 %FS	0.6 %FS	0.8 %FS
Non-Linearity	±0.3 %FS	±0.4 %FS	±0.3 %FS	±0.3 %FS	±0.4 %FS

*Expected offset values under no load conditions when a linear readout device is adjusted to the reference resistor value using a least squares fit.

FIGURE 13. SUMMARY REPORT SHEET

Appendix A. The Calibration Fixture

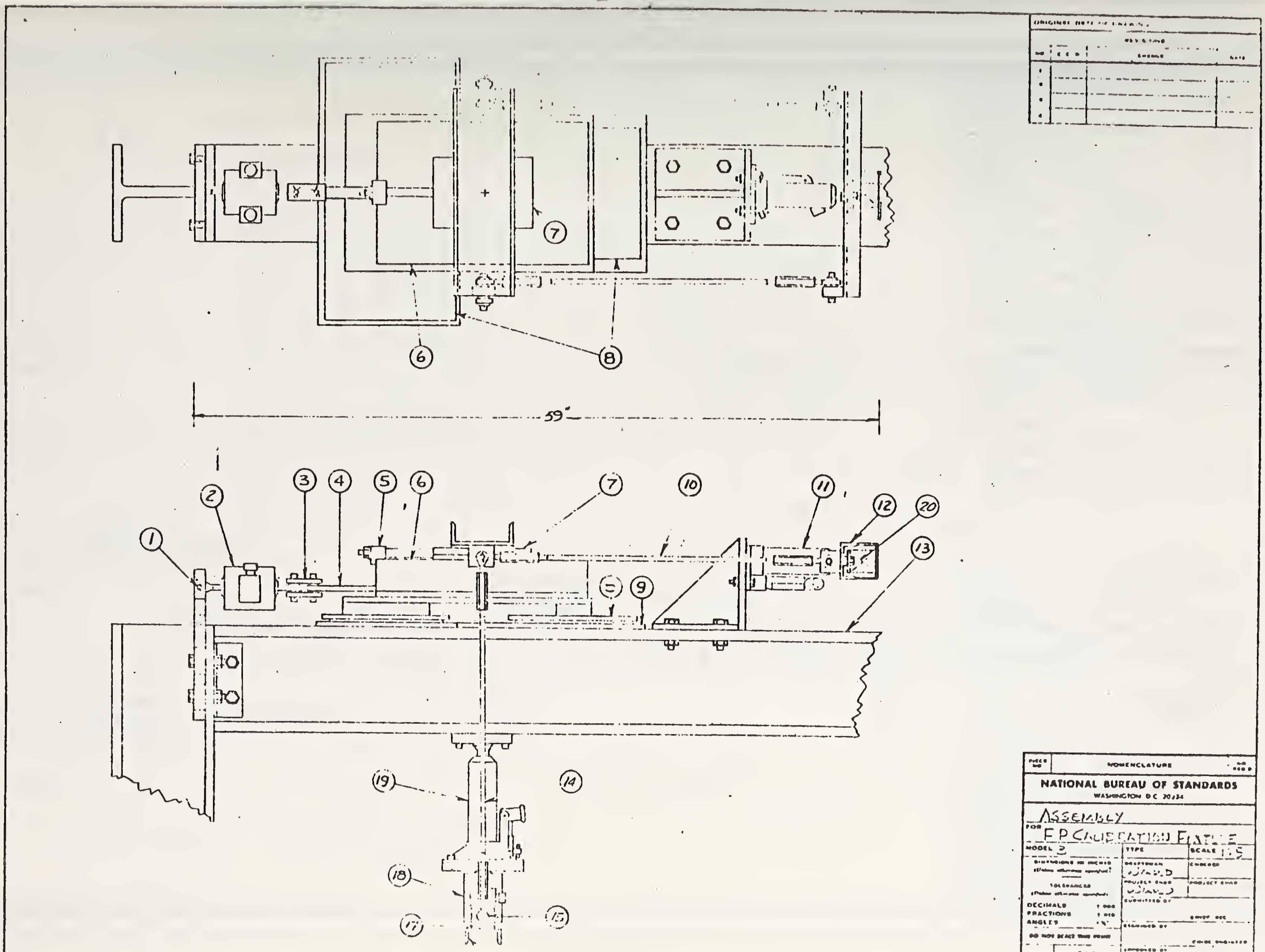
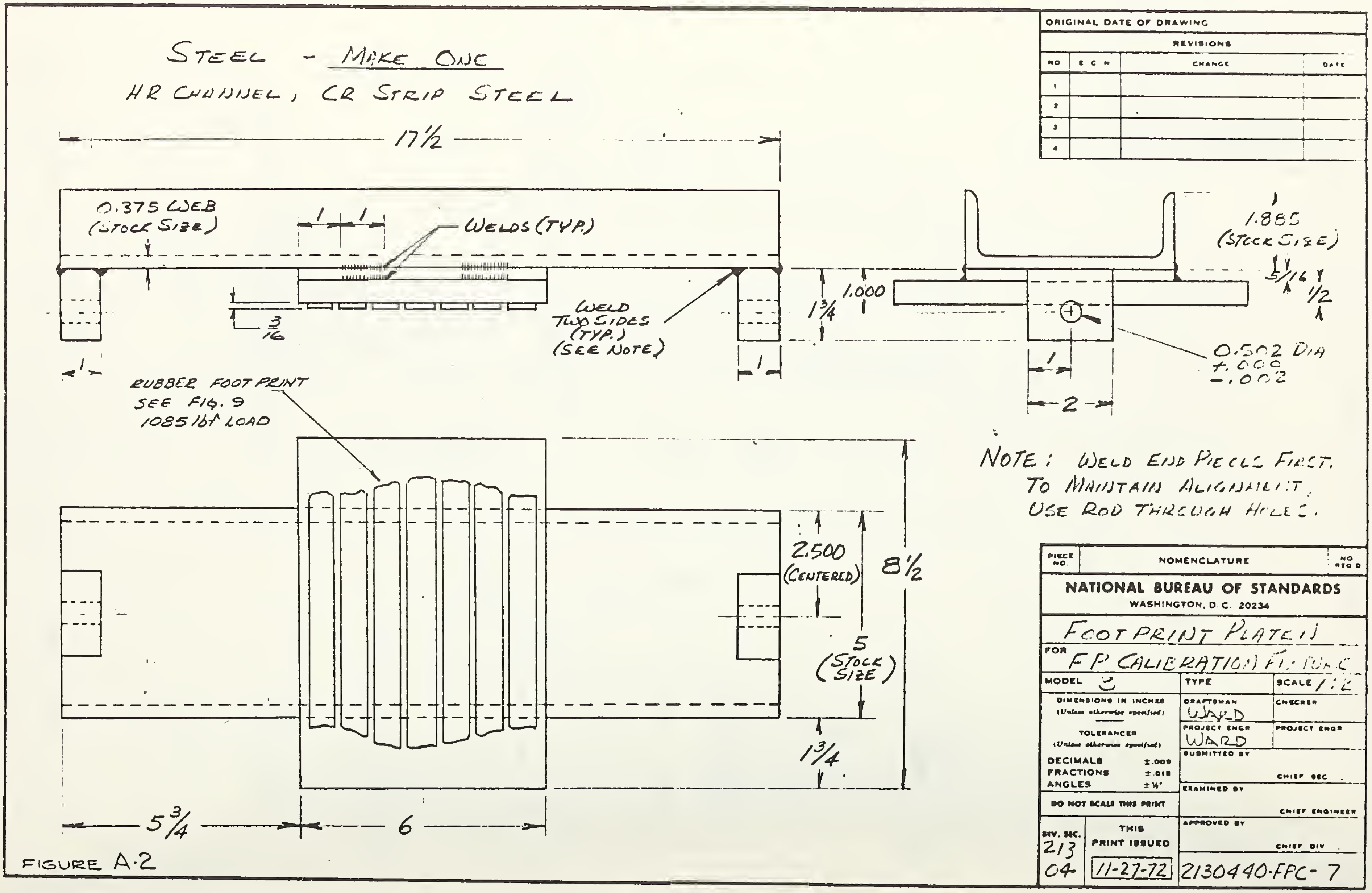

59"
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
NOMENCLATURE
NATIONAL BUREAU OF STANDARDS
WASHINGTON D.C. 20234
ASSEMBLY
FOR E.P. CALIBRATION FIXTURE
MODEL 2
TYPE
SCALE 1:5
DECIMALS
FRACTIONS
ANGLES
DO NOT SCALE THIS PRINT
THIS PRINT ISSUED
12-7-72

FIGURE A-1



STEEL - MAKE ONE
HR CHANNEL, CR STRIP STEEL
17½
0.375 WEB (STOCK SIZE)
WELDS (TYP.)
WELD TWO SIDES (TYP.) (SEE NOTE)
3/16
1.000
1¾
1.885 (STOCK SIZE)
5/16
½
0.502 DIA +.000 -.002
2
RUBBER FOOT PRINT SEE FIG. 9 1085 lbf LOAD
2.500 (CENTERED)
8½
5 (STOCK SIZE)
5¾
6
NOTE: WELD END PIECES FIRST. TO MAINTAIN ALIGNMENT, USE ROD THROUGH HOLES.
ORIGINAL DATE OF DRAWING
REVISIONS
NO
E C N
CHANGE
DATE
PIECE NO.
NOMENCLATURE
NO REQ D
NATIONAL BUREAU OF STANDARDS
WASHINGTON, D.C. 20234
FOOT PRINT PLATEN
FOR FP CALIBRATION FIXTURE
MODEL
TYPE
SCALE 1:2
DIMENSIONS IN INCHES (Unless otherwise specified)
TOLERANCES (Unless otherwise specified)
DECIMALS ±.009
FRACTIONS ±.018
ANGLES ±½°
DO NOT SCALE THIS PRINT
DRAFTSMAN WARD
CHECKER
PROJECT ENGR WARD
PROJECT ENGR
SUBMITTED BY
CHIEF SEC
EXAMINED BY
CHIEF ENGINEER
APPROVED BY
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DIV. SEC. 213 04
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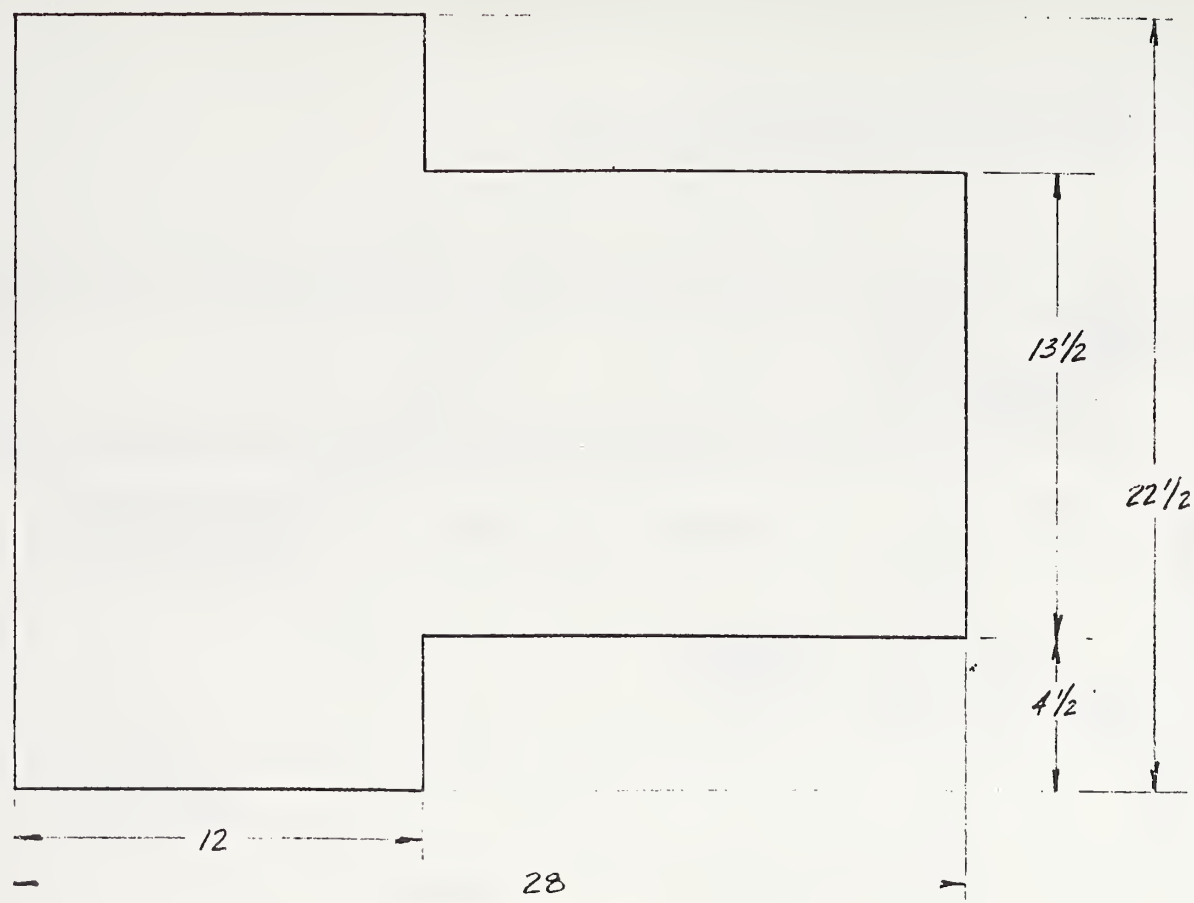
FIGURE A-2



1/2 IN. ALUMINUM PLATE
6061-T6

MAKE ONE

NOTE: SAW CUT.
BREAK SHARP EDGE

ORIGINAL DATE OF DRAWING			
REVISIONS			
NO	E C N	CHANGE	DATE
1			
2			
3			
4			

PIECE NO	NOMENCLATURE		NO REQ D
NATIONAL BUREAU OF STANDARDS WASHINGTON, D.C. 20234			
AIR-BEARING SUPPORT SURFACE			
FOR F P CALIBRATION FIXTURE			
MODEL 2	TYPE	SCALE	
DIMENSIONS IN INCHES (Unless otherwise specified)	DRAFTSMAN WARD	CHECKER	
TOLERANCES (Unless otherwise specified) DECIMALS ±.005 FRACTIONS ±.015 ANGLES ±½°	PROJECT ENGR WARD	PROJECT ENGR	
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FIGURE A-3

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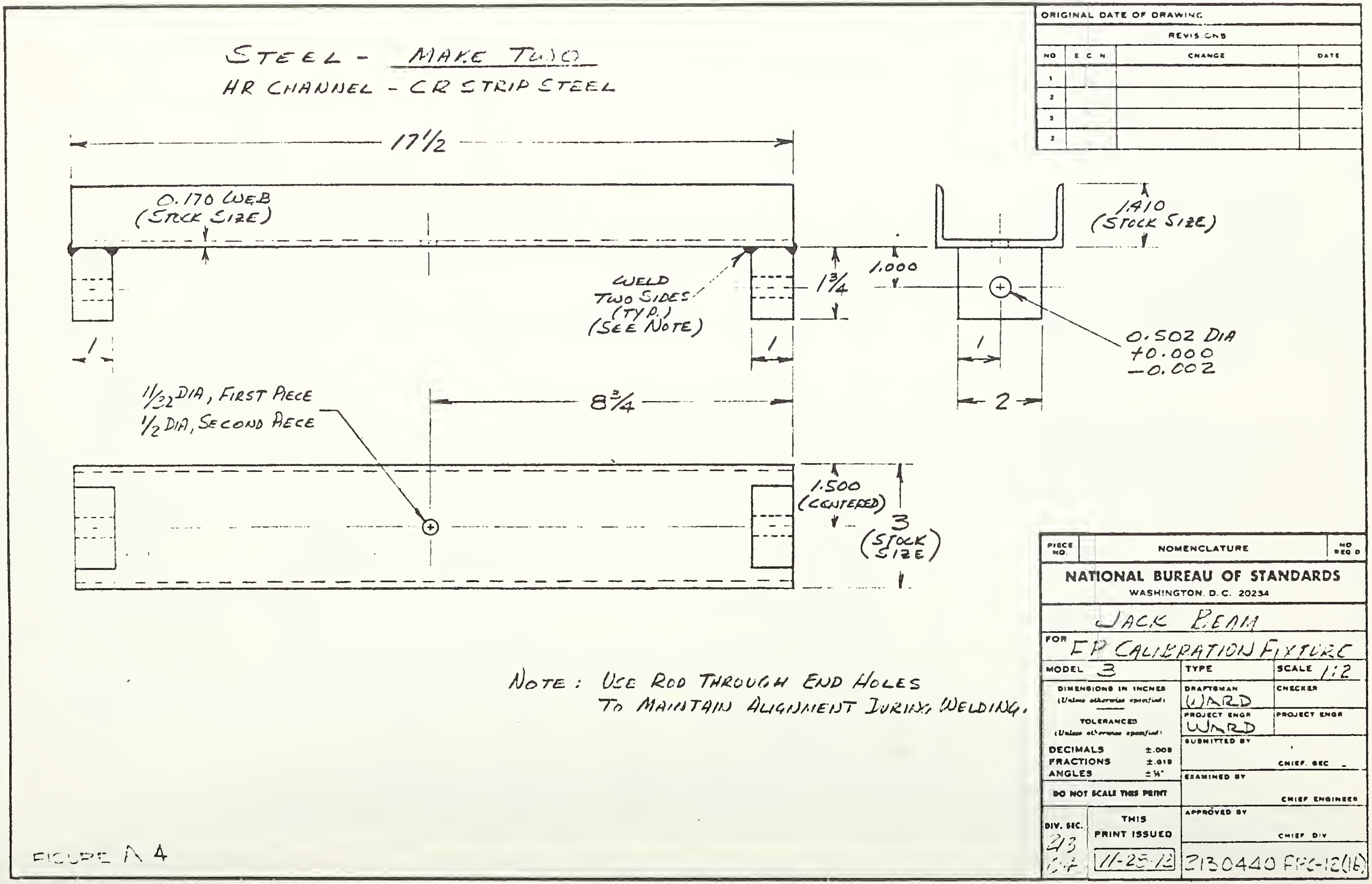

FIGURE A 4

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Appendix B. Load Cell Calibration Reports

This appendix contains the calibration reports of the load cells used with the fixture. The cell calibrated in tension is used in the horizontal force channel. The cell calibrated in compression is used in the vertical force channel.

OMNITAB - NATIONAL BUREAU OF STANDARDS LOAD CELL CALIBRATION

BLH LOAD CELL NO. 35420-A, BLH INDICATOR NO. 2006 213.04/10.35.3-A
CAPACITY 2,000 LBF COMPRESSION AND TENSION JANUARY 7,1975

TENSION CALIBRATION DATA FOR 23 DEGREES C

APPLIED LOAD	DEFLECTIONS OBSERVED DURING CALIBRATION RUN 1	DEFLECTIONS OBSERVED DURING CALIBRATION RUN 2	DEVIATION FROM CALIBRATION EQUATION RUN 1	DEVIATION FROM CALIBRATION EQUATION RUN 2	DEFLECTIONS ADJUSTED TO CALIBRATION EQUATION	CHANGE FROM PREVIOUS CALIBRATION EQUATION
LBF	UNITS	UNITS	UNITS	UNITS	UNITS	UNITS
100.	2506.	2504.	-.6	-2.6	2507.	6.
200.	5017.	5014.	1.9	-1.1	5015.	5.
300.	7522.	7524.	-1.3	.7	7523.	5.
400.	10032.	10033.	.8	1.8	10031.	5.
500.	12537.	12540.	-1.8	1.2	12539.	5.
600.	15047.	15050.	1.0	4.0	15046.	5.
700.	17552.	17552.	-.9	-.9	17553.	5.
800.	20058.	20060.	-1.5	.5	20059.	5.
900.	22565.	22566.	-.7	.3	22566.	5.
1000.	25072.	25075.	.3	3.3	25072.	6.
1100.	27575.	27577.	-2.2	-.2	27577.	6.
1200.	30085.	30083.	2.5	.5	30083.	6.
1300.	32586.	32584.	-1.4	-3.4	32587.	7.
1400.	35092.	35090.	-.0	-2.0	35092.	8.
1500.	37595.	37596.	-1.3	-.3	37596.	8.
1600.	40104.	40102.	3.7	1.7	40100.	9.
1700.	42604.	42599.	.1	-4.9	42604.	10.
1800.	45110.	45108.	2.8	.8	45107.	11.
1900.	47607.	47609.	-3.1	-1.1	47610.	12.
2000.	50116.	50113.	3.2	.2	50113.	13.

CALIBRATION READING 33195.00

O/I RATIO SWITCH SET TO 3 MV/V

DEFLECTION = (A) + (B)(LOAD) + (C)(LOAD SQUARED)

WHERE A = -2.315186+00 UNITS
B = 2.509041+01 UNITS/LBF
C = -1.643605-05 UNITS/(LBF SQUARED)

STANDARD DEVIATION = 2.065774+00 UNITS

UNCERTAINTY = .20 LBF

* * * * * * * * * * * * * * * * *

MINIMUM WORKING LOAD = 400.00 LBF AS .05 PERCENT REF. STD.

MINIMUM WORKING LOAD = 80.00 LBF FOR ASTM METHOD E4.

B-1. HORIZONTAL LOAD CELL CALIBRATION DATA

OMNITAB - NATIONAL BUREAU OF STANDARDS LOAD CELL CALIBRATION

BLH LOAD CELL NO. 89231-A, BLH INDICATOR NO. 150108 213.04/10.36.3-A
CAPACITY 2,000 LBF COMPRESSION AND TENSION JANUARY 7,1975

COMPRESSION CALIBRATION DATA FOR 23 DEGREES C

APPLIED LOAD	DEFLECTIONS OBSERVED DURING CALIBRATION RUN 1	RUN 2	DEVIATION FROM CALIBRATION EQUATION RUN 1	RUN 2	DEFLECTIONS ADJUSTED TO CALIBRATION EQUATION	CHANGE FROM PREVIOUS CALIBRATION EQUATION
LBF	UNITS	UNITS	UNITS	UNITS	UNITS	UNITS
100.	2997.	2998.	2.2	3.2	2995.	-4.
200.	5990.	5992.	-.8	1.2	5991.	-5.
300.	8985.	8986.	-2.3	-1.3	8987.	-5.
400.	11985.	11985.	.9	.9	11984.	-7.
500.	14977.	14979.	-4.3	-2.3	14981.	-8.
600.	17978.	17980.	-.9	1.1	17979.	-9.
700.	20977.	20979.	.1	2.1	20977.	-10.
800.	23972.	23976.	-3.3	.7	23975.	-11.
900.	26972.	26976.	-2.0	2.0	26974.	-12.
1000.	29968.	29970.	-5.2	-3.2	29973.	-14.
1100.	32972.	32976.	-.7	3.3	32973.	-15.
1200.	35973.	35978.	.4	5.4	35973.	-17.
1300.	38971.	38976.	-1.8	3.2	38973.	-18.
1400.	41975.	41980.	1.5	6.5	41974.	-20.
1500.	44968.	44972.	-6.5	-2.5	44975.	-21.
1600.	47976.	47980.	.0	4.0	47976.	-23.
1700.	50976.	50981.	-1.8	3.2	50978.	-24.
1800.	53977.	53982.	-3.0	2.0	53980.	-26.
1900.	56984.	56986.	1.5	3.5	56983.	-28.
2000.	59982.	59982.	-3.5	-3.5	59985.	-30.

CALIBRATION READING 59154.00

DEFLECTION = (A) + (B)(LOAD) + (C)(LOAD SQUARED)

WHERE A = -9.370117-01 UNITS
B = 2.995439+01 UNITS/LBF
C = 1.911303-05 UNITS/(LBF SQUARED)

STANDARD DEVIATION = 3.040775+00 UNITS

UNCERTAINTY = .24 LBF

* * * * * * * * * * * * * * * * *

MINIMUM WORKING LOAD = 480.00 LBF AS .05 PERCENT REF. STD.

MINIMUM WORKING LOAD = 96.00 LBF FOR ASTM METHOD E4.

NOTE: Use cable with 1500 ohm resistor permanently attached.

B-2. VERTICAL LOAD CELL CALIBRATION DATA

Appendix C. The Calibration Box

Figure C-1 Schematic Diagram of One Force Channel of the Calibration Box

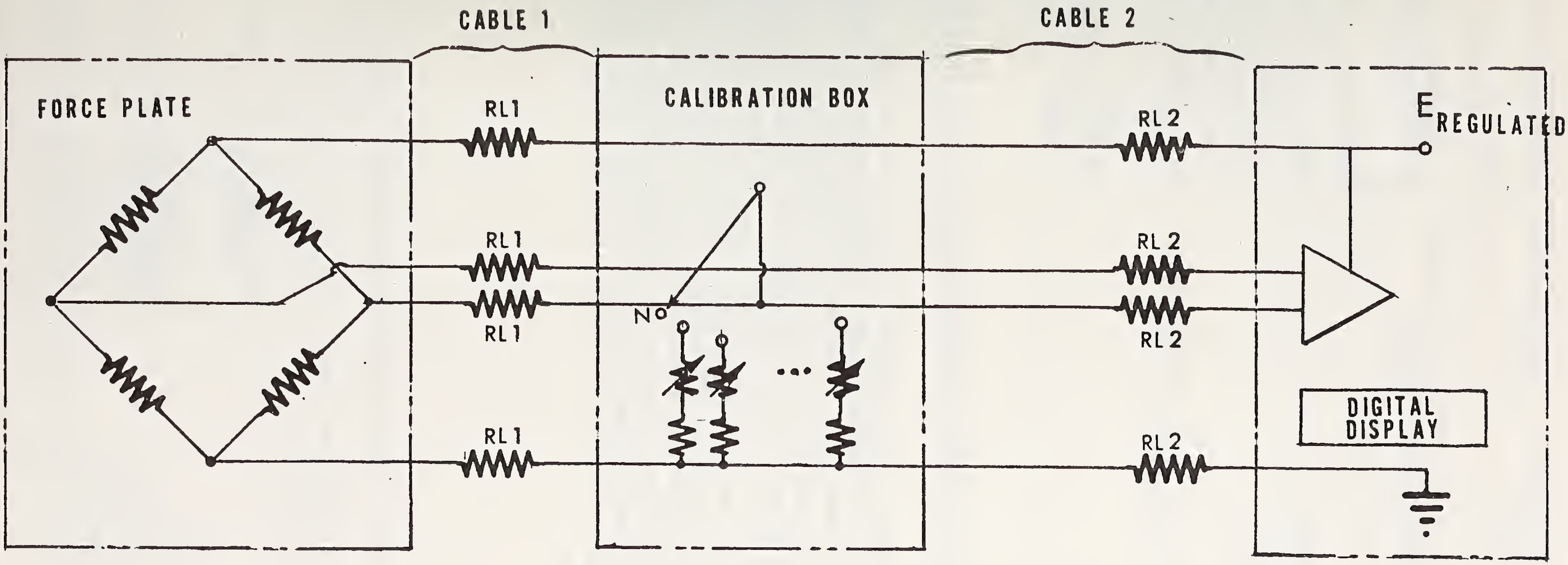

FIGURE C-1. SCHEMATIC OF ONE CHANNEL OF THE CALIBRATION BOX.

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET**	1. PUBLICATION OR REPORT NO. NBSIR 75-738	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

A METHOD AND MEANS OF CALIBRATING AN AIR-BEARING FORCE PLATE FOR USE WITH A TOWED PAVEMENT-FRICTION TEST TRAILER

5. Publication Date December 1974

6. Performing Organization Code

7. AUTHOR(S)

Robert W. Kearns, John F. Ward

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No. 2130440

11. Contract/Grant No. Inter-Agency Government Order 1-1-1261

12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)*

Federal Highway Administration
Washington, D. C. 20234

13. Type of Report & Period Covered Final

14. Sponsoring Agency Code FHWA

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The equations for the variation of the external forces acting at the tire-pavement interface of a symmetrical two-wheeled towed trailer are given. Estimates, derived from experimental results, have been made for the displacement of the tire-plate interface with respect to the ground of an unrestrained locked test tire on the trailer. A description of the force plate calibration test frame, instrumentation and test method is given. The means of applying simultaneous vertical (normal) and horizontal (longitudinal) forces at the contact surface of the air-bearing plate in accordance with the equations are discussed. The change in force plate output with changes in the dimensions of the trailer calibrated in-turn with the force plate are given. A method of locating the coordinate axes of the internal force sensors with respect to level is given. Consistent application of these methods to both the force plate and trailer transducer calibrations results in reduced vertical-to-horizontal cross-axis differences.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Calibration procedures; force plate; pavement skid resistance; skid accident reduction; tire-pavement interface forces.

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