HMS

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"TEST RESULTS OF BRIDGE BALANCING BY THE STRAIN GAGE TECHNIQUE OF A VERTICAL LIFT BRIDGE IN HANNIBAL MISSOURI"

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INTRODUCTION

The Hannibal Bridge is a vertical lift bridge which carries a single railroad line across the Mississippi River in Hannibal, Missouri. The lift span connects the west bank to a fixed span which extends from the east bank. The lift span was relocated from Alabama and floated up river to be installed in Hannibal. Final balance specifications for the relocation included balancing the lift span by the strain gage method.

TESTING

The specifications for final balance conditions required a span heavy condition of 9,300 pounds at each corner of the lift span. Access to the final pinions for each corner was not possible due to the arrangement of the operating machinery and the gears, however the drive shafts for each side, north and south, were accessible. Realizing this constraint, it was accepted that the critical balance state be the total span heavy condition of 37,200 pounds, as well as a side to side specification of 18,600 pounds each. An estimate of approximately 5,000 pounds in additional painting and other hardware were yet to be installed on the span at the time of testing, making the required balance state for testing purposes a span heavy condition of 32,200 pounds.

After strain gage installation, and zeroing and calibration of the data acquisition system, several test lifts were performed. The data acquisition system is setup to continuously collect and store measurements from the strain gages during a full lift cycle, up and down. The system supplies five volts excitation to each strain gage channel and measures the millivolt per volt output. The output is directly related to the torque applied to the shaft. Details about the strain gage installation, calibration and testing procedure, as well as the correlation between the strain gage output and the load applied are in the Discussion section.

Immediately following each test lift, the stored data was downloaded to a laptop computer and imported into a Lotus 1-2-3 spreadsheet for analysis. Results of each test lift were used to determine and confirm adjustments necessary to satisfy the balance specification for the bridge. Upon final counterweight adjustments, three separate test lifts are performed to ensure accurate results.

INSTRUMENTATION

The following instrumentation was used for span balance determination:

Strain Gages:	Micro-Measurements CEA-13-187UV-350
Data Acquisition System:	Campbell Scientific 21X Micro-Logger
Wire:	Belden S/N #9534 4-Conductor

RESULTS

After strain gage installation and zeroing, several test lifts were performed to establish the preliminary balance state. Initial tests, prior to any adjustments, showed the bridge to be below the acceptable balance specification by 8,700 pounds in the closed position.

The preliminary tests also indicated a discrepancy in the side to side balance state. The torque values obtained on the south drive shaft were significantly higher than the north, indicating higher loads on the south side. Corrections for this discrepancy were attempted by adjusting the tension in the uphaul and downhaul ropes of each side of the span. These adjustments were in increments of three (3) inches. The first adjustment, to the North side uphaul ropes, decreased the load difference during raising the span from twelve to seven thousand pounds but actually increased the discrepancy during the lowering of the span, from roughly 36,000 to 46,000 pounds (see figure 1). With additional adjustments to uphaul and downhaul ropes on both sides, the discrepancy during raising of the span was minimized to less than 5,000 pounds difference. During lowering of the span, the side to side load difference could not be decreased below 34,000 pounds.

In order to adjust for the span light condition of the bridge, correction is performed by adding or subtracting weight from the counterweight blocks. Using the preliminary balance condition of 8,700 pounds too light, approximately forty (40) blocks would be removed from each counterweight block. Testing was performed after thirty weights were removed from each counterweight, to test the preliminary indications. These new results indicated the bridge to be still below the specification by approximately 2,000 pounds, verifying the preliminary results. The additional ten blocks were removed from each counterweight and final testing was performed on the span. Final balance results from each side as well as the total balance state are in figures 2 through 4.

OBSERVATIONS AND CONCLUSION

Several notes of interest were made during the installation and testing of this bridge. One clear observation was the arrangement of hardware on the span. All walkways, catwalk, guard and handrails, and steps were on the South side of the span. This early observation was initially thought to be the clear reason for the side to side imbalance. However, if that were the case, the load difference between sides would be more consistent with each other during raising and lowering of the span.

Also, prior to final adjustment of uphaul and downhaul ropes and weight adjustment, the bridge operator had difficulty in completely seating and locking the span. One side was seated while the other remained a few inches above. This clearly demonstrated the importance of the adjustment of the up and downhaul ropes.

During raising and lowering of the span, some steel workers made another critical observation. They noticed that the counterweight blocks actually moved off center and made considerable contact with the counterweight guide rails on the South side. Contact with the guide rail was considerable to the point that the rail required re-coating. The test results confirm these observations. In figures 2 and 3, friction values for the North and South side are tabulated and plotted. Friction values for the South side were nearly twice those of the North side. Although the reason for the counterweight behavior was not established during the testing period, this behavior may help explain the discrepancy in the side to side balance state.

DISCUSSION

Strain Gages

In order to obtain accurate measurements of strain and moment in the pinion shafts, the strain gages are installed very precisely. Four strain gages are installed on each pinion shaft. The gages are arranged in pairs, 180 degrees apart on the shaft. The strain gages are then wired into a Wheatstone Bridge circuit as shown in figure 5. The combination of gage layout and wiring circuit provides the following advantages:

- Four times the output of a single strain gage.
- Any strain due to bending, direct shear, axial compression or tension is electrically canceled.
- The strain gage output is temperature compensated.

Zeroing and Calibration

The brakes were released manually and the shaft was rotated by hand until gear float was observed in each pinion. The offset observed in the output is adjusted in the final results. A known resistor was also used to calibrate the output. The calibration resistor was shunted across one leg of the Wheatstone Bridge, simulating a total bridge output of 42.25 micro-strain. Based on the calculation described below, this strain output simulates an imbalance of 24,880 pounds. The ratio of this value to the value observed during the shunt is used in the correlation of millivolt output to pounds of imbalance.

Calculations

Calculation of strain output from millivolt per volt measurement:

The correlation between mV/V output and $\mu\varepsilon$ is dependent on the strain gage configuration (number of active arms, N) and gage factor (Manufacturer Supplied, G.F):

$$\mu\varepsilon = \frac{4 * (\text{mV/V output}) * 1000}{\text{G.F.} * N}$$

Where:

G.F. = Gage Factor of Strain Gage (Manufacturer supplied)
N = Number of Active arms in the Bridge circuit

The factor of 1000 is to convert to proper decimal units, and the '4' is the total bridge output. The output without this factor would equal the output from one leg of the bridge circuit. For this particular test, the correlation is:

$$\mu\varepsilon \quad = \quad 487.8 * (\text{mV/V output})$$

Calculation of Imbalance Load from Strain Output:

The following constants and equations were used for calculating correlation between strain gage output and imbalance load:

Shear Modulus , G = 11,540 KSI
Pinion Shaft Diameter at Gage Location, D_p = 6.00 in.
Calibration Resistor = Output of 42.25 micro-strain ($\mu\varepsilon$)
Gear Ration between instrumented shaft and Rope drum, G.R. = 16.844

Equation 1	$\alpha = 2\varepsilon$
Equation 2	$\tau = G\alpha$
Equation 2A	$\tau = 2\varepsilon\, G$
Equation 3	$T_p = \tau\, \pi D_p^3/16$
Equation 4	$L = T_p * G.R/R_d.$

G	=	Shear Modulus
α	=	Shear Strain
T	=	Torque
T_p	=	Pinion Torque
ε	=	Measured Strain
τ	=	Shear Stress
D_p	=	Pinion Shaft Diameter
L	=	Imbalance Load
R_d	=	Rope Drum Radius
G.R.	=	Gear Ratio between Instrumented shaft and final pinion (Rope Drum)

Calculating the equivalent imbalance load of the calibration:

Solving Equation 2A for Shear Stress:

$$\tau = (11.54E6) * (2) * (42.25E\text{-}6) = 975 \text{ psi}$$

Solving Equation 3 for Pinion Torque:

$$Tp = (975) * (\pi) * (6.00)^3/16 = 41{,}357 \text{ in-lbs.}$$

Solving Equation 4 for Imbalance load (load on rope drums):

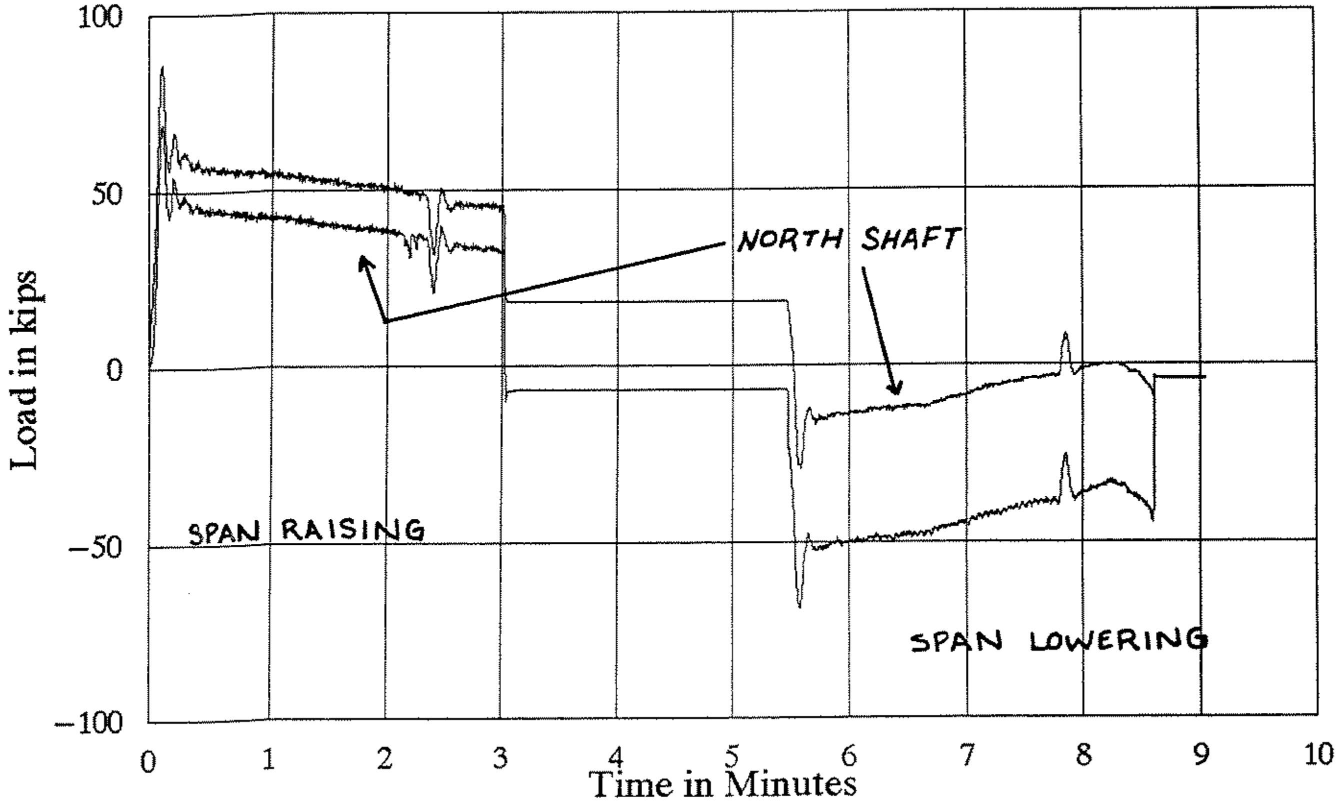
$$L = (41{,}357) * (16.844) / (28) = 24{,}879 \text{ lbs.}$$

The ratio of this calculated value to the value obtained by shunting the Wheatstone bridge for each strain gage channel is used to calibrate the test data.

APPENDIX

Load Measurements during Span Lift Cycle

Initial Loading Conditions



Load State After Adjustment to North Uphaul Rope

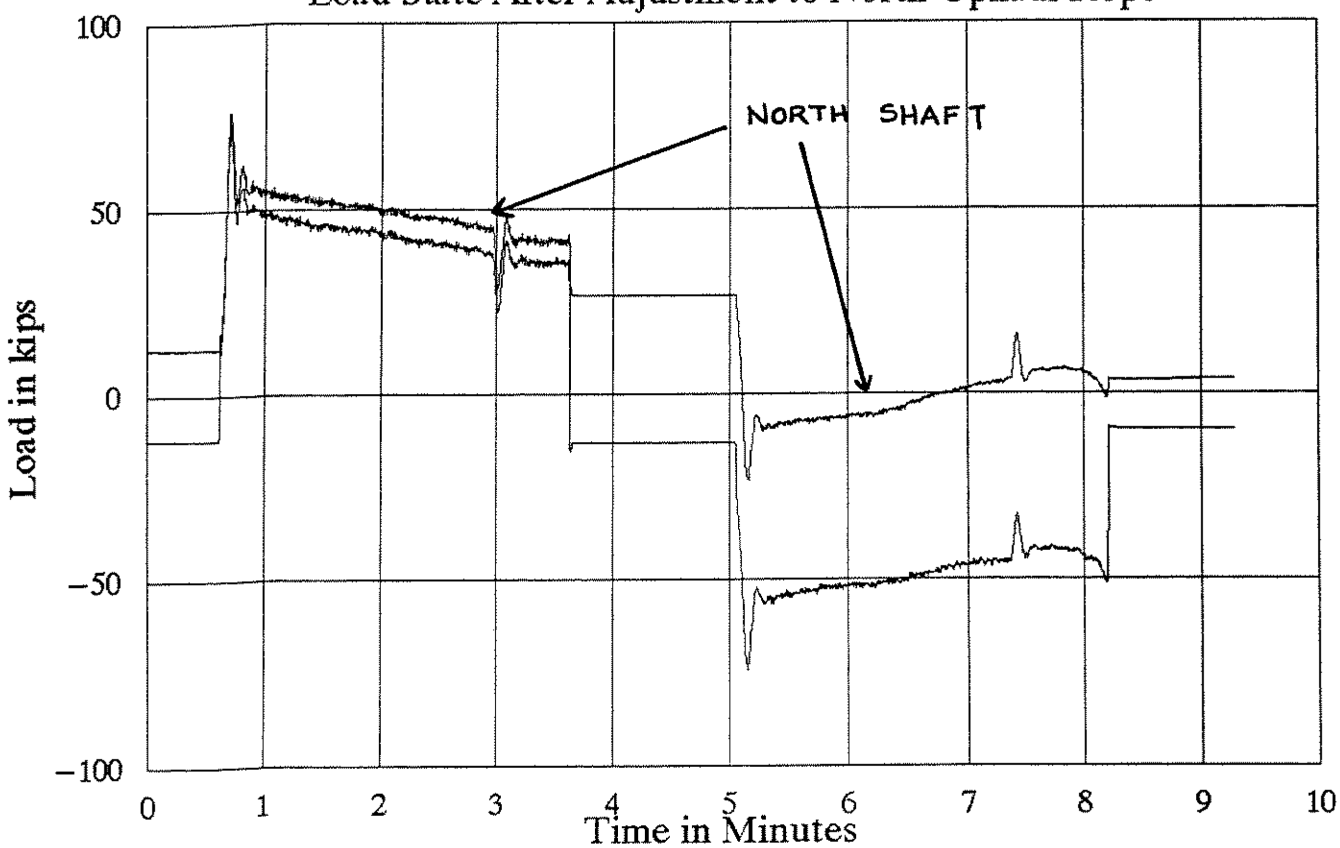


FIGURE 1

BALANCE TEST RESULTS

NORTH SHAFT RESULTS				
LIFT HEIGHT (feet)	LOAD UP (kips)	LOAD DOWN (kips)	AVG. LOAD IMBALANC (kips)	FRICTION LOAD (kips)
0	56.537	2.368	29.453	27.085
5	55.352	3.256	29.304	26.048
10	52.096	0.296	26.196	25.900
15	51.504	−3.256	24.124	27.380
20	49.432	−7.992	20.720	28.712
25	47.952	−11.544	18.204	29.748
30	45.584	−13.320	16.132	29.452
35	43.808	−15.984	13.912	29.896
40	41.440	−20.424	10.508	30.932

NORTH SHAFT RESULTS

DATA ANALYSIS

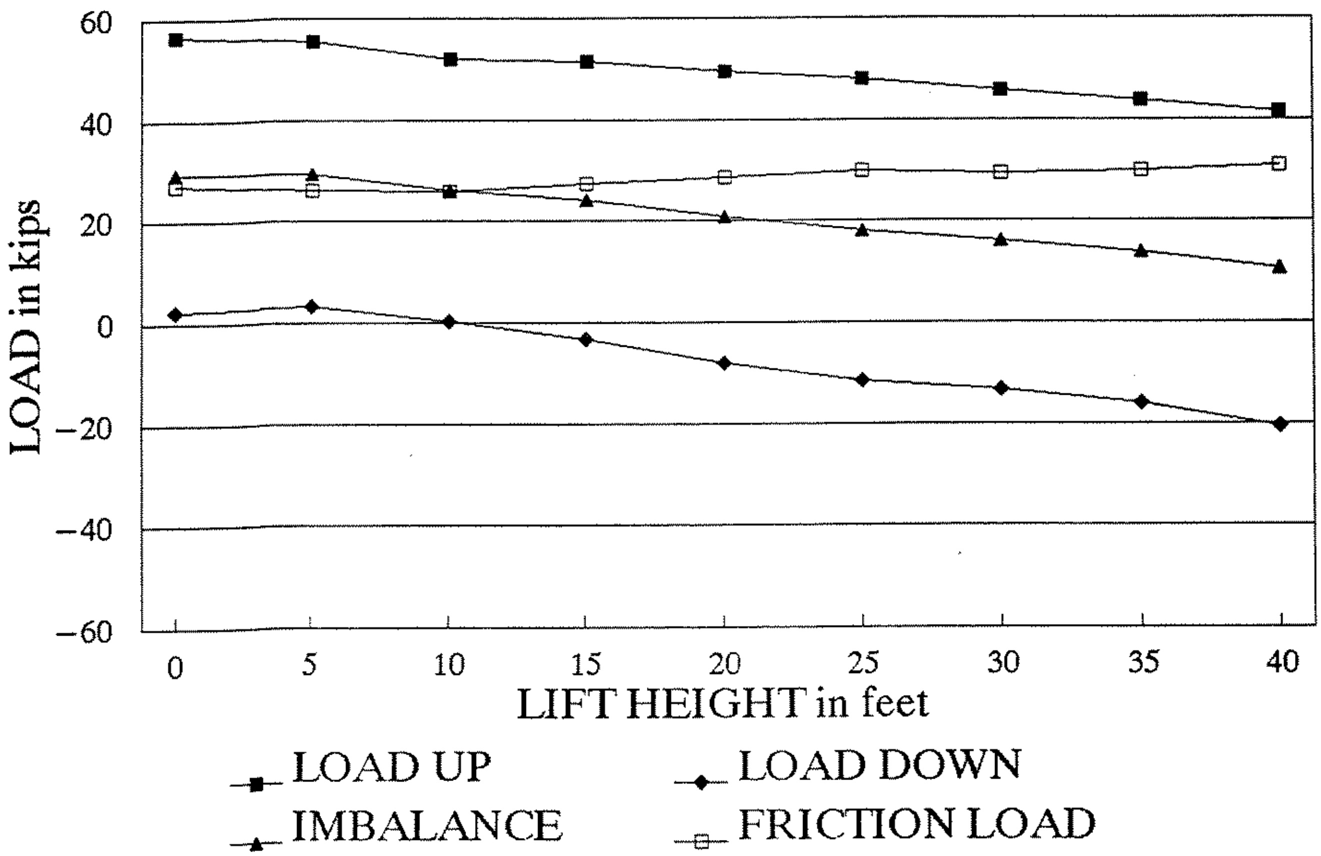


FIGURE 2

BALANCE TEST RESULTS

SOUTH SHAFT RESULTS				
LIFT HEIGHT (feet)	LOAD UP (kips)	LOAD DOWN (kips)	AVG. LOAD IMBALANCE (kips)	FRICTION LOAD (kips)
0	49.432	−43.512	2.960	46.472
5	48.544	−41.736	3.404	45.140
10	48.248	−47.360	0.444	47.804
15	47.360	−45.288	1.036	46.324
20	46.768	−47.656	−0.444	47.212
25	45.584	−49.728	−2.072	47.656
30	42.328	−51.208	−4.440	46.768
35	43.512	−51.504	−3.996	47.508
40	39.664	−54.464	−7.400	47.064

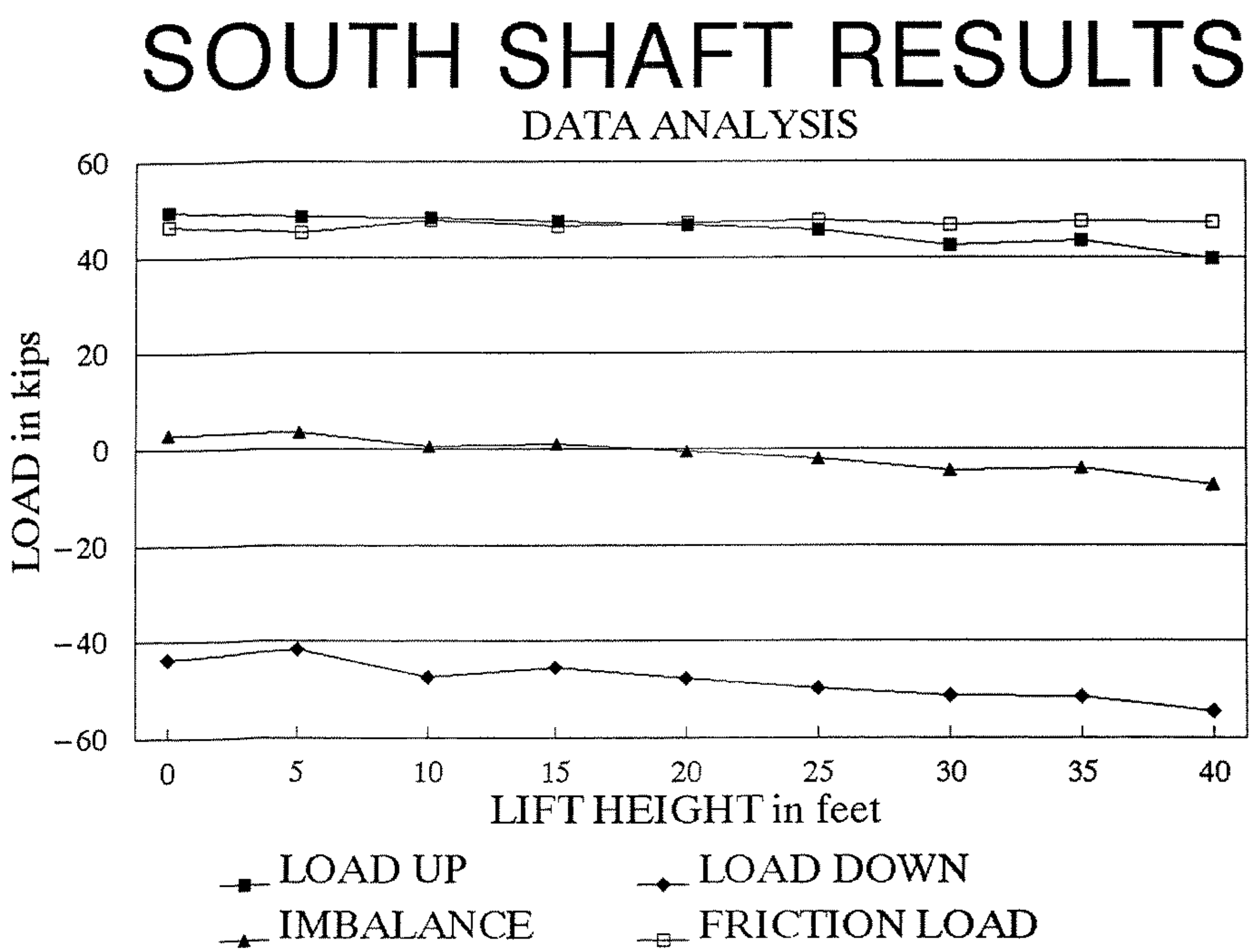


FIGURE 3

TOTAL BALANCE TEST RESULTS

FINAL BALANCE RESULTS				
LIFT HEIGHT (feet)	TOTAL UP (kips)	TOTAL DOWN (kips)	TOTAL IMBALANCE (kips)	FRICTION LOAD (kips)
0	105.969	−41.144	32.413	73.557
5	103.896	−38.480	32.708	71.188
10	100.344	−47.064	26.640	73.704
15	98.864	−48.544	25.160	73.704
20	96.200	−55.648	20.276	75.924
25	93.536	−61.272	16.132	77.404
30	87.912	−64.528	11.692	76.220
35	87.320	−67.488	9.916	77.404
40	81.104	−74.888	3.108	77.996

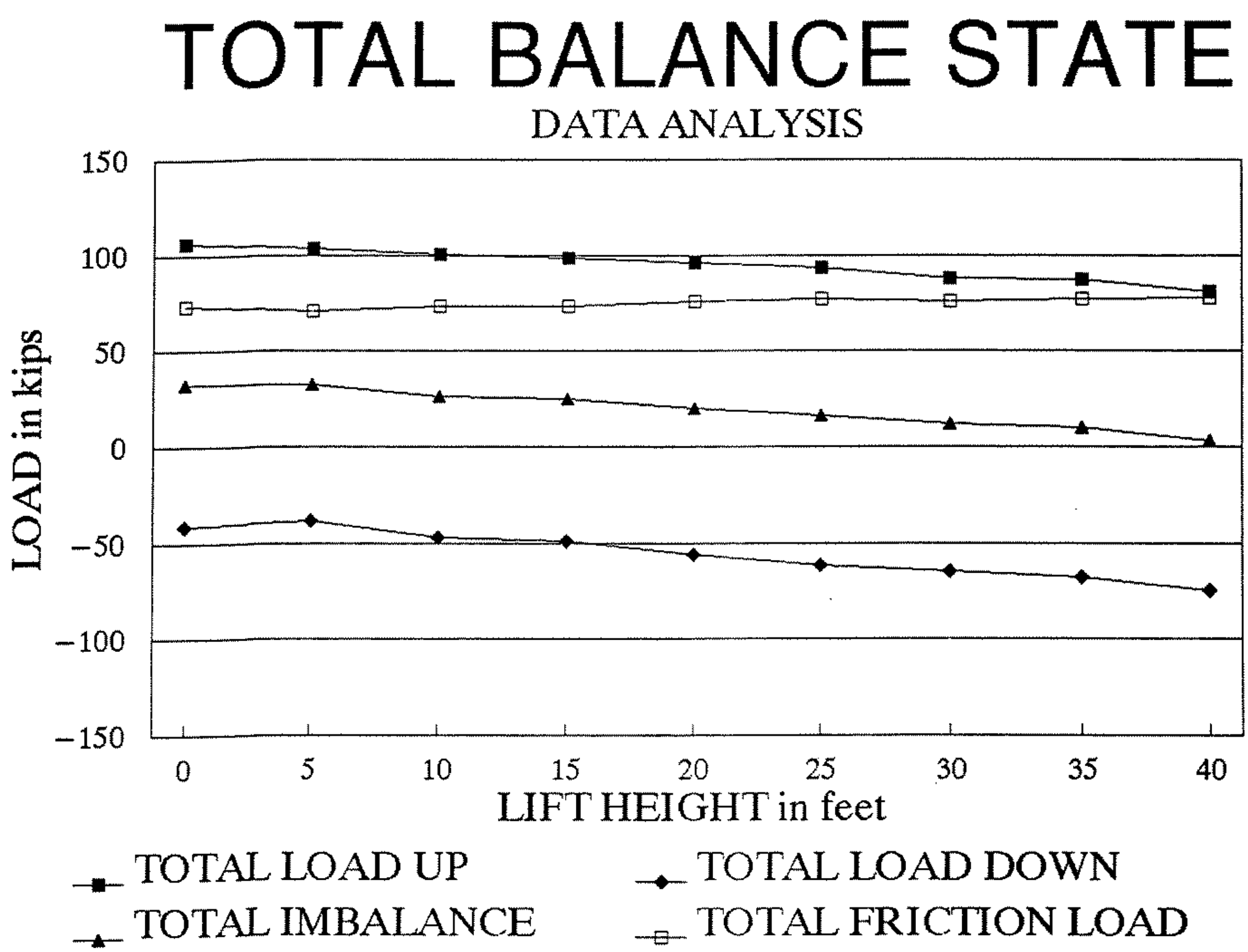
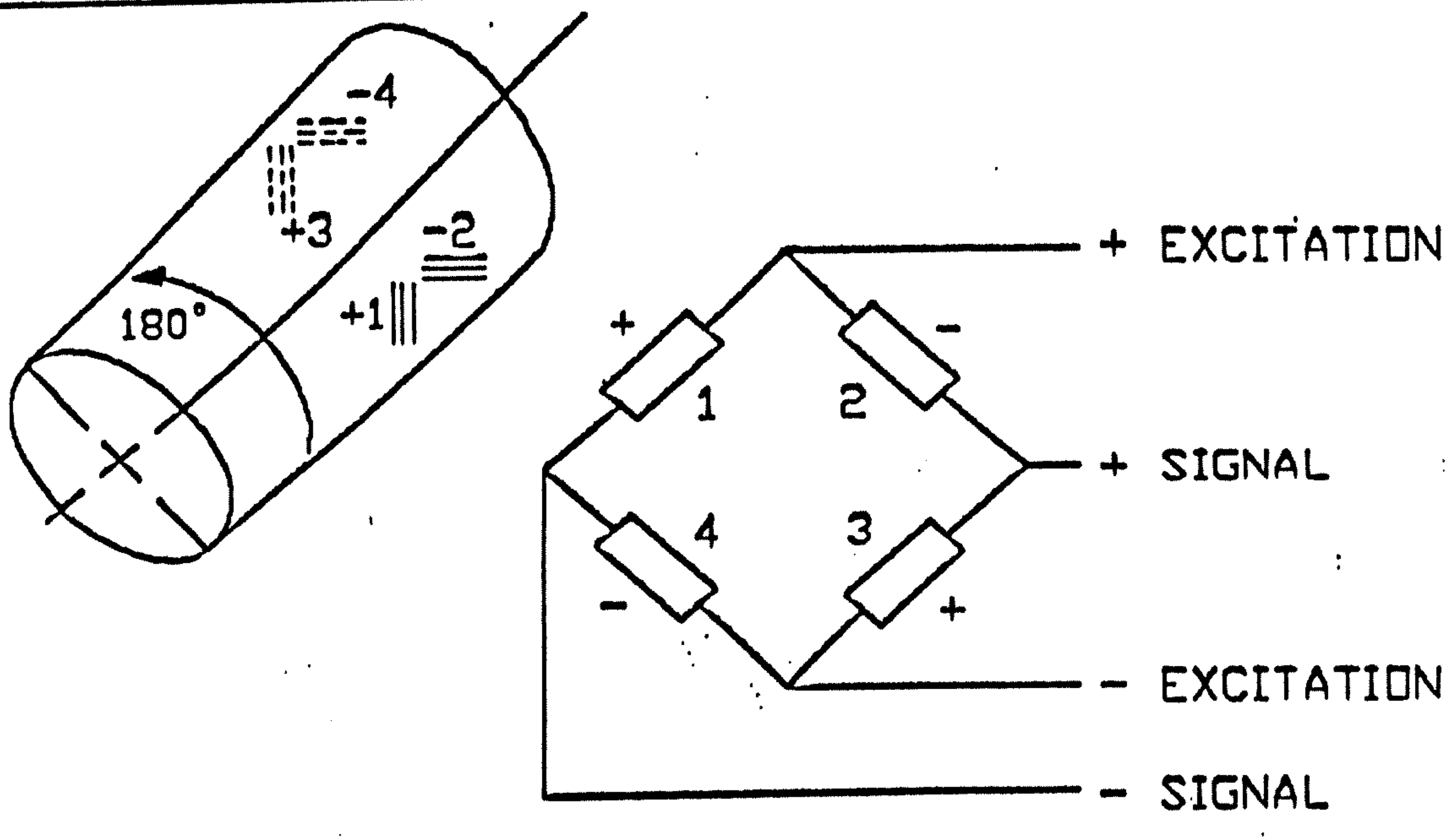


FIGURE 4



FULL WHEATSTONE BRIDGE

FIG. 5