PROGRESS REPORT No. 1

SUBGRADE SUPPORT CHARACTERISTICS EXPERIMENTAL & THEORETICAL

FEBRUARY, 1956

No. 5

by

Staff Members
Division of
Engineering
Sciences

**Joint
Highway
Research
Project**

PURDUE UNIVERSITY
LAFAYETTE INDIANA

PROGRESS REPORT NO. 1

SUBGRADE SUPPORT CHARACTERISTICS—EXPERIMENTAL AND THEORETICAL

TO: K. B. Woods, Director
Joint Highway Research Project

February 1, 1956

File: 8-12
C-36A

FROM: Harold L. Michael, Assistant Director

Attached is formal Progress Report No. 1 on the instrumentation for pavement deflection project. This study, C-36A, is a joint project between Purdue, the State Highway Department of Indiana, and the Bureau of Public Roads.

It was initiated in October, 1953 and brief monthly progress reports have been submitted since that date. This report summarizes all of the activity conducted to February 1, 1956. The report has been prepared by the staff of the Project, consisting of Professors R. C. Geldmacher, R. L. Anderson, Gordon Partridge, and Messrs. L. E. Wood and J. W. Dunkin. The project has been under the leadership of Professor Geldmacher.

The report is also being transmitted to the Bureau of Public Roads and to the State Highway Department of Indiana. A proposal for extension of the project after February 1, 1956 is also in the process of development at this time.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Assistant Director
Joint Highway Research Project

HLM:cjg

Attachment

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PROGRESS REPORT NO. 1

SUBGRADE SUPPORT CHARACTERISTICS
EXPERIMENTAL AND THEORETICAL

by

R. L. Anderson
J. W. Dunkin
R. C. Goldsacher
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G. R. Partridge

Project C-36A

File: 6-12

Confidential--Subject to Further Verification

Purdue University
Lafayette, Indiana

February 1, 1956

CONTENTS

ABSTRACT

A means was developed for measuring the relative deflection between a point in a concrete highway slab and a point in the earth beneath. This method was applied at a pilot section of U.S. 41 where 10 simultaneous measurements were made for 5 vehicle positions, 3 vehicle loads, and 5 vehicle speeds. Over 2,250 individual measurements were recorded.

All records were made using a 14-channel system designed and developed as part of the project. The system was designed specifically for use with Schaevitz 040L and 125S-L linear variable differential transformers and consisted of two separable 7-channel amplifying and control units, one 14-channel tape recorder, and a play-back device. The complete system could be used to record 14 simultaneous events on magnetic tape or it could be separated into two units, each of which could be used to drive 7 1,500 ohm recording galvanometers.

An analysis of variance of the measured data was made. At creep speeds the range of observations was less than 3.5% and a 95% confidence limit placed the mean within a band width of 1.2% based on the mean of the maximums of 10 observations. At speeds of 20 mph a 95% confidence limit placed the mean within a band width of 8.5% based on the mean of the maximums of 30 observations.

A method was proposed for defining and obtaining damping and elastic constants.

An investigation of earth motion beneath a loaded highway was begun.

PURPOSE

The purposes of project C-36A are:

To develop mobile, sensitive, simple to operate equipment that will record the deflections of concrete pavement;

To attempt to determine, in terms of elastic and damping constants, the relative support characteristics of the nine concrete highway sub-base subgrade systems, located on U.S. Highway 41 near Cook, Indiana;

To record the changes in surface contour of the nine concrete highway subgrade sub-base systems as loaded vehicles are driven over them;

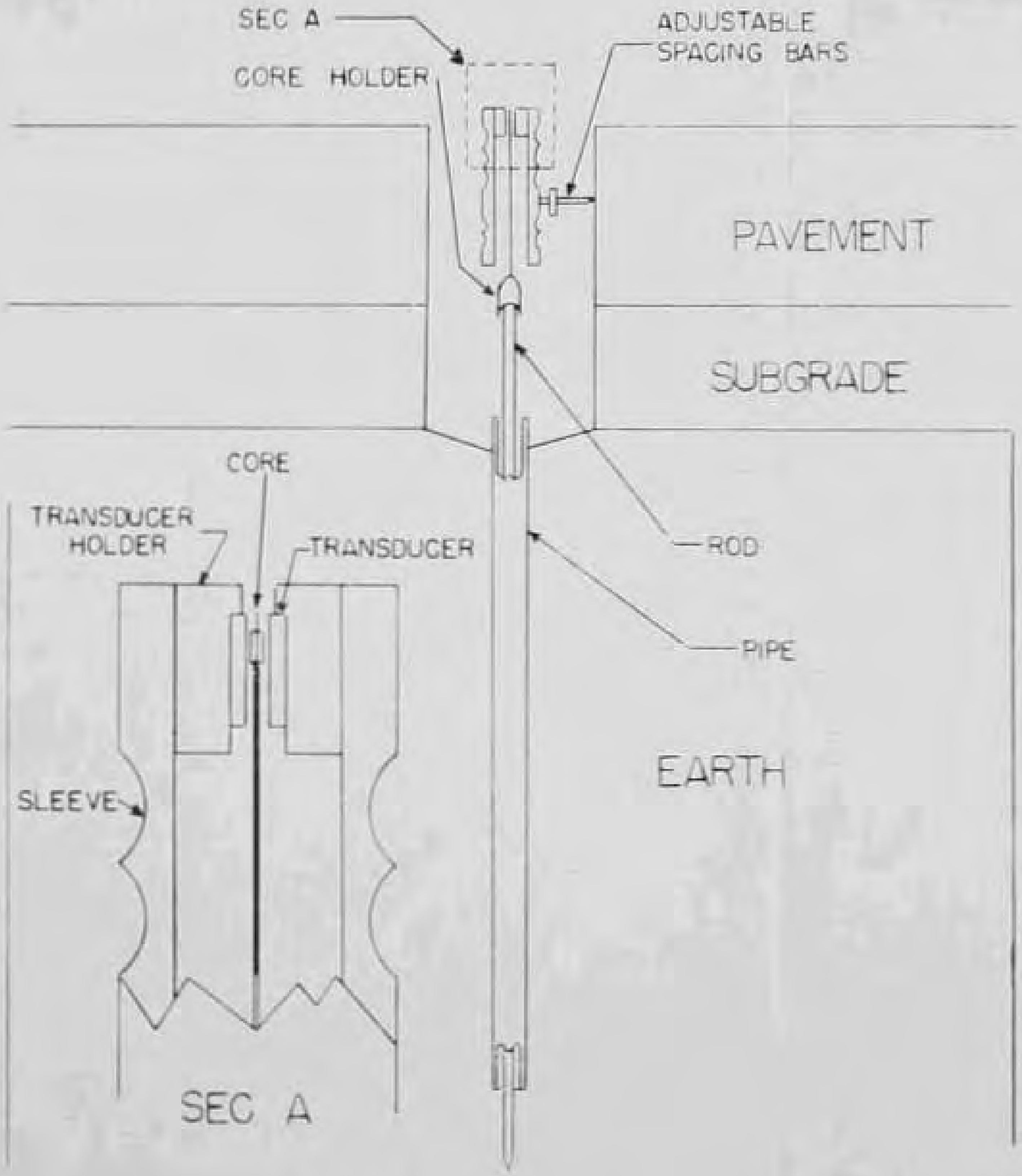
To attempt to analytically solve the problem of a concrete highway on a damped elastic foundation.

SUMMARY OF FIELD TESTS

Pavement deflection measurements were made by means of differential transformers. The transformers were attached to the pavement and the transformer cores were connected to reference rods driven into the bottom of a cylindrical hole in the earth (see Page 2). The relative motion between the pavement and the reference rods was the quantity measured.

A differential transformer holder was developed from which the transformer could be removed when not in use. The final design was tested and found satisfactory after using it in the JHRP Test Slab on U.S. 52 near Otterbein, Indiana. See Figure A-3,4,5,6 for a photograph of the holder and associated parts. The holder was composed of a 2-inch diameter by 7-inch long brass sleeve which was mortared to and moved with the pavement. In order to hold the sleeve firmly in place during the mortaring process, three adjustable spring bars were provided which could be forced against the sides of the hole in the pavement. The differential transformer was placed in a hollow externally threaded cylinder of non-magnetic steel which screwed into the brass sleeve. One revolution of the transformer holder provided a displacement of .025". The top of the brass sleeve was marked into 10 equal divisions to facilitate calibration. The holder has proved to be very satisfactory and the installation made in June 1954 was in good condition at the time this report was written.

Reference rods were made of 1/2" diameter steel having one end sharpened and having a removable head attached to the other for the



ALTERATIONS

MARK	DESCRIPTION	BY	DATE	APPD

GENERAL NOTES

REFERENCES

ENGINEERING SCIENCES
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PROJECT C3[illegible]A

SECTION THROUGH DISPLACEMENT ASSEMBLY

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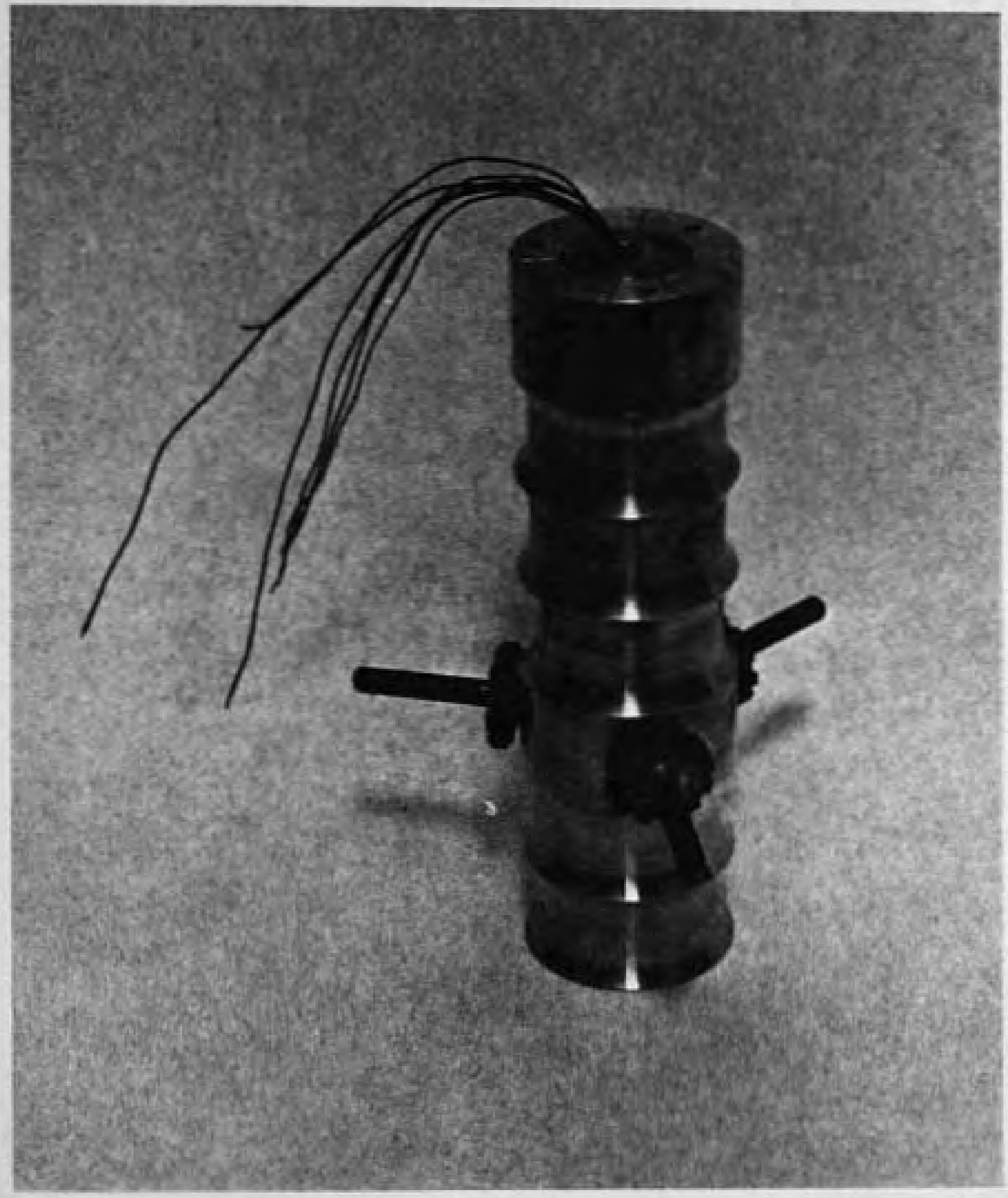

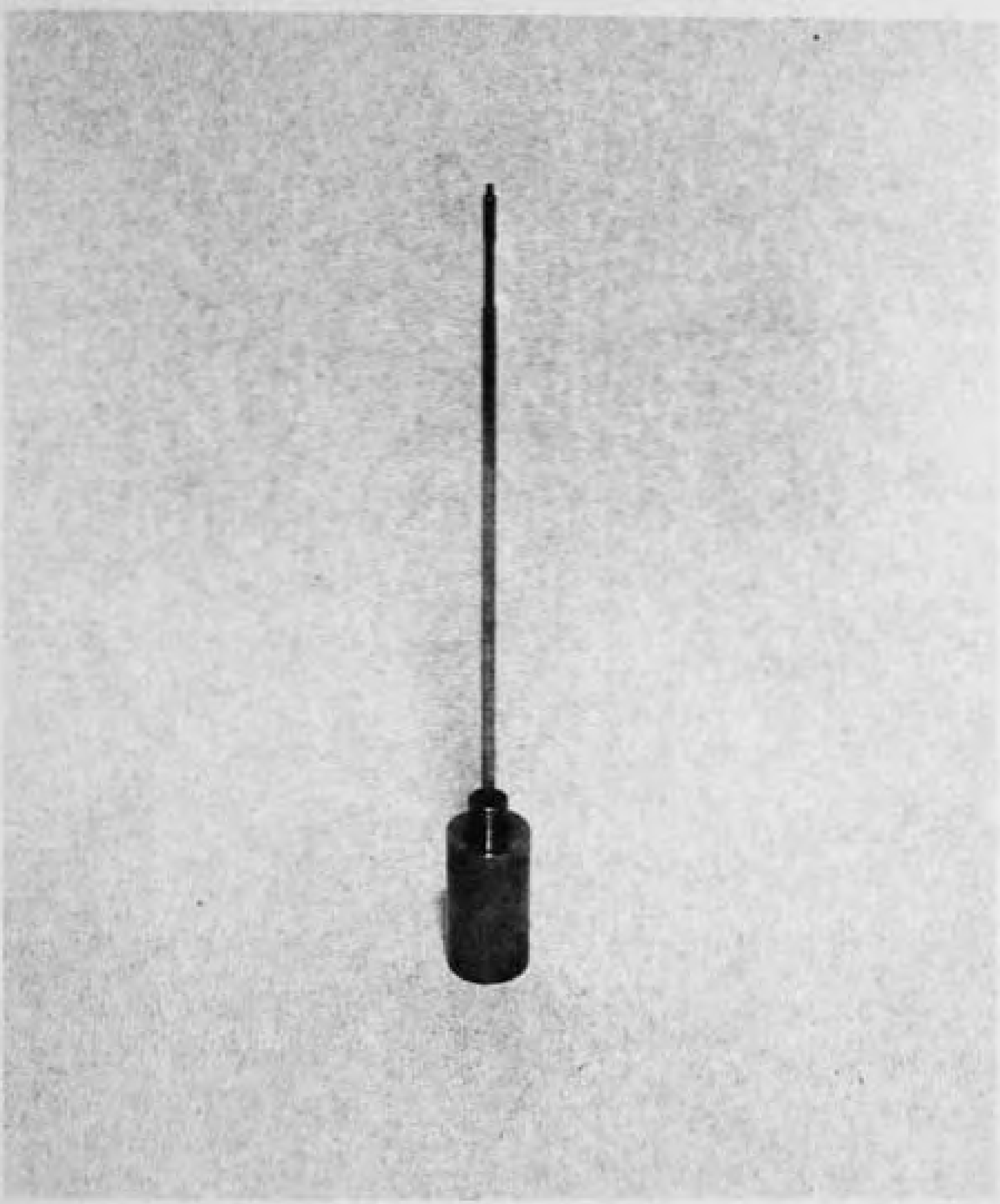

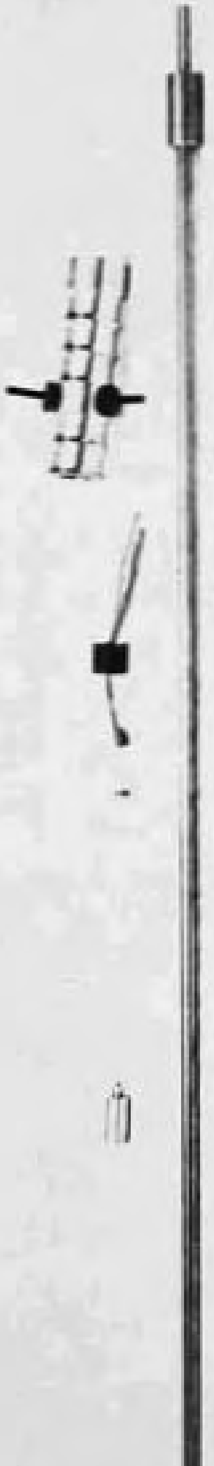

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purpose of driving the rod into the ground. The removable head also provided a hemispherical surface upon which the transformer core holder could rest.

The transformer core holder was made of a thin brass rod connected to a socket which fitted onto the top of the reference rod.

During the second week of September 1954, 16 transducer holders were installed in U.S. 42 test section (see Page _8_ for the arrangement). Acting on the best information available at the time, 6 foot reference rods were used. The top of the rods were driven so as to be at the level of the bottom of the pavement; the upper 2 feet of the rod was free from the soil and to insure continued freedom a 1-1/2" diameter galvanized iron pipe was placed around the upper 2 feet of the rod.

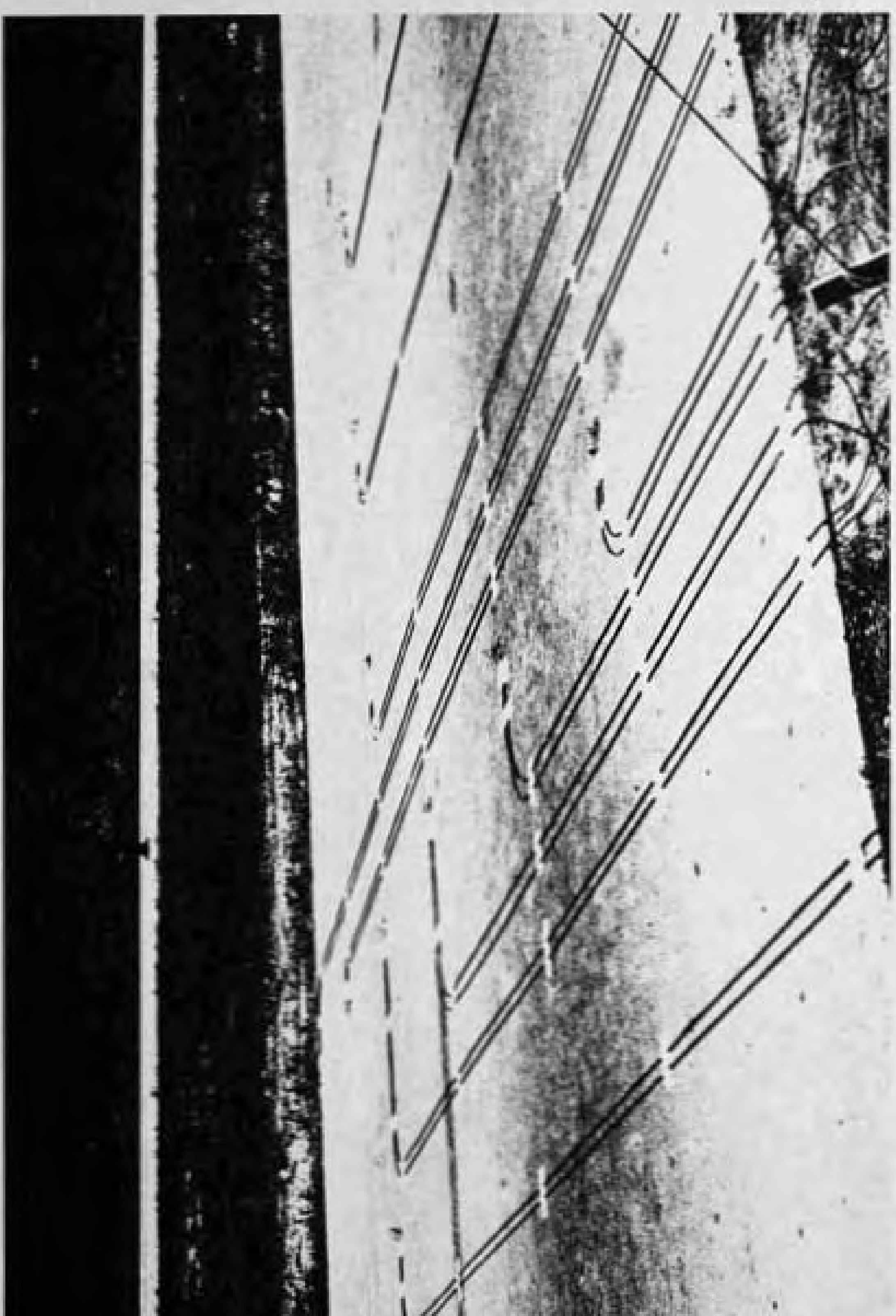
During the months of November and December 1954, the following tests were made:

A. With gages at positions 7, 8, 9, 10, the State Highway Bureau of Tests load truck was driven down the center line of the pavement at speeds of 5, 10, 20, 30, and 40 miles per hour. (See Page _9_ for gage positions).

B. At 5 miles per hour, a truck was driven down the pavement with the closest wheel one foot away from gage 10 and then one foot away from gage 7.

C. A static load supplied by the test truck was placed directly over gages 7, 8, 9, 10.

D. With gages at positions 1 and 4, the test truck was used as a static load and also driven at creep speed and 15 miles per hour at



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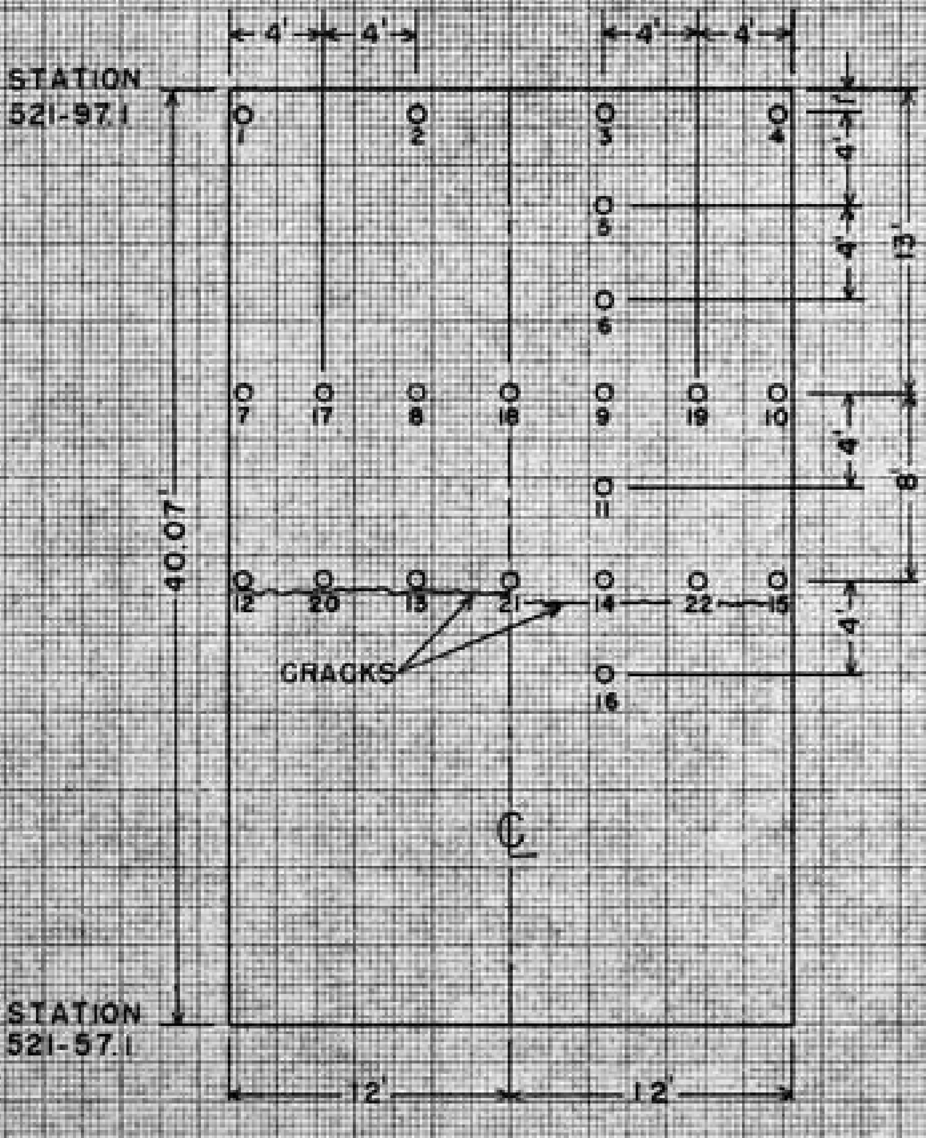
PILOT SECTION NO. ONE

U.S. 41

SECTION 4-B



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a position 1 foot from gage 1 and 1 foot from gage 4. This series of tests was then repeated with gages at positions 7, 10, 12, and 15. The purpose of this set of measurements was to determine the effect of the joint and the crack in the pavement. A preliminary analysis of these results has shown an appreciable difference in deflection obtained near the joint, but no appreciable difference in deflection near the crack.

B. With gages at positions 7, 8, 9, 10, a record of temperature versus deflection was obtained for a continuous 28 hour period, readings being taken at 1/2 hour intervals. (The results of this test are shown on Page 11).

During the first week of June 1955, 6 more transducer holders were installed in positions 17, 18, 19, 20, 21 and 22. The object of this installation was to determine if the gages weakened the pavement. The results of measurements at these positions will be compared with the original installation where there were 4 gages in the transverse row.

During the period of June 27 through 30, 1955, the following series of measurements were made on the pilot section:

A. Three identical trucks obtained from the LaPorte District of the Indiana State Highway Department were used to approximate a line load. The vehicles were loaded similarly and were run three abreast down the pavement. A test run in progress is shown on page 17 .

B. The three identical trucks were used with three different loads and were run at different speeds and different lateral positions.

C. The Bureau of Tests truck made 12 runs at five miles per hour passing directly over gage 9. These runs were made in order to determine

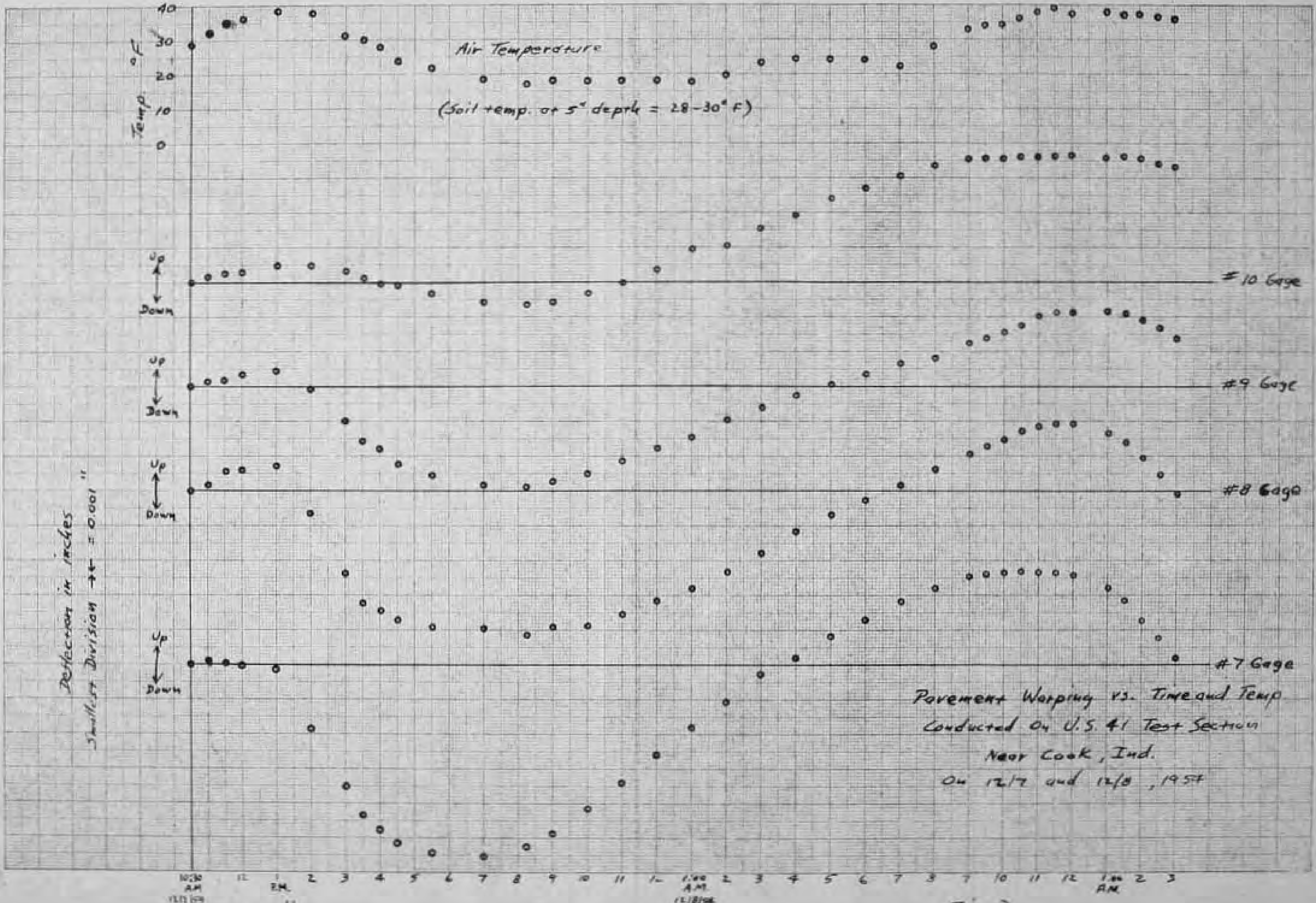
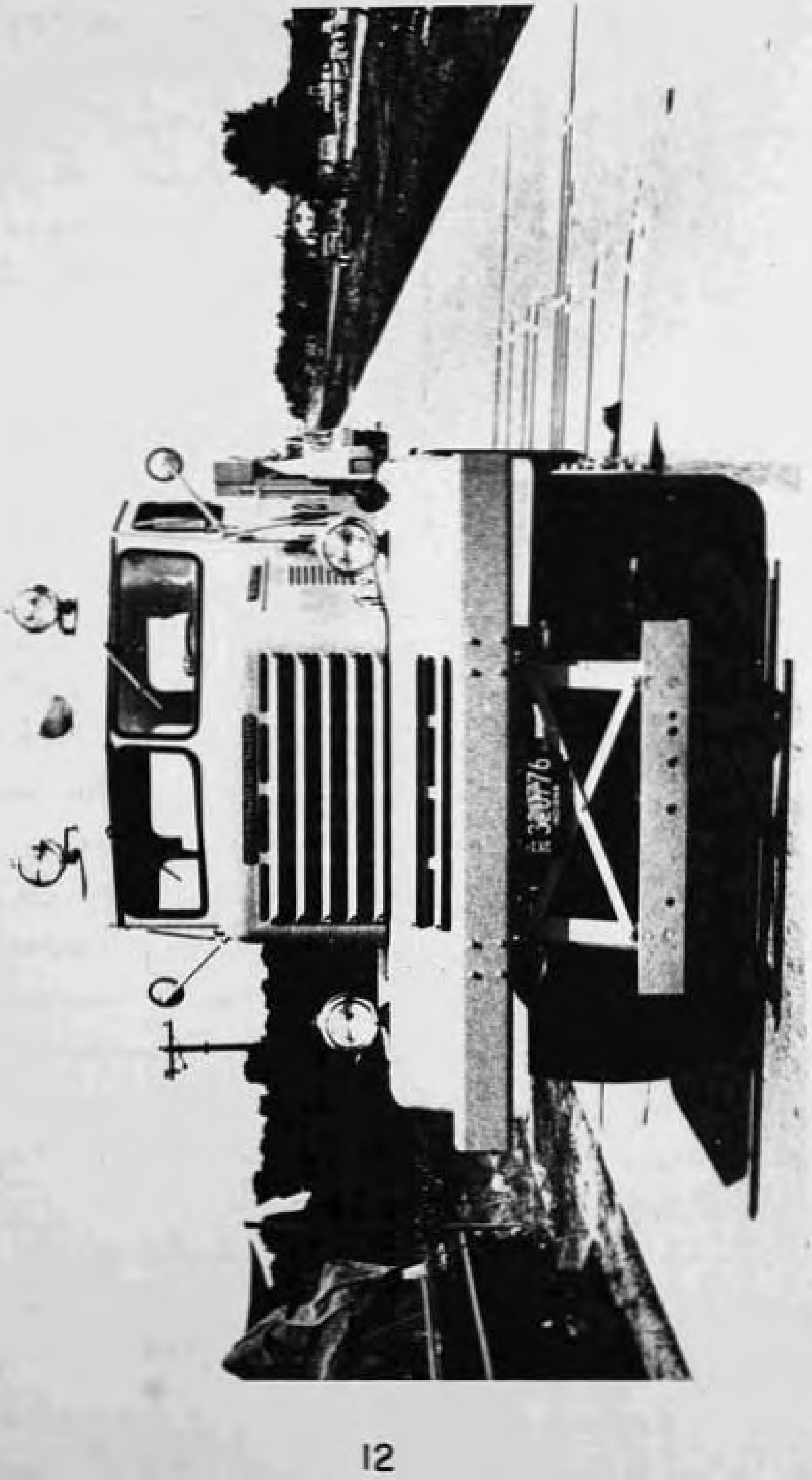

Air Temperature
(Soil temp. at 5" depth = 28–30° F)
Temp °F
40
30
20
10
0
Up
Down
#10 Gage
#9 Gage
#8 Gage
#7 Gage
Deflection in inches
Smallest Division = 0.001"
Pavement Warping vs. Time and Temp.
Conducted On U.S. 41 Test Section
Near Cook, Ind.
On 12/7 and 12/8, 1954
10:30 AM 12/7/54
12
1 P.M.
2
3
4
5
6
7
8
9
10
11
12
1:00 AM 12/8/54
2
3
4
5
6
7
8
9
10
11
12
1:00 AM
2
3

Fig 3



over-all variability resulting from environmental changes and from human error in determining speed and lateral position.

At the time the above-described series of measurements was completed, the question of proper depth at which reference rods should be placed was raised by Mr. L. W. Teller, of the Bureau of Public Roads. Since the answer to this question was of primary importance to the design of the over-all experiment, a theoretical and experimental study of earth motion was begun.

Exploratory observations were made by spanning the pavement with a 50 foot antenna mast supported at each end and having a differential transformer attached at its center (see Page 14). The core of the transformer was placed on a reference rod in the usual manner (see Page 2). As a result of measurements made with this arrangement, it was discovered that the reference rod moved on the order of one-half as much as the pavement. This meant that with 4 foot reference rods absolute deflections of the pavement were not being obtained.

A series of tests designed to measure earth motion at increasing depth was made in both a cut and a fill section of Route 41. All tests made in the fill section were reproduced in the cut section. On the assumption that the load bearing characteristic of the pavement changed with environmental conditions, it was decided to provide a control rod for each series of measurements. During each test, nothing was changed in the control installation and, therefore, changes indicated by the control could be applied as corrections to the test installation. At first the control rod was placed in an adjacent slab in the same relative position as in the test slab. It was discovered that these two supposedly

identical slabs did not act in the same manner. There were times when the two slabs were moving in opposite directions at the same time. As a result of this, new control rods were installed one foot from the test rods. This gave better results, but it was finally decided to begin tests at daybreak in order to minimize warping effects. Four series of measurements were made beginning at daybreak, two in the cut section and two in the fill section. It was only possible to run one test a day, but the two tests made in the fill on two different days gave almost identical results as was also true of the cut section. Still less effect due to temperature warping would have been obtained if the tests could have been run between midnight and daybreak, but equipment necessary for testing at night was not at hand and, furthermore, the traffic hazard always present by detouring around the test section would have been much greater at night.

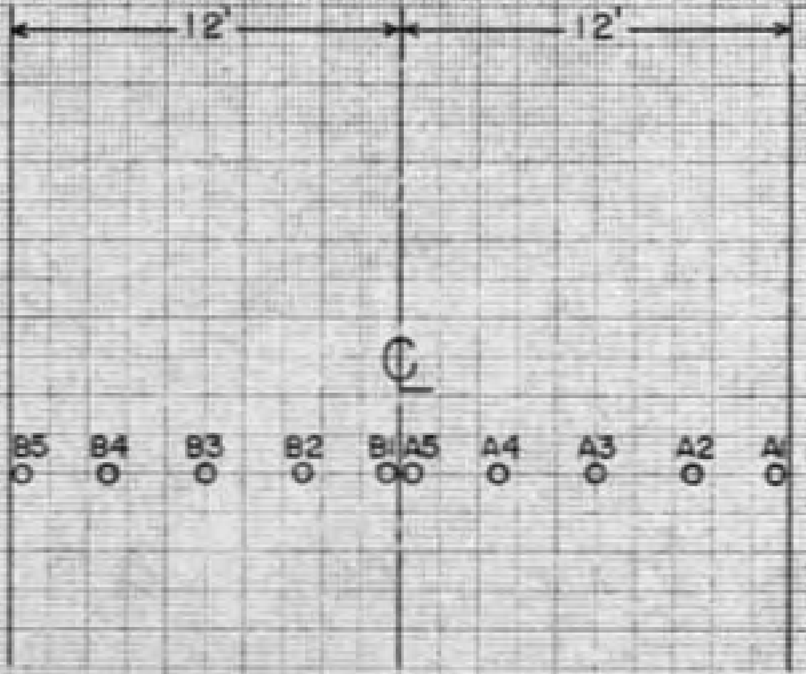
This series of depth of influence measurements was performed by installing the gage in the usual manner, running the test truck over the gage, and recording the deflection and reference rod length. The procedure was repeated for increasing reference rod lengths and a curve of deflection versus rod length was plotted. The depth of influence appeared to be greater in the fill section.

As a result of the depth of influence studies, a new pilot section was established just south of the original pilot section. The new pilot section consisted of 10 transducer holders installed on a line across the pavement (see Page 26). The reference rods used in this section were 12 feet long with the upper 10 feet free from contact with the soil.

PILOT SECTION NO. TWO

U.S. 41

SECTION 4-B



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A series of measurements was then made on the new pilot section. The same vehicles used in the earlier tests were again used and tests were made for five vehicle positions, three vehicle loads, and five vehicle speeds. In addition, in order to determine the effect of variability in vehicle speed and lateral position, one vehicle made 30 consecutive runs in the same position and at the same speed. The series of measurements consisted of over 2,250 individual records.

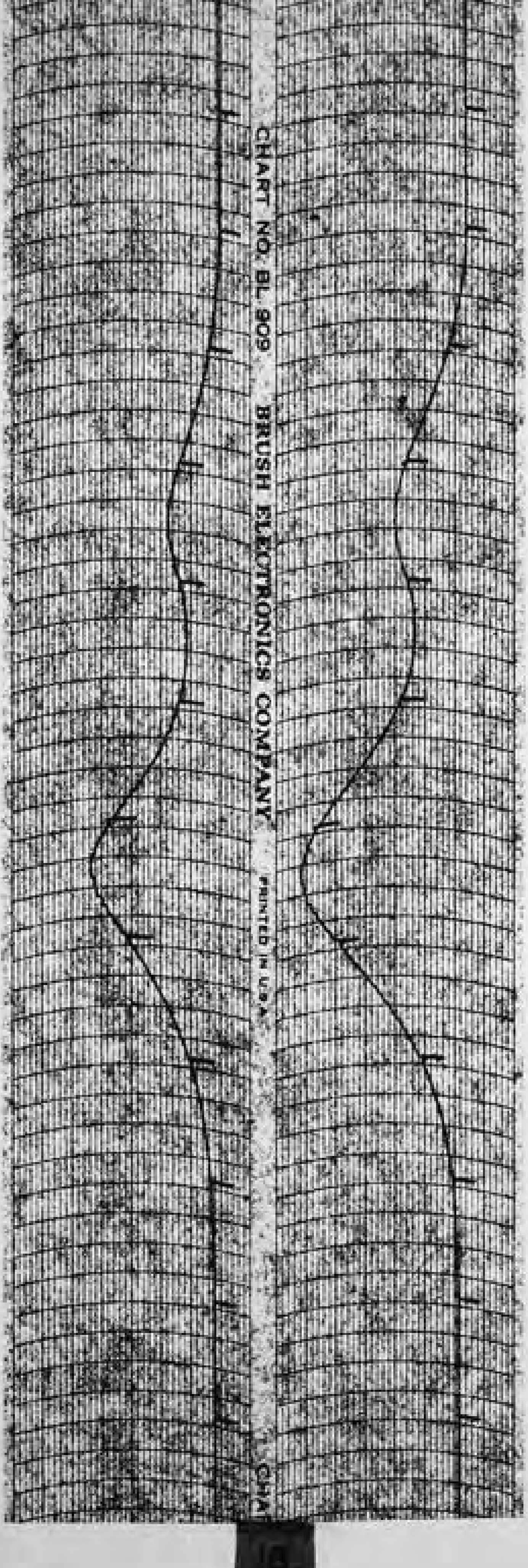
A series of preliminary measurements was made to determine how the load bearing characteristics of the pavement changed with environmental changes. For this purpose, a transducer was installed in the center of the driving lane and the State Highway Test truck passed over the transducer at creep speed at 15 minute intervals. During the period of the test from 10 A.M. to 2 P.M., it was observed that the pavement deflection with this same load increased steadily until it was finally approximately 2-1/2 times as great as the original deflection. It was also observed that during this period, the center of the pavement was continually moving upward.

In order to determine the longitudinal change in shape of pavement, a test was made on the original pilot section using the seven longitudinal gages and running the Bureau of Tests truck at creep speed down the center line of the passing lane for 15 consecutive runs.

In order to determine the dynamic effect on deflection in cut and fill sections, a test was made with one gage installed at the center of the driving lane in a fill section and a similar gage in the cut section. The Bureau of Tests truck was then passed over these gages at creep, 10, 20 and 30 miles per hour

A representive deflection record is shown on page 18.

A summary of measurements made during September 1955 is shown on pages 19 thru 31.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SUMMARY OF TESTS TO DETERMINE EFFECTS OF VEHICLE WEIGHT, SPEED, AND LATERAL POSITION

Tests Conducted On Pilot Section Two
September 15 and 16, 1955

Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Bottom	Time	Speed MPH	Change In Null	Cloudy	Sunny
1	105	A	86	70	11-35	Creep	A1-CCW-0.3		X
2	104				11-37		A2-CW-0.3		
3	103				11-39		A3-CCW-05		
4	105	↓	↓		11-41		A4-CW-0.2		↓
							A5-CW-0.3		
5	105	B	86		11-44		B1-CW-0.1	X	
6	104		85.5		11-45		B2- 0		
7	103		85		11-47		B3-CCW-0.2		
8	105	↓	85		11-49		B4-CCW-0.2		
							B5-CCW-0.2		
9	105	C	85		11-51				
10	104		84.5		11-53				
11	103		84.5		11-55				
12	105	↓	84.5		11-57				
13	105	D	84		11-59				
14	104				12-01				
15	103				12-09			↓	
16	105	↓	↓		12-11				X
17	105	E	84.5		12-13				
18	104		84.5		12-14				
19	103		85		12-15				
20	105	↓	85	↓	12-16	↓			↓

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Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Bottom	Time	Speed MPH	Change in Null	Cloudy	Sunny
21	105	A	94	71	1-37	Creep	A1-CCW-1.2		X
22	104		94				A2-CW-1.9		
23	103		94				A3-CW-1.7		
24	105	↓	94.5		↓		A4-CW-1.7		
							A5-CCW-0.7		
25	105	B	95		1-40		B1-CCW-0.8		
26	104				1-42		B2-CW-1.2		
27	103				1-42		B3-CW-2.2		
28	105	↓			1-43		B4-CW-1.1		
							B5-CCW-1.2		
29	105	C			1-45				
30	104				1-45				
31	103				1-45				
32	105	↓	↓		1-46				↓
33	105	D	94		1-48			X	
34	104		93		1-48				X
35	103		93		1-48				X
36	105	↓	935	↓	1-49				X
37	105	E	92	71.5	1-51			X	
38	104				1-51				X
39	103				1-51			X	
40	105	↓	↓	↓	1-53	↓		X	

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Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Bottom	Time	Speed MPH	Change in Null	Cloudy	Sunny
41	105	A	95	72	2-02	Creep	A1-CCW-1.3		X
42	104	↓	95	↓	2-02	↓	A2-CW-2.05		↓
43	103	↓	95	↓	2-02	↓	A3-CW-2.1		↓
44	105	↓	96	↓	2-04	↓	A4-CW-1.8		↓
						↓	A5-CCW-0.5		↓
45	105	B	97	72	2-06	↓	B1-CCW-0.8		↓
46	104	↓	↓	↓	2-06	↓	B2-CW-1.5		↓
47	103	↓	↓	↓	2-06	↓	B3-CW-2.2		↓
48	105	↓	↓	↓	2-08	↓	B4-CW-1.0		↓
						↓	B5-CCW-1.2		
49	105	C	95.5	72	2-09	↓		X	
50	104	↓	95.5	↓	2-09	↓			X
51	103	↓	95	↓	2-09	↓			X
52	105	↓	95	↓	2-11	↓		X	
53	105	D	95	72	2-12	↓		X	
54	104	↓	↓	↓	2-12	↓		X	
55	103	↓	↓	↓	2-12	↓			X
56	105	↓	↓	↓	2-14	↓			X
57	105	E	95	72	2-16	↓			X
58	104	↓	94.5	↓	2-16	↓		X	
59	103	↓	94.5	↓	2-16	↓		X	
60	105	↓	94.5	↓	2-18	↓		X	

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Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Bottom	Time	Speed MPH	Change in Null	Cloudy	Sunny
61	105	A	95	72	2-40	Creep	A1-CCW-1.0		X
62	104		95		2-41		A2-CW-2.0		
63	103		95		2-42		A3-CW-2.3		
64	105	↓	95.5		2-43		A4-CW-2.0		
							A5-CCW-0.1		
65	105	B	95.5		2-45		B1-CCW-0.1		
66	104				2-48		B2-CW-1.5		
67	103				2-49		B3-CW-1.6		
68	105	↓	↓	↓	2-51		B4-CW-1.0		
							B5-CCW-0.8		
69	105	C	95	72.5	2-57				
70	104				2-58				
71	103				2-59				
72	105	↓	↓		3-01				
73	105	D	95		3-03				
74	104		95		3-04				
75	103		94.5		3-06				
76	105	↓	94.5		3-07				
77	105	E	94.5		3-09				
78	104		94.5		3-10				
79	103		94		3-11				
80	105	↓	93.5	↓	3-12	↓			↓

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Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Bottom	Time	Speed MPH	Change in Null	Cloudy	Sunny
81	105	A	95	73	3-24	Creep	No Reading In Null		X
82	104	↓	↓	↓	3-24	10			↓
83	103	↓	↓	↓	3-24	10			↓
84	105	↓	↓	↓	3-26	10			↓
85	105	B	95	73	3-28	Creep			↓
86	104	↓	↓	↓	3-28	10			↓
87	103	↓	↓	↓	3-28	10			↓
88	105	↓	↓	↓	3-30	10			↓
89	105	C	95.5	73	3-32	Creep			↓
90	104	↓	↓	↓	3-32	10			↓
91	103	↓	↓	↓	3-32	10			↓
92	105	↓	↓	↓	3-34	10			↓
93	105	D	95.5	73	3-35	Creep			↓
94	104	↓	95	↓	3-40	10			↓
95	103	↓	95	↓	3-40	10			↓
96	105	↓	95	↓	3-41	10			↓
97	105	E	95	73	3-43	Creep			↓
98	104	↓	↓	↓	3-43	10			↓
99	103	↓	↓	↓	3-43	10			↓
100	105	↓	↓	↓	3-44	10			↓

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Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Bottom	Time	Speed MPH	Change In Null	Cloudy	Sunny
101	105	A	95	73	3-50	Creep	A1- 0		X
102	104	↓	↓	↓	3-50	20	A2-CW-2.1		↓
103	103	↓	↓	↓	3-50	20	A3-CW-0.8		↓
104	105	↓	↓	↓	3-52	20	A4-CW-2.0		↓
							A5-CW-0.8		↓
105	105	B	95	73.5	3-53	Creep	B1-CW-0.8		↓
106	104	↓	↓	↓	3-53	20	B2-CW-1.4		↓
107	103	↓	↓	↓	3-53	20	B3-CW-1.0		↓
108	105	↓	↓	↓	3-55	20	B4-CW-0.2		↓
							B5-CCW-0.2		↓
109	105	C	94.5	73.5	3-59	Creep			↓
110	104	↓	↓	↓	3-59	20			↓
111	103	↓	↓	↓	3-59	20			↓
112	105	↓	↓	↓	4-01	20			↓
113	105	D	94	73.5	4-03	Creep			↓
114	104	↓	↓	↓	4-03	20			↓
115	103	↓	↓	↓	4-03	20			↓
116	105	↓	↓	↓	4-05	20			↓
117	105	E	94	73.5	4-06	Creep			↓
118	104	↓	↓	↓	4-06	20			↓
119	103	↓	↓	↓	4-06	20			↓
120	105	↓	↓	↓	4-08	20			↓

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Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Bottom	Time	Speed MPH	Change In Null	Cloudy	Sunny
121	105	A	92	74	11-47	Creep	A1-CW-2.6		X
122	104	↓	↓	↓	11-49	↓	A2-CCW-1.0		↓
123	103	↓	↓	↓	11-50	↓	A3-CCW-4.3		↓
124	105	↓	↓	↓	11-51	↓	A4-CCW-0.8		↓
							A5-CW-3.1		
125	105	B	92.5	74	11-53	↓	B1-CW-2.8		↓
126	104	↓	92.5	↓	11-54	↓	B2-CCW-1.4		↓
127	103	↓	92.5	↓	11-55	↓	B3-CCW-3.1		↓
128	105	↓	93	↓	11-56	↓	B4-CCW-2.5		↓
							B5-CW-1.5		
129	105	C	93.5	74	11-58	↓	DATA ABOVE RECORDED AT 9-00AM		↓
130	104	↓	93.5	↓	11-59	↓			↓
131	103	↓	93.5	↓	12-00	↓			↓
132	105	↓	94	↓	12-02	↓			↓
133	105	D	94	74	12-04	↓			↓
134	104	↓	94	↓	12-05	↓			↓
135	103	↓	94.5	↓	12-06	↓			↓
136	105	↓	94.5	↓	12-07	↓			↓
137	105	E	94.5	74	12-09	↓			↓
138	104	↓	94.5	↓	12-09	↓			↓
139	103	↓	95	↓	12-11	↓			↓
140	105	↓	95	↓	12-12	↓			↓

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Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Bottom	Time	Speed MPH	Change in Null	Cloudy	Sunny
141	105	A	95	74	12-15	Creep			X
142	104	↓	95	↓	12-15	1.0			↓
143	103	↓	95	↓	12-15	1.0			↓
144	105	↓	94.5	↓	12-16	1.0			↓
145	105	B	94.5	74	12-18	Creep			↓
146	104	↓	↓	↓	12-18	1.0			↓
147	103	↓	↓	↓	12-18	1.0			↓
148	105	↓	↓	↓	12-19	1.0			↓
149	105	C	94.5	74.5	12-20	Creep			↓
150	104	↓	↓	↓	12-20	1.0			↓
151	103	↓	↓	↓	12-20	1.0			↓
152	105	↓	↓	↓	12-22	1.0			↓
153	105	D	94.5	74.5	12-24	Creep			↓
154	104	↓	↓	↓	12-24	1.0			↓
155	103	↓	↓	↓	12-24	1.0			↓
156	105	↓	↓	↓	12-26	1.0			↓
157	105	E	94.5	74.5	12-28	Creep			↓
158	104	↓	94.5	↓	12-28	1.0			↓
159	103	↓	94.5	↓	12-28	1.0			↓
160	105	↓	95	↓	12-29	1.0			↓

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Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Botton	Time	Speed MPH	Change In Null	Cloudy	Sunny
161	105	A	95	74.5	12-31	Creep	A1-CCW-1.5		X
162	104	↓	↓	↓	12-31	20	A2-CW-2.3		↓
163	103	↓	↓	↓	12-34	20	A3-CW-4.5		↓
164	105	↓	↓	↓	12-35	20	A4-CW-2.1		↓
							A5-CCW-08		
165	105	B	95	75	12-36	Creep	B1-CCW-09		↓
166	104	↓	95	↓	12-37	20	B2-CW-1.5		↓
167	103	↓	95	↓	12-37	20	B3-CW-1.2		↓
168	105	↓	95.5	↓	12-39	20	B4-CW-1.2		↓
							B5-CCW-2.1		
169	105	C	95.5	75	12-41	Creep			↓
170	104	↓	↓	↓	12-41	20			↓
171	103	↓	↓	↓	12-41	20			↓
172	105	↓	↓	↓	12-43	20			↓
173	105	D	95	75	12-44	Creep			↓
174	104	↓	95	↓	12-45	20			↓
175	103	↓	95	↓	12-45	20			↓
176	105	↓	95.5	↓	12-46	20			↓
177	105	E	95.5	75	12-48	Creep			↓
178	104	↓	↓	↓	12-48	20			↓
179	103	↓	↓	↓	12-48	20			↓
180	105	↓	↓	↓	12-50	20			↓

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Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Bottom	Time	Speed MPH	Change In Null	Cloudy	Sunny
181	105	A	84	72.5	10-13	Creep			X
182			84		10-15	Creep			
183			84.5		10-16	5			
184					10-18	10			
185					10-19	20			
186	↓		↓		10-21	30			
187	103		85		10-23	Creep			
188					10-24	Creep			
189					10-25	5			
190					10-26	10			
191					10-27	20			
192	↓				10-28	30			
193	104				10-30	Creep			
194					10-32	Creep			
195					10-33	5			
196			↓		10-34	10			
197			85.5		10-35	20			
198	↓	↓	85.5	↓	10-37	30			↓

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Run No	Vehicle No	Lateral Position	Temp TopSlab	Temp Bottom	Time	Speed MPH	Change In Null	Cloudy	Sunny
199	105	A	86	73	10-41	Creep	A1-CCW-0.3		X
200			86		10-43	20	A2-CW-1.5		
201			86.5		10-44		A3-CW-3.0		
202					10-45		A4-CW-1.1		
203					10-46		A5-CW-0.2		
204					10-46				
205			↓		10-47		B1-CW-0.2		
206			87		10-48		B2-CW-0.8		
207			87		10-49		B3-CCW-1.0		
208			87.5		10-53		B4-CCW-0.2		
209					10-54		B5-CCW-2.0		
210					10-55				
211			↓		10-56		DATA ABOVE RECORDED AT 11-30		
212			88		10-57				
213					10-59				
214			↓		11-00				
215			88.5		11-01				
216					11-02				
217			↓		11-03				
218			89		11-04				
219					11-05				
220					11-06				
221			↓		11-08				
222			89.5		11-09				
223					11-10				
224					11-11				
225			↓	↓	11-12				
226			90	73.5	11-13				
227					11-15				
228					11-16				
229					11-17				
230	↓	↓	↓	↓	11-18	↓			↓

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Run No	Vehicle No	Lateral Position	Temp Top Slab	Temp Bottom	Time	Speed MPH	Change In Null	Cloudy	Sunny
231		A	97	76		Creep	A1-CCW-1.3		
232		↓	↓	↓		Creep	A2-CW-3.0		
233		↓	↓	↓		5	A3-CCW-4.5		
234		↓	↓	↓		10	A4-CW-3.0		
235		↓	↓	↓		20	A5-CCW-0.7		
236		↓	↓	↓		30			
237		↓	↓	↓		Creep	B1-CCW-1.0		
238	State Test Truck	↓	↓	↓		Creep	B2-CW-2.0		
239		↓	↓	↓		5	B3-CW-0.8		
240		↓	↓	↓		10	B4-CW-1.0		
241		↓	↓	↓		20	B5-CCW-2.9		
242		↓	↓	↓		30			
243		↓	98	↓		Creep			
244		↓	↓	↓		Creep			
245		↓	↓	↓		5			
246		↓	↓	↓		10			
247		↓	↓	↓		20			
248		↓	99	↓		30			

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SUMMARY OF TESTS

COMPARISON OF CONSTANTS

FOR CUT & FILL

Tests Performed On 9/21/55.

No.1 gage (Hole 15'2" from top of pavement)-12' from south joint in first slab north of new pilot slab.

No.2 gage (Hole 10'2" from top of pavement)-12' from south joint in third complete slab south of north section lane.

Test No.	Speed	Lane Position
1	Creep	A
2	10	
3	20	
4	30	
5	Creep	
6	10	
7	20	
8	30	
9	Creep	
10	10	
11	20	
12	30	
13	Creep	

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ANALYSIS OF VARIANCE

General

The ultimate goal to be achieved from an investigation of variance is that of establishing the sources of variance in order that randomness may be reduced and of establishing a minimum for the number of observations required once randomness has been minimized.

Three sets of data have been made for the purpose of exploring variability in field measurements. One set of data was taken on pilot section 1 and is shown on page 33 . Another set of data was taken on pilot section 2 and a representative display is shown on page 34 . Still another set of data was taken as part of the depth of influence study at the Purdue University Airport. This data is shown on page 35 .

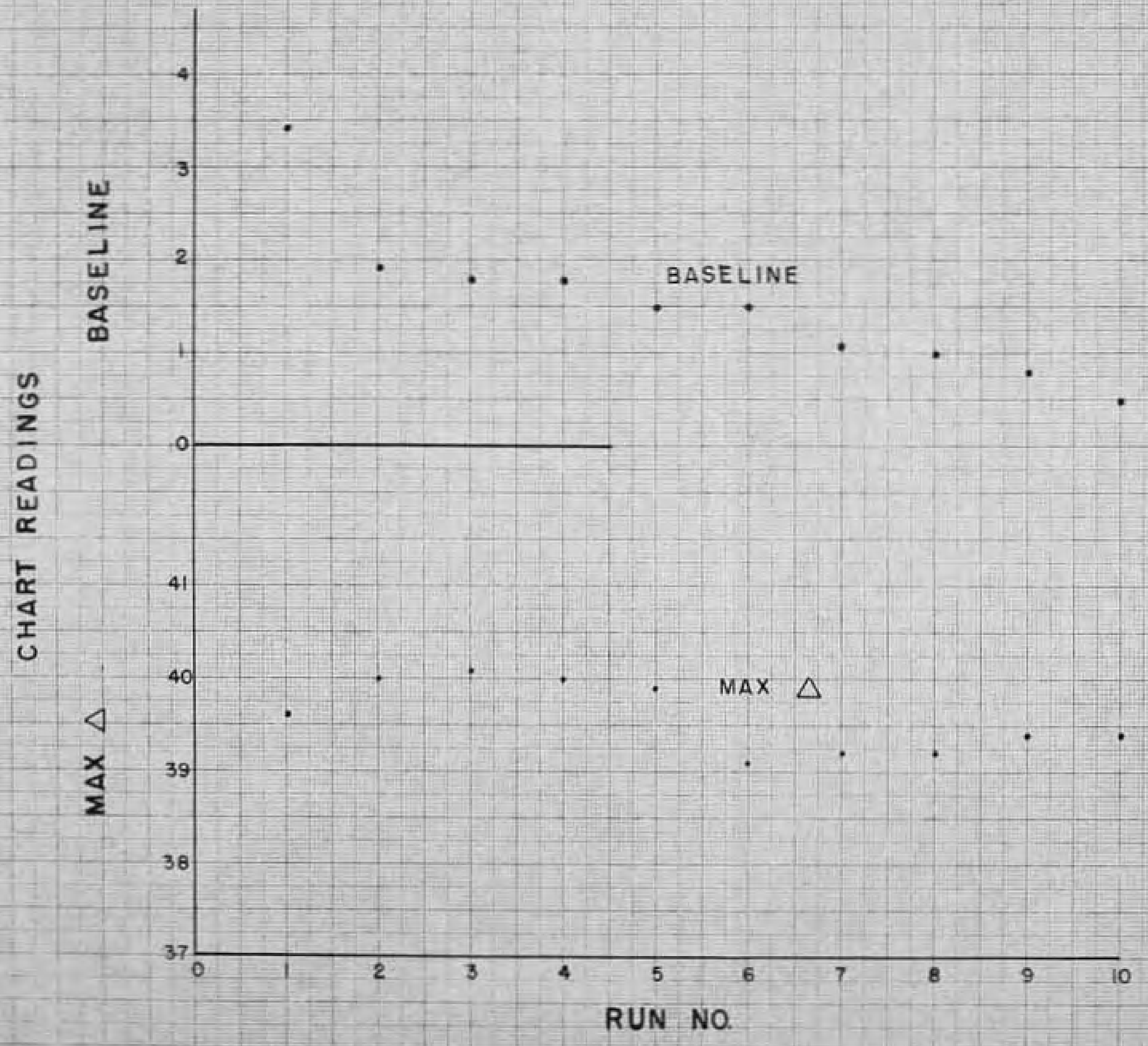
A tabulation of all results in terms of mean, standard error, confidence limits and range is shown on page 36 .

Pilot Section 1

The variability data for pilot section 1 resulted from 10 separate runs at 5 mph. These runs were made with the Indiana State Test Truck and deflection was measured at one point in the pavement. The mean deflection was 0.00247 inches and the standard error was 0.00002. The range of measured deflections was 0.00244 to 0.00251 inches. This range represents a band around the mean of less than ± 1.7 per cent. The confidence limits indicate that of 100 such series of measurements 95 will have a mean between 0.00245 inches and 0.00249 inches, a band width of 1.2 per cent based on the mean of the observations.

Pilot Section 2

The variability data for pilot section 2 resulted from 30 separate



ALTERATIONS

MARK	DESCRIPTION	BY	DATE	APPD

GENERAL NOTES

40 CHART DIV. = 0.0025"

REFERENCES

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VARIATION OF DATA AT 5 MPH
PILOT SECTION I

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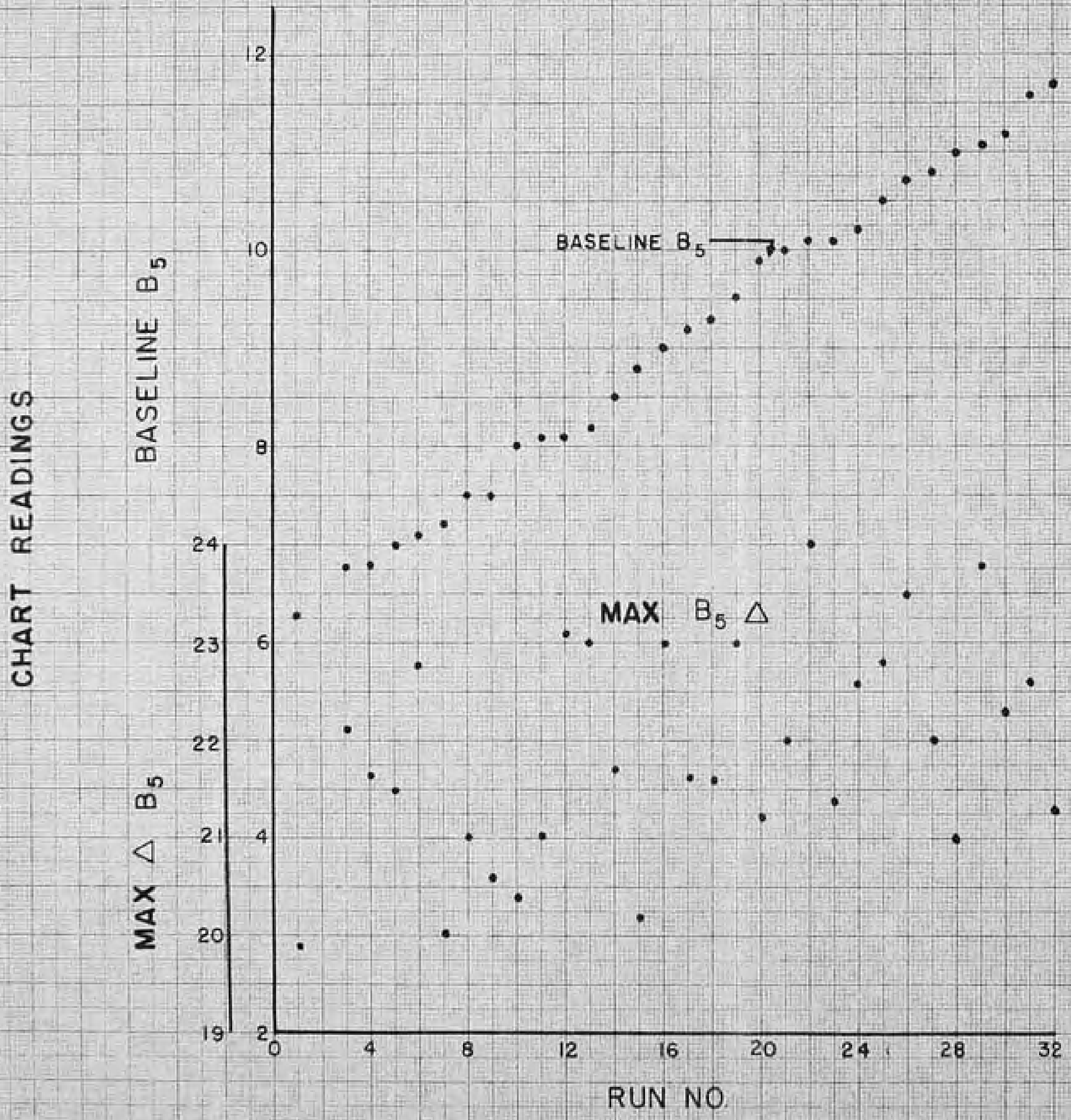

ALTERATIONS

MARK	DESCRIPTION	BY	DATE	APPD

GENERAL NOTES

40 CHART DIV. = 0.0125"

REFERENCES

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VARIATION OF DATA AT 20 MPH
POS. B_5 PILOT SECTION 2

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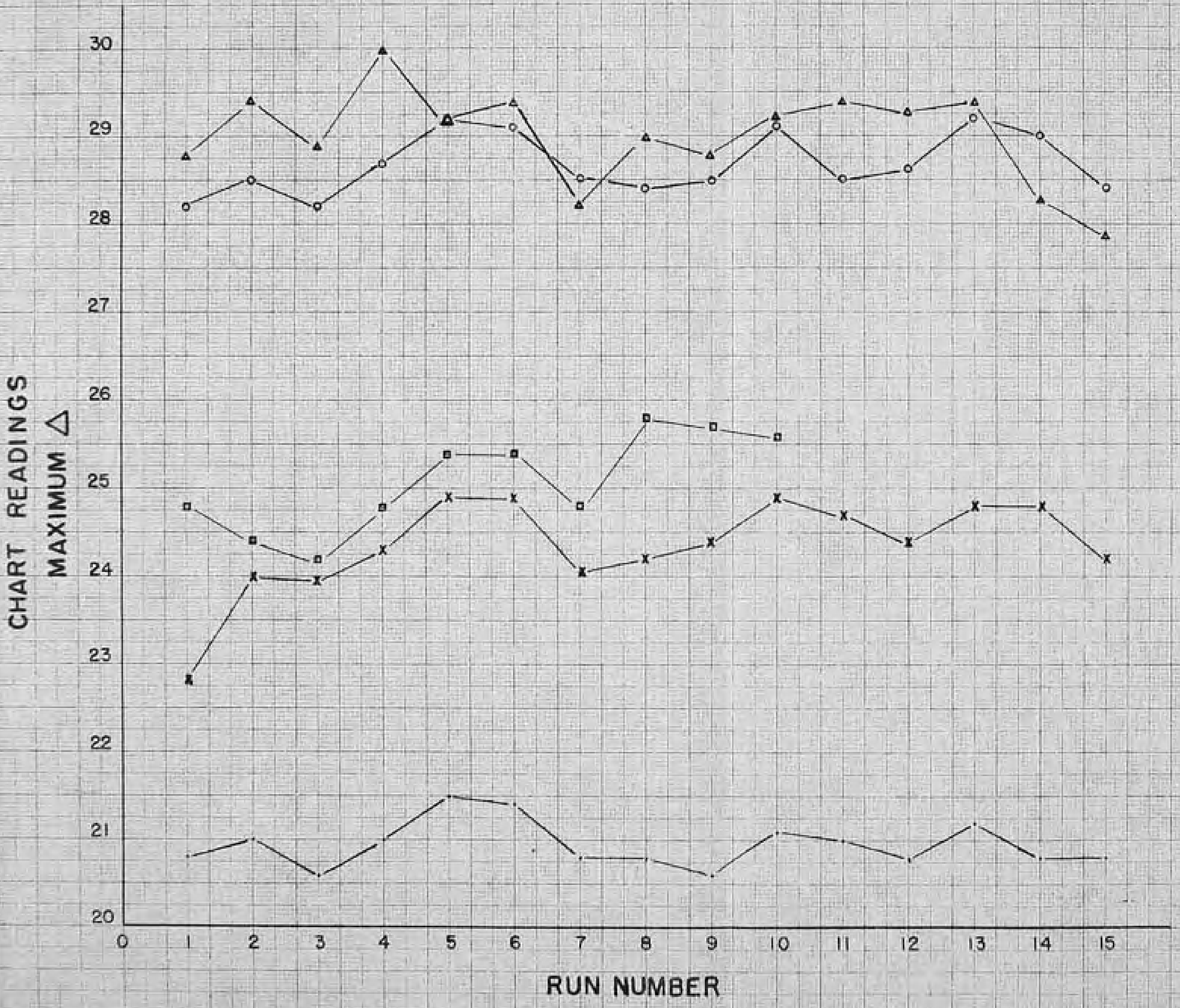

ALTERATIONS

MARK	DESCRIPTION	BY	DATE	APPD

GENERAL NOTES

DEPTH OF
INFLUENCE STUDY

SLAB 8" THICK

• ——— • 3' FROM TOP OF SLAB
X ——— X 6' " " " "
□ ——— □ 10' " " " "
○ ——— ○ 15' " " " "
△ ——— △ 19' " " " "

40 CHART DIV. = 0.01"

REFERENCES

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RELATIVE MOTION BETWEEN PAVEMENT
AND EARTH AT VARIOUS DEPTH

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VARIABILITY OF DATA

		MEAN DEF (IN)	STANDARD ERROR (IN)	95% CONFIDENCE LIMITS ON THE MEAN	RANGE
20 MPH - PILOT SEC-2	A-3	-.00009	.00009	$-.00013 < \mu < .00006$	-.00022 — .00031
	A-4	.00024	.00008	$.00021 < \mu < .00026$	.00016 — .00059
	A-5	.00096	.00015	$.00091 < \mu < .00102$	.00075 — .00163
	B-1	.00172	.00014	$.00167 < \mu < .00177$	.00153 — .00222
	B-2	.00432	.00024	$.00423 < \mu < .00440$	.00397 — .00478
	B-3	.00545	.00032	$.00534 < \mu < .00557$	.00503 — .00613
	B-4	.00611	.00029	$.00600 < \mu < .00621$	.00566 — .00659
	B-5	.00684	.00035	$.00669 < \mu < .00698$	.00623 — .0075
	5 MPH SEC-1	0.0247	0.0002	$0.0246 < \mu < 0.0249$	0.0244 — 0.0251
AIRPORT	1	0.0052	0.0001	$0.0052 < \mu < 0.0053$	0.0052 — 0.0054
	2	0.0061	0.0001	$0.0060 < \mu < 0.0062$	0.0057 — 0.0062
	3	**0.0064**	**0.0001**	$0.0062 < \mu < 0.0064$	0.0061 — 0.0065
	4	0.0073	0.0001	$0.0071 < \mu < 0.0072$	0.0071 — 0.0074
	5	0.0073	0.0001	$0.0072 < \mu < 0.0073$	0.0070 — 0.0075

ALTERATIONS

MARK	DESCRIPTION	BY	DATE	APPD

GENERAL NOTES

REFERENCES

ENGINEERING SCIENCES LABORATORY
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PROJECT C36A

VARIABILITY ANALYSIS

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runs at 20 mph. These runs were made with a LaPorte District Truck and deflection was measured simultaneously at 10 positions in the pavement.

The 20 mph speed was used because it was felt that the greatest variability in results might result from lack of control of vehicle speed and position. It will be noted that a considerable variability is present as indicated by the standard error and the range. With thirty samples we can be 99 per cent confident that the mean of the maximum deflection falls in a band width of ± 4.2 per cent.

Since the study at 5 mph in pilot section 1 indicated a considerable reduction in variability over that in section 2 one is led to believe that the variation is primarily due to rates of speed and displacement rather than to random fluctuations in the measuring devices.

Measurements have been made which should give information on the rate of change of deflection with respect to both speed and velocity. Analysis of these records should provide information from which limits can be set for the control of these variables.

In addition to measuring deflections occurring as a loaded vehicle passed over the pavement a measure was made of pavement drift during the time the 30 runs were made. The results of these measurements are also plotted on page 34 .

A linear regression analysis was run relating pavement drift to the measurement of load-caused deflections at positions B-2, B-3, B-4, and B-5. For this series of measurements there was no significant correlation at the one per cent level.

Influence Tests on Airport

The tabulated data for the Airport tests are shown on page 36 .

A METHOD FOR OBTAINING THE ELASTIC AND VISCOUS DAMPING CONSTANTS FOR A CONCRETE PAVEMENT UNDER A LOAD MOVING WITH CONSTANT VELOCITY

The following method is an adaptation of a solution for the "Steady State Vibrations of Beam on Elastic Foundation for Moving Load", by J. T. Kenney, Jr., Project Engineer, Sandberg-Serrell Corp., and presented at the West Coast Meeting of the Applied Mechanics Division of the A.S.M.E. This paper was published in the December, 1954, Journal of Applied Mechanics.

The dynamics of a moving load on a beam on an elastic foundation has been treated previously, but the paper by Kenney is the first where damping action was considered.

It is proposed to apply Kenney's solution to the concrete pavement problem, by assuming that we can load the pavement continuously in a transverse direction thereby simulating beam action.

Assumptions

In addition to the usual assumptions made in beam theory the following additional assumptions are made:

(a) The pavement is assumed to be infinitely long.

(b) There is no shear or moment along the edges of the pavement or foundation.

Equations

For $x = 0$ equations (14) in paper by Kenney both reduce to:

(1) $$y = \frac{P\lambda}{2K}\left[\frac{\eta}{\eta^4 + (\eta\theta)^2 + \frac{1}{2}\left(\theta B/\eta\right)^2}\right]$$

where η is the positive real root of

$$(2) \quad \eta^6 + 2c^2\eta^4 + (\Theta^4 - 1)\eta^2 - \Theta^2\beta^2 = 0$$

which is equation (15) in the paper.

In the above equations the origin of the coordinate system is attached to the moving load.

The significance of letting x = 0 is that we get the deflection of the pavement directly under the load.

Equations (1) and (2) can be rewritten as follows:

$$(1) \quad \eta^6 + \left[\frac{v}{v_{cr}}\right]^2\eta^4 - \frac{P\lambda}{2Ky}\eta^2 - \frac{1}{2}\left[\frac{v}{v_{cr}}\right]^2\left[\frac{c}{c_{cr}}\right]^2 = 0$$

$$(2) \quad \eta^6 + 2\left[\frac{v}{v_{cr}}\right]^2\eta^4 + \left[\left(\frac{v}{v_{cr}}\right)^4 - 1\right]\eta^2 - \left[\frac{v}{v_{cr}}\right]^2\left[\frac{c}{c_{cr}}\right] = 0$$

In the above equations η and c will be the only unknowns so it is possible to solve for c, the damping coefficient. This assumes we know k, the modulus of subgrade reaction which can be determined by a static load. Since v = 0 then $\Theta = \frac{v}{v_{cr}} = 0$ and
(2) reduces to $\eta = 1$ and (1) becomes

$$y = \frac{P\lambda}{2K} = \frac{P}{[4EI]^{1/4}K^{3/4}}$$

or

$$K = \left[\frac{P}{y(4EI)^{1/4}}\right]$$

Nomenclature

P = applied load, lbs.

λ = static wave characteristic, 1/in. = $\left(\frac{K}{4\,EI} \right)^{1/4}$

k = spring constant per unit length of beam, lb./in.

E = modulus of elasticity, psi

I = moment of inertia of beam, in.^{4}

η = numerical coefficient

θ = velocity ratio = $\frac{v}{v_{cr}}$

v_{cr} = critical velocity, in./sec. = $\left(\frac{4\,K\,EI}{\rho^2} \right)^{1/4}$

ρ = mass per unit length of beam, lb. sec.^{2}/in.^{2}

β = ratio of damping coefficients = $\frac{c}{c_{cr}}$

c = coefficient of viscous damping/unit length, lb.sec./sq.in.

c_{cr} = coefficient of critical damping = $2(k\rho)^{1/2}$

A STUDY OF EARTH DISPLACEMENT

In the Summary of Field Tests, reasons were cited for the need of further information concerning earth motion beneath a loaded pavement. This problem was approached from both a theoretical and experimental standpoint.

General Statement of Problem

One approach to the problem could have begun by finding the normal stresses at the top surface of the earth through considering the pavement to be a beam on an elastic foundation. However, a first approximation to the displacements at the top surface of the earth was already available from experimental data on hand and it was therefore decided that the deformation of the earth should be considered alone in terms of a specified boundary deformation.

The earth model was reduced to two dimensions giving a further simplification in the theory but requiring that the experiment be conducted so as to reasonably simulate this restricted behavior.

There was no complete quantitative knowledge of either the tangential forces or the horizontal displacements at the interface between the pavement and the earth although it could be assumed that both the stresses and displacements vanished at positions far from the point of application of the load.

In summary, the earth beneath the pavement was considered to be an elastic homogeneous isotropic medium subjected to surface loads which caused the top surface to assume a shape varying in one horizontal direction only. In the region occupied by the earth the equilibrium equations in terms of displacement components were assumed to be valid and were solved subject to the specified boundary conditions: (1) that the displacements must vanish far from the load and (2) that the vertical displacement of the top surface was a known function varying in one direction only and hence gave rise to a plane strain condition in the earth. The horizontal displacement was unspecified to be determined at the proper time. The only restriction on the horizontal displacement was that it be intuitively reasonable.

The selection of the displacement of the top surface was made by examining the deflection of a point on the pavement, recorded as a loaded truck was driven down the pavement at creep speed. It was noticed that the effect of either the front or back wheels could be approximated by a surface that varied in the direction of the truck motion according to one cycle of a cosine curve. Hence, by adding two such curves, one with a large amplitude and long period to represent the deflection due to the rear wheels and one with a smaller amplitude and a smaller period to represent the deflection due to the front wheels, a curve was obtained which very closely approximated the shape of the deflected surface of the pavement and hence the upper surface of the earth just under the pavement. Thus the type of boundary condition for the displacement of the upper surface was assumed to be an infinitely long trench having a cross-sectional shape of one cycle of a cosine curve. (See Page 43). Such a trench might be approximated experimentally by superimposing the deflections from several laterally displaced passes of the test truck.

The Theoretical Problem

Let there be a semi-infinite, homogeneous, isotropic, elastic medium whose upper surface is displaced in the form of an infinitely long trench having a transverse profile in the form of a single cycle of a cosine curve. Choose a set of axes as shown in Fig. 1 and let the movement of the point P to a new position P^1 be described by the three displacement


Y
X
N
P
u
w
p'
Z

components u, v & w in the x, y & z directions respectively.

Due to the nature of the boundary configuration a condition of plane strain exists. Hence, we consider only the u (x, z) and w (x, z) displacements of a typical x, z half plane.

The equilibrium equations in terms of displacements

$$(\lambda + 2G)\frac{\partial^2 u}{\partial x^2} + G\frac{\partial^2 u}{\partial z^2} + (\lambda + G)\frac{\partial^2 w}{\partial x \partial z} = 0 \qquad (1)$$

$$(\lambda + 2G)\frac{\partial^2 w}{\partial z^2} + G\frac{\partial^2 w}{\partial x^2} + (\lambda + G)\frac{\partial^2 u}{\partial x \partial z} = 0 \qquad (2)$$

are to be solved subject to the boundary conditions

1.) $u, w \rightarrow 0$ as $x \rightarrow \infty$ and $z \rightarrow \infty$

2.) $$w(x,0) = \begin{cases} 0 & x \leq -a \\ \frac{A}{2}\left(1 + \cos\frac{\pi x}{a}\right) & -a \leq x \leq a \\ 0 & a \leq x \end{cases}$$

3.) $u(x,0)$ is unspecified at this point.

where λ and G are the Lame constants for the material. Equations (1) and (2) may be solved indirectly by solving a more general set of equations, namely, the biharmonic equations

$$\frac{\partial^4 u}{\partial x^4} + 2\frac{\partial^4 u}{\partial x^2 \partial z^2} + \frac{\partial^4 u}{\partial z^4} = 0 \qquad (3)$$

$$\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial z^2} + \frac{\partial^4 w}{\partial z^4} = 0 \qquad (4)$$

Solutions were assumed in the form

$$u(x,z) = U(z) \sin \alpha x \qquad (5)$$

$$w(x,z) = W(z) \cos \alpha x \qquad (6)$$

since one could visualize this type of symmetry existing in the problem. Hence, α is an arbitrary parameter.

The substitution of the trial solutions (5) & (6) reduces equations (3) & (4) to the following pair of ordinary differential equations for U and W in terms of Z

$$\frac{d^4U}{dz^4} - 2\alpha^2 \frac{d^2U}{dz^2} + \alpha^4 U = 0 \qquad (7)$$

$$\frac{d^4W}{dz^4} - 2\alpha^2 \frac{d^2W}{dz^2} + \alpha^4 W = 0 \qquad (8)$$

The solutions of (7) and (8), upon considering the implications of the boundary condition at ∞, are

$$U = (B + Cz) e^{-\alpha z} \qquad (9)$$

$$W = (D + Ez) e^{-\alpha z} \qquad (10)$$

where B, C, D, and E are undetermined constants. The deflections may now be written as

$$u(x,z) = (B + Cz) e^{-\alpha z} \sin \alpha x \qquad (11)$$

$$w(x,z) = (D + Ez) e^{-\alpha z} \cos \alpha x \qquad (12)$$

Since (11) and (12) must satisfy the original partial differential equations (1) and (2), we find by substituting (11) & (12) into (1) and (2) that

$$\begin{aligned} C &= E \\ B &= D \end{aligned} \qquad (13)$$

At this point it should be noted that the freedom to specify an arbitrary boundary condition on u has been sacrificed to allow the assumed simple type of solution to the biharmonic to represent the solution to the problem. In fact the solutions are harmonic in the final form. Since B = D, we see that a relation between the specified boundary condition on w at z = o and the values of u on the boundary has been fixed.

Solutions of the form

$$u = A e^{-\alpha z} \sin \alpha x \qquad (14)$$

$$w = A e^{-\alpha z} \cos \alpha x \qquad (15)$$

satisfy equations (1) and (2) and all boundary conditions accept the one on w at z = o. This will be satisfied by taking the proper sum of solutions (15) such that on the boundary z = o the sum reduces to the Fourier integral expansion of the boundary condition there. Now this boundary condition

$$w(x,0) = \begin{cases} 0 & x \leq -a \\ \frac{A}{2}\left(1+\cos \frac{ax}{\pi}\right) & -a \leq x \leq a \\ 0 & a \leq x \end{cases}$$

may be expanded into the Fourier cosine integral

$$w(x,0) = \Delta\pi\int_0^\infty \frac{\cos \alpha x \sin \alpha a}{\alpha(\pi^2-\alpha^2a^2)}\,d\alpha \qquad (16)$$

Thus, we choose for $w(x,z)$ the expression

$$w(x,z) = \Delta\pi\int_0^\infty \frac{e^{-\alpha z}\,\text{[illegible]}\,\sin \alpha a}{\alpha(\pi^2-\alpha^2a^2)}\,d\alpha \qquad (17)$$

which then requires that

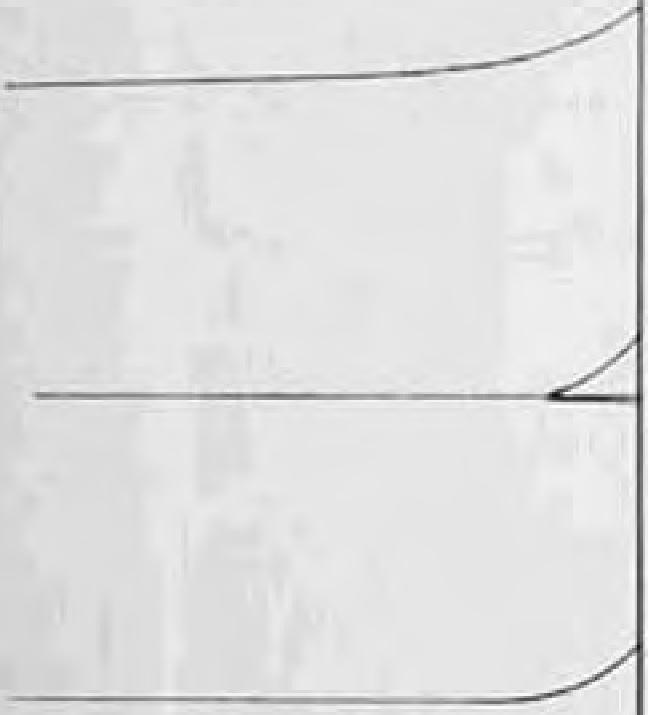
$$u(x,z) = \Delta\pi\int_0^\infty \frac{e^{-\alpha z}\,\text{[illegible]}\,\sin \alpha a}{\text{[illegible]}\,\alpha^2a^2)}\,d\alpha \qquad (18)$$

(17) reduces to (16) for z = 0 and [illegible] (17) and (18) together represent the solution to the [illegible]

The integrals in (17) and (18) cannot be integrated in terms of elementary functions and so were evaluated numerically. They were evaluated at horizontal positions $x = 0, a/4, 2a/4, ----, 6a/4$ and vertical positions $z = 0, a/4, 2a/4, ----, 8a/4$.

On Page 47A is shown the results of the numerical integration for $u(x,z)$ and $w(x,z)$ respectively. In each figure the displacement is shown as a function of x for [illegible] values of z. Another representation of the solutions appears on Page 48. Here are drawn lines connecting points having equal values of u and lines connecting points having equal values of w.

In order to show the effect of a [illegible] load, two solutions similar to those just obtained were superimposed. Page 49 shows the way in which an actual record of the deflection of the pavement caused by a



ALTERATIONS

RK	DESCRIPTION	BY	DATE	APPD

GENERAL NOTES

REFERENCES

ENGINEERING SCIENCES
LABORATORY
PURDUE UNIVERSITY
PROJECT C 36A

SYNTHESIS OF PAVEMENT
DEFLECTION

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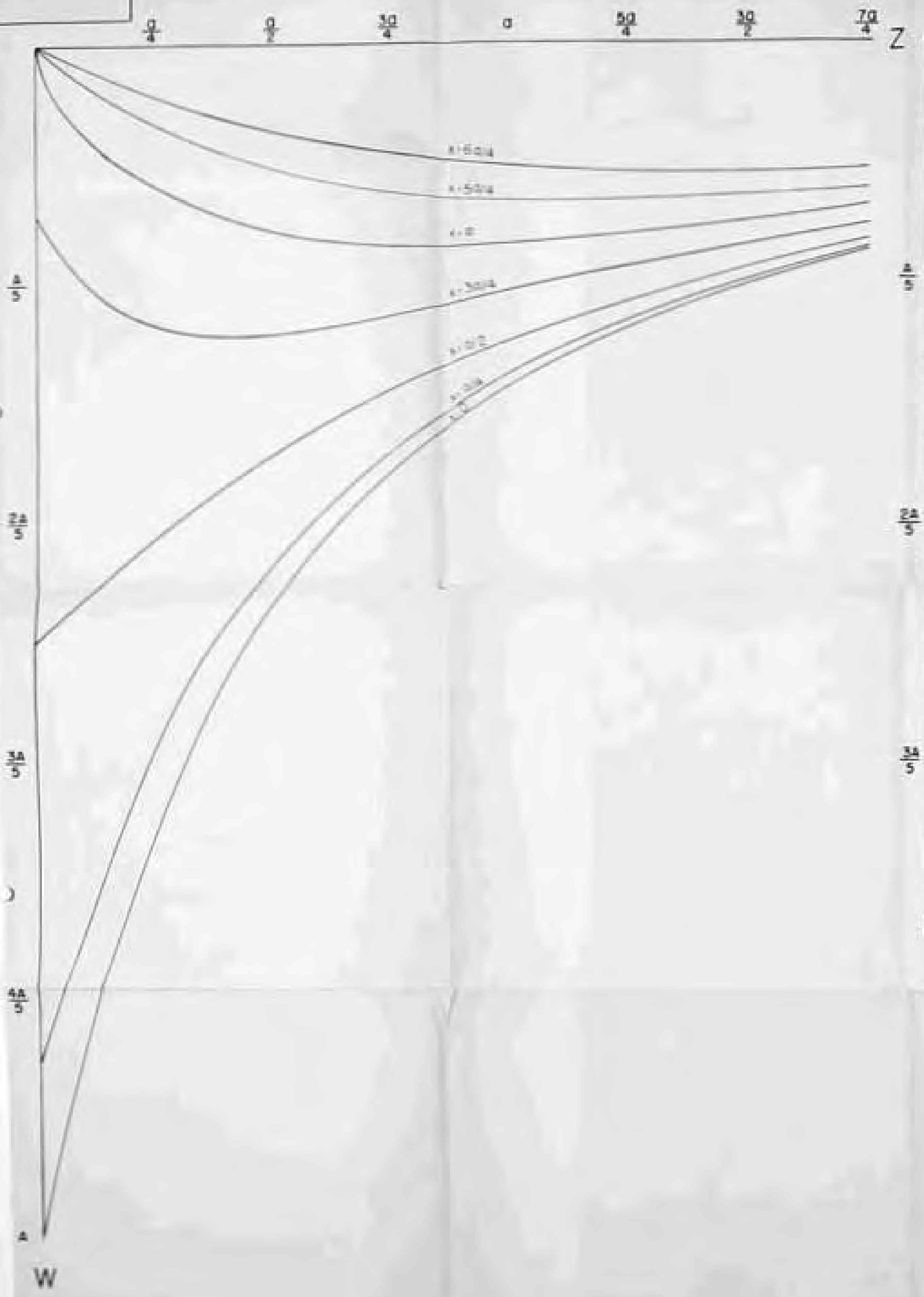

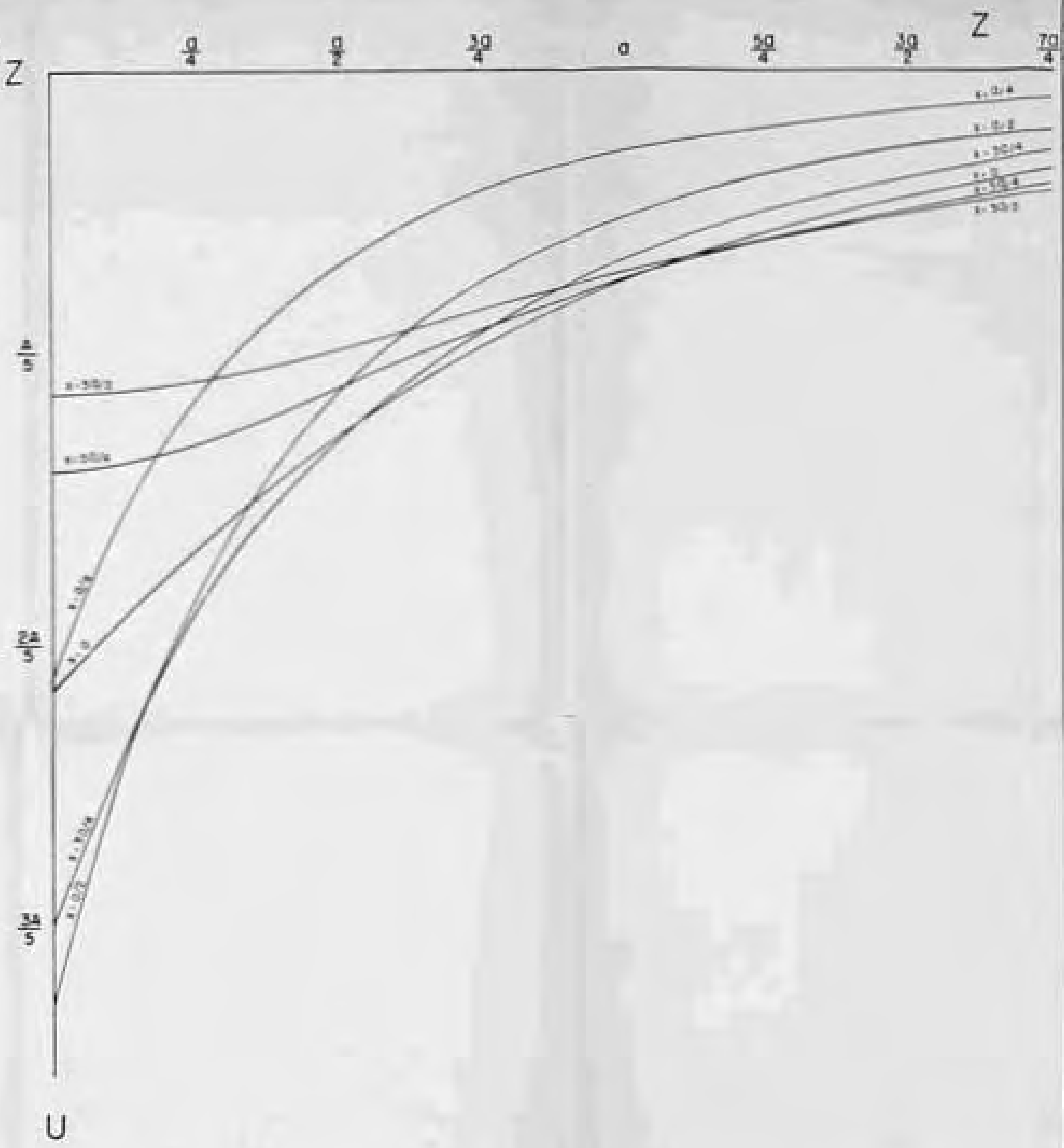

ALTERATIONS

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GENERAL NOTES

REFERENCES

ENGINEERING SCIENCES
LABORATORY
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PROJECT C 38A

HORIZONTAL AND VERTICAL DEFLEC-
TION AS A FUNCTION OF Z FOR
SELECTED VALUES OF X

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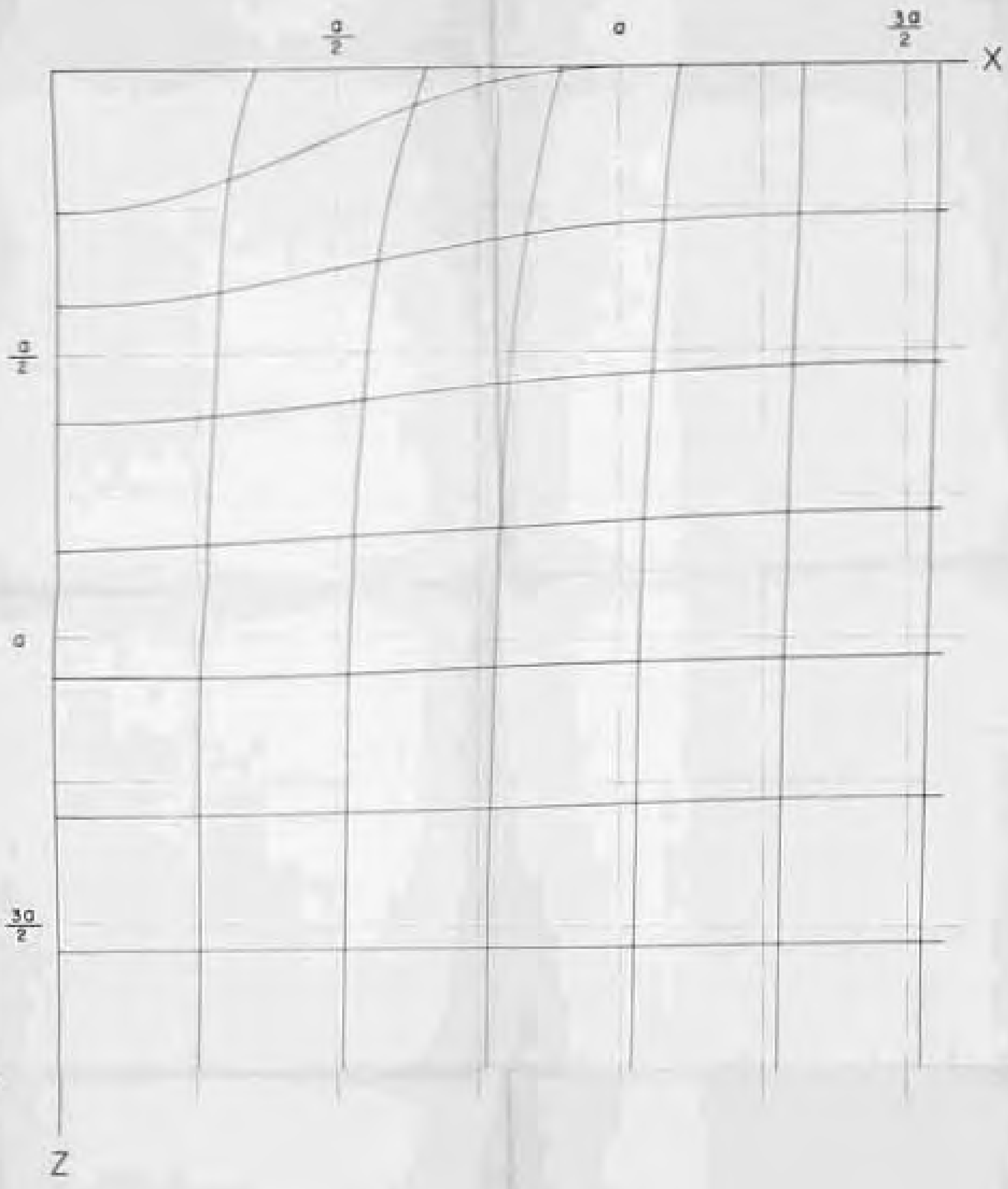
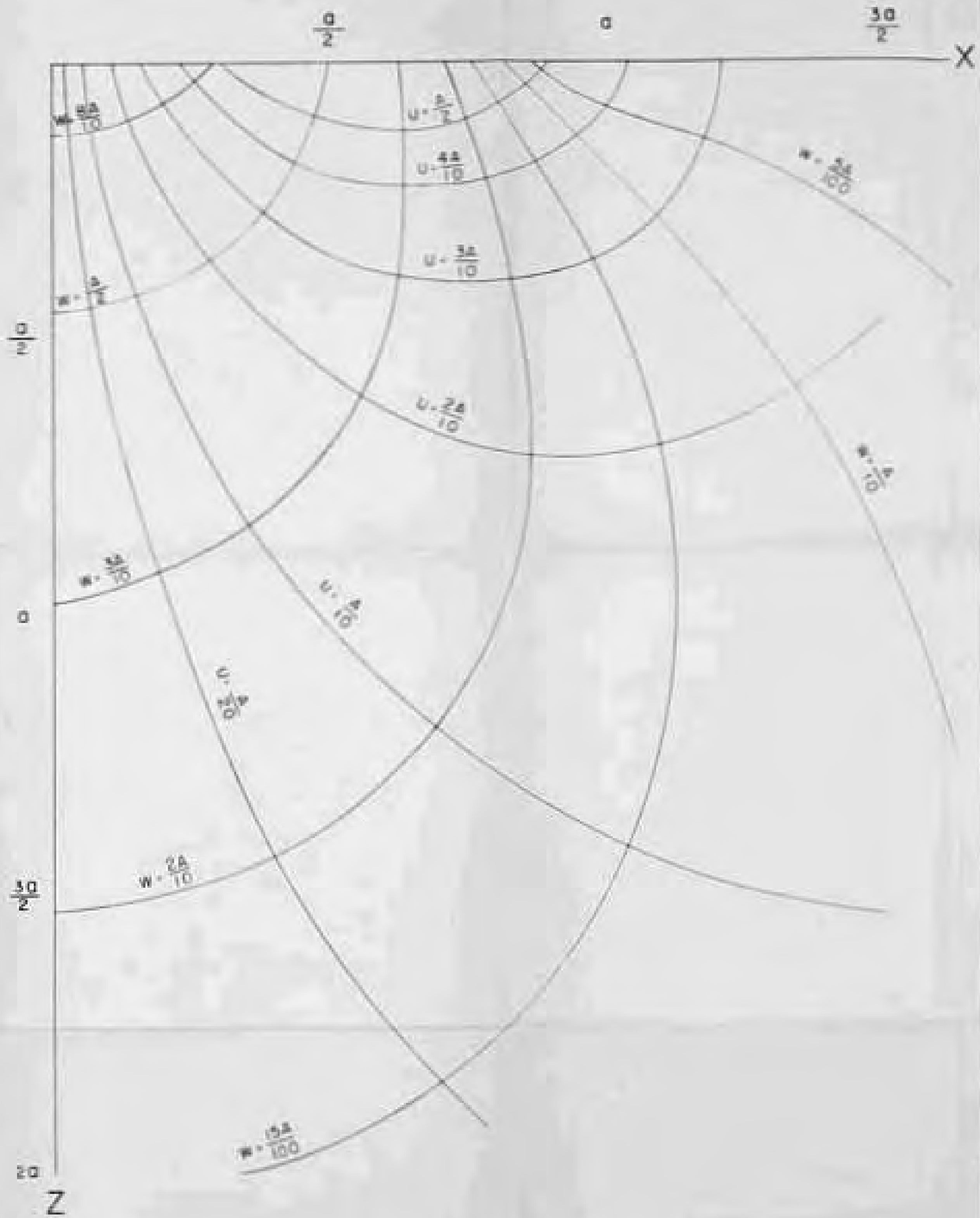


HORIZONTAL AND VERTICAL DEFLECTION OF SELECTED VERTICAL AND HORIZONTAL LINES IN THE HALF PLANE



CURVES OF CONSTANT HORIZONTAL AND VERTICAL DEFLECTIONS

ALTERATIONS				
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GENERAL NOTES

REFERENCES

ENGINEERING SCIENCES
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PROJECT C 36A

SOLUTION FOR ELASTIC HALF PLANE
DEFORMED AT IT BOUNDARY BY A
SINGLE CYCLE COSINE

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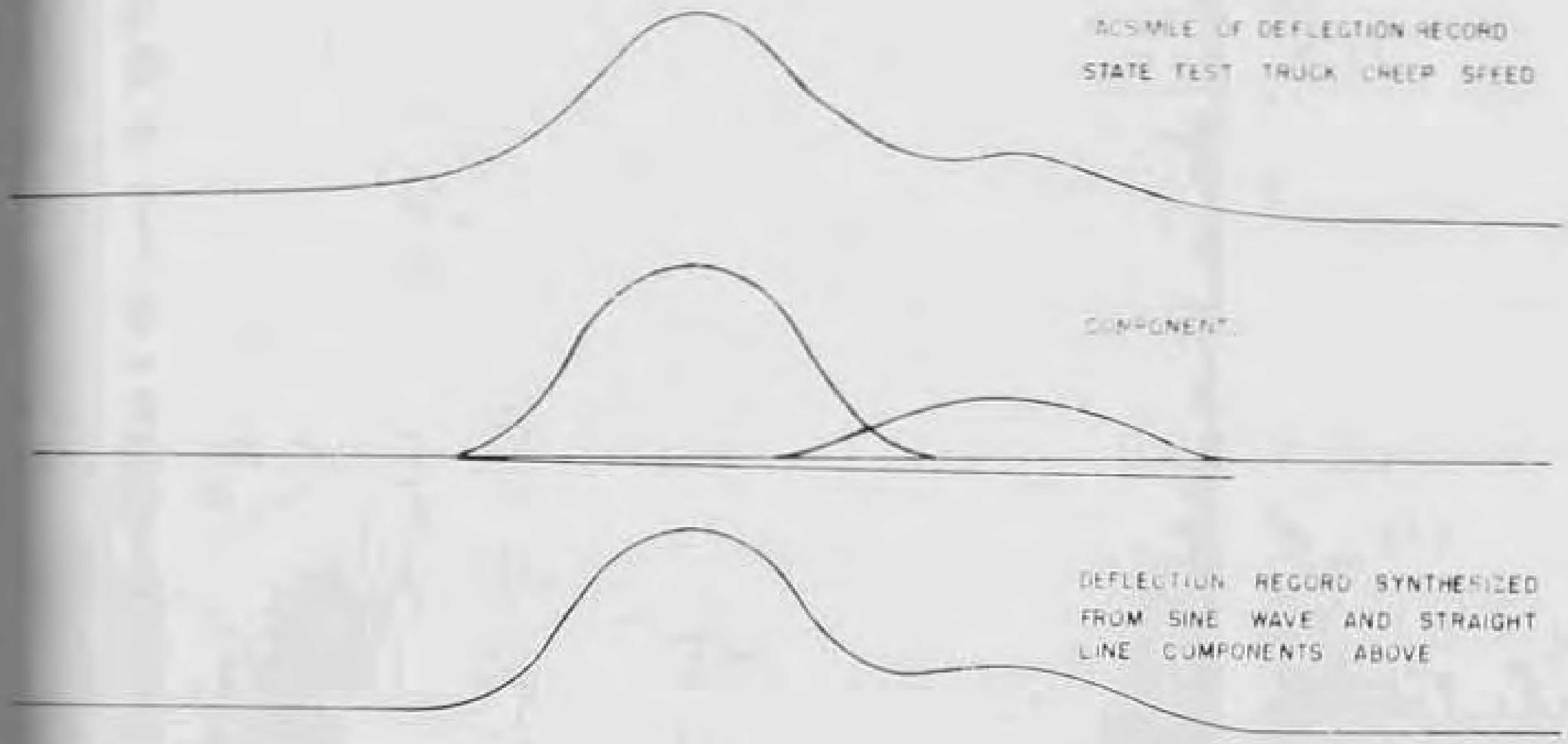

ALTERATIONS

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GENERAL NOTES

REFERENCES

ENGINEERING SCIENCES
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PROJECT C 36A

SYNTHESIS OF PAVEMENT DEFLECTION

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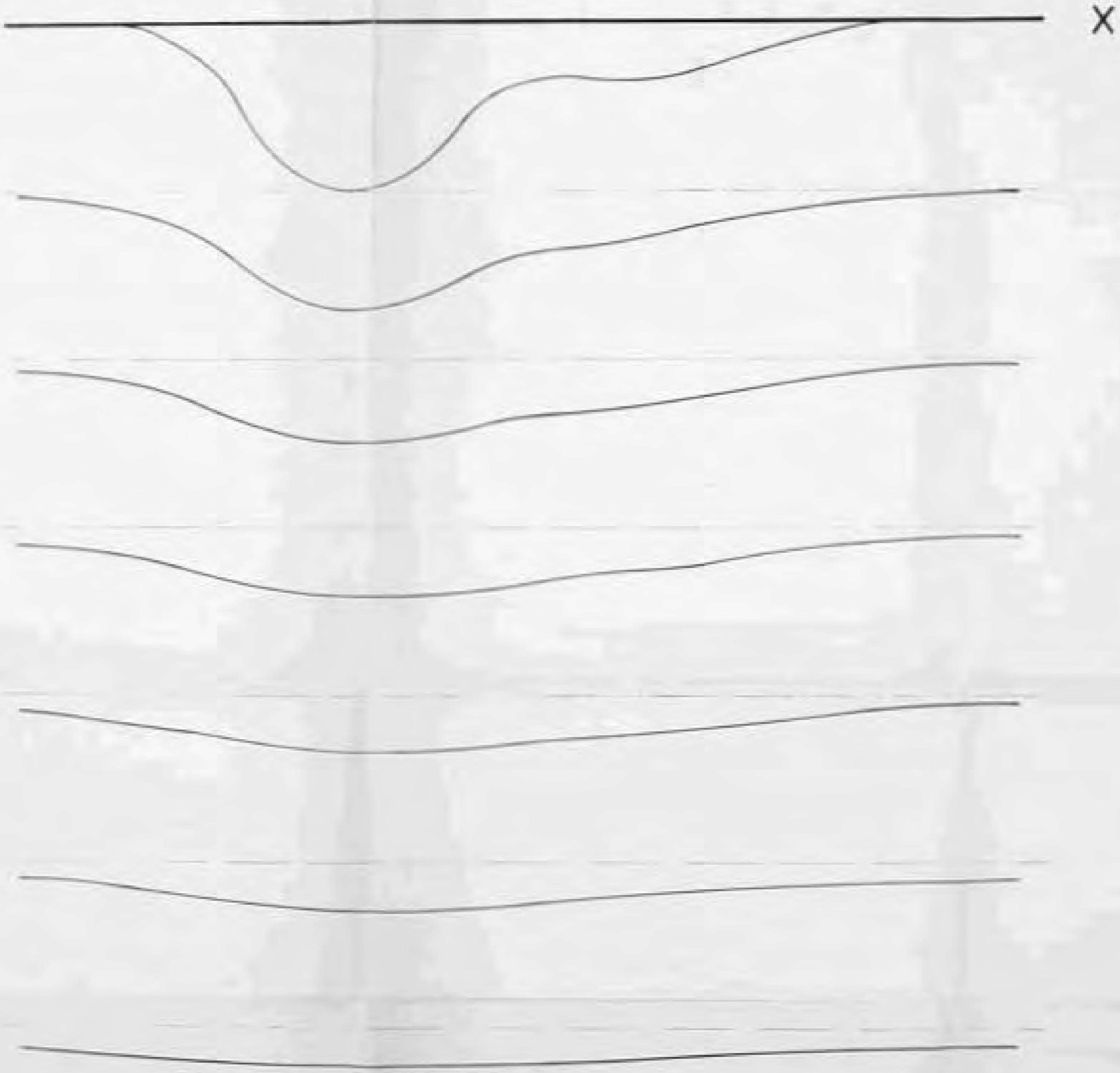
truck was decomposed into two curves, one representing the deflection due to the front wheels and the other the deflection due to the rear wheels. These deflections occurred at one point as the truck was driven along the pavement at creep speed and, actually, are a plot of deflection versus time. However, since the section of continuous pavement used in the experiment was sufficiently long to allow a vehicle to come on to it without deflecting the section at its center, and since the speed of the truck was small, the time record of the motion of the single point can be interpreted as an instantaneous profile of the pavement. Thus the decomposition of the record to give the two boundary conditions is plausible. The theoretical motion of the earth beneath the synthesized boundary is shown on page 51.



ALTERATIONS

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GENERAL NOTES

REFERENCES

ENGINEERING SCIENCES
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PROJECT C 364

RELATIVE DISPLACEMENT BENEATH
SYNTHESIZED BOUNDARY

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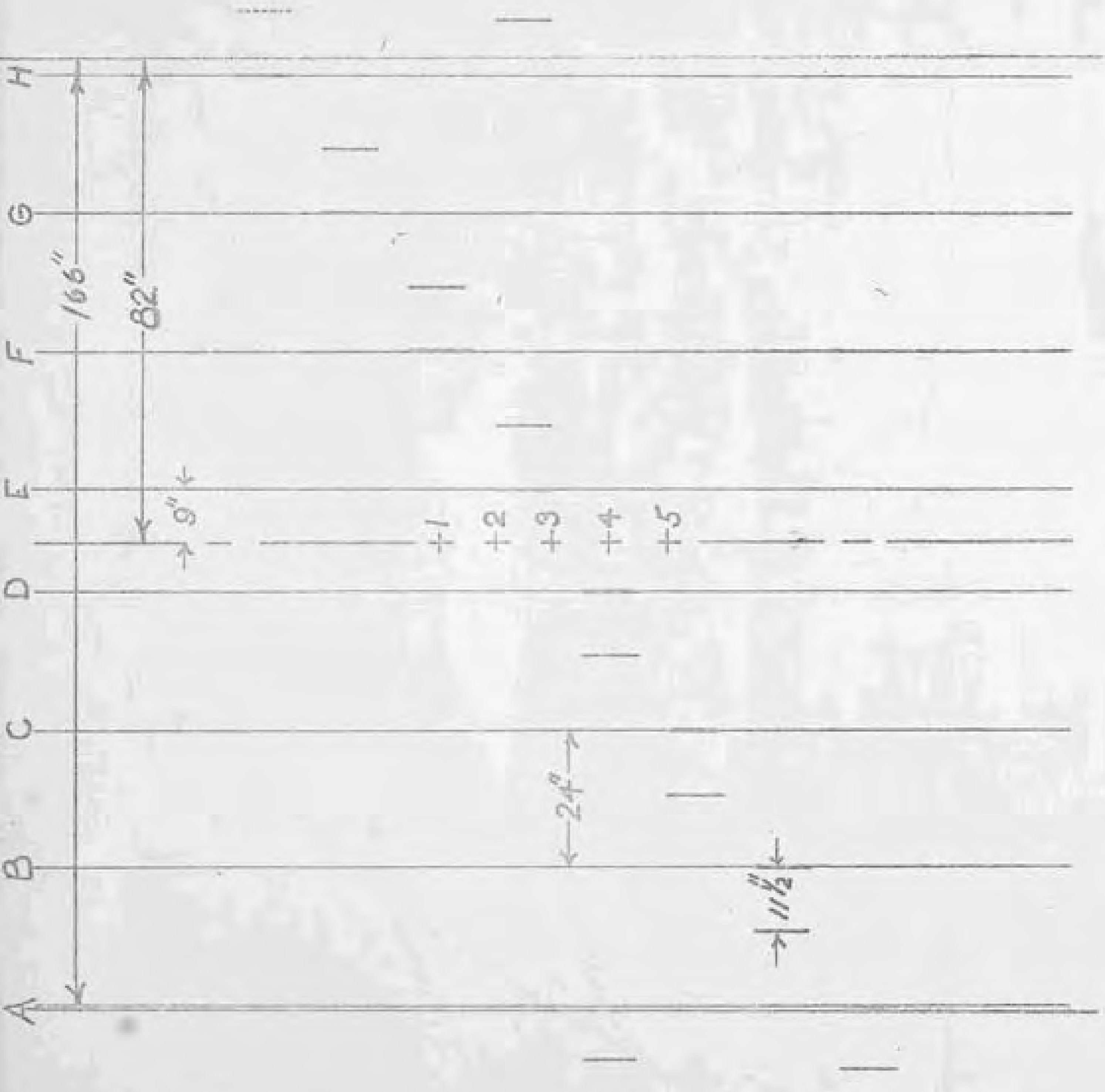
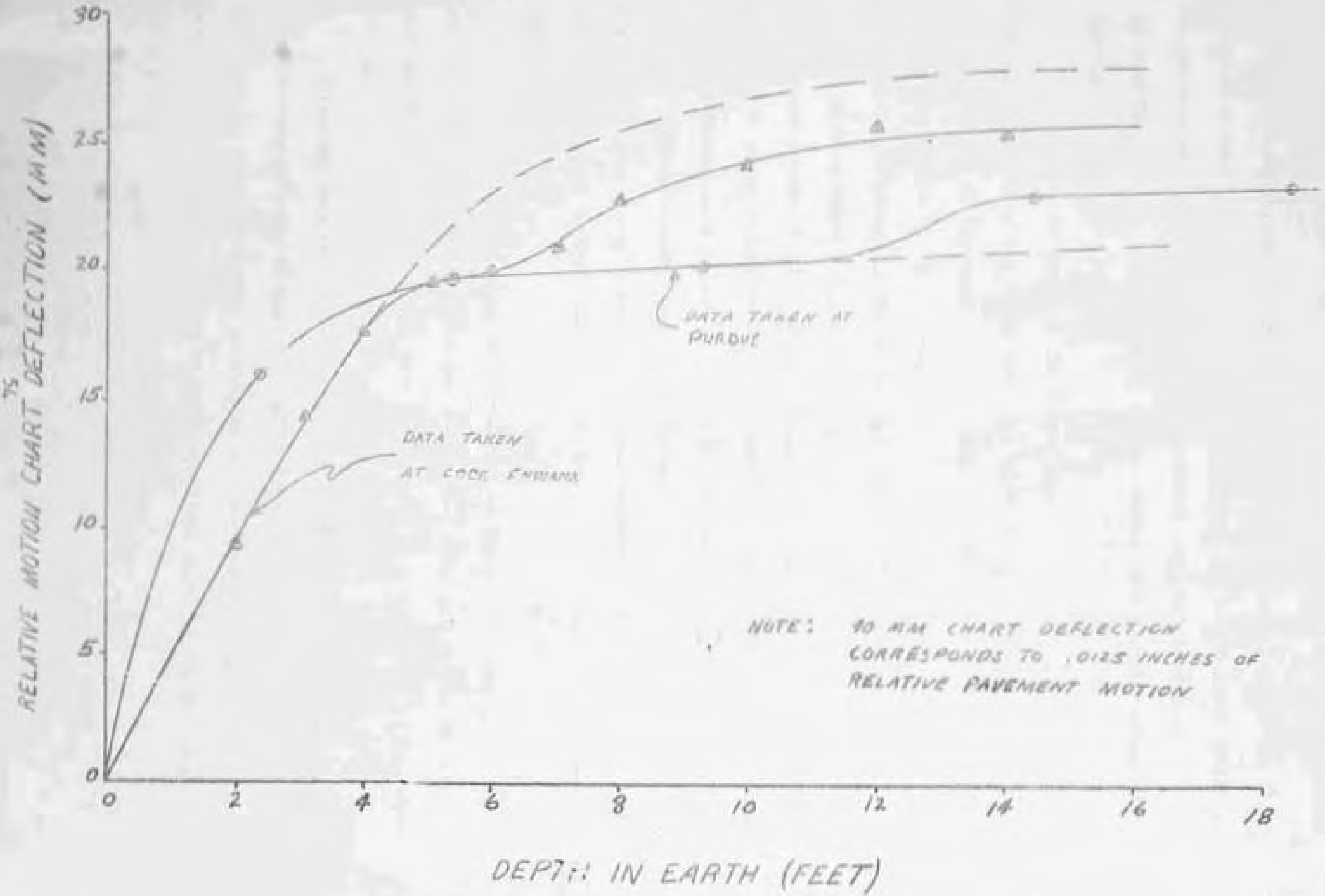


WHEEL & TRANSDUCER POSITIONS AT AIRPORT SLAB

EARTH MOTION DATA TAKEN AT COOK INDIANA
AND AT THE P.U. AIRPORT



of about 5 feet and in the other case at a depth of about 13 feet. At route 41 a hard layer of earth was encountered at the 5-foot level while at the Airport a layer of earth was encountered under thirteen feet of sand fill. This layer of earth in turn rested on a gravel glacial terrace.

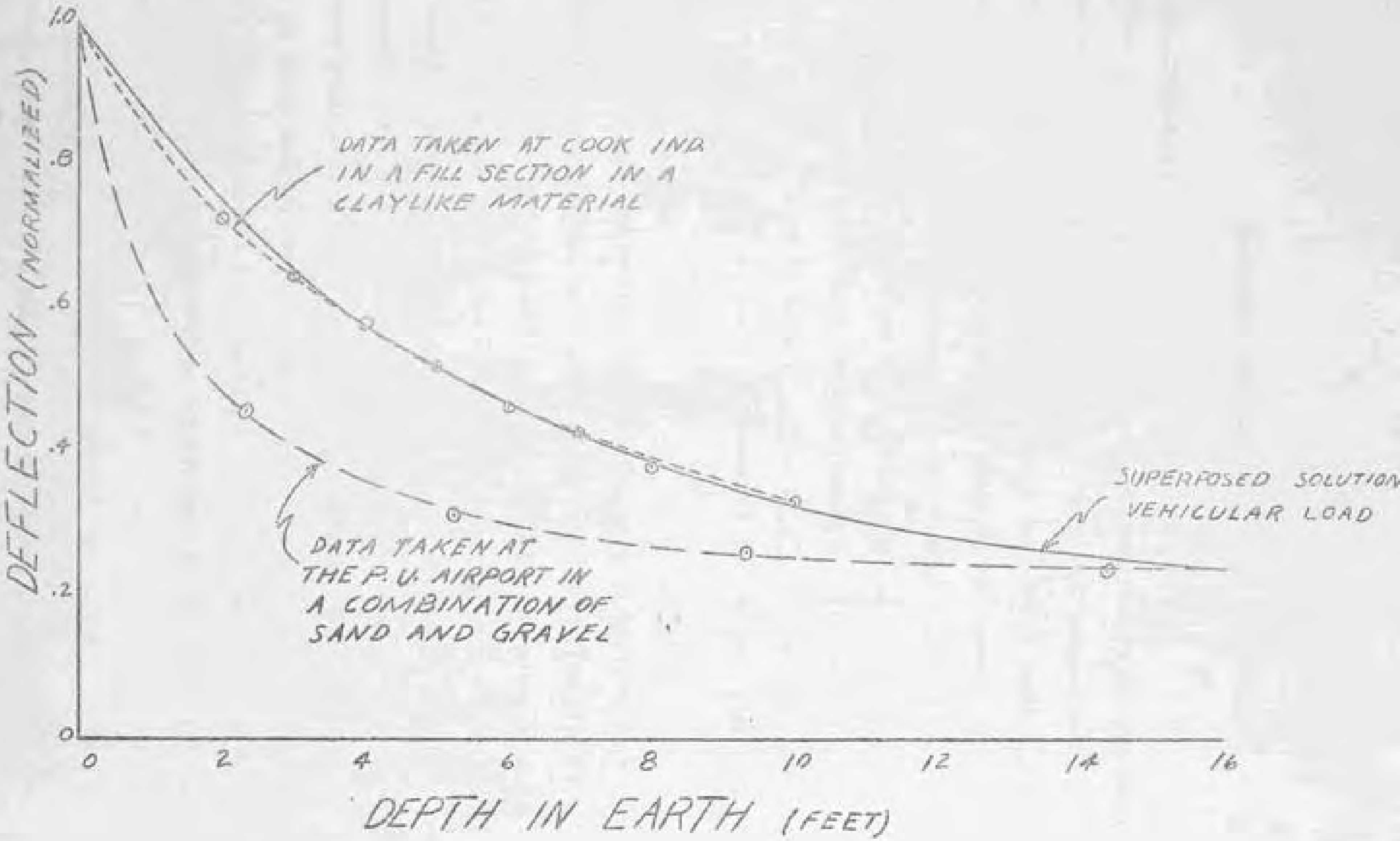
If the layer of earth at the 6-foot depth on route 41 has a higher elastic modulus than the earth above and below, a change in slope such as occurred should be expected. If the layer of earth at the 13-foot depth at the Airport has an elastic modulus lower than the sand above and the gravel below, a change in slope such as shown should be expected.

A plot of theoretical earth displacement beneath the mid-point at the rear tandem of the static test truck and plots of experimental results obtained at route 41 and the Purdue University Airport are shown on page 56. The experimental curves were obtained under the assumption that the changes in slope described earlier result from a hard layer in the one case and a soft layer in the other. With these assumptions the curves have been extrapolated in such a manner as to effectively eliminate the assumed inhomogeniety.

Each experimental curve was normalised to the relative deflection between the surface of the earth and the deepest reference point. A half wavelength of 9 feet was chosen from an analysis of a test truck displacement record.

Since the measured displacements were normalized with respect to relative displacements it was not possible to assign an absolute value to any point in the experimental curves; as a consequence the experimental curves were arbitrarily matched to the theoretical curve at its origin and at 16 feet.

A COMPARISON OF THEORETICAL AND EXPERIMENTAL RESULTS



14-CHANNEL RECORDER

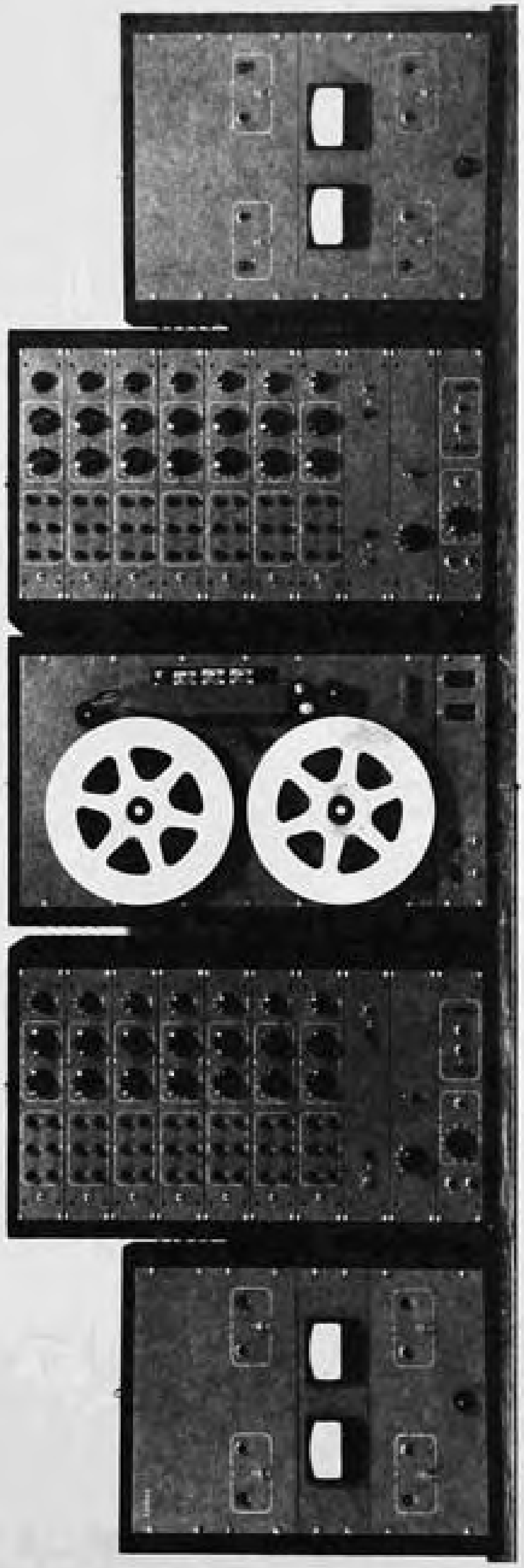
General Description

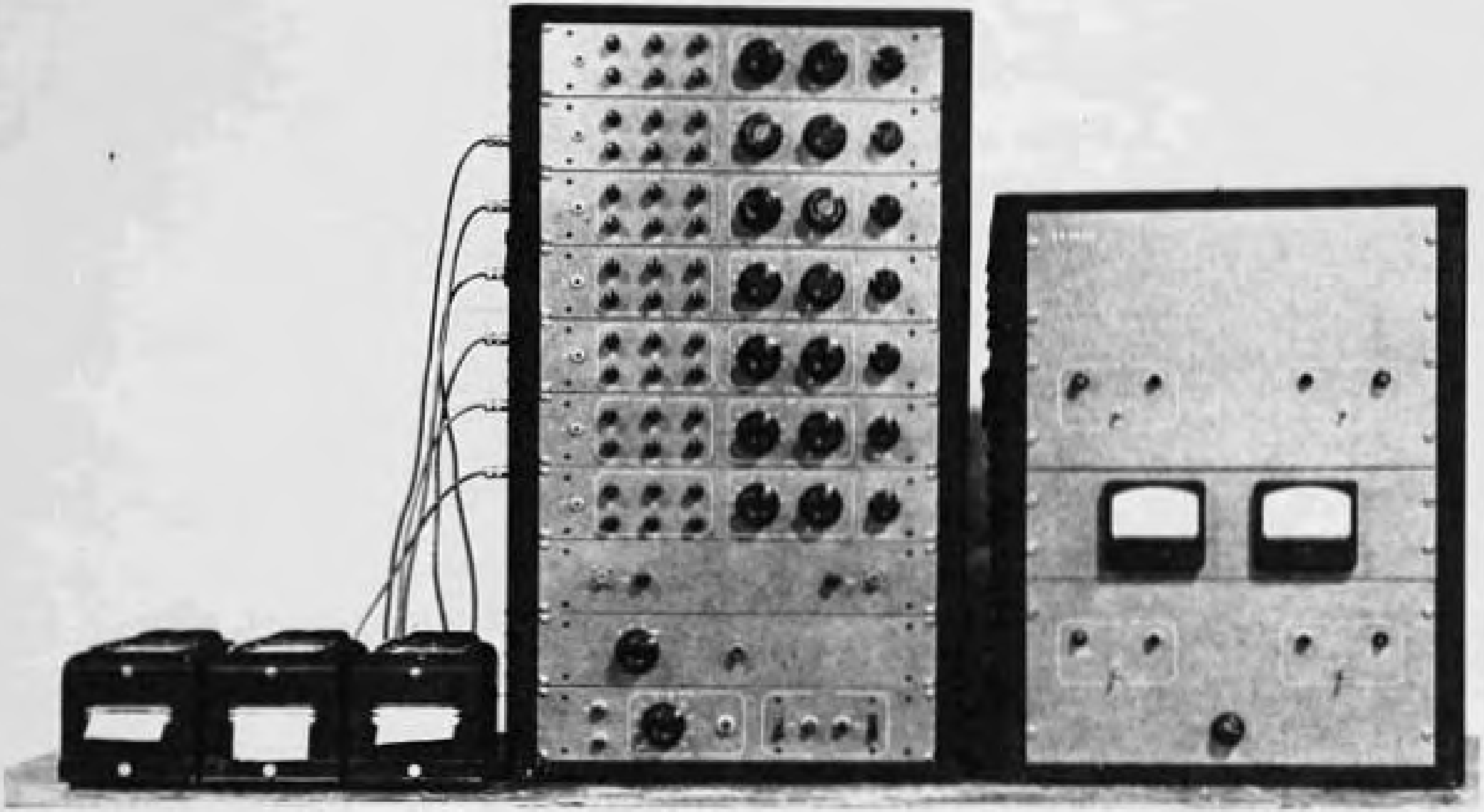
The 14-channel recorder has been designed specifically for use with Schaevitz 040L and 125S-L linear variable differential transformers and consists of two separable 7-channel amplifying and control units, one 14-channel tape recorder, and a play back device. The complete system (shown in Page 58) may be used to record fourteen simultaneous events on magnetic tape or it can be separated into two units, each of which can be used to drive seven 1500 ohm recording galvanometers. The separated system is shown in Pages 59 and 60. Page 61 shows a rear view of one unit. A view of instrument in use in the field is shown in Page 62.

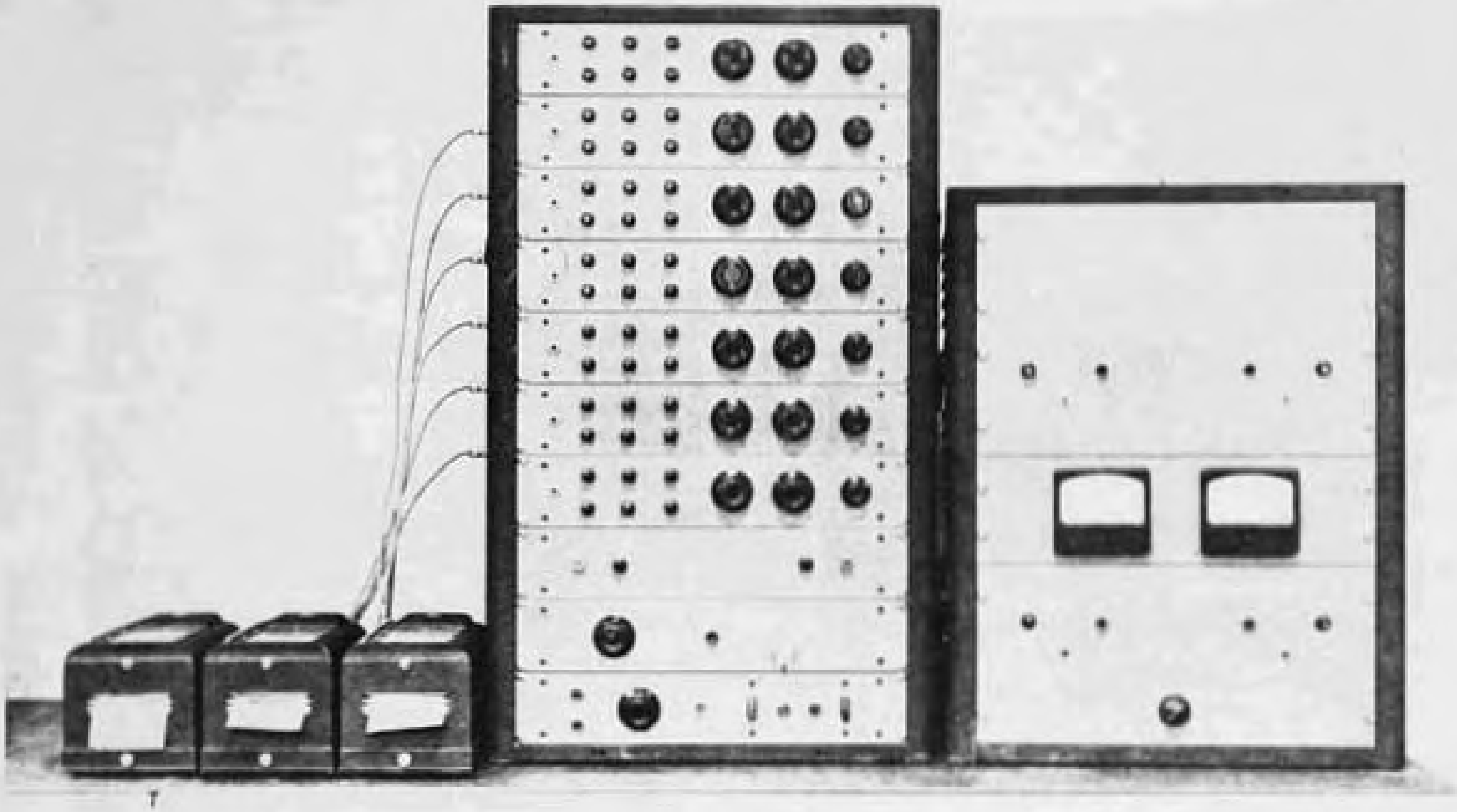
Each amplifying and control unit contains seven amplifiers, seven frequency modulating units, seven power amplifiers for driving galvanometers, oscillators which generate voltages at 30,000 cycles per second and 2,000 cycles per second, two power amplifiers to provide energy for differential transformers, a vacuum tube voltmeter, and control and interlocking circuits. The rectified 30KC voltage is used as a bias for power amplifier. The 2KC voltage drives the power amplifiers which serve as energy sources for differential transformers. One of these sources may be adjusted to three volts and will drive seven 040L transducers. The other may be adjusted to 7 volts and will drive one 125S-L transducer.

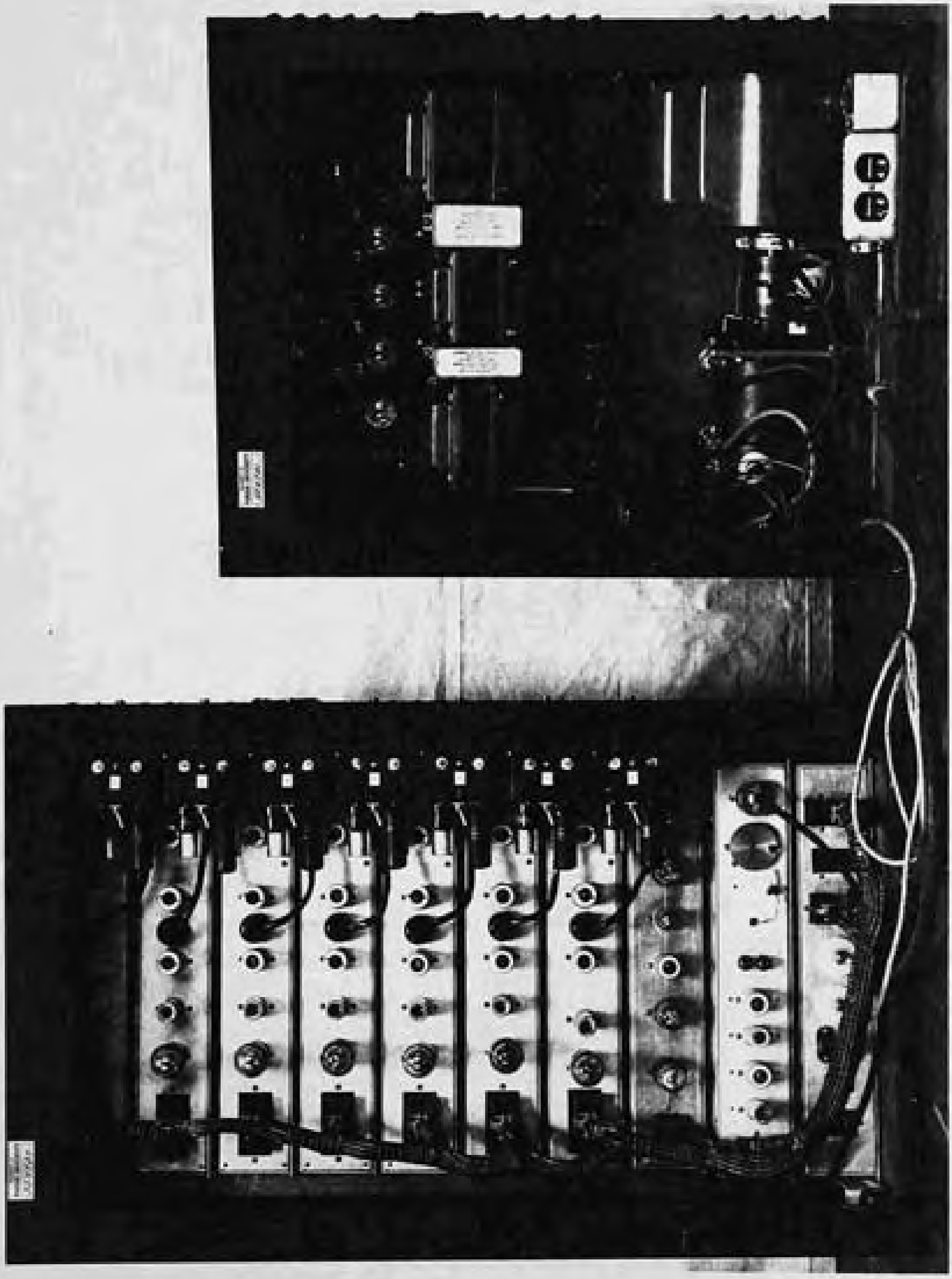
Mode of Operation

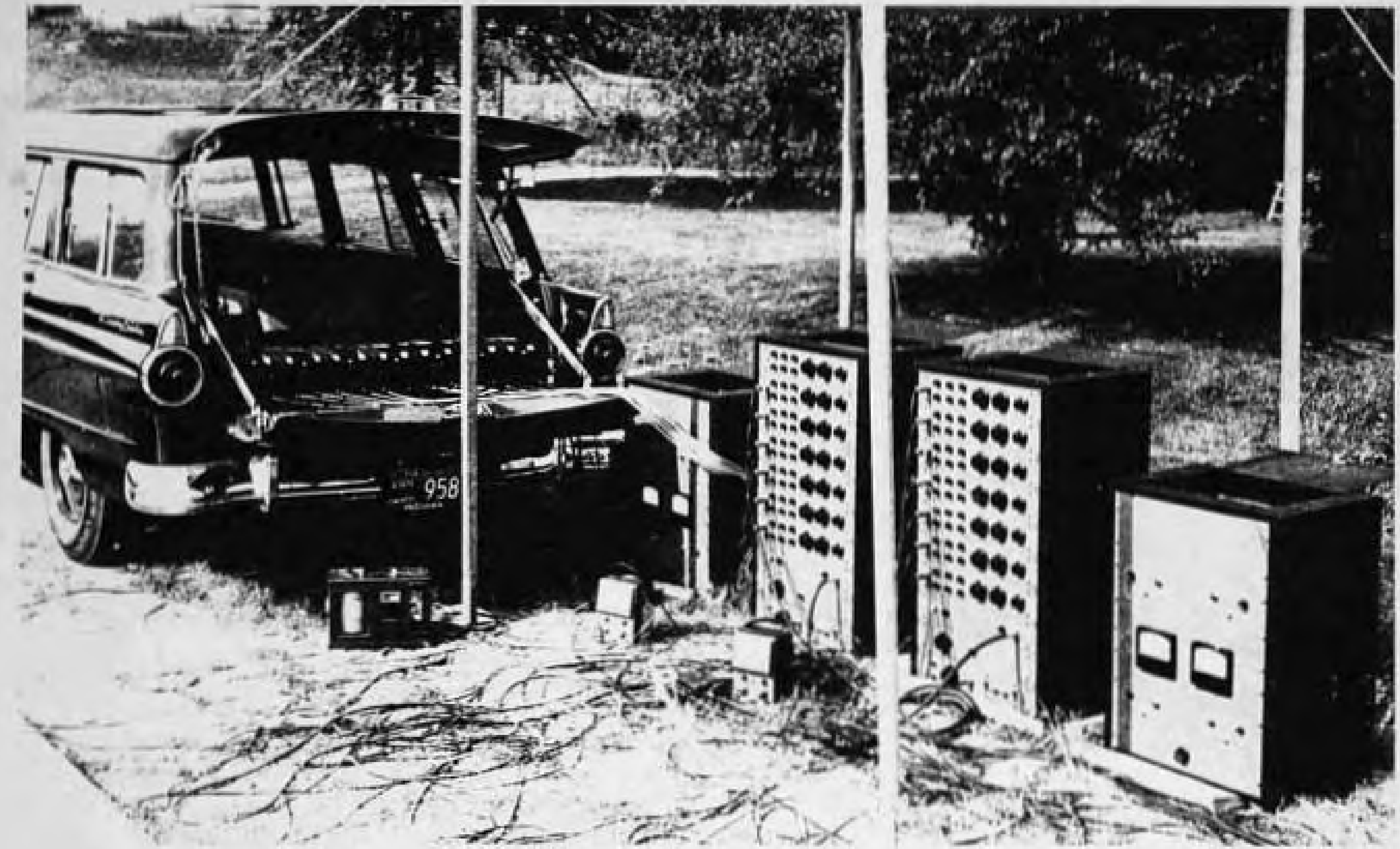
The basic elements of a single recording channel consist of a










958

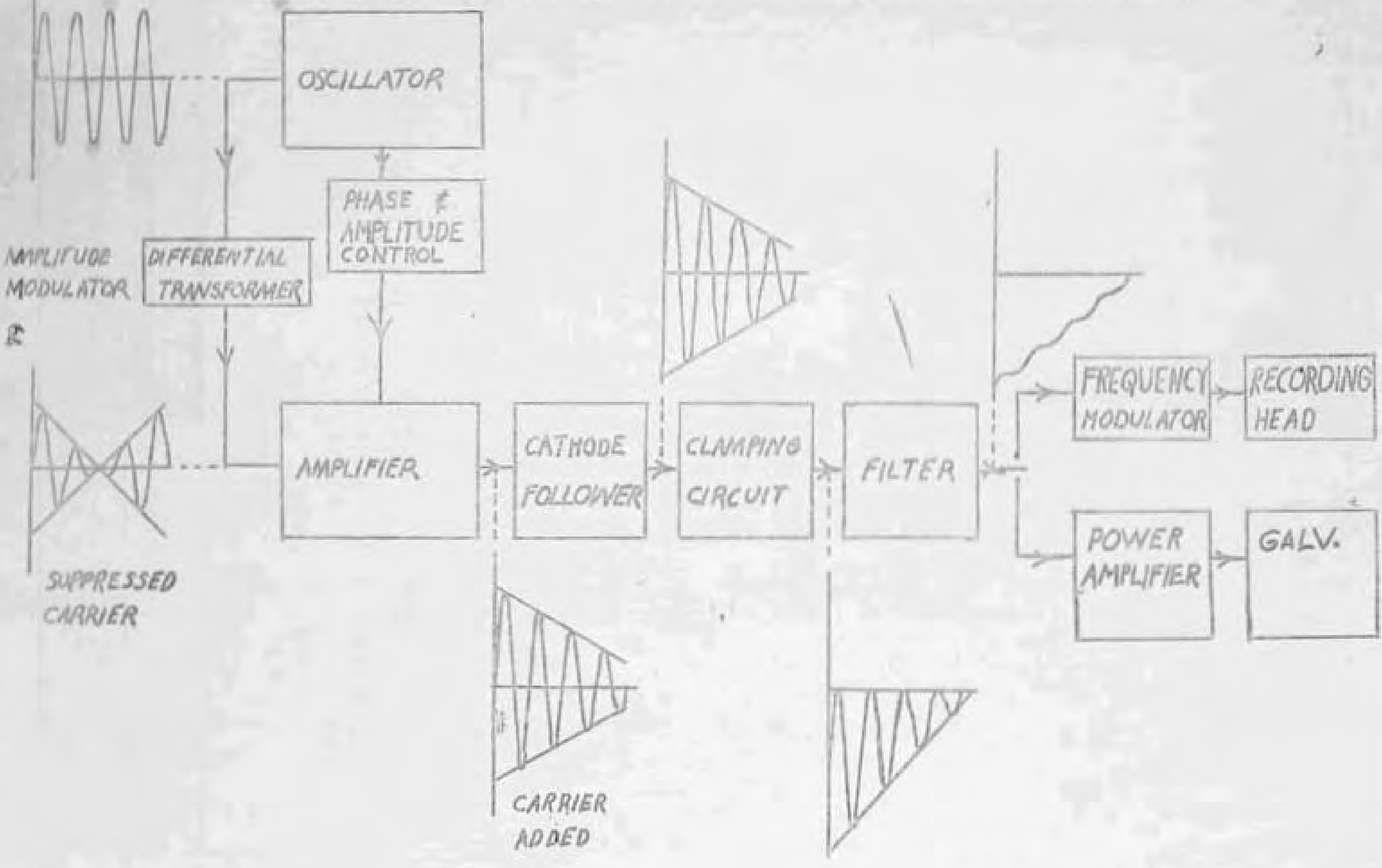
2000 cycle source voltage, a transducer which is supplied by the 2000 cycle source, an amplitude and phase controllable voltage which is obtained from the 2000 cycle source and which may be added to the output signal of a transducer, a voltage amplifier for amplifying transducer signals, a frequency modulator for providing an F.M. signal for the tape, and a power amplifier for driving a 1500 ohm galvanometer.

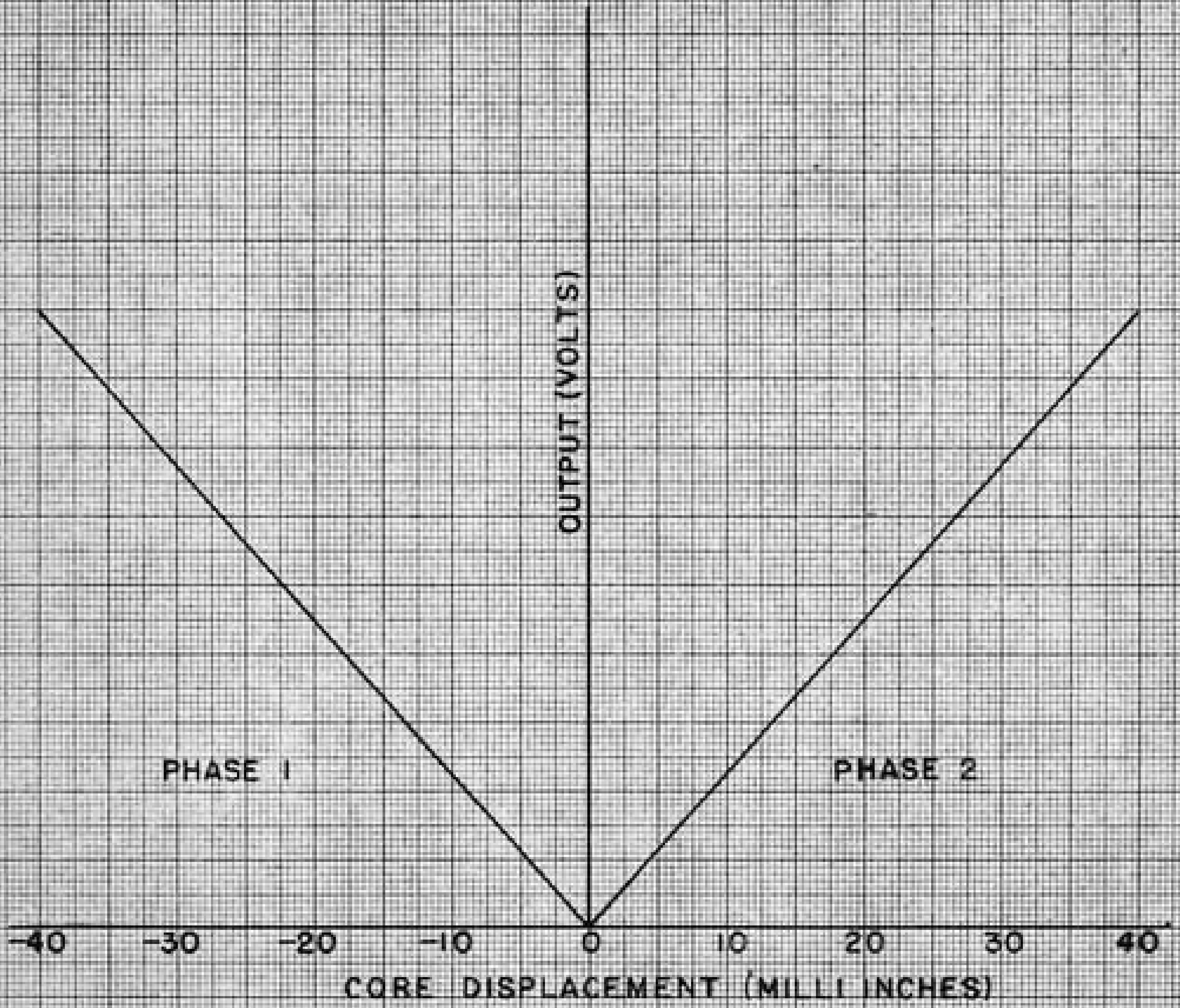
A simplified block diagram of a single channel is shown in Page 64.

A representative calibration curve for a differential transformer is shown in Page 65. Since the phase of the transformer output shifts 180° as the transformer core passes through null it is necessary to detect such phase shifts when they occur. An amplitude and phase controllable additive carrier voltage has been provided for this purpose. The principle of using the additive carrier voltage to detect phase shift is demonstrated in the block diagram.

Circuit arrangements have been made so that additive carrier may also be used to introduce periodic pulses to provide a time coordinate and to introduce coding pulses for record identification.

RECORDING SYSTEM BLOCK DIAGRAM & WAVEFORMS





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INPUT OUTPUT CURVE FOR
DIFFERENTIAL TRANSFORMER

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ACKNOWLEDGMENTS

Project C-36A was initiated through the offices of Professor R. B. Wiley, former head of the School of Civil Engineering of Purdue University, and Professor K. B. Woods, present head. The project was administered through the offices of Professor H. L. Michael, Assistant Director of Joint Highway Research Project.

Mr. L. W. Teller and Mr. Harold Allen represented the interests of the Bureau of Public Roads.

Mr. W. T. Spencer coordinated activities between the State of Indiana and the Bureau and in addition provided valuable field assistance.

Technical supervision of project C-36A was provided by members of the staff of the Division of Engineering Sciences, Dr. Paul F. Chenea, head.

The members of the project staff wish to express their appreciation to Mr. C. Hodler, who along with his assistant, Mr. R. Webb, contributed substantially to the success of the field work.

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