EVALUATION OF THE PERFORMANCE OF ULTRASONIC EQUIPMENT FOR PAVEMENT THICKNESS MEASUREMENT

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AND

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Technical Paper

EVALUATION OF THE PERFORMANCE OF ULTRASONIC EQUIPMENT FOR PAVEMENT THICKNESS MEASUREMENT

To: J. F. McLaughlin, Director
Joint Highway Research Project

February 14, 1969

From

From: H. L. Michael, Associate Director
Joint Highway Research Project

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The attached Technical Paper "Evaluation of the Performance of Ultrasonic Equipment for Pavement Thickness Measurement" was presented at the 1969 Annual Meeting of the Highway Research Board. The paper was authored by C. F. Scholer and R. D. Pavlovich of our staff.

The content of the paper is in general a summary of a Progress Report previously presented to the Board on this HPR research project. This report has been reviewed and accepted as partial fulfillment of the objectives of the research by the ISHC and the BPR.

The paper is presented to the Board for the record and for approval of publication. The paper will also be forwarded to the ISHC and the BPR for such approval.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

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NOT FOR PUBLICATION

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by

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Indiana State Highway Commission

and the

U.S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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EVALUATION OF THE PERFORMANCE OF ULTRASONIC EQUIPMENT FOR PAVEMENT THICKNESS MEASUREMENTS

Introduction

This study used commercially available equipment, a V-Scope and an E-meter to non-destructively determine the thickness of portland cement concrete pavements.

Pulse velocity and longitudinal resonant frequency in the thickness direction are determined by use of the ultrasonic equipment. Thickness is calculated by the relationship proposed by Muenow, (10)

$$t = \frac{V_p}{2N_R}$$

where t = slab thickness (an average over an area approximately 3 feet in diameter)

V_p = pulse velocity through the slab

N_R = longitudinal resonant frequency of the slab

Field power (120 V a.c.) was provided by installing an a.c. inverter in a small station-wagon type van thus establishing a mobile and completely self contained unit.

Two series of tests are reported; one set consists of measurements of thickness of control slabs at the ISHC Research Training Center and the other set was run on actual pavement slabs in the field.

Figure 1 shows the arrangement and actual thickness of control slabs at the Research and Training Center. Field test locations were

1. I-465; Indianapolis
2. U.S. 40; Terre Haute
3. U.S. 50; Versailles
4. I-70; Knightstown
5. I-65; Haubstadt

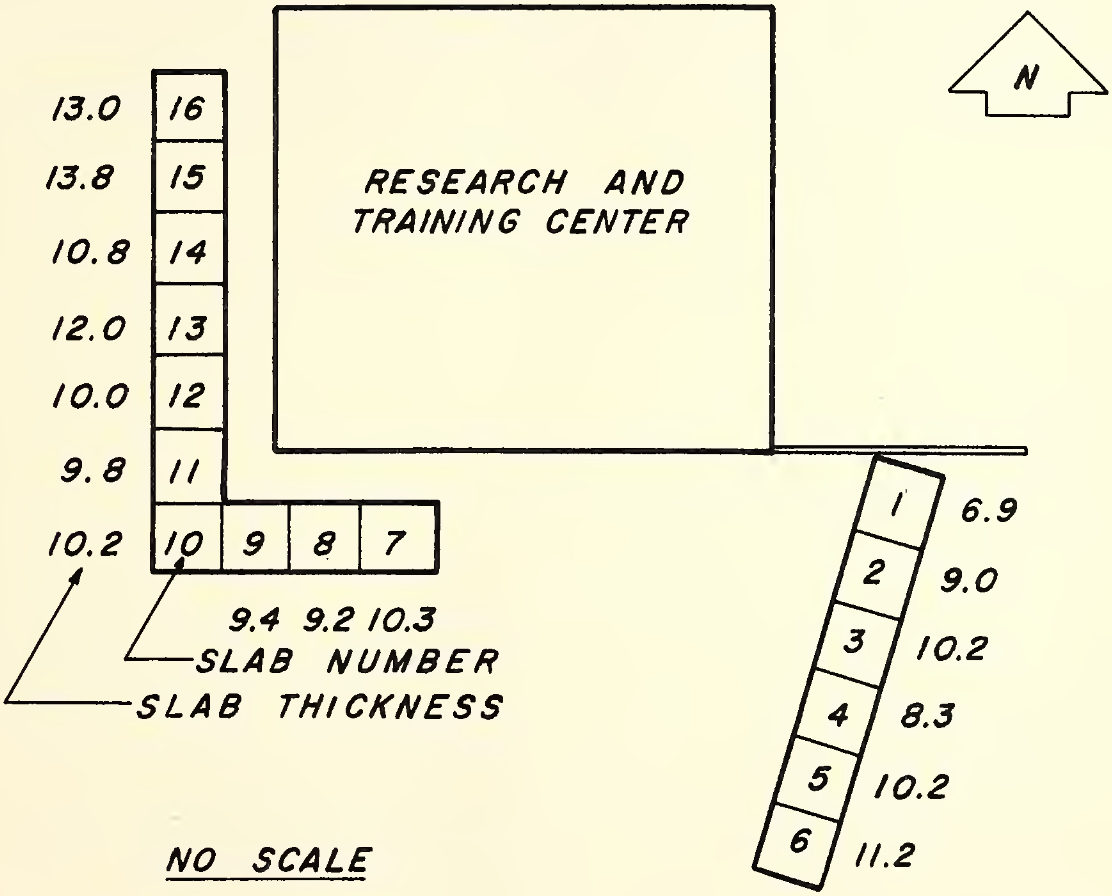

FIGURE 1. SCHEMATIC DIAGRAM SHOWING THE LAYOUT AND THICKNESS OF 5'x 5' TEST SLABS AT I.S.H.C. RESEARCH AND TRAINING CENTER.

Sonic thickness measurements of pavement slabs were compared, at the site, with ISHC cores that were taken from the same location.

Summary of Results and Conclusions

The technique used does not consistently provide sufficient precision to justify use as a means of determining thickness of pavement slabs. The influence of the base course is a factor in the applicability of the technique.

Figure 2 shows a best fit line through data obtained from test slabs and Figure 3 shows cumulative number of tests versus percent error for all tests conducted.

It should be noted that only about 40 percent of the tests provide precision of $\pm$ 5 percent; this error amounts to a deviation of one half inch for a ten inch pavement slab. Figure 4 shows a plot of sonic thickness versus actual thickness for all measurements. $\pm$ 5 percent limits are included to show scatter of these data.

Table I is a tabulation of reduced data from the test slabs and Figure 5 is a plot of average sonic thickness versus actual slab thickness.

Discussion

A brief introduction to the principles of operation of this equipment is included to show why errors are introduced and perhaps how these can be overcome.

Thickness determination is based on measuring two parameters: pulse velocity and slab resonant frequency. Pulse velocity is the speed that sound travels through a material and resonant frequency is that condition where the slab will have a maximum vibration for a given force. There are three basic resonant frequencies: longitudinal, flexural, and torsional. We measured the longitudinal resonant frequency in the thickness dimension.

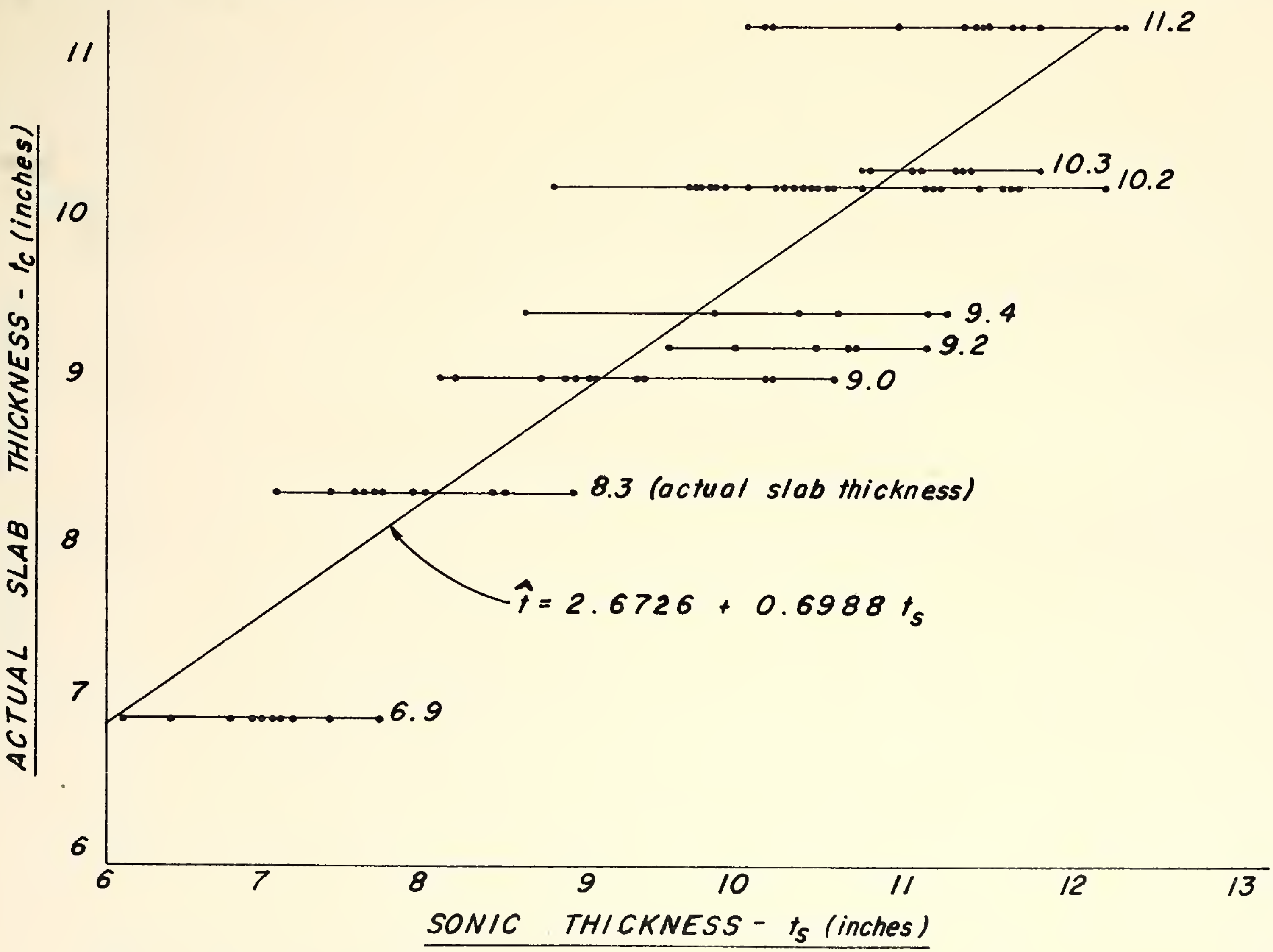

FIGURE 2. SONIC THICKNESS (t_s) VS. ACTUAL THICKNESS (t_c) FOR TEST SLABS.

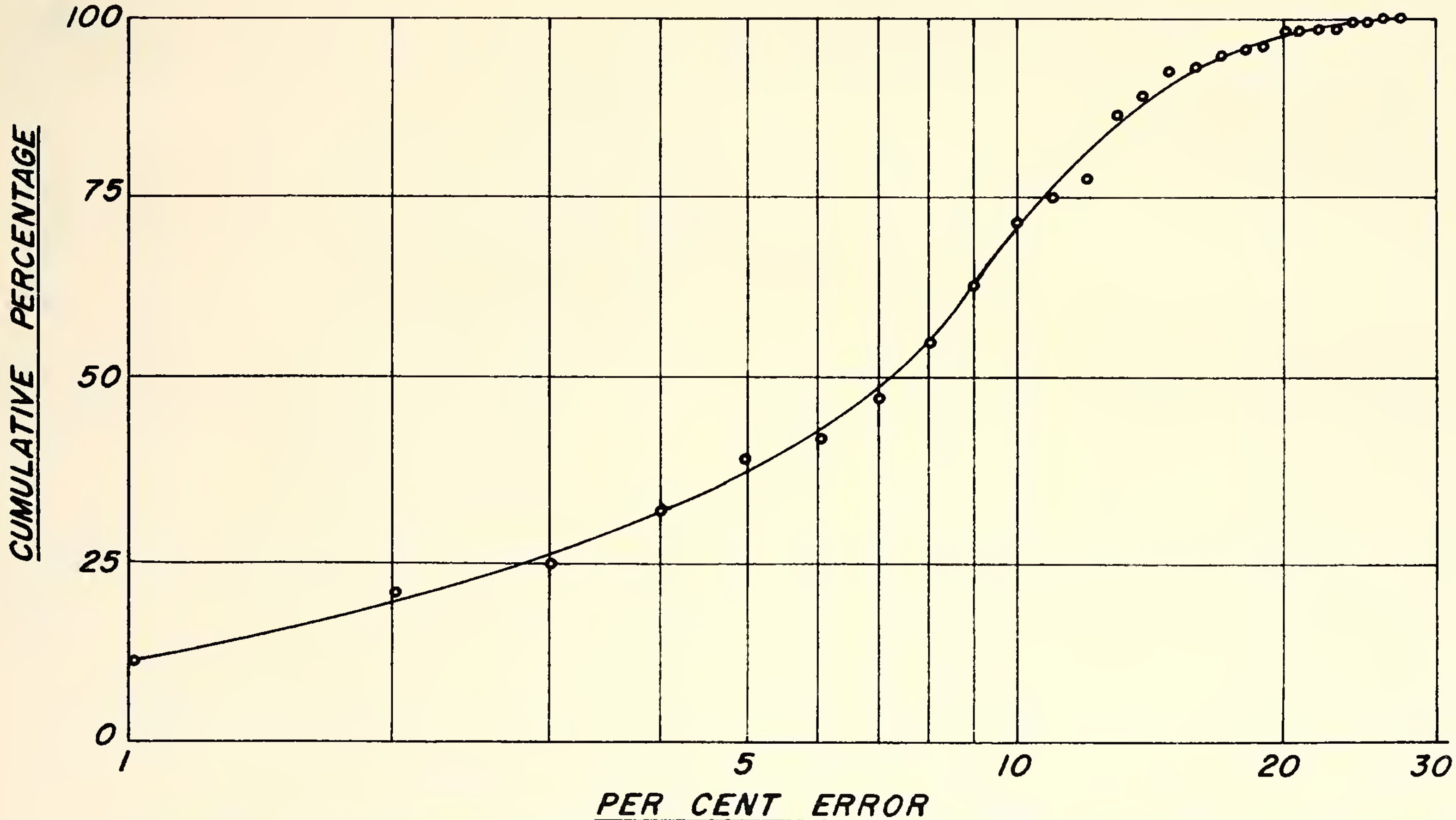

FIGURE 3. CUMULATIVE PERCENTAGE CURVE FOR THE PER CENT ERROR IN THICKNESS MEASUREMENTS OF TEST SLABS AND PAVEMENTS.

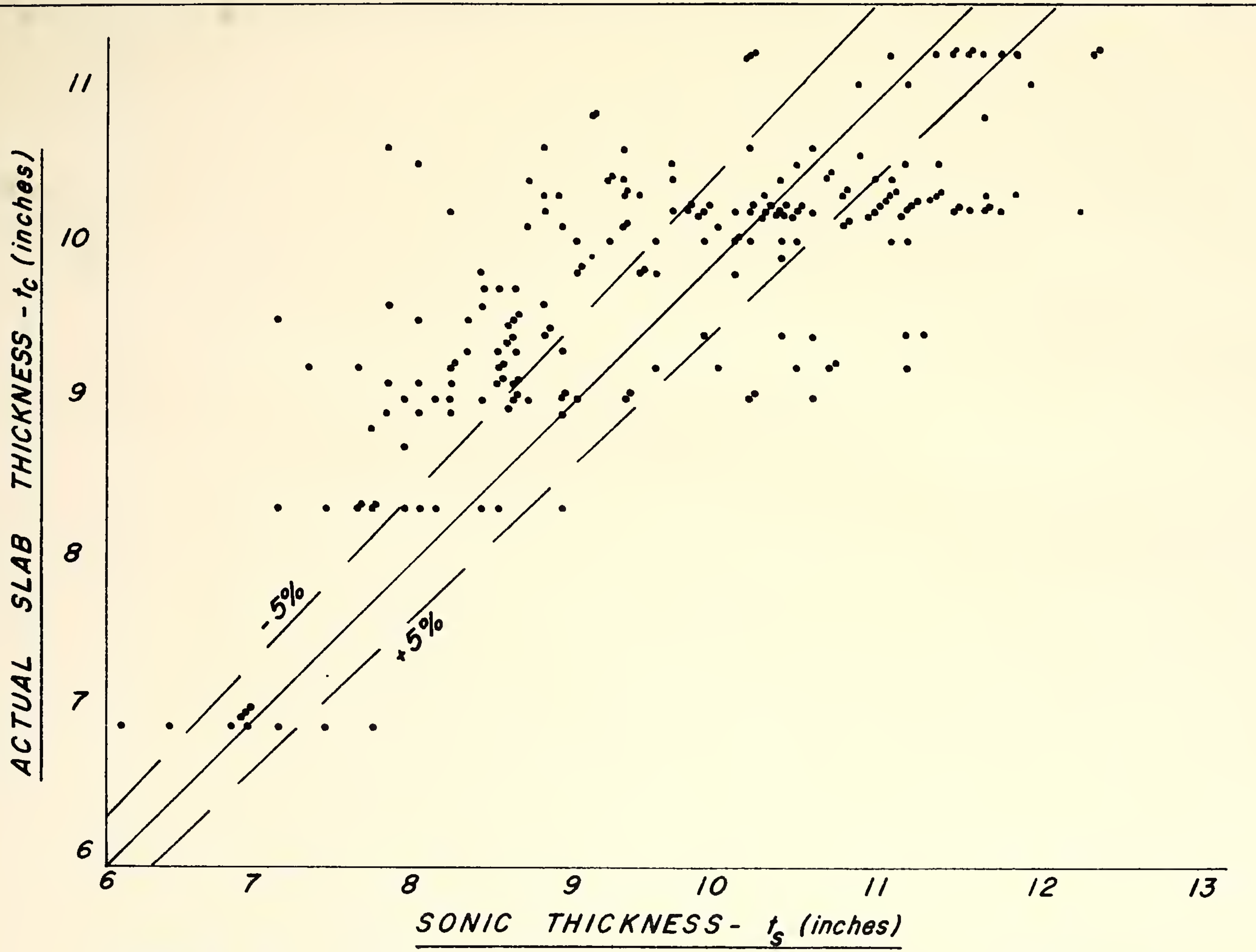

FIGURE 4. SONIC THICKNESS (t_s) VS. ACTUAL THICKNESS (t_c) FOR TEST SLABS AND PAVEMENT.

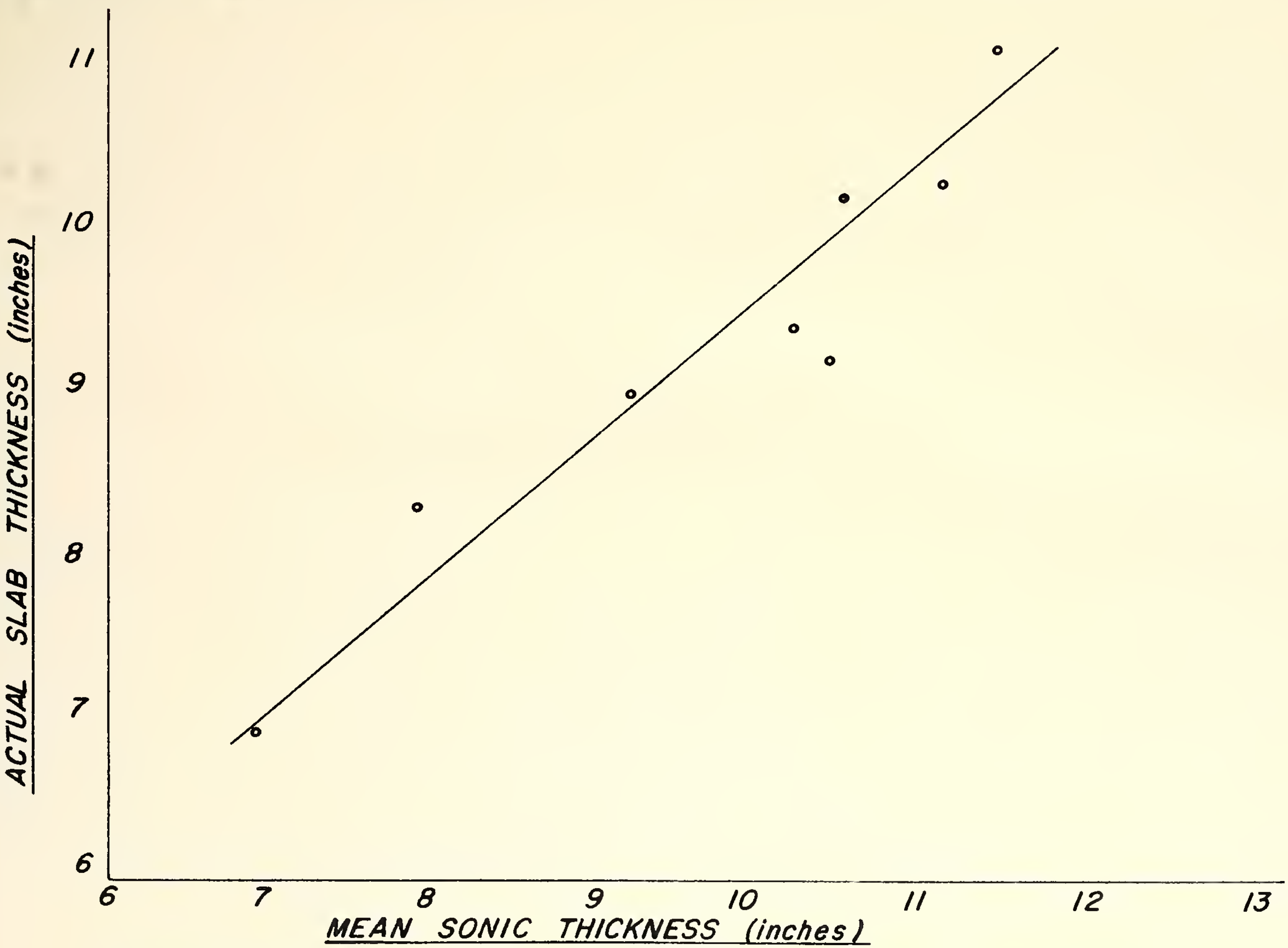

FIGURE 5. MEAN SONIC THICKNESS VS. ACTUAL THICKNESS FOR TEST SLABS.

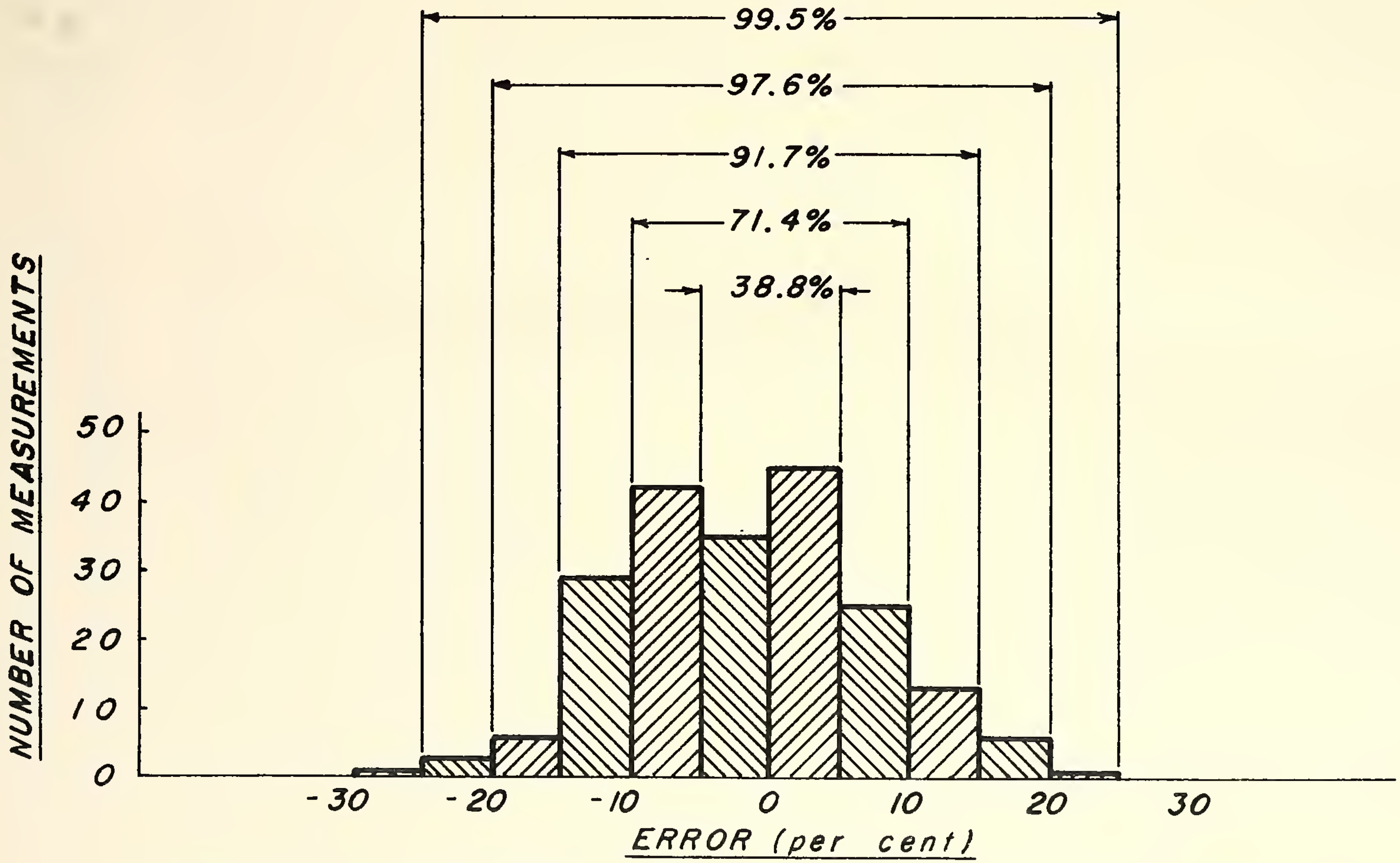

FIGURE 6. PER CENT ERROR DISTRIBUTION FOR TEST SLABS AND PAVEMENTS.

TABLE I

INDIVIDUAL TEST SLAB DATA

n = no. observations

t_s = average sonic thickness

$$s_{ts}^2 = \frac{n \quad t_s^2 - (\quad t_s)^2}{n \ (n-1)}$$

Slab (t_c)	n	Et_s^2	Et_s	S_{ts}^2	s_{ts}	(Ave.) ts	Range
6.9	10	483.48	69.4	0.20	0.45	6.9	6.1 - 7.7
8.3	12	753.31	94.9	0.26	0.51	7.9	7.1 - 8.9
9.0	12	1016.21	110.1	0.55	0.74	9.2	8.1 -10.5
9.2	6	644.35	62.1	0.32	0.57	10.4	9.5 -11.1
9.4	6	634.99	61.5	0.92	0.96	10.2	8.6 -11.2
10.2	26	2871.99	272.5	0.63	0.79	10.5	8.8 -12.2
10.3	8	993.29	89.1	0.13	0.36	11.1	10.7 -11.8
11.2	14	1809.21	158.9	0.44	0.66	11.4	10.0 -12.3

The heart of the measuring system is a transducer that will convert mechanical energy (vibrations) to measurable electrical energy or vice versa. Piezoelectric crystals (Rochelle salts in this equipment) exhibit the property that when compressed they emit an electrical impulse. Conversely when an electrical charge is imposed on the crystal, it responds by dilating or compressing. The equipment then functions by detecting and measuring the current emitted from the crystals or by electrically exciting these crystals thus causing them to vibrate.

One other property of a piezoelectric material worthy of note is the Curie point. At some temperature, dilations or compression of the crystal will produce no current or it will be so low as to not be measurable with ordinary amplification. If the Curie point is sufficiently above normal operating conditions no problems of loss of sensitivity arise. However, the transducers for the instruments used for this study commenced to show losses in response at temperatures above 90°F. Solution of this problem consisted of artificial cooling by simply storing in an ice chest when not in use and by using cooled couplant fluid. There are also synthetic piezoelectric materials that have Curie points at temperatures considerably higher than those which would be encountered on highway pavements. Their use, however, is limited because of their low power efficiency.

Pulse velocity is determined by placing driving and receiving transducers a known distance apart and measuring the time, in microseconds, it takes a pulse to travel between them through the concrete.

The "V-Scope" functioned very well and provided good, reproducible measurements of the pulse velocity of concretes. It should be mentioned that pulse velocity of concrete is a function of several variables including moisture content, paste aggregate ratio, air content, type of aggregate, paste porosity and deteriorating of the concrete. Therefore, one cannot assume that pulse velocity, once determined, will remain a constant value throughout a pavement.

The other parameter, resonant frequency, is not as simple to determine as is pulse velocity. The concept of resonance as applied to pavement slabs is as follows:

Resonance is measured by driving and receiving transducers placed side by side on the surface. By means of a variable frequency generator the driving transducer excites through a frequency spectrum from 2 to 20 KC and concurrently the receiving transducer's output is monitored for maximum response indicative of the slabs maximum amplitude of vibration.

The determination of resonant frequency with this technique was most difficult. The correct identification of the true resonant frequency of the actual slab thickness was often masked by too many spurious responses through the frequency range. The cause of the spurious responses is believed to be the transducers which themselves have resonant frequencies of their own depending upon their size and shape.

Operation and Maintenance in the Field

The electrical portion of this measuring system is very stable, portable and rugged. Mechanical and electrical malfunctions were rare, minor, and easily repaired. Exposure to field conditions and field use, except for the transducers temperature susceptibility, presented no problem to adequate functioning of the instruments.

Operation of the instruments is simple and should be able to be taught to a technician in a matter of three or four hours. Interpretation of output from the cathode ray tube for both instruments is easily interpreted with the exception of the spurious resonant responses.

Core Sampling and Sonic Techniques Compared

Due to variations in determining resonant frequency, four sonic measurements were made at each core location. Times for making sonic determinations were about the same as those involved in obtaining a core sample with the drill crew occasionally working faster on green concrete or on those with softer aggregates. It is the opinion of the investigators that without the difficulties encountered in identifying the true resonant frequency of the slab thickness, production rates could be from three to five times that of conventional drilling operations.

The sonic methods followed involved two persons and one vehicle whereas core sampling includes two to three persons, a drill rig plus one to two other vehicles. It is not necessary for the vehicle on the sonic method to be on the pavement thus enabling earlier thickness determinations.

It was observed that if a second core was obtained within a relatively close distance to the first, say three or four feet, differences of one half inch between core lengths could be measured. Sonic gear on the other hand averages the thickness of a circle of approximately three feet in diameter.

Acknowledgments

The authors wish to acknowledge the assistance of the Bureau of Public Roads, U.S. Department of Transportation, Federal Highway Administration; Bureau of Materials and Tests, Research and Training Center, Indiana State Highway Commission who supported the investigation and James Electronics, Inc. and Mr. Richard Muenow who provided extra transducers and considerable technical assistance during the investigation.

Laboratory testing was carried out in the Concrete Materials Laboratory of the Joint Highway Research Project at Purdue University and at the Indiana State Highway Commission Research and Training Center, Lafayette, Indiana.

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Appendix A

Typical Field Data

SONIC PROJECT

0201-62-284

TEST SERIAL 256 DATE July 25, 1967

LOCATION Test Slab #3 (10.2")

73°F point 75°F air 53°F Chest 0745

Small Transducer (Receiver)

Run No. 1

Time (6") 40 V_p(6") 12,500

Time (12") 74 V_p(12") 13,514

Time (24) 153 V_p(24) 13,072

N_R 7535 V_{ave} 13,029

Thickness 10.37

Run No. 2

Time (6") 39 V_p(6") 12,820

Time (12") 72 V_p(12") 13,889

Time (24) 149 V_p(24) 13,423

N_R 7205 V_{ave} 13,377

Thickness 11.14

Run No. 3

Time (6") 41 V_p(6") 12,195

Time (12") 72 V_p(12") 13,889

Time (24) 146 V_p(24) 13,699

N_R 8074 V_{ave} 13,261

Thickness 9.85

Run No. 4

Time (6") 39 V_p(6") 12,820

Time (12") 71 V_p(12") 14,084

Time (24) 149 V_p(24) 13,423

N_R 8001 V_{ave} 13,442

Thickness 10.08

Remarks: Ave. thickness = 10.3"