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Eddy Current Proximity Gage for the
Determination of Thickness of Portland Cement Concrete Pavements

Final Report for NASA Contract NAS8-22532

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TABLE OF CONTENTS

ABSTRACT

An Eddy Current Proximity Gage developed by the National Aeronautics and Space Administration, Geroge C. Marshall Space Flight Center, for the nondestructive determination of thickness of insulation over aluminum was borrowed by Pennsylvania Department of Transportation for inclusion in National Cooperative Highway Research Program Project 10-3, "Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Location" for which Penn Dot is contractor. This two year project is concerned with examining the techniques of measuring concrete pavement thickness and/or reinforcement location over a wide range of variables to determine whether one or more nondestructive devices may be advanced enough to diminish expensive coring operations on finished pavements.

Multiple tests were taken with the Eddy Current Proximity Gage on specially prepared test slabs with aluminum plates and aluminum foil placed on the subbase prior to placing concrete. Calibration was found to be semi-logarithmic with greater sensitivity on six inch slabs than nine or twelve inch. A statistical treatment of data is presented to compare the gage to coring results.

It appeared that with different calibration techniques,correction factors or gage modification, the instrument is well suited to detect concrete thickness when parallel reinforcement bars are used, but cannot detect pavement thickness when steel mesh or fabric reinforcement is used as in continuously reinforced concrete pavement construction.

The gage did appear to offer more potential than any other device included in the project and it was recommended that the gage be included in Phase II of Project 10-8, wherein instruments are used on actual construction projects in several different states.

Eddy Current Proximity Gage for the Determination of Thickness of Portland Cement Concrete Pavements

Introduction

The Commonwealth of Pennsylvania, Department of Transportation, is presently contractor for National Cooperative Highway Research Program Project 10-8, "Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Location." This two-year project is concerned with examining the techniques of measuring concrete pavement thickness and/or reinforcement location over a wide range of pavement variables to determine which methods are most suited to solution of the problem, such that one or more nondestructive devices may be advanced enough to diminish expensive coring operations on finished pavements.

Obviously, coring is further undesirable since the pavement has been in place for some time, while it would be much more advantageous to determine thickness of concrete as it is placed or as soon as possible after construction. Thus any depth defficiencies could be immediately corrected during the paving operation.

Instrument Acquisition

The Eddy Current Proximity Gage was loaned to this project by the National Aeronautics and Space Administration through the George C. Marshall Space Flight Center, Huntsville, Alabama. The inventor, an employee of NASA, had been previously contacted by Penn Dot after a review of a NASA Technical Brief describing the device. Although the gage was still in the prototype stage, its promise of high sensitivity and low cost made it desirous to include it in the NCHRP 10-8 Project.

This device operated on an eddy current principle whereby a ferrite core antenna radiated a low power radio frequency into a material under test. Power lost to eddy currents induced in an aluminum plate or foil was detected by a second receiver antenna in a bridge network with the transmitting antenna. The differential output of the receiver was amplified and displayed on a microammeter.

The gage had been specifically designed to measure the thickness of foam insulation over aluminum basically by measuring the depth to the aluminum, since, it was claimed, no other materials except nonferrous metals produced an output in the device. Since concrete is a nonferrous material, it should be possible to place aluminum foil on the subbase prior to paving and, after concrete placement, the depth to the foil should be equal to the thickness of the concrete.

Testing Program Design

Five of the slabs included in the NCHRP Project were chosen for inclusion in testing the Eddy Current Proximity Gage. The slab designation and pertinent design criteria are shown in Table I. The test slabs were constructed by subcontract with a local construction firm. Slabs A, C and E were placed over six inches of compacted gravel subbase material, Pennsylvania No. 2A with a maximum size of two inch aggregates. Slab B was over six inches of compacted Penna. No. 3A gravel

TABLE 1

SLAB DESIGN CRITERIA

Slab	A	B	C	E	H
Surface:					
Smooth			X	X	
Rough	X	X	X	X	X
Strength:					
High	X	X	X		X
Low				X	
Thickness:					
6 inches	X	X			
9 inches			X		X
12 inches				X	X
Reinforcement:					
Reinforced	X	X	X	X	
Plain	X	X	X	X	X
Bottom:					
Smooth		X			X
Rough	X		X	X	
Membrane:					
Yes	X				
No	X	X	X	X	X
Base Mat'l:					
Gravel	X	X	X	X	
Slag					X

of maximum size two inches. Slab H was placed over six inches of compacted Penna. No. 2A slag of maximum size two inches. Slabs were ten feet square, divided into sixteen test sites with a one foot edge between outer test sites and slab edge. Steel reinforcing bars and wire fabric were placed in slabs A, B, C and E and an asphaltic membrane placed under half of slab A. Prior to placement of concrete, aluminum plates and aluminum foil were placed under the selected test slabs. The slab configurations, nominal design criteria, reinforcement size and location and aluminum placement are shown in Figures 1, 2, 3, 4 and 5. The concrete mix designs for the slabs are shown in Table 2.

Prior to pouring concrete, differential level readings were taken at all points shown in Figure 6; these points were to be cored after all instrument evaluations had been completed. It was intended that the differential level readings would be used as the standard thickness and thus act as a basis of comparison for both cores and instrument values of thickness.

It was intended that at least four separate instrument readings of thickness would be taken at different ages of the concrete, with hope that tests could be attempted immediately after concrete placement. Due to contract negotiations, the Eddy Current Proximity Gage was not received until the end of July, 1970, after the last slab had been placed. However, due to its portability and ease of operation, it is felt that the Eddy Current Gage could be used immediately after concrete is placed.

Figure 1

SLAB A

6 Inch Concrete, High Strength, on Subbase
Reinforcing Bar, 2 Inch Depth

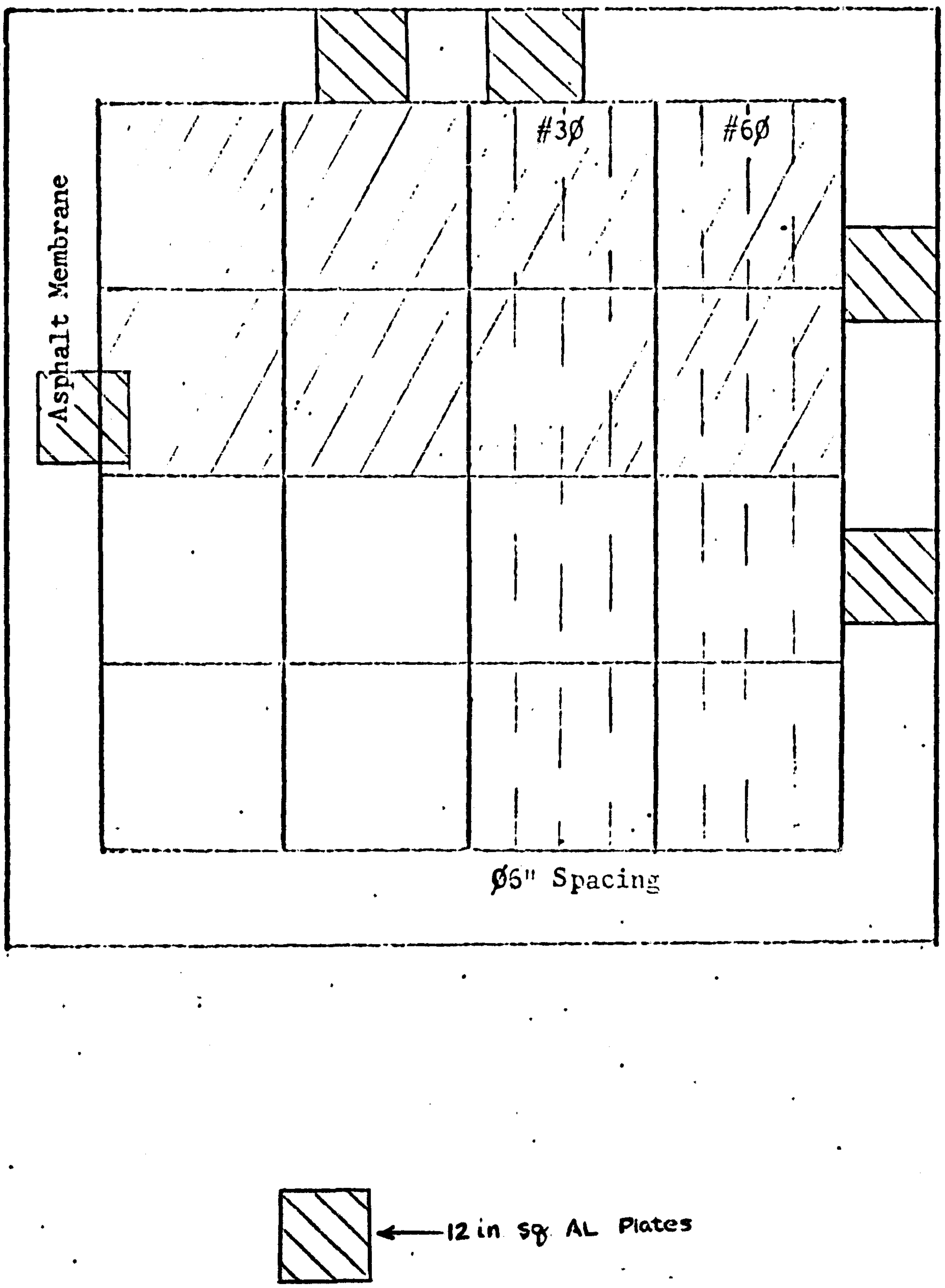


Figure 2

SLAB B

6 Inch Concrete, High Strength, on "   Subbase
Reinforcing Mesh, 2 Inch Depth

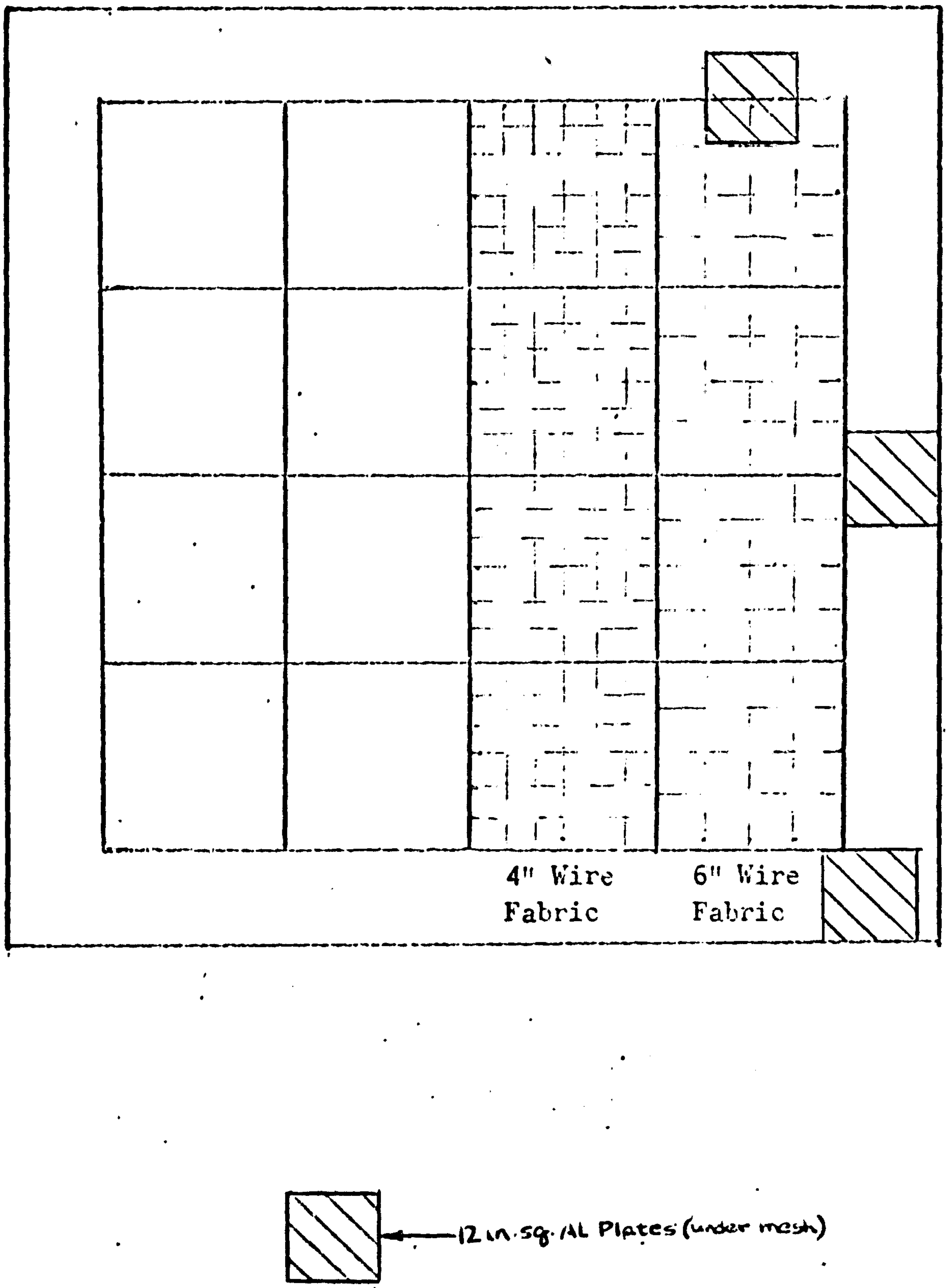


Figure 3

SLAB C

9 Inch Concrete, High Strength, Subbase
Bar Reinforcement @ 4" Depth

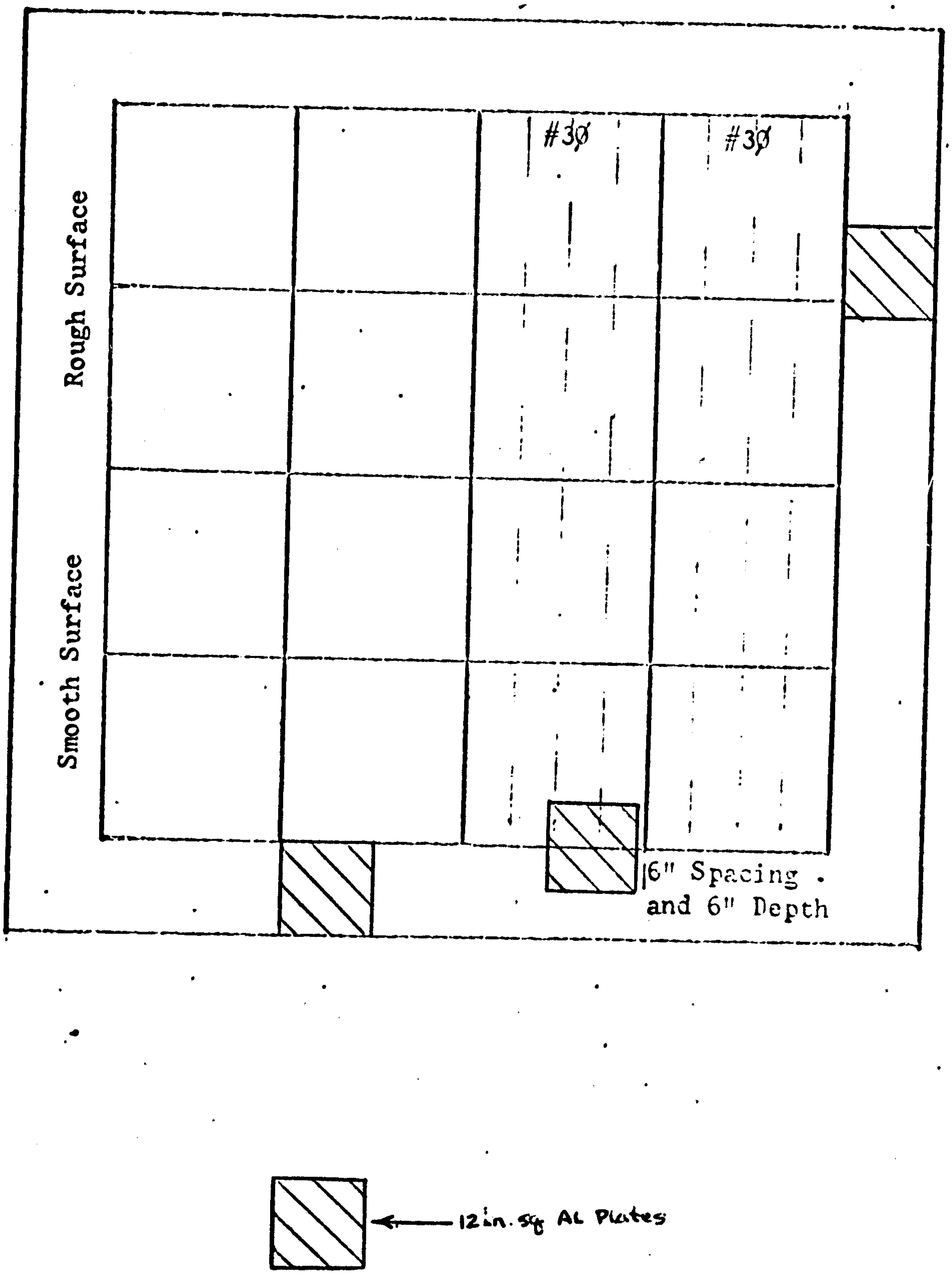


Figure 4

SLAB E

12 Inch Concrete, Low Strength, Subbase
Bar Reinforcement @ 6" Depth

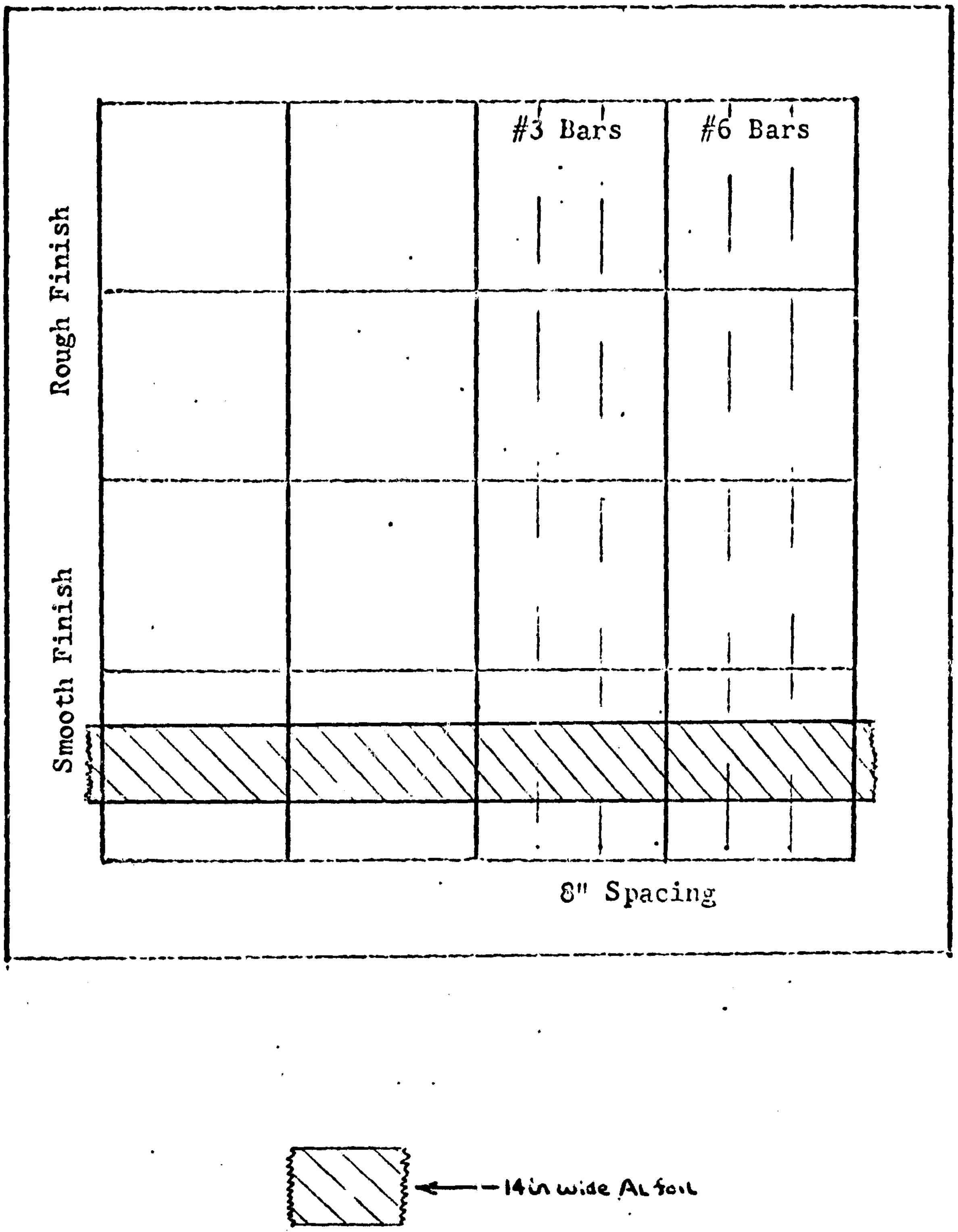


Figure 5

SLAB H

Variable Thickness, High Strength, Smooth Slag Subbase
No Reinforcement

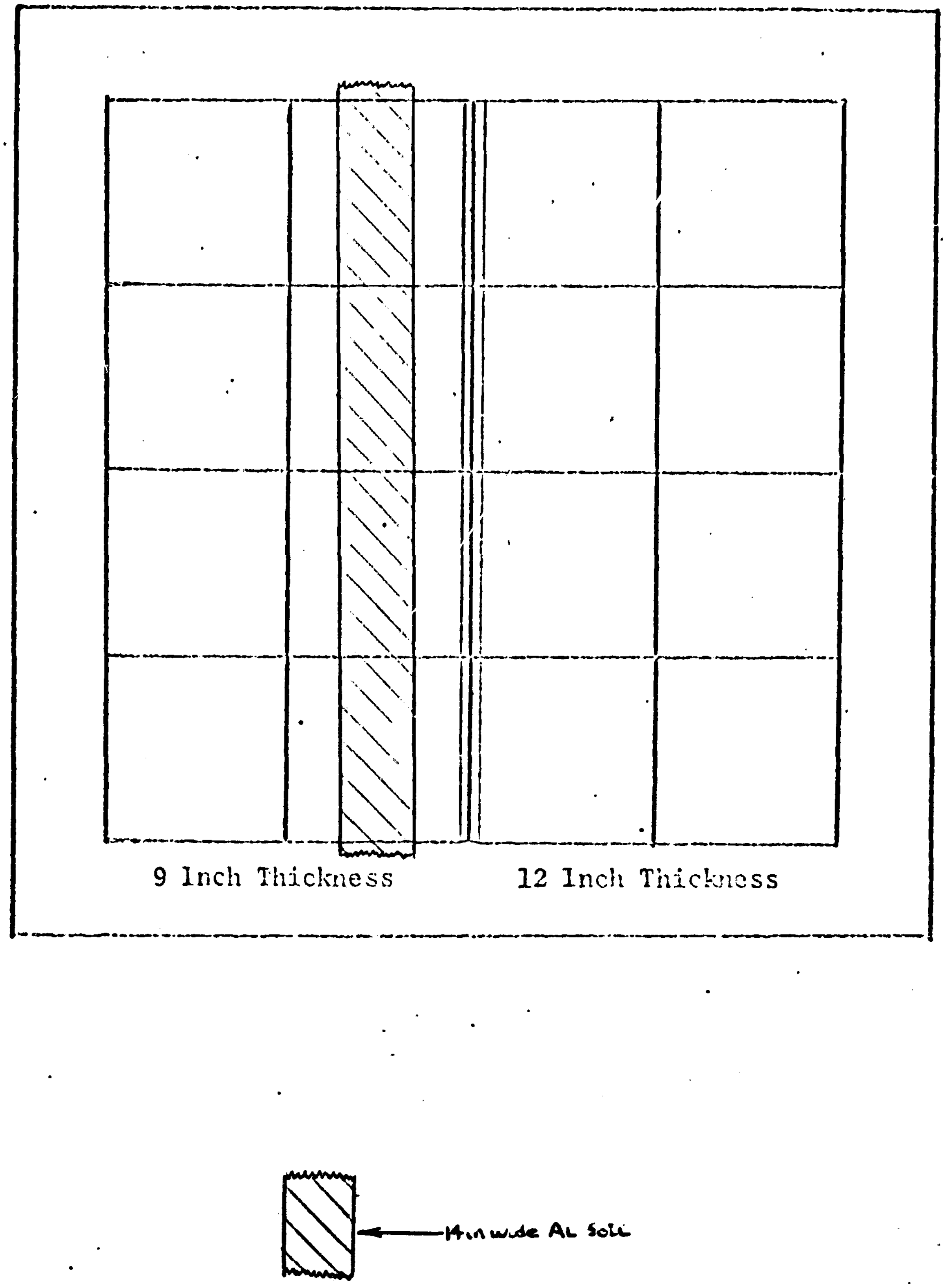


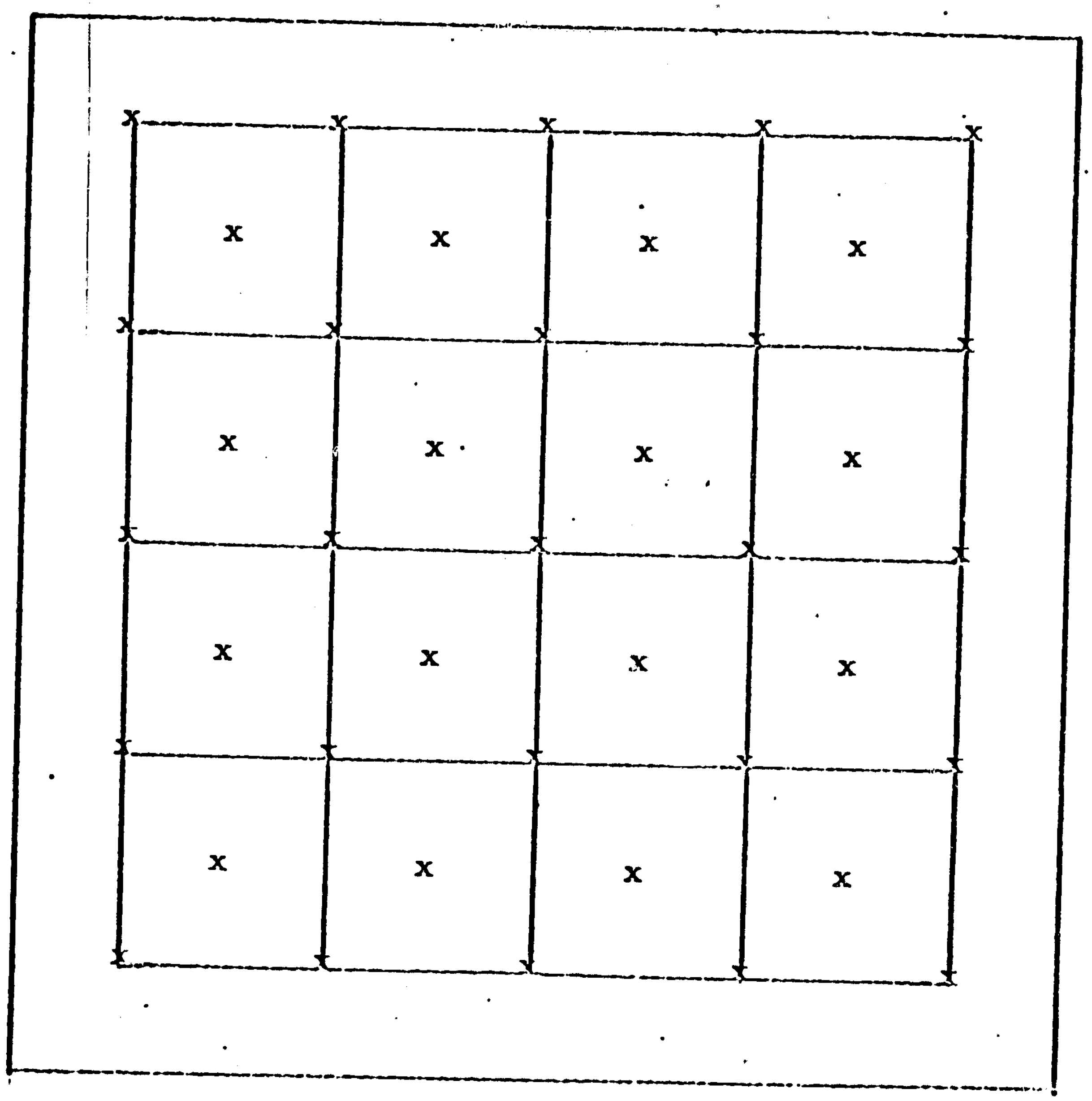
TABLE 2

CONCRETE MIX DESIGN BATCH WEIGHTS (LB.)

Slab	Mix	Cement	Sand	Coarse Agg.	Water	Air (oz)
A	Class AA	1323	2565	4329	567	19.7
B	Class AA	1470	2850	4632	630	23.4
C	Class AA	2058	3990	6485	913	39.4
E	Class B	2585	6374	10,977	1460	41.2
H	Class AA	2940	5700	9265	1305	56.2

Figure 6

Survey Pattern



Field and Laboratory Studies

Laboratory evaluation of the device was limited to calibration and simulated environment studies.

The gage was calibrated by placing an aluminum plate twelve inches square by one-eighth inch thick at various distances from the gage and recording instrument output between zero and fifteen inches spacing. This technique was repeated for aluminum foil approximately fourteen inches square of nominal commercial grade. These sizes were chosen since they appeared to yield optimum gage response. The plates and foil placed under the slabs were of the same dimensions. The gage was rezeroed to compensate for drifting instability by pointing its detecting end away from any metals. It was noticed during this period that the gage was affected by larger ferrous objects. Calibrations were found to be semi-logarithmic with maximum slope change between zero and eight inches. Greater spacings of aluminum beyond this depth produced slight gage responses; thus great care must be taken in arriving at a valid instrument reading since slight reading error at the greater depths can introduce large errors in final depth determination.

A limited laboratory study was carried out after final calibration which consisted of subjecting the device to several conditions simulating extreme ambient environments which might possibly be encountered. More intensive studies were not carried out due to lack of time. The instrument was placed on a test slab of concrete approximately two feet square by six inches thick over a twelve inch square aluminum plate for each simulated condition. A test conducted at 70 $\pm$ 5F, 40 $\pm$ 10 RH (%)

was condidered to yield a normal result. Other tests were compared to those at the above ambient. Results for the Eddy Current Proximity Gage were:

Condition	Test Result
0F, 20% RH	Normal
70F, 100% RH	Normal
120F, 5% RH	Erratic

Aside from the drifting and erratic results when temperatures rose above 85F in the field, the unit functioned quite well during field tests on the slabs. The drifting and erratic indications were minimized by testing early in the day and constantly rezeroing the device. These tendencies have been claimed to have been deleted by the inventor by circuitry changes since this phase of the project was completed. The aluminum foil and plates were located by scanning the slabs and outlining the areas where meter indications were maximum. The plates under bar reinforcement were found quite easily but it proved apparent that the gage did not detect plates under the wire fabric reinforcement in Slab B, but rather was tremendously effected by the fabric. Separate calibrations for this wire fabric proved identical to that for the foil and the gage was thus used on Slab B to detect the depth of the fabric reinforcement.

Data Analysis and Interpretation

A. Concrete Thickness

Since the NCHRP Project entailed the evaluation of several other instruments besides the Eddy Current Proximity Gage, an analysis was first conducted to establish whether the presence of aluminum under the test slabs would adversely effect readings of other devices if they were used on the same test sites. The other instruments evaluated included a nuclear counting device, a resistivity apparatus and two separate ultrasonic devices relying on two different techniques of ultrasonic depth determination. Where sufficient data existed to carry out an analysis, Student's t-test was used to determine whether a difference was apparent at the 95% confidence level between plain subbase and aluminum covered subbase. The tests indicated that no significant difference existed at the 95% confidence level.

An insufficient number of test sites was available to permit an analysis of variance to examine the contributions of the various slab design factors to the overall variance by the Eddy Current Method. In comparing slab thickness measurements by the Eddy Current Proximity Gage with "standard" values, core lengths as determined by multiple readings of the core depth with a 1/8" ball-ended rod in a measurement frame were used rather than differential levels for the "standard" thicknesses. This was necessitated by the fact that eight of the test sites were in areas not covered by differential level readings. Cores, however, were extracted at those locations. The comparison of instrument readings to core thicknesses is made in Table 3. It is readily evident that the Eddy Current Proximity Gage compares favorably with core measurements (95% significance level) for the six inch slab, but not for the thicker ones. However, the fact that the mean standard deviation for this instrument is very low (0.248 inches, the smallest value for all instruments tested), this instrument shows considerable promise with, possibly, use of other calibration techniques, calibration factors or instrument modifications for slabs deeper than six inches.

B. Wire Fabric Reinforcement Depth

As mentioned previously, it was discovered that the gage could not detect aluminum beneath wire fabric reinforcement but had no trouble detecting aluminum beneath parallel, unconnected reinforcement bars. This is believed due to a loop being formed by the fabric which influences the Eddy Current Proximity Gage. Thus the gage was used in an attempt to predict fabric depth in Slab B as described previously and also Slab D which was not included in other Eddy Current Gage Tests since no aluminum had been placed on the subbase. Slab D was nominally nine inches thick, low strength, rough surface, rough bottom with six inch square opening mesh reinforcement at four inches deep in four test sites within the slab and an additional layer at six inches deep in four other test sites within the slab.

Comparison of depths of mesh measured by the gage to depths from cores showed significant differences at the 95% level in all test areas as shown in Table 4. However, the mean difference between the gage and core measurements was fairly constant though large, such that a correction

TABLE 3

CORE LENGTHS AS COMPARED TO EDDY CURRENT PROXIMITY GAGE RESULTS

Slab	Reading	a	b	c	d	e
	E.C.P. Gage (mean)	5.91	6.03	5.94	6.90	6.50
	Std. Dev.	0.16	0.12	0.11	0.46	0.36
A	Core	5.93	6.11	5.83	6.74	6.29
	Diff.	-0.02	-0.08	+0.11	+0.16	+0.21
	Student's T for Diff.	0.28	1.53	2.25	0.79	1.31
	E.C.P. Gage (mean)	9.11	9.29	10.03		
	Std. Dev.	0.08	0.10	0.09		
C	Core	9.44	9.37	9.36		
	Diff.	-0.33	-0.08	+0.67		
	Student's T for Diff.	8.11*	1.60	15.26*		
	E.C.P. Gage (mean)	13.83	13.79	13.89	13.69	
	Std. Dev.	0.37	0.45	0.42	0.48	
E	Core	13.78	13.03	12.77	13.17	
	Diff.	-0.05	+0.76	+1.12	+0.52	
	Student's T for Diff.	0.29	3.75*	7.78*	2.78*	
	E.C.P. Gage (mean)	9.18	9.26	9.38	9.36	
	Std. Dev.	0.06	0.10	0.40	0.18	
H	Core	10.39	10.75	11.20	11.28	
	Diff.	-1.21	-1.49	-1.82	-1.92	
	Student's T for Diff.	19.48*	33.56*	10.29*	22.30*	

*Significant difference exists at 95% level

TABLE 4

DEPTH OF MESH

Test Area	Method	Average (in.)	Standard Deviation (in.)
B-1	Coring	3.42	0.460
B-2	Coring	3.76	0.792
B-1	E.C.P. Gage	2.31	0.122
B-2	E.C.P. Gage	2.27	0.135
D-1	Coring (Top Layer)	4.67	0.554
D-2	Coring	4.82	0.462
D-1	E.C.P. Gage	3.46	0.453
D-2	E.C.P. Gage	3.69	0.467

factor of $^{+}1.25$ inches would be needed to allow better comparison between the gage and core measurements. The mean standard deviation of the gage measurements on mesh, however, was only 0.294 inches, again lower than any other method tested in the NCHRP Project. With this low standard deviation, it appears that with the application of suitable correction factors this instrument might be sutiable for measuring the depth of steel fabric reinforcement. It should be noted that the instrument could not detect the presence of a deeper layer of mesh when more than one existed.

Based on the data of core depth determinations and Eddy Current Proximity Gage results, sample size requirements for the gage/test variable are listed below.

Test	Method	Mean Std. Dev. (in.)	n
Slab Thickness	Differential Levels	0.3465	8
" "	Coring	0.3560	8
" "	Eddy Current Proximity	0.2475	4
Depth of Mesh	Coring	0.6156	24
" " "	Eddy Current Proximity	0.2942	6

The above values for the number of samples are determined from the relationship

$$\text{Confidence Interval} = \pm Z \alpha/2 \frac{\sigma}{\sqrt{n}}$$

where the Confidence Interval is expressed as deviations from the sample mean, σ is the population standard deviation, n is the sample size and $Z \alpha/2$ is the value in the standard normal distribution such that the probability of a random deviation numerically greater than $Z \alpha/2$ is α. Values of $Z \alpha/2$ can be obtained from standard statistical tables for various significance levels. For the 95% level $Z\,\alpha/2 = 1.960$. For σ, the best available estimate is the value of the mean standard deviation for the various instrument/test variable combinations. Also, a confidence interval must be selected arbitrarily; in this case $\pm$ 1/4 inch was chosen since many highway specifications regarding slab thickness and steel reinforcement placement use this figure as a tolerance interval.

Correction factors were arrived at by comparing the mean values of the standard method to the Eddy Current Proximity Gage results, yielding corrections of -0.25 inch for slab thickness and +1.25 inches for depth of mesh. The thickness correction factor did not include data from Slab H. Thus, the mean values obtained from the required number of samples and the algebraic addition of correction factors should yield thickness values which lie within $\pm$ 1/4 inch of the true population mean 95% of the time. Two assumptions are made here:

(1) The instrument readings correlate significantly and in a direct manner with actual measurements, and (2) the variability involved in field measurements approximates that incurred in measurements of the test slabs in this project. Regarding the first assumption, shown below are the correlation coefficients for the Eddy Current Proximity Gage and cores at the 99% significance level.

			Correlation Coefficient	
Test	Method	Standard	Calculated	Critical (99%)
Slab Thickness	Coring	Levels	+0.998	0.456
" "	E.C.P.Gage	Cores	+0.950	0.590
Depth of Mesh	E.C.P. Gage	Cores	+0.974	0.917

Note: Coring not listed for Depth of Mesh since differential levels were not taken on the mesh.

The second assumption can only be checked by obtaining field data.

Conclusions

The Eddy Current Proximity Gage appears to offer excellent potential as a rapid nondestructive method for the determination of concrete pavement thickness and mesh depth determination. Due to the mesh effect, it cannot be used to determine pavement thickness when steel fabric reinforcement is used, as in continuously reinforced concrete pavements but it can be used when parallel reinforcement bars are used in pavement construction. The use of calibration factors or some instrument modification is recommended, particularly for the determination of pavement thickness in the nominal twelve inch thick range. It is recommended that field data be gathered with the Eddy Current Proximity Gage During Phase II of NCHRP Project 10-8 scheduled to begin in April, 1971. This data would be supplemented by coring over a range of common pavement variables on actual Portland Cement Concrete highway construction projects.

Acknowledgement

The statistical analysis text was excerpted from that prepared by Dr. P. C. Cady, Pennsylvania State University for the Interim Report of NCHRP Project 10-8, January, 1971.