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These Digests are issued in the interest of providing an early awareness of the research results emanating from projects in the NCHRP. By making these results known as they are developed and prior to publication of the project report in the regular NCHRP series, it is hoped that the potential users of the research findings will be encouraged toward their early implementation in operating practices. Persons wanting to pursue the project subject matter in greater depth may obtain, on a loan basis, an uncorrected draft copy of the agency's report by request to: NCHRP Program Director, Transportation Research Board, 2101 Constitution Ave., N.W., Washington, D.C. 20418

Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position

An NCHRP staff digest of the essential findings from the final report on NCHRP Project 10-8, "Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position," by W. G. Weber, Jr., and R. L. Grey, Pennsylvania Department of Transportation, and P. D. Cady, The Pennsylvania State University

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THE PROBLEM AND ITS SOLUTION

The survival of portland cement concrete pavements is strongly related to thickness. This has long been recognized, as indicated by the severity of the penalties that historically have been assessed against paving contractors for thin sections. The importance of thickness also was demonstrated effectively in the AASHO Road Test.

Many thousands of measurements are made each year to assure that the thicknesses of newly constructed concrete pavements are in compliance with those specified. For pavements in which steel reinforcement is used, the position of the steel must be similarly determined. Cores taken from the hardened concrete, usually at the rate of one per 1,000 lane-feet, figure prominently in the measurement process. Unfortunately, coring is time consuming, costly, a cause of troublesome discontinuities, and of no value in thickness control during the construction process. Highway engineers have been attracted for many years by the possibility that most or all of these disadvantages could be overcome through the application of rapid nondestructive methods in the measurements.

Nondestructive testing techniques are well known and widely used in manufacturing processes. Unfortunately, the testing equipment that has been successful elsewhere has not performed well when applied to con-

crete. However, several researches, including NCHRP Project 10-6 (covered in NCHRP Report 52, 1968) and other studies conducted mostly by FHWA and by state highway departments in cooperation with FHWA, have produced information encouraging to the eventual application of nondestructive testing techniques to concrete.

This project reviewed available nondestructive testing instruments and conducted extensive laboratory and field studies to determine the applicability of selected instruments in the acceptance testing of pavement thickness and reinforcement depth. Results obtained with several of the instruments were encouraging, and tentative specifications and test methods were developed for their use. It is believed that the application has been suitably verified for immediate further trial application by highway agencies.

FINDINGS

In the research with which this report is concerned, nine existing nondestructive testing instruments that appeared to have some potential for measuring pavement thickness were located and examined. Two of these, and an additional device, were examined for determining reinforcement location and depth. Final selection of the most promising devices was made after applications on eight paving projects in six states.

In most instances, experimentation with measurement techniques to make the most advantageous use of the various devices was required. In all cases, the test instruments were examined for use in conjunction with construction acceptance specifications having a statistical basis. Although this is not in accord with current practice in which one sample represents a lot unless deficient thickness is encountered, it was recognized that the time, cost, and destructiveness of the coring operation now in general use has heretofore discouraged the more rational statistical approach to acceptance testing.

An ultrasonic gauge (Fig. 1) developed by the Ohio State University was found to perform thickness measurements for both plain and reinforced pavement with acceptable accuracy for construction control in conjunction with a statistical-type acceptance specification. However, before it can be applied routinely, further development, for which success seems predictable, is needed to reduce its cumbrousness and to improve its resistance to construction jobsite rigors. An eddy current proximity gauge (Fig. 2) proved to be satisfactory for measuring the thickness of hardened plain (nonreinforced) concrete pavement, and seems also to be capable of determining the position of the steel reinforcement in reinforced concrete pavements with acceptable accuracy. It cannot be used to determine the thickness of pavements containing steel reinforcement. A device called a "pachometer" (Fig. 3) was found to be satisfactory for use in determining the depth and position of distributed steel reinforcement in both plastic and hardened pavement concrete.

APPLICATION

During the course of the investigation of the nondestructive instruments for testing pavement thickness and determining reinforcement position, construction acceptance specifications and test methods were devised for application of the equipment. In the development of a specification for pavement-

thickness acceptance, the following guidelines based on practice, experience, and preliminary results of the investigation were taken into consideration:

1. "A realistic specification is one that recognizes that there is a cost associated with every specified limit and that the characteristics of all materials, products, and construction are inherently variable" (NCHRP Report 17).

2. An "end result" statistical-type specification should be used. This will provide the contractor with the greatest freedom of operation while assuring that the desired quality of pavement is constructed.

3. A lot size of either ½ lane-mile or 1 lane-mile is realistic. This should represent from 1 to perhaps 4 or 5 hours of normal operation in modern-day paving.

4. A minimum number of tests should represent a lot, with the number based on normally expected variations.

5. Thickness evaluations should utilize average test values and deviations of values by lot.

6. All acceptances, penalties, or rejections should apply to an entire lot. A lower limit should be placed on all measurements for acceptance of a lot.

7. Through the application of nondestructive testing, thickness measurements for acceptance or rejection should be made within a day following paving. This will provide information that will enable the contractor to regulate his operations during progress of the work to assure adequate thickness.

8. A 0.5-in. deficiency should be the maximum allowable for any one test result.

9. For simplicity, a fixed number of tests per lot should be used. Acceptance should be based on the average of these tests, with a maximum allowable number of deficient test values.

10. Assuming that satisfactory work is being obtained under present practice, a new specification should be designed to produce the same, or a slight improvement in, quality.

11. The statistical risk to the contractor and to the highway agency should be small and equal.

The following specification for the acceptance of pavement thickness was deemed to meet the foregoing guidelines. The general plan of application is shown in Figure 4. Use of six tests will result in a confidence level of greater than 95 percent in an acceptance decision being correct if the standard deviation of the pavement thickness is not greater than 0.25 in., and the mean value is equal to the design thickness. Evaluation of pavement thickness by coring in this research, and data taken from the literature, indicate that pavements produced under present controls probably come close to meeting these criteria.

Proposed Tentative Specification for Pavement Thickness Acceptance

1. The lot size will be either one-half (½) lane-mile, or one (1) lane-mile, of finished concrete pavement.

2. Six (6) tests will be conducted at random locations within each lot.

3. If the average of the six (6) tests is greater than the design thickness, and not more than one (1) test falls below the design thickness, the lot will be accepted.

4. If the average of the six (6) tests is above the design thickness minus one-half (½) inch, and not more than one (1) test falls below the design thickness minus one-half (½) inch, penalties shown in Table 1 (or 2, or 3), based on the average of the six (6) tests, will be applied.

5. If two (2) or more tests, or the average of the six (6) tests, are below the design thickness minus one-half (½) inch, the lot will be rejected.

Experience gained during the course of the investigation suggested the following test procedure for pavement thickness acceptance:

Proposed Tentative Method of Test for Pavement Thickness Acceptance

1. Scope

1.1 This method covers procedures for determining the thickness of portland cement concrete pavement utilizing nondestructive test methods and instruments.

2. Apparatus

2.1 Nondestructive apparatus employed for thickness testing of portland cement concrete pavement shall have been proven capable of determining pavement thickness within a standard deviation of three-tenths (0.3) inch.

2.2 The apparatus shall be capable of measuring concrete pavement thickness over a range of four (4) to twelve (12) inches within two (2) hours of concrete placement.

2.3 The apparatus shall have proven stable and its results repeatable within one-tenth (0.1) inch over the temperature range of 40 F to 120 F.

2.4 The apparatus shall have its operation checked on each project by one of the following methods:

2.4.1 Correlation with Cores

2.4.1.a Conduct five (5) tests on the first one-half (½) mile of pavement placed by the Contractor, marking each location with paint or by some other method.

2.4.1.b The next day, obtain cores at each test location and measure their length as described in ASTM Specification C174.

2.4.1.c Determine at each location the difference between the nondestructive test thickness and the measured core thickness.

2.4.1.d Average the results in 2.4.1.c and apply as a correction to all future nondestructive test results on the project.

2.4.1.e If mix design, cement, or aggregate changes occur, repeat 2.4.1.a through 2.4.1.d to establish a new correction.

2.4.2 Correlation with Prepared Test Blocks

2.4.2.a Select an area near the start of paving where the base will be the same as will exist under the completed pavement. This area should be three (3) by seven (7) feet in size, planed to one-tenth (0.1) inch.

2.4.2.b Construct a form containing three (3) two (2)-foot square steps: design thickness minus one-half (½) inch, design thickness, and design thickness plus one-half (½) inch.

2.4.2.c At the start of paving operations, fill the form with the same concrete being used in the paving operations. Compact the concrete by vibration or rodding, and strike off a plane surface.

2.4.2.d After two (2) or more hours, conduct two (2) or more nondestructive tests on each step.

2.4.2.e Determine, for each step, the difference between the nondestructive test thickness and the step thickness.

2.4.2.f Average the results in 2.4.2.e and apply as a correction to all subsequent nondestructive test results on the project.

2.4.2.g If mix design, cement, or aggregate changes occur, repeat 2.4.2.a through 2.4.2.f to establish a new correction.

3. Procedure

3.1 Turn on the test apparatus and allow it to warm up for at least five (5) minutes.

3.2 Select the lot size at either one-half (½) lane-mile or one (1) lane-mile.

3.3 Select six (6) test sites in a random manner within the lot.

3.4 Conduct a nondestructive test at each test site as soon as possible after placement without causing displacement. Calculate the thickness at each site, using the correction obtained in 2.4.1.d or 2.4.2.f.

3.5 Average the results from the six (6) tests and note the number of individual test results below the design thickness.

3.6 Using items 3, 4, and 5 of the Proposed Tentative Specification for Pavement Thickness Acceptance, determine the acceptance, penalties, or rejection of the lot.

Experience in the investigation showed the following procedure to be appropriate for testing and accepting reinforcement depth:

Proposed Tentative Method of Test and Acceptance for Depth of Reinforcement

1. Scope

1.1 This method covers the procedures for determining the depth of reinforcement below the surface of portland cement concrete pavement, utilizing nondestructive test methods.

2. Apparatus

2.1 Nondestructive apparatus employed for determining the depth of reinforcement shall have been proven capable of determining the depth with a standard deviation of less than one-half (½) inch.

2.2 The apparatus shall be capable of determining depth of reinforcement from zero (0) to five (5) inches.

2.3 The apparatus shall be proven stable and the results repeatable to one-eighth (1/8) inch over a temperature range of 40 F to 120 F.

3. Procedure

3.1 Turn the instrument on for the warm-up period recommended by the manufacturer.

3.2 In each one hundred (100) feet of pavement, take two (2) depth-to-reinforcement measurements between the strike-off and finishing operations in a random manner.

4. Acceptance

4.1 If the depth to reinforcement is deficient by more than one-half (½) inch, notify the paving inspector so that corrective action may be taken.

Figure 1. Thickness determination with the Ohio State ultrasonic gauge.

Figure 2. Eddy current proximity gauge in operation.

Figure 3. Pachometer in operation.

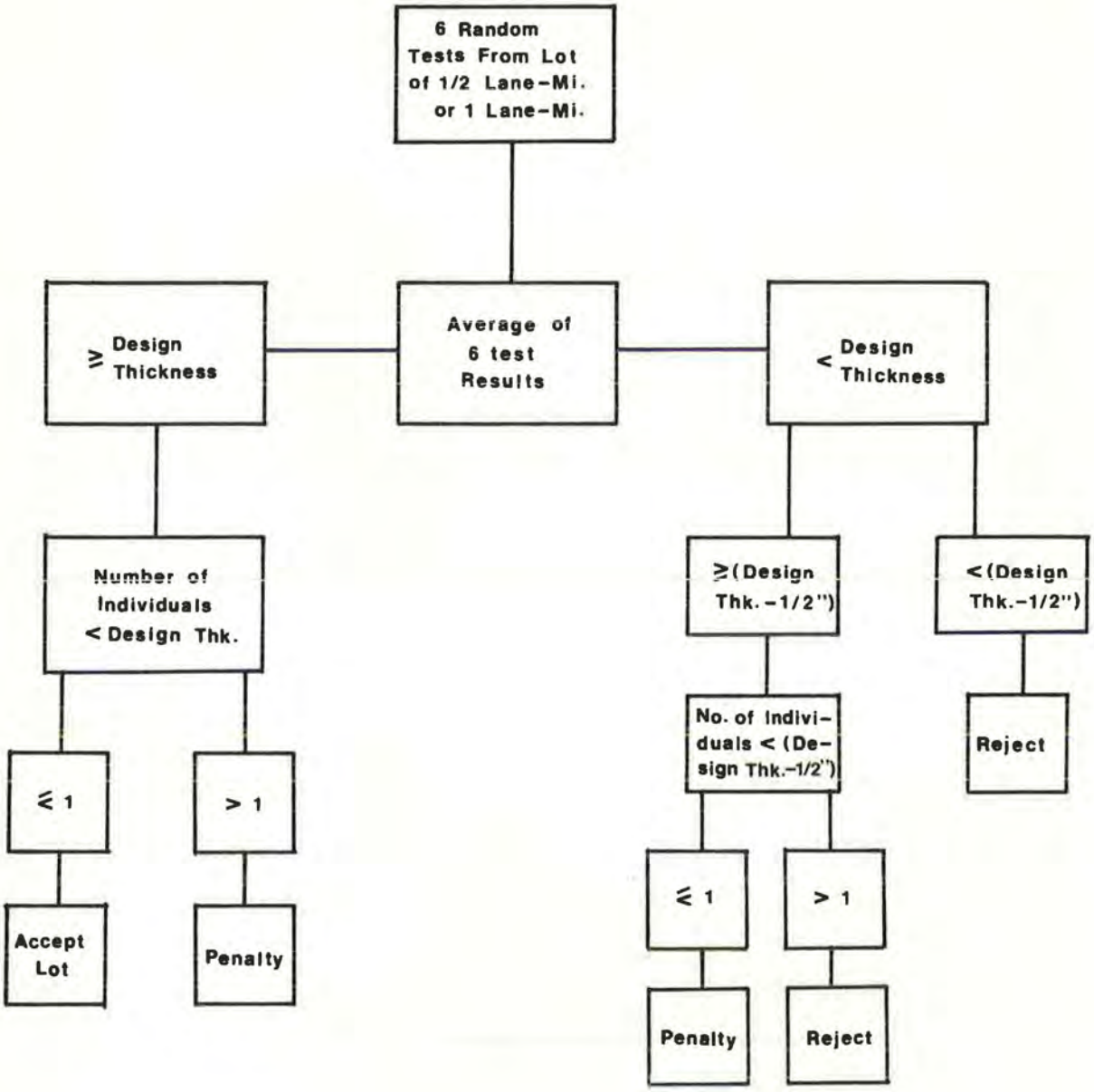

Figure 4. Proposed tentative pavement thickness acceptance plan.

TABLE 1

PENALTIES BASED ON NUMBER OF TEST RESULTS BELOW DESIGN THICKNESS (Six Tests)

Using 6 Tests		Using 10 Tests	
No. Tests Deficient	Percent Payment	No. Tests Deficient	Percent Payment
0-1	100	0-3	100
2-3	88	4-6	88
4-5	75	7-8	75
6	50	9-10	50

TABLE 2

PENALTIES BASED ON PERCENTAGE OF DESIGN THICKNESS ACTUALLY PLACED

Use equation: $(t/T)C$ = payment (not to exceed contract price)

where t = average measured thickness, in.
T = design thickness, in.
C = contract price

TABLE 3

PENALTIES BASED ON REDUCTION IN PAVEMENT LIFE (from AASHO Road Test)

11 in. Design Thickness		10 in. Design Thickness	
Average Test Thickness, in.	Percent Payment	Average Test Thickness, in.	Percent Payment
11.0	100.0	10.0	100.0
10.9	95.5	9.9	95.1
10.8	91.2	9.8	90.4
10.7	87.0	9.7	85.9
10.6	83.0	9.6	81.5
10.5	79.2	9.5	77.4
9 in. Design Thickness		**8 in. Design Thickness**	
Average Test Thickness, in.	Percent Payment	Average Test Thickness, in.	Percent Payment
9.0	100.0	8.0	100.0
8.9	94.5	7.9	93.9
8.8	89.3	7.8	88.1
8.7	84.4	7.7	82.6
8.6	79.6	7.6	77.3
8.5	75.1	7.5	72.4