National Cooperative Highway Research Program

NCHRP Synthesis 187

Rapid Test Methods for Asphalt Concrete and Portland Cement Concrete

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

National Cooperative Highway Research Program

Synthesis of Highway Practice 187

Rapid Test Methods for Asphalt Concrete and Portland Cement Concrete

WOODROW J. HALSTEAD
Palmyra, Virginia

Topic Panel

DANIEL W. (Bill) DEARASAUGH, *Transportation Research Board*
FREDERICK D. HEJL, *Transportation Research Board*
CHARLES S. HUGHES, *Consultant, Charlottesville, Virginia*
PETER A. KOPAC, *Federal Highway Administration*
DEBBIE J. LAWRENCE, *U. S. Army Corps of Engineers Construction Engineering Research Laboratories*
WILLIAM J. QUINN, *Oregon State Highway Division*
MICHAEL RAFALOWSKI, *Federal Highway Administration*
GARY L. ROBSON, *West Virginia Department of Highways*
SHASHIKANT C. SHAH, *Strategic Highway Research Program*
FREDERICK S. SZCZEPANEK, *New York State Department of Transportation*

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

Subject Areas
Materials and Construction

NATIONAL ACADEMY PRESS
Washington, D.C. 1993

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NOTE: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

NCHRP SYNTHESIS 187

Project 20-5 FY 1991 (Topic 23-02)
ISSN 0547-5570
ISBN 0-309-05311-9
Library of Congress Catalog Card No. 93-060012

Price $10.00

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to materials and construction engineers, and others interested in the use of rapid test methods for asphalt concrete and portland cement concrete. Information is provided on the various test methods in use for process control and acceptance of these materials, as well as methods under development. State experience with these procedures, as well as discussions from the literature, are presented.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

There is growing use of rapid test methods for asphalt concrete and portland cement concrete in highway construction. This report of the Transportation Research Board describes the current state of the practice with respect to the use of rapid test methods for these materials. Experience with shortcut and rapid test procedures for process control and acceptance is summarized, and a general description of the methods, their advantages and disadvantages, and their time and labor requirements are discussed based on a review of the literature and a survey of the states.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Robert E. Skinner, Jr., Director for Studies and Information Services. The Principal Investigators responsible for conduct of the synthesis were Sally D. Liff, Senior Program Officer and Scott A. Sabol, Program Officer. This synthesis was edited by Linda Mason.

Special appreciation is expressed to Woodrow J. Halstead who was responsible for collection of the data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Charles S. Hughes, Consultant, Charlottesville, Virginia; Peter A. Kopac, Research Highway Engineer, Federal Highway Administration; Debbie J. Lawrence, Chemical Engineer, U.S. Army Corps of Engineers Construction Engineering Research Laboratories; William J. Quinn, Engineer of Materials and Research, Oregon State Highway Division; Michael Rafalowski, Federal Highway Administration; Gary L. Robson, Director, Materials Control Soil and Test Division, West Virginia Department of Highways; Shashikant C. Shah, Senior Staff Engineer, Strategic Highway Research Program; and Frederick S. Szczepanek, Assistant Director, Materials Bureau, New York State Department of Transportation.

Daniel W. (Bill) Dearasaugh, Jr., Senior Program Officer, Transportation Research Board; and Frederick D. Hejl, Engineer of Materials and Construction, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

RAPID TEST METHODS FOR ASPHALT CONCRETE AND PORTLAND CEMENT CONCRETE

SUMMARY

This synthesis is concerned primarily with those tests used for process control and early confirmation of compliance to specifications for asphalt concrete and for portland cement concrete. A review of various programs conducted by the Federal Highway Administration (FHWA) and other national associations since the 1960s is also included. This document contains an update of the present use of various rapid test methods for these materials by highway agencies in the United States and Canada. Information was obtained by a questionnaire, which is summarized and discussed.

Rapid tests must be a part of the total system of quality control and acceptance. The primary need for speed in testing is for early assurance that the product being placed on a highway or as part of a structure has the desired properties within the accepted variability of the production. Speed in obtaining results for some materials or parts of the system does little good if delays are encountered for other parts and final decisions concerning the acceptability of the product are not accelerated. For most highway agencies, a need for additional personnel to run a "new" rapid test or an inability to coordinate application of the test with other activities negates its usefulness. If frequent calibrations are necessary, the cost-effectiveness of a rapid method becomes dependent on the uniformity of the materials being used and the size of a project.

With respect to asphalt concrete, the primary need is to confirm quickly that the compacted mixture on the pavement has the desired characteristics. Generally, this means that aggregate grading and asphalt content are in accordance with the job-mix formula and the percentage of voids in the compacted mixture is within the desired range. Despite some difficulties and rejection by some states, there is an increasing acceptance of nuclear gauges to determine asphalt content of a mixture and to measure the degree of compaction of the mixture in place.

Present research points to the need for early determination of the characteristics of mixtures being produced at the plant so that adjustments can be made to the job-mix formula, if needed, to optimize the characteristics of the mixture and enhance performance throughout the project life. At present, the primary emphasis of research and development relating to quality assurance of asphalt concrete is on performance-related specifications. Development of rapid test methods related to properties affecting performance is a part of this overall research effort.

The situation with respect to portland cement concrete differs from that of asphalt concrete in that the needed characteristics of portland cement concrete do not exist at the time of placement. Tests must be relied on to confirm that the proper ingredients are being used and that they are being combined in the correct proportions. In addition,

various predictive tests to ensure that proper characteristics such as strength and durability will develop have also been proposed; the use of each is summarized here.

Despite considerable studies by highway agencies and the Federal Highway Administration (FHWA), very few of the procedures developed to measure cement and water content in the concrete as placed (before it hardens) have been made a part of the standard quality control and acceptance procedures of the highway agencies. Also, test methods designed to predict the expected strength of the concrete are more generally used in cases where special properties are required or when the quality of hardened concrete may be in question. As with asphalt concrete, present emphasis is on the development of performance-related specifications and test methods whose results will relate to performance.

A review of major research efforts relating to the development of rapid test methods by national organizations and programs to improve the overall quality assurance of highway construction is included in this synthesis. This review should aid researchers in understanding the scope of the efforts in this area over the last 25 years.

This synthesis was prepared at a time when a number of results from the Strategic Highway Research Program (SHRP) were being made public and implementation of findings was just beginning. Consequently, while reference to some rapid test methods considered by SHRP are included in the synthesis, such references should not be considered as representing the complete findings of SHRP. It is likely that SHRP will have an impact on the future design procedures, specifications, and test methods used for quality assurance for both asphalt concrete and portland cement concrete, as well as other facets of highway construction.

CHAPTER ONE

INTRODUCTION

The development of suitable test methods for all elements of construction of highways and other transportation facilities has been a continuing objective of both consumer and producer organizations since the inception of a national program of highway construction in the early 1900s. Such test methods should be relevant to the quality of the product being tested, must have adequate precision, and must provide the needed information within a time frame consistent with the speed of construction. Over the last 20 or more years, as the pace of construction operations has increased, considerable effort has been expended to develop quick and reliable test methods so that proper process control adjustments and verification of the acceptability of the product being placed can be made before large volumes of noncomplying materials have been incorporated in the construction. These efforts have developed a number of rapid test methods, some of which have been used extensively. However, in a number of cases, tests developed under research conditions have proved to be unsuitable or difficult to use under the conditions that exist at the construction site.

Present efforts of the Federal Highway Administration (FHWA), the National Cooperative Highway Research Program (NCHRP), the Strategic Highway Research Program (SHRP), as well as those of individual highway agencies and commercial organizations continue to place emphasis on improved quality assurance procedures. These include better and faster test methods for both process control and acceptance of all elements of highway construction. For the products of such programs to be used to the maximum extent and as a guide to further development of performance-related specifications, a review of the successes and failures of previous developments and an understanding of the constraints to greater use of rapid test methods is needed. Thus, this synthesis of available information and present practices has been prepared.

Overview

Chapter Two discusses the necessary characteristics of rapid test methods, Chapters Three through Five of the synthesis focus on test methods for two of the major materials used in highway and bridge construction: asphalt concrete and portland cement concrete. Chapter Six includes a summary of major efforts relating to development of rapid test methods in conjunction with overall efforts to improve quality assurance of highway construction.

The primary emphasis of the synthesis is on those test methods used for process control and acceptance of materials and units of construction. Responses to a questionnaire directed to state and provincial transportation agencies in the United States and Canada, to selected producer organizations, and to independent laboratories are reported. These responses, along with published reports, are used to assess, to the extent possible, the advantages and disadvantages, time requirements, costs, labor requirements, test method precision, bias, and reliability of known rapid test methods relating to asphalt concrete and portland cement concrete. Information concerning tests currently under development is also included where available.

The test methods for which information was requested by the questionnaire are listed in Table 1. The questionnaire is included as Appendix A, and the methods in the questionnaire include many well-known procedures. Emphasis was placed on those methods considered to have a potential application for process control and for making early decisions on the acceptability of asphalt and portland cement concrete mixtures as they were being produced and placed in the roadway or structure. Condition surveys, procedures for nondestructive evaluation, thickness, and other as-built characteristics of the pavement or structure are not included in the synthesis. Nor are discussions of rapid tests used for chemical and physical analyses of ingredient materials such as asphalt cement, portland cement, or admixtures presented here. Tests to determine the grading of aggregates used in the production of asphalt concrete are discussed, but tests relating to the suitability of the aggregate based on its source or lithology are not included.

DEFINITION

For the purposes of this synthesis, a rapid test method is one that is expected to provide a measurement of a property or characteristic of a material or item of construction in less time than the customary method used for such purposes. These may be procedures that have been standardized by the American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM) or those proposed for use and still under development. In some cases the test methods measure the level of a characteristic at one time from which a prediction is made for the expected value of that characteristic at a later time based on calibration curves. For example, using 1-day strength of portland cement concrete test cylinders to predict values at 28 days based on the maturity concept. In other cases, instrumental test methods (usually nondestructive) produce a dial or gauge reading as an indication of the level of a desired property based on calibration curves with similar materials of known characteristics; nuclear gauges, for example. Under some circumstances, portions of a standard procedure may be omitted to shorten the testing time (shortcut). For example, elimination of aggregate washing to remove adhering fine particles while determining the aggregate grading is a shortcut method. The accuracy of tests using shortcuts will often depend on the specific material being tested.

TABLE 1
USE OF RAPID TEST METHODS BY HIGHWAY AGENCIES

Test Method	Standard Method	Agencies Evaluating	Agencies Accepting	Agencies Rejecting
		Asphalt Concrete		
Nuclear density	C 2950	40	38	2
Continuous monitoring	------	1	0	1
Nuclear asphalt content	D 4125, T287	33	22	11
Cold feed grading	------	29	24	5
Dry sieving (agg)	------	19	16	3
Selected sieves (agg)	------	3	3	0
		Portland Cement Concrete		
K-Slump factor	------	7	1	6
Chace air factor	T199	21	13	8
Pulse Velocity	C 597	5	2	3
Nuclear density	C 1040	9	8	1
Cement cont.(concrete)	C 1078	5	1	4
H_2O content (concrete)	C 1079	2	0	2
H_2O in concrete by MW	------	3	1	2
H_2O in agg. by MW	------	3	2	1
Speedy moisture (agg.)	------	20	13	7
Acc. cure	C 684	8	4	4
Early age	C 918	7	4	3
Strength-maturity	C 1074	11	7	4
Windsor probe	C 803	18	9	9
Schmidt hammer	C 805	32	21	11
Pullout strength	C 1150	3	0	3
Fund. frequency	C 215	7	6	1
Rapid chloride perm.	T277	12	8	4
Reusable caps	T22	28	24	4

Note: C and D prefixes indicate ASTM methods, T prefixes indicate AASHTO methods; MW indicates microwave.

CHAPTER TWO

USE OF RAPID TEST METHODS BY HIGHWAY AGENCIES

Despite widespread desire for rapid test methods, there are requirements other than rapidity that such methods must meet in order to be useful for process control and acceptance testing. They must have adequate precision and accuracy. If biased, the bias must be reasonably constant and predictable under known conditions. Such methods must also measure characteristics known to be related to the quality of the material or unit of construction under test.

A rapid test method may be used for process control or as part of an acceptance plan agreed on by the supplier and purchaser under the contract. It also may be used as a screening test to determine if further testing is needed.

USEFULNESS AND LIMITATIONS

A technical advisory issued by the FHWA in April 1989 recognizes two types of specifications: pass/fail and statistically based (*1*). The pass/fail type is often referred to in the literature as a recipe or method specification. In this type of specification, the level of measurement is specified with or without a tolerance limit and the material passes or fails based on the test result or the average of several test results. Rapid test methods are particularly useful in this situation, provided they are reasonably precise and unbiased. A rapid test that provides incorrect information can cause losses of time and money that far outweigh any initial saving.

For one-sided specification limits, a rapid test can often establish that a sample meets the specifications on the basis of a result that is well within a specified limit so that normal testing error or bias would not affect the decision. Often, a rapid test also can be used as a screening test. If results fall within a "safe" zone, further testing with a more time-consuming standard test is not needed. However, when the results are borderline, additional testing by a standard method is usually necessary. The average of several rapid test results also may provide equal assurance of compliance to the specification in less time than conducting a standard test.

In a statistically based specification that includes partial payment provisions, a rapid test method can be used in the same manner as in the pass/fail specifications, provided the results are within the acceptable range. However, for application of a pay reduction, the precision of the test method is a factor in establishing the variability of the production, which is recognized in establishing specification limits and payment factors. Thus, the results of a rapid test method cannot be substituted for the results of the standard test on which the tolerances were established. A rapid test method can, of course, be used as the standard to establish acceptance criteria if such use is spelled out in the contract.

The FHWA technical advisory also recognizes two distinct purposes for tests: process control and acceptance. Rapid test methods can be useful in either application. Process control is the responsibility of the contractor or producer. The advisory stipulates specific elements of the process control system that must be established by the contractor. These include calibration of equipment, designation of persons responsible for process control, process control sampling and testing frequencies, documentation of control activities (e.g., control charts, test reports) and process control limits. While often the contractor is free to choose process control tests, generally the tests made will be the same as those used by the highway agencies for acceptance.

The separation of process control testing from acceptance testing, although a recognized goal, is not an accomplished fact in all highway agencies. Often, the agency's tests are used both as process control and acceptance. This is especially true for producers of small amounts of material.

Under some circumstances, shortcut methods can be used to save time, but caution is needed regarding their use. Potential bias of results or differences in variability can lead to difficulty. For example, in the production of asphalt concrete, grading without washing aggregates may at times significantly affect the determination of the fine material because of its adherence to larger particles. Such errors may lead to the inclusion of excess amounts of undetected fine material in the mixture being produced. When it is established that no significant difference exists between wet (aggregate washed to remove adhering particles) and dry sieving, the dry sieving can save significant testing time by eliminating the need to dry the aggregate after sieving.

Because of potential legal problems, some highway agencies have a policy forbidding the use of any nonstandard rapid test or shortcut as a basis for accepting material. Recognizing the problem that can arise, the AASHTO Subcommittee on Materials includes rapid alternatives in some methods. The Subcommittee also has adopted other rapid tests as standards to provide alternatives. The limitations for using these rapid or shortcut procedures are usually stated. Some ASTM committees have also established a number of standard rapid test procedures in the areas of asphalt and portland cement concrete technology.

A review of the literature concerning rapid test methods and the responses to the project questionnaire clearly show that the value of such methods must be considered within the context of the total system of process control and quality assurance. The usefulness of a given test method cannot be judged solely on the speed of the test, but consideration must be given to the speed at which decisions can be made concerning acceptability of the total project.

Often the time saved for a given procedure depends on the volume of testing required. A very rapid test requiring extensive or frequent calibrations is not useful for small volumes of work but can save much time on large projects. Similarly, if the testing equipment is expensive, the cost per test may be too high for small volumes of work but cost-effective for large projects. When using statistical procedures for evaluating the quality of production, several repetitions of a rapid test may provide equal or better precision and less testing error than would a single determination of a more precise but longer test.

RESULTS OF QUESTIONNAIRE

The questionnaire (Appendix A) was sent to all states of the United States and to the provinces of Canada. In addition, it was sent to several private laboratories involved in testing or research on materials used in construction of highways or other transportation structures. Replies were received from 45 states, three provinces of Canada, and one private organization. In addition, agencies were requested to include any procedures in use or under evaluation that were not listed in the questionnaire. Three such responses were received, but they were not "rapid tests" as defined for this synthesis and are not included in the summary.

Table 1 summarizes the replies from the highway agencies that had evaluated and were using (or had rejected) each of the methods listed in the questionnaire. Table 2 (methods for asphalt concrete) and Tables 3 and 4 (methods for portland cement concrete) identify those highway agencies indicating acceptance or rejection of each of the methods and the indicated uses or reasons for rejection. Those states or provinces not listed in the tables did not reply. No indication of acceptance or rejection means that the highway agency did not indicate evaluation.

A summary of the principles of each method, replies concerning advantages and disadvantages, time and cost estimates, and reasons for rejecting the procedures for use where appropriate, is given in Appendix B.

These replies show a wide diversity of opinion among the highway agencies concerning many of the tests. Although more limited in number, rapid test methods for asphalt concrete have been more widely evaluated by highway agencies and are more frequently used than rapid test methods for portland cement concrete. As will be discussed later in Chapter Three (Asphalt Concrete) and Chapter Four (Portland Cement Concrete), basic differences exist in these two technologies that partially account for this disparity.

TABLE 2
HIGHWAY AGENCY EVALUATIONS OF RAPID TEST METHODS FOR ASPHALT CONCRETE

State or Province	Nuclear Density ASTM D 2950	Continuous Monitor (DOR)	Nuclear Asphalt Content D 4125, T287	Cold Feed Gradation	Dry Sieving (agg)	Selected Sieve (agg)
AL	A-1		A-1			
AK	A-1		A-1	R-1		
AZ	A-3			A-3	A-3	
CA	A-1		A-1	A-1	A-1	
CO	A-1		A-1	A-1		
CT	A-1			A-3		
FL	A-1		R-2,5	R-1	R-1	
GA	A-2		R-7	R-1		
HI	A-1		A-1	A-1	A-3	
ID	A-1		A-1	A-1	R-1	
IL	A-1,2		A-1,2	A-3	A-3	A-3
IN	A-1		R-2,4,5		A-1	
IA	R-1	R-1	A-3	A-3	R-1	
KS	A-1		A-3	A-1		
KY	A-1		A-1	A-1	A-3	
LA	A-3					
ME	A-3		A-1		A-3	
MD	A-1		A-1			
MA	A-1		R-1,4,5,6	A-3	A-3	
MI	A-1		A-7	R-7		
MN	A-1		R-5,7	A-1		

TABLE 2 (*Continued*)

State or Province	Nuclear Density ASTM D 2950	Continuous Monitor (DOR)	Nuclear Asphalt Content D 4125, T287	Cold Feed Gradation	Dry Sieving (agg)	Selected Sieve (agg)
MS	A-1		A-1			
MO	A-1		A-3	A-1		
NC	A-1				A-1	
NE	A-1		A-1	A-1	A-3,4	
NM	A-1		R-7	R-7		
NY	A-3				A-1	
ND					A-1	A-1
OH	R-1		A-1,3	A-1,3	A-1,2,3	
OR	A-1		R-1	A-1	A-4	
PA	A-3		A-4	A-4		
RI	A-1		A-4	A-4		
SC	A-3		A-3			
SD	A-1		R-1,7	A-1		
TN	A-1		R-7	A-1,3	A-3,4	A-4
TX	A-3		A-1	A-3	A-3	
VA	A-1					
WV	A-1,2		A-1	A-3		
WI	A-1	A-4	R-7	A-1		
WY				A-1		
CANADA						
MB	A-1					
NB	A-1					

A - accepted for some use:
1. Test and limits are specified and materials or products are accepted or rejected based on results.
2. Test used for screening or triggering other tests. Results used only in acceptance, not in rejection which requires standard test.
3. For process control only.
4. Other.

R - rejected for use:
1. Insufficient precision or accuracy.
2. Equipment too costly.
3. Reagents or procedures hazardous.
4. Overall time saved not sufficient.
5. Calibration too difficult or time-consuming.
6. Training of operators too difficult.
7. Other.

Note: No agency reported evaluation of the compaction robot.

TABLE 3
HIGHWAY AGENCY EVALUATIONS OF RAPID TEST METHODS FOR PORTLAND CEMENT CONCRETE

State or Province	K-Slump	Chace (T-199)	Pulse Velocity C 597	Nuclear Density C 1040	Cement Content C 1078	Water Content C 1079	Water Content Micro-Wave	Agg. Drying Micro-wave	Speedy Moisture	Accel-erated Cure C 684	Early Age C 918	Strength by Maturity C 1074
AL		A-2							A-3			
CA	R-7	R-7				R-1						R-7
CO												R-1
CT		A-4										
DE												
GA										A-2		
ID								A-2				R-1,2,6
IL					R-2	R-2						
IN		A-2	A-4	A-1								
IA			R-1	A-1	R-1			R-4	R-4		R-1	R-1
KS			A-4	A-1	R-7							A-4
KY		A-2						A-3	A-3			
LA				A-1						R-7		
ME									A-4			
MD		R-1									R-6	R-7
MA										A-2		
MN									R-3			
MS									A-3			
MO			A1									
NC		A-1,2			A-2				A-3			
NE		R-1							R-1	R-1		R-7

TABLE 3 (*Continued*)

State or Province	K-Slump	Chace (T-199)	Pulse Velocity C 597	Nuclear Density C 1040	Cement Content C 1078	Water Content C 1079	Water Content Micro-Wave	Agg. Drying Micro-wave	Speedy Moisture	Accel-erated Cure C 684	Early Age C 918	Strength by Maturity C 1074
NV	A-2	A-2		A-1					A-2		A-3	
NH	R-1						A-2		A-2			
NY		R-1		A-2					R-1,3,4	R-1,2,4		
ND				A-1								
OH		A-2										
PA		A-4								R-7		A-4
RI											A-2	A-2
SC	R-1	A-2,3						A-3	A-3			
SD									A-3			
TN	R-1	A-4							R-1			
TX		R-1						A-3	A-3		R-7	
VT	R-7	R-1					R-1	R-4,7	R-2			
VA	R-1	A-2							A-3		A-3	
WV		A-1					R-2,4		A-3		A-1	
WY												R-1,2,4
Ont.										A-2		
Man.			R-1									A-1

A - accepted for some use

1. Test and limits are specified and materials or products are accepted or rejected based on results.
2. Test used for screening or triggering other tests. Results used only in acceptance and not in rejection. Standard test required for rejection.
3. For process control only.
4. Other.

R - rejected for use

1. Insufficient precision or accuracy.
2. Equipment too costly.
3. Reagents or procedures hazardous.
4. Overall time saved not sufficient.
5. Calibration too difficult or time consuming.
6. Training of operators too difficult.
7. Other.

Note: No agency reported evaluation of fiber optics or air void laser tests.

TABLE 4
FURTHER EVALUATIONS OF RAPID TEST METHODS FOR PORTLAND CEMENT CONCRETE

State or Province	Penetration resistance (Windsor probe) C 803	Rebound number (Schmidt Hammer) C 805	Pull-out strength C 900	Break-off number C 1150	Fundamental frequency C 215	Rapid Chloride Permeability T277	Reusable end caps T22-annex
AL	A-2						A-1
AK							A-1
AZ		A-1					A-1
CA	R-1,3	R-2				A-4	
CO	A-4	A-2					A-1
CT	A-2						A-1
FL							A-1
GA		A-2					
HI		R-1					
ID	R-1,3,5	R-1,5					A-1
IL	A-4	A-2,4			A-1,2		
IN	R-1,7	A-4		R-1	A-4	A-4	
IA	R-1	R-1	R-1	R-1	A-1	R-1	A-1
KS		A-1,4			A-1	A-4	
KY		A-4					A-1
LA							R-7
ME							R-7
MD	R-1,4,5	R-1			A-1	A-2	A-1
MI		R-1				R-1	A-1,7
MN		A-4					A-3
MS							A-1
MO		A-4					A-1
NC		A-4					A-1
NE		R-1					A-1
NV	A-4	A-4					R-1,7
NH	A-2	R-1					A-1
NM		R-1					A-4
NY	R-1	R-1				A-4	A-2

TABLE 4 (*Continued*)

State or Province	Penetration resistance (Windsor probe) C 803	Rebound number (Schmidt Hammer) C 805	Pull-out strength C 900	Break-off number C 1150	Fundamental frequency C 215	Rapid Chloride Permeability T277	Reusable end caps T22-annex
OH	A-4	A-4				A-4	A-1
PA	A-4	A-4				R-1	A-1
SC	R-1	A-4					A-1,3
SD		A-2,4					A-1
TN	R-1	A-2					A-1
TX	R-1	R-1	R-1		A-1,4		R-7
VT		A-2					
VA	A-2						
WV					R-7		A-1
WI		A-4				A-4	A-1
WY		A-4				R-7	A-1
Canada							
ON		A-2	R-1			A-1	A-4
MB							A-1
NB		A-2					

Note: C and D prefixes indicate ASTM methods, T prefixes indicate AASHTO methods; MW indicates microwave.

A - accepted for some use

1. Test and limits are specified and materials or products are accepted or rejected based on results.

2. Test used for screening or triggering other tests. Results used only in acceptance and not in rejection. Standard test required for rejection.

3. For process control only.

4. Other.

R - rejected for use

1. Insufficient precision or accuracy.

2. Equipment too costly.

3. Reagents or procedures hazardous.

4. Overall time saved not sufficient.

5. Calibration too difficult or time consuming.

6. Training of operators too difficult.

7. Other.

CHAPTER THREE

RAPID TEST METHODS FOR PROCESS CONTROL AND ACCEPTANCE OF ASPHALT CONCRETE

OVERVIEW OF REQUIREMENTS

The quality of the ingredients in asphalt concrete pavements, the proportions at which such ingredients are mixed, and the grading and particle shape of the aggregate all have appreciable effects on the characteristics and performance of pavements. Even the use of the best materials can result in catastrophic failure if they are improperly combined. Thus, there is a need to monitor production at the asphalt concrete plant to determine as quickly as possible if materials being produced and placed on the road meet the established criteria for good performance.

The usual procedure is to establish the proper asphalt content and the proper grading of the aggregate by tests on trial mixtures in the laboratory. Extensive research has been conducted to devise mixture proportioning procedures that will result in a job-mix formula (JMF) that defines the proper values for the desired grading of the aggregate, the desired percentage of asphalt, and the desired voids in the compacted mixture. It has been customary to assume that if the plant-produced product matches the JMF within established tolerances for grading and asphalt content, the properties of the plant-produced mixture will be essentially the same as the properties obtained in the laboratory-produced mixtures with respect to compactibility, voids in the mixture, and stability. However, D'Angelo and Ferragut have shown that significant differences often occur between the plant-produced mixture and what was obtained in the laboratory mixtures and that adjustments in the JMF are needed for proper results (*2*). Thus, test results on the plant production are needed quickly—not only for assurance that the tolerances of the JMF are being met, but also to provide for adjustments of the JMF to secure optimum characteristics of the compacted pavement and good performance. The parameters key to accomplishing this result are the grading of the aggregate, the asphalt content, and the voids in the pavement after compaction. The voids are determined from the density of the compacted mixture and the aggregate characteristics.

TESTS FOR GRADING AGGREGATE

Production and Stockpile

Kopac and others report that "The gradation test, probably the most frequently performed test in highway construction, is performed by all parties closely involved in actual construction work." (*3,4*)

Proper aggregate grading is necessary for good performance of both asphalt and portland cement concretes but it is generally considered more critical with asphalt concrete. Not only are the relative amounts of different sizes important, but the shape of the particles and how they "fit together" affect performance. While discussion of these aspects is beyond the scope of this synthesis, it is appropriate to consider problems relating to the speed at which required information can be acquired. An evaluation of the effects of variations in grading on the properties of both asphalt concrete and portland cement concrete was made early in the NCHRP program and the results are reported in *NCHRP Reports 34* (*5*) and *69* (*6*). Also, FHWA conducted an investigation of aggregate grading control practices and development of shortcut or alternative methods as a part of its contract research program (*7*). That study was conducted by the Office of Federal Highway Projects, Region 10 of FHWA. The report summarizes control practices being used by highway agencies in 1976-77. Information was reported concerning the method of sample drying and time required; size and number of sieves; length and method of shaking; source of sample (e.g., stockpile, truck, roadway); and who (producer or consumer) performs the test.

These efforts, as well as those by individual highway agencies, were summarized by Kopac et al. (*4*). They analyzed then-current grading control problems and suggested a model program to be considered for optimum results. They concluded that:

> The cost of aggregate gradation is lowest where the highway agency does not involve itself in process control testing. Although process control should be exercised at various steps in the production, transportation and handling of aggregates, it is not efficient for the State Highway Agency to do such testing.

Grading of Aggregate in Final Asphalt Mixture

In the traditional approach to evaluating the quality of asphalt concrete, it is important that the grading of the aggregate in the final mixture be known as precisely as possible to provide comparison with the JMF for acceptance of the mixture. This is accomplished by extraction of the asphalt from a sample (or samples) of the mixture produced at the plant.

The extraction test accomplishes two purposes: it provides the basis for determining the asphalt content, and it makes the aggregate available for determination of its grading. A comparative study conducted by Jones and others in 1968 showed that with vacuum extraction, results could be attained in approximately one hour compared to eight hours and four hours, respectively, for results by the reflux and centrifuge procedures (*8*). The one-hour completion, while significantly reducing the time for the determination, is still not fast enough to permit early adjustment to the mixture being produced at the plant. Thus, means have been sought to determine separately the asphalt content and the grading of the aggregate in the mixture.

Cold Feed Grading

A number of agencies are now using the aggregate grading from the cold feed into the dryer to represent the grading in the mixture.

While there are some disadvantages to this procedure, this practice has been found generally acceptable by a number of highway agencies, as shown in Table 1.

Investigation of the effects of using samples from the cold feed aggregate stream as the point of acceptance for grading aggregate in the mixture was conducted and reported in the FHWA *Asphalt Content Determination Manual* (*9*). Data collected from several highway agencies are given and the findings are summarized as follows:

> This chapter addressed the two areas of aggregate gradation analysis testing that must be evaluated to determine the quality of material being produced and compliance with specifications. The first was the level of variability as demonstrated by the standard deviation expected for gradation determinations from different procedures. The published data indicate that the variability is similar for gradations determined following all extraction procedures. The second area dealt with the comparability between the gradations determined by the different procedures. The studies presented here show that it is possible to use cold feed gradations to determine the quality of the gradation of an asphalt concrete mixture and produce statistically reliable comparisons with the gradations performed on samples taken after mixing following extraction of the asphalt cement. The data is variable, and not uniformly consistent to a level that could be considered universal. It is necessary that individual plants and operators be evaluated to ensure that sampling procedures are appropriate and can produce reliable results. With care, reliable results can be obtained that could allow a reduction in extractions if cold feed sampling is desired.
>
> From the studies reported at the present time there is insufficient data to state that there are any correction factors which can be applied to cold feed gradations to match extraction gradations. The main problem demonstrated in the data is in a variable determination of the fines (<200 sieve) in the mixtures. In general it appears that the cold feed gradations may be coarser in one study and finer in the next with no consistency. Individual plants should be evaluated to determine if the sampling and testing procedures produce gradation data that are comparable. The accuracy of the comparison of two different gradation determinations will depend to a great extent on how well the extraction procedure used accounts for fines in the process. There is no reason not to expect good comparisons between cold feed samples and extraction gradations.

ASPHALT CONTENT

Extraction Procedures

Asphalt content traditionally has been determined by extraction of the asphalt from a sample of asphalt mixture of known mass by means of a solvent. The solvent containing the dissolved asphalt is washed from the aggregate, the aggregate is dried, and its mass determined. The asphalt content is determined by the difference between the mass of the mixture and the mass of the aggregate after extraction. Early rapid tests for this determination centered around speeding up the solution of the asphalt or the process of drying the extracted aggregate. Other methods involved comparing the intensity of light transmitted through the asphalt solution from known mass of mixture per volume of solution and comparison with a calibration curve using a known concentration of the asphalt in the mixture (*10*). Other procedures included using large pycnometers to relate densities of the asphalt solution from the test sample to the density of calibration solutions of known asphalt content (*11*). However, increasing awareness of the toxicity of the solvents used and increasing EPA regulations on the use and disposal of such solvents have greatly diminished interest in such procedures and have accelerated interest in alternative methods.

The FHWA *Asphalt Content Determination Manual* includes a summary of procedures used by highway agencies for determining asphalt content and discusses the suitability of replacing older methods with newer equipment and procedures (*9*). Of particular interest in this manual is the discussion of use of biodegradable solvents for extraction of the asphalt and nuclear gauges for asphalt content.

The manual reports a survey of state practices for determining asphalt content made by the National Asphalt Pavement Association (NAPA) in 1988. That survey, which includes replies from all 50 states, showed that 40 highway agencies permitted the use of solvent extraction methods, 10 approved nuclear gauges, 11 permitted use of automatic recording (the number is greater than 50 because some approved the use of more than one procedure). Thirty-eight agencies approved only one procedure. Of these, 28 used solvent extraction, three used nuclear gauges, and seven used automatic recording.

Nuclear Asphalt Content Gauges

Nuclear asphalt content (NAC) gauges first became available in the 1960s and a number of evaluations of them have been made. Many of these evaluations apply to specific models of gauges no longer available. Results attained are also often dependent on the characteristics of that specific model. Thus, these evaluations are not specifically referenced. Collectively, these references establish the principles of the gauges and the effects of a number of variables on the results. Procedures for using and calibrating gauges are standardized in ASTM Method D 4125 and AASHTO Method T287.

A summary of findings from evaluations conducted by a number of highway agencies using various gauges is included in the FHWA *Asphalt Content Determination Manual* (*9*). The overall conclusions reached are stated in the manual as follows:

> The studies reported here indicate that individual calibration is required for accurate determination of asphalt contents using the NAC gauge. Aggregate types will alter readings slightly, and different gradations will produce different results and must be calibrated individually. Asphalt sources will cause differences if not individually calibrated. Moisture must be controlled with the NAC gauge as it will record the presence of moisture in addition to asphalt content. A quick means of determining moisture, such as microwave drying of asphalt mixes from the plant, may provide a quick and repeatable means of determining the presence of moisture in a mixture. Moisture determination must be a standard procedure.
>
> When the individual calibrations are performed, the accuracy and repeatability in determinations using the NAC gauge is within the limits for other procedures normally used. The studies in the literature clearly indicate that accurate results can be obtained when using a properly calibrated NAC gauge. The studies in the literature do provide some indication that extraction results may be more questionable than the NAC asphalt content determinations.
>
> Variability and Accuracy
>
> The relative prediction of asphalt content comparing extraction and NAC gauges provided conflicting results. Most studies show a very strong statistical relationship exists supporting the conclusion that there is no difference between solvent extraction and the NAC gauge. Other studies do not support such a finding, which may be due to a question over whether the extraction test procedure has determined the asphalt content accurately. The procedures to correct for fines in solvent extractions can have a large influence on the asphalt content calculation. The NAC gauge does not require

> corrections beyond ensuring that moisture presence has been corrected for and the NAC gauge has been properly calibrated for the mix being tested. Great care must be taken in applying statistical significance to these comparisons. In general, the procedures compare favorably and the NAC gauge provided better comparisons with plant tickets and plant methods of recording asphalt content. Generally the NAC gauge produced a higher asphalt content than did the extraction test.

A drawback to greater use of NAC gauges for acceptance testing is that, under existing procedures, most highway agencies require determination of aggregate grading in the mixture as well as asphalt content, thus extraction of the asphalt from the mixture is still necessary. This negates to a considerable extent the time saved by the use of the NAC gauge for asphalt content. Because of uncertainty about the accuracy of the grading based on cold feed samples, some highway agencies have not used the NAC gauge for acceptance.

DENSITY OF COMPACTED MIXTURES

The density of asphalt mixtures after compaction in the pavement is a means for judging the adequacy of the compaction and consequently, to determine that the proper volume or percentage of voids is present in the pavement. The most useful rapid procedure for this determination is the nuclear density gauge. Nuclear gauges have been available since the early 1960s and a large number of evaluations of different commercially available models have been made by individual highway agencies. Some agencies have concluded that some models did not provide the desired accuracy and precision but continuing development of the gauges has led to considerable use at the present time. Such use is likely to increase as more experience is gained and improvement of equipment continues. Some agencies have developed their own procedures and ASTM has developed a standard, D 2950, that describes the general requirements, limitations, and use of equipment employing either a backscatter or direct transmission mode. The significance and use of these gauges is described in ASTM standard D 2950 as follows:

> **3.1** The nuclear density method is employed to determine the relative density of bituminous concrete. It can be used to establish the optimum density for a given rolling effort and pattern, and to check the bituminous concrete for density compliance.
>
> **3.2** The density results obtained by this method are relative. If actual density results are required, a factor can be developed to convert nuclear density to actual density by taking nuclear density measurements and core densities at the same randomly selected locations. It is recommended that the averages of at least seven core densities, in accordance with Test Methods D 2726 or D 1188, and seven nuclear densities be used on a section of pavement to establish the conversion factor. It may be desirable to check this factor at intervals during the course of the paving project. A new factor should be determined when there is a change in the job mix, a change in the source of materials or in the materials from the same source, a change from one gage to another, or there is reason to believe the factor is in error. NOTE—Accuracy of the nuclear test modes is not equal and is also affected by the type and surface texture of the mixture under test. The nuclear test mode to be used and the number of tests required to determine a satisfactory factor is dependent on the accuracy required.
>
> **3.3** The user should recognize that density readings on thin layers of bituminous concrete may be erroneous if the density of the underlying material differs significantly from that of the surface course. Correction procedures are available for some gage models.

As stated, early published reports of gauge evaluations were often based on specific models of equipment and are not referenced in this synthesis. However, two reports that became available in 1991 are of interest. These were issued by the Federal Highway Administration (*12*) and the Missouri Highway and Transportation Department (MHTD) (*13*).

The FHWA report demonstrates continuing progress in the development of nuclear gauges. The report includes the results of a three-phase study consisting of a literature search, a laboratory study, and field trials. Phase 1 included a review of current literature on the theory and operating characteristics of commercially available equipment and highway agency procedures and specifications for monitoring asphalt concrete density. The second phase included tests to verify factory calibrations and to determine the depth sensitivity and thin-lift capabilities under laboratory conditions. The third phase consisted of five sets of field trials in which the capabilities of five commercially available static and two prototype roller-mounted gauges were evaluated. A roller-mounted gauge developed for the FHWA was also evaluated. The conclusions from this study are summarized as follows (*12*):

> Under carefully controlled laboratory conditions, the accuracy and precision of all the gauges were well within manufacturers' specifications. When compensated for chemical composition, lift thickness, and density of the underlying material, the depth sensitivity and the thin-lift measurement capabilities of the gauges were impressive. In the field, however, the correlation of individual gauge density readings with core density measurements and with each other ranged from excellent to fair. The inability to precisely field-calibrate the gauges prior to each use hampered their performance.
>
> The data show that, within limitations, static nuclear gauges can be used for acceptance testing of thin-lifts, but only when all parameters affecting the measurements are precisely known. The dynamic gauges can be effectively used to monitor relative density growth.

The MHTD report provides evaluations of eight nuclear density gauges and an assessment of their usefulness as a part of the standard quality assurance procedures (*13*). Nuclear density results are compared to core densities for a wide variety of roadway types and conditions. It is reported that nuclear density results often do not agree with core densities and that differences vary with each gauge. However, the report shows that the averages of 16 nuclear density tests and four cores can be used to develop acceptable correction factors. A correction factor for each day's production is recommended for final density values but it is reported that the inspector can use the nuclear gauge readings as a means of judging the acceptability of the compaction as it occurs.

A proposed test method is included in the report. The previous day's correction factor is applied to current nuclear readings to provide immediate estimates of the density and degree of compaction that permits corrective action to be taken before the pavement cools and hardens. The report also provides useful information on the principles employed by the various gauges involved in the study.

Density Control Strips

Nuclear density gauges are often used to establish the proper density and the rolling pattern for a given installation. In such cases, a control strip density is established based on the roller pattern. Generally, multiple cores of the compacted control strip are used to establish the relation of gauge readings to density. Thereafter, nuclear gauge readings are used as indications of proper density of the in-place mixture.

As shown by replies to the questionnaire in Table 1, 40 highway agencies have evaluated nuclear density gauges. Thirty-eight use the gauge either for acceptance or for process control. One state reported no use but indicated that contractors used the gauges to establish their rolling patterns. Another indicated that no recent evaluations had been made.

As discussed in the FHWA report (*12*), several gauge manufacturers have reported the development of gauges that can be mounted on compaction equipment to provide instantaneous readouts as the pavement is compacted. This provides the contractor with a convenient means of adjusting compaction patterns for the most efficient operation. Only two states reported that they have as yet evaluated this type of equipment. However, increasing interest is likely.

MIXTURE VERIFICATION PROCEDURE

While the mixture verification procedure is not a rapid test, it embodies efforts to provide better overall quality assurance and early acceptance of asphalt mixtures being produced at the asphalt plant. FHWA has conducted an extensive demonstration project relating to field management of asphalt mixtures. In this project, a mobile test trailer was set up at the asphalt plant and tests were made to demonstrate the usefulness of the mixture verification system and a voids acceptance plan for asphalt concrete mixtures (*2*). Mixture verification is defined as the validation of the mixture proportions within the first several tons of production. It is a process control screening technique aimed at determining the acceptability of a mixture when compared to the highway agency's requirements. The described voids acceptance plan includes performing four Marshall tests per lot of material (in tons) and determining asphalt content (AC), voids in the mineral aggregate (VMA), voids in total mix (VTM), flow, and stability. Target values with stated tolerances are established for AC, VMA, VTM, and flow. A minimum stability is required. The plan also provides for conducting four asphalt content and grading tests per lot of material. Two options are given for these tests: 1. Extracted AC with grading of the aggregate from the mixture. 2. Determination of the asphalt content with a nuclear gauge with grading of the aggregate from the cold feed. The second option provides for a significant reduction in the time required to verify that the mixture being produced is acceptable. This is done by eliminating extraction of the asphalt and determination of the grading of the aggregate in the final mixture as an acceptance test.

D'Angelo and Ferragut summarized the results of demonstrations conducted in 15 states for 17 different mixtures (*2*). The verification procedure provides for one of three decisions based on the tests of the early production from the plant. They are:

1. GO AS IS—No changes to mixture or documentation
2. GO WITH CHANGES—Minor JMF adjustments or administrative changes
3. REDESIGN—Major changes requiring a new mixture

For the 17 mixtures used in that study, only two would have been classified as GO AS IS. Ten of the mixtures were classed as GO WITH CHANGES, and five were classed as REDESIGN. It was concluded from these results that the characteristics of production at the asphalt plant are not always consistent with the characteristics expected from the tests conducted in the laboratory. It is stated that "expecting a mixture produced in a large mix plant to match material mixed in a bowl does not appear to be realistic" (*2*). It was also reported that the plant-produced mixtures generally matched the grading requirements within normal production tolerances but in 6 of the 17 mixtures tested, void properties were consistently outside recommended limits. The void properties of specimens compacted in the field laboratory were effective in identifying fluctuations in the grading of the aggregates contained in the mixture being produced. The VTM and flow fluctuated as expected with shifts in aggregate grading. Typically, the field-conducted Marshall testing was completed in less time than the extraction of the asphalt and grading of aggregate from the plant material.

PRESENT AND FUTURE TRENDS

Present research emphasis is to develop better specifications for asphalt concrete pavements based on performance-related characteristics. The framework of such specifications is discussed by Anderson and others (*14*). Looking to the future, SHRP has made recommendations for new specifications and test procedures. Implementation of such recommendations involves innovative changes in test methods for the characteristics of asphalt mixtures and asphalt cements.

Speed of testing will continue to be an important consideration, but this will be within the framework of adopting a total system of quality assurance that provides, as quickly as possible, information on acceptability of the final pavement with respect to potential performance. A task of the SHRP program is to investigate the potential usefulness of innovative methods based on scientific developments such as microwave reflections and transmission lasers, with accompanying automatic evaluation of responses through computer or other techniques. Early implementation of successful procedures by highway agencies will depend greatly on the cost of new equipment and personnel requirements for such new tests. Close cooperation between producers of material, contractors, and highway agencies to develop a knowledge and understanding of the new procedures and to train personnel will also be a key to success.

CHAPTER FOUR

RAPID TEST METHODS FOR PROCESS CONTROL AND ACCEPTANCE OF PORTLAND CEMENT CONCRETE

OVERVIEW OF REQUIREMENTS

Pavements and structures built with portland cement concrete or other hydraulic concretes using combinations of cementitious materials present special problems with respect to quality assurance. The major properties of ultimate concern for these materials, such as strength and abrasion resistance, do not exist until long after placement. Thus, reliance must be placed on proper proportioning of ingredients, proper placing, finishing, and curing of the concrete. It is also assumed that unusual environmental conditions will not exist during placing and finishing. All responsible concrete producers intend to provide materials complying with specifications, but unpredictable changes from expected normal conditions will occur during placement, such as extreme variations in temperatures, unexpected rains, or high winds. Undetected changes in proportions and characteristics of ingredients that affect final results may also occur. Thus, emphasis on "rapid tests" in this area is in seeking ways to verify the proper proportioning of ingredients, the proper placement and curing of the concrete, and to predict, in a short time, what will be the long-term properties, such as ultimate strength. Under these conditions, "rapid tests" may mean tests conducted 1, 2, or even 7 days after placement. Using today's rapid construction procedures, when something goes wrong very large volumes of concrete will have been placed before deficiencies are detected by acceptance tests now in use.

Since it has been established that the strength of the concrete will depend primarily on the water/cementitious material ratio, considerable effort has been expended in search of a means to determine both the water content and the cement content of freshly mixed concrete as affirmation that the proper ratio exists. When this is true, it is assumed that the proper strength will develop. Considerable emphasis has also been placed on the development of accelerated tests to predict 28-day strengths of concretes. Similarly, the durability of the concrete is greatly affected by the water/cementitious material ratio. Durability also depends on the quality of the aggregate and proper air entrainment, especially in areas subject to cycles of freezing and thawing.

Process control and acceptance of hydraulic cement concrete for transportation applications have much in common with process control and acceptance of concrete in other technical areas, but there are also significant differences that create different priorities. For example, the development of adequate strength of concrete pavement is important and there is a desire to obtain confirmation that specifications have been met as quickly as possible, but the same urgency does not exist for a section of portland cement concrete pavement as it does for a reinforced concrete bridge substructure. In the case of the pavement, it is possible to tear out and replace a segment after 28 days, but this cannot be done for the piers of a long-span bridge if the superstructure has been completed. Similarly, less than adequate strength and durability of the concrete at the base of a dam would have far greater implications than poor durability of bridge deck concrete even though long-term durability of the bridge deck concrete is very important. These differences accommodate the acceptance of "borderline" concrete for a number of transportation projects. In some applications, the additional cost of inspection and testing to assure early acceptance is not warranted from the standpoint of the highway agency. The ensuing discussions are made from the viewpoint of the needs relating to pavements and bridges or other transportation structures.

An overall review of highway concrete technology has been prepared by Whiting et al. as a part of the SHRP efforts with respect to portland cement concrete technology (*15*). Chapter Six of that review deals with the aspect of job-site testing of the concrete for acceptance.

Traditional Procedures

Whiting et al. state that job-site testing of concrete has changed very little over a number of generations. They cite interpretations of strength data and its statistical treatment that have been promulgated by the American Concrete Institute (ACI) but conclude that "the basis of acceptance of concrete still remains the compressive strength cylinder or flexural beam cured for a specified period of time under largely artificial conditions." They further point out that acceptance tests made prior to hardening are primarily the slump and air content where appropriate. Once the concrete has hardened, virtually no tests are performed on the actual structure. The concrete is accepted on the basis of cylinders cured under laboratory conditions, or under field conditions that represent the same general environment as the structure (*15*). The cylinders may respond quite differently to the environment than does the actual massive structure and they do not reflect effects of placement, consolidation, and finishing on the performance of concrete in the actual structure. However, the cylinder strengths have been shown to be reliable evaluations of the potential for adequate strength in a structure, provided proper placement and curing procedures have been followed.

With respect to transportation applications, hydraulic cement concrete mixtures are proportioned and pre-tested in the laboratory to determine that proper strength will develop at the desired entrained air content and with established ratios of water to cement (or in the case of mixtures including cementitious materials in addition to portland cement, water to cementitious material). Proper consistency, workability, and setting time can be controlled by the use of various admixtures. The process control problem is then one of reproducing, within established tolerances, the same proportions of ingredients in the plant production as called for by the established mixture proportions. Because water in the aggregate from the stockpile can vary, tests are necessary to estimate the amounts present in a given batch to adjust the amount of water added during mixing. From the standpoint of product acceptance, the purchaser's representative needs to determine that the concrete temperature and air content are within established acceptable ranges. There is also a need to verify that the concrete delivered to the job-site has the proper proportions of constituents. When the amount of aggregate, cement, and water (including proper adjustment for water in the aggregate) added to a batch of concrete is accurately measured, the water/cement ratio obviously can be correctly determined. However, in many situations, especially for small jobs, erratic plant operations, moisture variations in the aggregate, and, at times, secondary addition of water at the project site all lead to possibilities of greater variability in the water/cement ratio than is permissible for uniform concrete of the desired strength. It is desirable that all of this should be determined before the concrete is completely unloaded from the delivery truck, or as quickly as possible. This need has led to a considerable volume of research to establish suitable rapid tests for water and cement contents and consequently, water/cement ratio, that can be conducted at the job site. Considerable effort also has been expended to develop procedures to predict in a short period of time whether the ultimate strength will be adequate. There is also a need for a rapid and nondestructive test to determine the actual strength of concrete in a structure as a guide for further construction operations, loading, form removal, and other activities. The research efforts have led to a number of different techniques, some of which have been standardized by ASTM and AASHTO and adopted by various agencies with varying degrees of success, often depending on the specific situation.

RAPID TEST METHODS FOR PORTLAND CEMENT CONCRETE PROPERTIES

As was shown in Table 1, the questionnaire sent to transportation agencies in the United States and Canada listed 21 procedures related to rapid testing of portland cement concrete. Some of these are relatively new and were found not to have been thoroughly evaluated by transportation agencies, but others have a significant background of research, covering 20 or more years. A number have been used by highway agencies under special circumstances, but others have not been used to any appreciable extent. Tables 3 and 4 and Appendix B summarize the replies to the questionnaire and provide a general assessment of the extent of use of each method by highway agencies. A description of each method and its standard ASTM and AASHTO designation where appropriate are also given in Appendix B.

In this chapter, research relating to the various procedures is summarized and implementation problems faced by highway agencies are identified to the extent possible. Some recent developments relating to methods not included in the questionnaire are also discussed.

Consistency (k-slump Factor)

The "k-slump Tester" was developed in the early 1970s as a tool for the rapid measurement of the consistency of concrete. Nasser and others first reported its development in 1972 (*16*). Nasser reported on an improved model of the apparatus in 1976 (*17*). He shows that there is a correlation between the k-slump measured with the tester and the slump measured with the standard cone. The slump is measured at a designated time of one minute from the beginning of the test. A workability index can also be obtained by the tester using additional time. Further evaluation of the tester was reported by Al-Manaseer and others in 1989 (*18*). These authors claim that the use of high-range water-reducing admixtures in concrete negates the usefulness of the standard slump cone, and that the k-slump tester can be used to measure the consistency and workability of fresh concrete in general and that of flowing concrete in particular. They claim also that the method provides a procedure for monitoring the most suitable time for placement of flowing concrete.

Replies to the questionnaire did not indicate any appreciable use of the k-slump tester by highway agencies at the present time. Only five agencies indicated that they have evaluated the instrument and four of these rejected it as having insufficient accuracy and precision.

Air Content

Chace Air Indicator

The Chace Air Indicator (CAI), first designated as the AE-55 Indicator for air in concrete, was developed in the 1950s. Grieb reported an evaluation in 1958 (*19*) and a discussion of his evaluation was presented by Mather (*20*). Newlon reported the procedure to be suitable for field use (*21*). These generally favorable reports led to considerable use of the CAI and standardization by AASHTO as Test Method T199. Sprinkel and Lee evaluated results with the CAI against results with the air pressure method (*22*). Their study showed the necessity of calibrating the Chace instruments to provide results in agreement with those obtained by pressure meters. Several steps are necessary to obtain the correct value. First, the Chace Factor (the volume of one graduation on the stem as a percentage of the volume of the bowl) must be determined. Another step is a correction for the mortar content of the concrete under test and a third is a curve-correction that compensates for the lack of a straight-line relationship between results with the air pressure meter and the CAI. With these corrections, it was reported that the Virginia Department of Transportation had adopted a policy of using the average of two CAI results for acceptance of air content in concrete provided the two results did not show differences in air contents of more than 2 percent. When differences in the determined air contents are greater than 2 percent, acceptance is based on an average of three CAI readings. However, a failing pressure meter test is required for rejection of the concrete. Pressure meter tests are also required for acceptance or rejection of concrete for bridge decks.

A later extensive evaluation and review of the literature regarding the CAI was reported in 1984 by Henly et al. (*23*). These authors stress the need for careful training of operators and calibration of the instruments. Although they recognized the usefulness of the indicator in field applications, they question its use for judging air content within ± 1.5 percent of the target value as required by the Texas State Highway and Public Transportation Department.

As indicated in Appendix B, a number of agencies use the CAI for information concerning the variability of air content from load to load and as a guide to determine a need for further tests. However, only two agencies use it in acceptance procedures. One highway agency accepts concrete on the basis of the average of three tests and another uses the method only for incidental concretes.

New Procedures Under Study

Three newer procedures for determining the air content of portland cement concrete were considered by the SHRP research program. These are the air content by the fiber-optic procedure, the air void distribution with laser beams, and air content and void size distribution by the Danish Elutriation Method (DBT method). The first two of these were included in the questionnaire but no highway agency is now using any of these concepts. One highway agency reported working with the developer of the fiber-optic equipment but stated it was unable to comment on its practicability until more data are available. No highway agency reported evaluation of the laser procedure.

The DBT method was not included in the questionnaire. However, it has been used in field projects in Europe and may be useful in the future (*15*). This procedure is based on the fact that large bubbles rise through a column of liquid faster than small bubbles and that bubble size can be accurately inferred from bubble rise time. In the test, a sample of mortar from the concrete is injected in the DBT air void measuring device. Air voids up to about 0.3 mm in diameter and the spacing factor are indicated by the instrument.

It is likely that further evaluation of all these new methods for air content of concrete will be provided by SHRP reports.

Density of Freshly Mixed Concrete (Nuclear Gauge)

The degree of consolidation of concrete is an important aspect of its quality. Density measurements are often used to determine the level of consolidation. A comprehensive evaluation of the relation of consolidation to concrete quality was made by Whiting and Tayabji in a 1987 report prepared for the Federal Highway Administration (*24*). The report includes a discussion of the principles of the nuclear density gauges and the procedures for their use in measuring concrete density.

A summary of highway agency experiences with various nuclear gauges for density measurements is included in that report. It includes replies from 37 highway agencies, seven of which indicated no use. The general assessment of the uses reported in the 1985 survey were compared to a similar survey in 1977. This is partially quoted as follows:

> In general most highway agencies surveyed found the nuclear density gauges to be a useful and practical tool for measurement of density of portland cement concrete.
>
> Performance was considered satisfactory, although in many cases use was limited so conclusions were drawn from experiences on only a few projects. The rapidity of the measurement was listed as a major advantage, as was the ability of the gauge to detect other changes in concrete mixtures, such as large variations in air content.
>
> In spite of these positive evaluations, as mentioned previously, use of the gauges has not increased appreciably since the 1977 survey.

Whiting and Tayabji suggest that highway agencies believe that consolidation is generally satisfactory and does not need to be monitored (*24*). Thus, difficulties with respect to licensing and safety requirements for nuclear gauges along with added costs tend to discourage routine acceptance of the gauges for normal quality assurance.

The relation of density to consolidation is also discussed by Ozyildirim (*25*). His study concluded that variability in density resulting from acceptable variations in the grading and amounts of individual ingredients of concrete, including air content, is of the same order of magnitude, or greater, than the variability resulting from small but detrimental amounts of large air voids. Thus, he questioned that matching nuclear densities with densities obtained by mass per volume measurements would assure the absence of such detrimental voids. He noted, however, that the presence of an appreciable amount of entrapped air or excessive amounts of entrained air would be detected by nuclear density measurements.

In the questionnaire conducted for this synthesis only seven highway agencies responded concerning present use of nuclear density gauges for portland cement concrete. All indicated that the procedure was being used to measure the in-place density of high-density bridge deck overlays.

Recognizing that "static" gauges as represented by those described in ASTM C 1040 provide only a point measurement and thus represent only a small sample of the concrete, efforts have been made by FHWA to develop a consolidation monitoring device (CMD) based on continuous measurements. Results of those efforts were reported by Mitchell et al. (26).

A summary of the relative advantages and disadvantages of various types of nuclear density gauges is given by Whiting et al. (*15*) and is reproduced as Table 5. This table also appears in Whiting and Tayabji (*24*).

CEMENT AND WATER CONTENTS OF FRESHLY MIXED CONCRETE

As previously discussed, accurate recording of the amounts of cement and water being added to a batch of concrete coupled with accurate knowledge of the amount of water in the aggregates provides good process control. However, because inaccuracies in such determinations, accidental or otherwise, can greatly affect the ultimate properties of the concrete, there is much worldwide interest in measuring the cement and water content of the fresh concrete as it is placed at the job site. Such a method would be particularly valuable for quality assurance by the purchaser where small volumes of concrete are involved and it is not cost-effective to establish close inspection procedures at the concrete mixing plant. Considerable effort has been made to develop such procedures.

Methods Based on Kelly-Vail Procedure

Numerous reports have been published concerning the rapid determination of cement and water content of freshly mixed concrete based on the Kelly-Vail procedure first developed in England in 1968 (*27*). Modifications and evaluations of these procedures resulted in the development of the Concrete Quality Monitor (CQM) system by the Construction Engineering Research Laboratory (CERL) of the Corps of Engineers. Several reports relating to the system were published between 1975 and 1984 and important improvements and refinements were reported for each subsequent generation of the system. The latest operational guide is Technical Report M-293 (*28*). In 1980 a report on the state of technology for quality assurance for freshly mixed concrete was prepared by

TABLE 5
RELATIVE ADVANTAGES AND DISADVANTAGES OF NUCLEAR DENSITY GAUGE TYPES FOR PORTLAND CEMENT CONCRETE (*15*)

Gauge Type	Advantages	Disadvantages
Direct Transmission	Includes full concrete thickness in measurement. Little chemical interference. Widely used in other areas, commercially available. Precision is good. Can avoid steel by proper gauge positioning.	Disturbance of concrete. Only measures small volume of concrete placed. Relatively slow measurement. Difficult to clean gauge completely. May be difficult to use where reinforcement is congested. Radiation monitoring required.
Backscatter	Easy to perform. Minimal disturbance of concrete. Widely used in other areas, commercially available. Satisfactory precision. Useful on thin overlays (more sensitive to surface layers.) Facilitates cleanup.	Insensitive to deep layers. Volume of influence ill-defined. Sensitive to chemical effects. Reinforcing steel and underlying concrete may interfere. Radiation monitoring required.
Twin-Probe	Depth localization of density. Long path length included in measurement. Sensitive to small voids. Little chemical effect. Small radiation source. Good precision.	Increased disturbance of concrete. Slow measurement. Difficult to operate. Equipment not commercially available.
CMD	Large volume of concrete included in measurement. Adaptable to process control. No disturbance of concrete. Satisfactory precision.	Sensitive to surface layers only. Measurement value represents average of volume scanned. Sensitive to chemical effects. Difficult to calibrate. Awkward to handle. Increased radiation hazard. Needs "custom" installation for each paver type. Measurements near pavement edges restricted.

West Virginia University and published by FHWA (*29*). A general evaluation was also published by Head and others in 1983 (*30*). These reports generally indicated that useful results were obtained by these methods and prompted standardization of procedures for cement content (C 1078) and for water content (C 1079) by ASTM Committee C-9. As described in Appendix B, both methods provide optional procedures permitting either manual or instrumental titration. Generally, the manual titration requires more skill in chemical analysis. The equipment for instrumental titration is more expensive but proper use will provide faster results.

Nuclear Cement Content Gauge

A nuclear gauge for the determination of cement content of concrete was developed by FHWA in 1973. The principle of the procedure is described by Mitchell (*31*). The gauge is sensitive to all elemental calcium in the sample, thus concretes prepared with calcareous or dolomitic aggregates will not be measured accurately unless calibrated with concretes containing the aggregate of interest in the exact proportions in which they occur in the job and with known cement contents. FHWA had two prototypes of the instrument manufactured and these were used by several highway agencies in evaluating the procedure. Results of these evaluations are described by Mitchell (*32*). He reported results from two laboratory evaluations and from five highway construction projects. The laboratory evaluations showed accuracies of the gauge to be ± 13 kg/m^3 (± 22 lb/yd^3) for concretes containing siliceous aggregates and ± 18 kg/m^3 (± 31 lb/yd^3) for calcareous aggregate mixtures. In most cases, the results of the nuclear gauge measurements agreed with calculated cement factors established by batch tickets but unexplained discrepancies occurred on two field projects. The necessity to recalibrate the instrument whenever the aggregate source or the ratio of coarse to fine aggregate changes, and the reduced accuracy when calcareous aggregates are present, were cited as disadvantages and limitations of the method. Because of these difficulties and the lack of interest by commercial instrument manufacturers, further consideration is not now being given to this procedure.

In addition to the procedures based on the Kelly-Vail principle, other procedures for cement or water contents have been proposed. A summary of these follows.

Rapid Analysis Machine

The Rapid Analysis Machine (RAM) involves an instrument that separates the material passing a 150 μm (No. 100) sieve from the rest of the concrete batch (*33*). Special chemical solutions are added to the material passing the 150 μm (No. 100) sieve so that the solids are flocculated. The total amount of solids and the amount of silt or non-cementitious materials trapped with the cement are determined. Calibration with concretes of known cement contents is required. The RAM is almost totally automated and is relatively rapid and simple. It is frequently used in England but has not been used extensively in the United States and Canada. An evaluation of the procedure by the Western Direct Federal Division (formerly Region 17) of the FHWA led to the conclusion that this procedure would not be suitable for use by most highway agencies because of the calibration difficulties and the high cost of the equipment (*34*).

Centrifuge (Willis-Hime) Method

This procedure was developed by the Research and Development Laboratories of the Portland Cement Association (*35*). It relies on the wide disparity in densities of cement and fine aggregate which allows separation by centrifuging in a heavy media fluid with a density intermediate between the two. The procedure was developed in 1955 and evaluated by Walker and others in 1961 (*36*). There is little present-day interest because it requires the use of highly toxic and flammable reagents.

Flotation Method

This technique was developed in Germany (*37*). It uses a flotation agent to float the cement particles in a froth. The froth is then removed and the cement content of the concrete is determined by the solids content of the froth. Evaluation by Williamson indicated accuracy equal to that of the CQM and RAM procedures (*38*). No reports of evaluation for this procedure by highway agencies were found.

Colormetric Silica Method

This method was developed by Hime and others (*39*). It involves the determination of silica (SiO_2) based on the development of yellow beta silico molybdic color. A calibration curve of absorbance vs. percent silica is prepared and the cement content is calculated as a function of its silica content from the calibration curve. Whiting et al. (*15*) suggest that this procedure fulfills the conditions for a field test, but state that more research is needed to evaluate its use under field conditions and to determine the degree of interference by aggregates and admixtures. No reports of evaluations by highway agencies were found.

Microwave Oven for Water Content

This procedure uses a microwave oven to determine the water content by drying a sample of the freshly mixed concrete. The water/cement ratio is then determined by assuming that the recorded amount of cement added is correct. Evaluation of this procedure is reported in *NCHRP Report 284* (*40*). The major difficulties cited are those associated with obtaining a representative sample; calculations to take into account absorbed water in the aggregate; additional calculations to account for evaporable liquid in liquid admixtures; decomposition of aggregate particles during the heating of the sample; and popping of aggregate particles during the heating of the sample resulting in loss of sample material.

Evaluations of Usefulness of Rapid Tests for Cement and Water Contents

Several general evaluations have been conducted for a number of the methods for early acceptance of portland cement concrete. One such study is that by Halstead and Ozyildirim in 1985 (*41*). These authors made laboratory tests in accordance with ASTM methods C 684 and C 918 and in addition reviewed the evaluations of five highway agencies for several other methods which included: (a) the Kelly-Vail for water and cement content, (b) determinations of water/cement ratios by microwave drying for water content and assumptions that the weigh tickets for cement were correct, (c) the RAM, and (d) CERL/CQM (*34,42,43,44,45*). The conclusions from these studies reached by Halstead and Ozyildirim are as follows (*41*).

> Even though some early reports indicate that satisfactory determinations of water and cement contents can be obtained using the Kelly-Vail system, the experience of the various highway agencies in evaluating the application of the system is not readily adaptable for use in either quality control or acceptance testing. The water-cement ratio determined often varies significantly from the ratio determined by weight (mass) of added material with corrections for water in the aggregate. Representative samples could not be consistently obtained. A reliable relationship between 28-day strengths and determined water-cement ratios was not obtained by any state agency testing field concrete, most likely because special training of personnel is needed. Similar problems are encountered with the RAM test procedure. Accordingly, it is concluded that laboratory or field evaluations of either the RAM equipment or the Kelly-Vail procedure by the Virginia Department of Highways and Transportation is not warranted at this time.

The evaluation of seven test methods were reported in *NCHRP Report 284* published in 1986 (*40*). These are:

(1) CERL/CQM
(2) FHWA Nuclear Cement Content Gauge
(3) Rapid Analysis Machine
(4) X-ray Emission Spectrometer
(5) Modified U.S. Army Engineers Centrifuge
(6) Hot Plate
(7) Microwave Oven

The study included tests with each of the procedures on 21 concrete mixtures containing different amounts of concrete materials such as portland cement, water, siliceous and calcareous aggregates, fly ash, ground granulated blast-furnace slag, high-range water-reducing admixtures, and accelerating admixture (calcium chloride).

Table 6, taken from the report, presents the assessment of the ability of the methods to provide accurate results in the field (*40*).

The conclusions reached from this investigation were stated as follows:

1. No test procedure for determining water or cement content can rapidly and without bias determine the water and cement content of all portland cement concrete mixtures studied.

2. The ingredients of portland cement concrete can significantly affect the ability of a test procedure to rapidly and accurately determine water or cement content of a freshly mixed concrete mixture.

3. If a procedure is to be used in a quality assurance program, the type or types of concretes proposed will determine which procedure or combination of procedures should be used.

4. None of the procedures evaluated has the ability to quantitatively detect the unexpected presence of ground granulated iron blast-furnace slag or fly ash.

The limited usefulness of these various methods of determining cement and water content of portland cement concrete for extensive use as normal acceptance procedures by highway agencies is confirmed by the responses to the questionnaire conducted for this synthesis. No agency reported the use of ASTM methods C 1078 and C 1079 for acceptance testing. Two states indicated evaluation of water by drying concrete in a microwave as a means of estimating water/cement ratio (assuming cement content to be accurately indicated by weight tickets). One indicated some use but the other rejected the procedure for rapid determination of water/cement ratio.

DIRECT MEASUREMENT OF WATER/CEMENT RATIO

In addition to separate determinations for water and cement, several attempts have been made to measure the water to cement ratio directly but no record of evaluations by highway agencies was found.

Instantaneous Procedure

NCHRP Project 10-25A had as its objective the development of an "instantaneous" method for determining the water/cement ratio by means of a probe that could be inserted in the concrete

TABLE 6
FIELD ASSESSMENT DATA (*4*)

Test Method	Percent Recovery Range	
	Cement Content (%)	Water Content (%)
CF	No Data	N/A[a]
CQM	9.7 to 106.8	98.8 to 129.5
HP	N/A	No Data
MW	N/A	94.6 to 99.9
NCCG	98.5 to 104.8	N/A
RAM	97.8 to 115.8	N/A
X-Ray	No Data	N/A

[a] Not applicable

Note: Acronyms are as follows:

CF: Centrifuge, Willis-Hime (modified by WES)
CQM: Concrete Quality Monitor
HP: Hot Plate
MW: Micro Wave Oven
NCCG: Nuclear Cement Content Gauge
RAM: Rapid Analysis Machine
X-Ray: X-Ray Emission Spectrometer Procedure

and provide a direct read-out of the ratio. The researchers were unsuccessful in this attempt and their work is summarized in *Research Results Digest 174* (*46*) (see Appendix C—Project 10-25A). The researchers suggest that future development in specific ion technology and instrumentation may make such equipment possible.

Buoyancy Principle

Naik and Ramme have developed equations to calculate the water/cement ratio based on knowing the mass of the concrete test sample in air and under water, the density of the aggregates and cement, and the aggregate to cement ratio used in the concrete mixture (*47*). No record of the use of this procedure by United States or Canadian transportation agencies was found.

EARLY PREDICTIONS OF STRENGTH

General Applications

Various methods have been proposed for early predictions for strength development. These test methods do not permit corrective action before the concrete hardens, but early indications of possible lower-than-specified values can avoid placement of large volumes of unsuitable concrete. All of these methods depend on correlation of the results of the accelerated tests with standard tests conducted on cylinders. Apart from specification compliance, some of these test methods provide means of estimating the actual strength of the field-placed concrete at a given time as a basis for form removal or subsequent construction. These methods fall into two categories: the accelerated curing methods and those applying the maturity concept.

Accelerated Curing Methods

Four accelerated curing procedures are included in ASTM Method C 684. These are: (a) Warm Water Method, (b) Boiling Water Method, (c) Autogenous Curing Method, and (d) High Temperature and Pressure Method. An evaluation of these procedures was conducted by the New York State Department of Transportation (*48*). This report indicated that, with the exception of the boiling water method with type III cement, all of the procedures were capable of predicting 28-day strengths within acceptable variations. Predictions of one-year strengths from either the accelerated curing tests or the normal 28-day tests were not within an acceptable range. The report recommends the use of the autogenous procedure for estimating concrete strengths.

The American Concrete Institute evaluation of Accelerated Strength Testing (ACI 214.1R-81) states that correlations should be based on at least 30 tests for each mixture (*49*). While this may be practical for massive construction such as a large dam, it becomes time and cost prohibitive for highway agencies dealing with relatively small projects in different areas and with different material sources. Suitable application to dam construction is described in Corps of Engineers Miscellaneous Paper SL-84-4 (*50*).

Seven agencies indicated evaluations in the questionnaire response with four indicating rejection. The uses indicated were for early verifications of mixture proportions, mostly where project constraints did not permit normal mixture proportion testing.

Methods Based on Maturity Concept

The second category of early predictions of strength involves the use of the maturity concept. Under this concept, the combined effects of time (age of concrete) and temperature are considered to represent the "maturity" of the concrete and different batches or portions of the same concrete are assumed to have equal strengths at equal maturities. It has also been shown that strength plotted against the logarithm of maturity approximates a straight line for a given concrete. When these principles are used to estimate strengths at 28 days or other ages from early strengths, a correlation curve of strength versus log maturity is established for the concrete under test and the slope of the line is determined. This slope is used with the strength of the test specimen to predict the strength at the desired later ages, usually 28 days, for acceptance testing. ASTM C 918 describes the procedure for using this concept and ASTM C 1074 provides a practice for estimating concrete strengths by the maturity method. Carino discusses the theory of the strength-maturity relation of mortar which is assumed to be generally applicable to concrete (*51*). The development of prediction equations and means for using them for early acceptance of concretes were discussed by Hudson and others (*52*). A report prepared by the West Virginia Division of Highways (WVDH) of the West Virginia Department of Transportation and published by FHWA describes a successful application of the principle for acceptance of highway concrete (*53*). WVDH is the only highway agency that has reported extensive use of this concept as part of its standard quality assurance procedures.

The success is primarily attributable to the fact that WVDH systematically revised its total quality assurance system to define clearly the responsibilities of the concrete producers, contractors, and the highway agency. The philosophy behind the system and its main elements are reviewed by Steele and Higgins (*54*). A key part of the system is that quality control (process control) is made the responsibility of the contractor. The contractor controls purchase of materials, assigning equipment, and the work done by the workmen. The quality control system must be set up by the contractor and approved by the agency, but the contractor is fully responsible for the results obtained. The early strength results are used as a part of the highway agency's quality assurance program and results are primarily a means for statistically establishing the suitability of the contractor's quality control rather than an absolute measure of the concrete strength. A recent assessment of the success of the WVDH program was made by Burnside, a ready-mix concrete contractor, in *FOCUS*, a publication of SHRP (*55*). He endorsed the WVDH system and emphasized the need for cooperative efforts by all parties concerned.

NONDESTRUCTIVE TESTS ON HARDENED CONCRETE RELATED TO CONCRETE QUALITY

The four tests—penetration resistance (Windsor Probe) (*56*), rebound number (Schmidt hammer) (*57*), pull-out strength (*58*), and break-off number (*59*)—included in the questionnaire are all used to estimate concrete quality, but no state reported their use in acceptance testing. The Windsor Probe (ASTM C 803) and the

Schmidt hammer (ASTM C 805) are long-standing techniques used primarily in evaluations of concrete where problems exist. Neither is used for acceptance or rejection of concrete on the basis of strength. However, both are used for investigative purposes. The pull-out test (ASTM C 900) and the break-off number (ASTM C 1150) have not been used extensively by highway agencies.

RAPID TESTS FOR MISCELLANEOUS CONCRETE PROPERTIES

Tests for Concrete Aggregate Moisture

There are no acceptance limits for moisture in concrete aggregates, but a determination of the amount of moisture present is often needed as a means for establishing the total water present in a mixture. Two rapid tests have been proposed for this purpose; the microwave oven and the speedy moisture meter (applicable to fine aggregate, see Appendix B for description). As shown by the results of the questionnaire, relatively few agencies have used the microwave for determining the moisture content of the aggregate. The speedy moisture meter has been tried by a greater number of agencies. Thirteen reported some use.

Reusable Neoprene Pads and End Caps for Compression Test Cylinders

This is a "shortcut procedure" included in AASHTO method T22 that has been accepted as standard practice for 6-in. x 12-in. test cylinders. While not standard practice for 4-in. x 8-in. cylinders, it is frequently used. The results are accepted as valid measures of compressive strength. Of the 33 highway agencies reporting evaluations, only five indicated no use. Two of these five indicated that the specimens with the caps did not fit into their present testing equipment and a third was just beginning to evaluate the procedure. The other two agencies reported that the procedure did not give results comparable to those obtained with the sulfur capped specimen and thus was not used for acceptance testing.

Rapid Chloride Permeability

This procedure was developed under contract for the FHWA by Whiting (*60*). The method consists of monitoring the amount of electrical current passed through a test specimen across which a potential difference of 60 volts DC is maintained for 6 hours. It was first adopted by AASHTO as Method T277 and ASTM has adopted a slightly revised procedure with the designation C 1202. Although designated "rapid" by title, it requires about two full days to obtain results. However, the new test provides an early assessment of the relative permeability of the concrete to chloride ions, and the results have been shown to generally relate to the penetration of chloride ions into the concrete after 90 days ponding. Results of the questionnaire showed that 10 highway agencies have evaluated the method. One highway agency reported its use in accepting high-density concrete overlays for bridge decks, while the others report its use for other investigations and comparisons of relative permeabilities of concretes of different compositions. Mobasher and Mitchell have reported the precision of the procedure as shown by a round robin test series (*61*).

PRESENT AND FUTURE TRENDS

The assessment of future trends reported by Whiting et al. is for increasing demands for job-site testing at different stages of manufacturing (as-delivered, as-placed, and as-cured) (*15*). They believe concrete researchers will seek to apply developments in science and technology used in other fields, e.g., optics and electronics, to develop better test methods. They recognized that none of the present methods for measuring water and cement contents is completely satisfactory in terms of rapidity, accuracy, and field applicability and expect the search for better techniques to continue.

From the viewpoint of a highway agency, past experience has demonstrated that methods that require extensive calibration and for which correlation of the measured property is highly dependent on proportions or sources of ingredients are not likely to be cost-effective. Thus, emphasis will likely be placed on cost-effectiveness of the total system of quality assurance with application of statistical principles that use performance-related characteristics to assess the risks and potential cost of non-compliance against the cost of testing and the personnel required.

As more results from the SHRP program become available, it is likely that new methods of measuring characteristics of the freshly mixed concrete or early assessment of the quality of the concrete as placed will emerge. In this respect, the results of SHRP project C-204, published in a report dated March 1990, (*62*) are of interest. This project was undertaken to obtain information on the nondestructive test methods and procedures that are currently being used by various highway agencies; to identify the need for new or improved test procedures; to ascertain the level of understanding among highway engineers of the importance of the various concrete characteristics; and to assess the degree of interest for participation in the full-scale field trials.

The results of a questionnaire concerning the practices of the states and provinces are summarized in the report. Researchers note that the number of agencies employing state-of-the-art technology for nondestructive testing of concrete is small. However, agency interest in participating in field trials of new nondestructive tests is reported to be high. The report also concludes that additional efforts are needed to promote new nondestructive technology among state and provincial transportation agencies.

CHAPTER FIVE

CONCLUSIONS, NEEDS, AND RECOMMENDATIONS

CONCLUSIONS

The conclusions drawn from this review of the literature and the responses from highway agencies concerning rapid test methods for determining the acceptability of asphalt concrete and portland cement concrete as they are produced and placed on the roadway are as follows.

Asphalt Concrete:

• Progress is being made toward general acceptance of nuclear gauges for determining density of asphalt concrete as it is compacted. While care in calibration and operation is required, commercially available gauges provide acceptable values early enough that corrective action can be taken when needed. Gauge indications of relative changes in density also provide good guidelines for establishing efficient roller patterns.

• With proper calibration, accurate determinations of asphalt content can be made using a nuclear asphalt content gauge (NAC). NAC tests at the production plant have been found suitable as acceptance tests by many highway agencies.

• With proper recognition of potential changes from the addition of bag-house fines, the grading of aggregate based on samples taken from the cold feed into the mixing plant or other suitable locations prior to mixing with asphalt can be used to judge the acceptability of the grading of aggregate in the asphalt mixture. This procedure is particularly useful for process control.

• A combination of NAC gauge for asphalt content and cold feed grading permits elimination of the use of large volumes of toxic and flammable solvents and the accompanying problems of their disposal.

• Compliance to laboratory determined JMF does not always assure good performance; thus, a system permitting rapid evaluation of the mixture being produced at the plant should be established with adjustments to the JMF being made as needed.

Portland Cement Concrete:

• The needed characteristics of hydraulic cement concrete do not exist at the time of placement. Whether or not such characteristics will develop depends not only on the constituents used in the mixture, but also on environmental conditions under which it is placed, how it is finished, and the curing process.

• Despite successful applications in research studies and experimental projects, methods to determine the cement content (e.g., ASTM C 1078) and water content (e.g., ASTM C 1079) of concrete before it hardens have not been adopted widely by highway agencies. Such procedures generally are not cost-effective for typical construction operations by the agencies. The calibration procedures and personnel requirements for conducting such calibrations in addition to the tests on the concrete being produced deter greater use.

• The air content of concrete as delivered to the jobsite can be rapidly estimated by the Chace Air Indicator, but most highway agencies do not consider this procedure sufficiently accurate for rejection of concrete. By averaging the results of two or more tests, some agencies find the results suitable for screening for acceptance but not for rejection. Results from the SHRP program to determine air content show potential applications that should be useful to highway agencies provided equipment of sufficient ruggedness can be developed for continuous field use.

• Tests based on accelerated development of strength as a prediction of ultimate strength development have been found useful under special conditions, but generally have not been used for process control or acceptance.

NEEDS

A 1990 report, prepared by the Transportation Research Board for the Office of Highway Operation of the FHWA, summarizes the needs for a research and development program for highway construction engineering management (*63*). The report identifies 16 of the highest priority needs among the 72 identified by invited participants at workshops representing all segments of the transportation construction industry. A standing committee established the priorities from evaluations of the total list by the attendees. That report establishes the "Development of More Effective Rapid Test Methods and Procedures" as the third highest priority program, the first two being "Performance-Based Specifications for Highway Construction" and "Construction Claims and Their Resolution" in that order (*63*). Thus, all three of these are related to attaining improved quality assurance procedures.

The report recognizes the 98 percent completion of the Interstate highway system and the need to shift efforts to rehabilitation and maintenance of existing highways rather than new construction. The need for efforts to replace competent construction engineers to counteract retirements and loss of day-to-day construction expertise through cutbacks in staff and loss of resources is emphasized. It is stated:

> The staffing shortage puts a premium on cost-effective sampling and testing programs. A concerted effort must be made to develop programs that can rapidly and reliably predict the performance of the end product.

One of the recommendations of this report is that development of new rapid test methods be encouraged by funding unsolicited proposals to foster innovative approaches to rapid test methods.

Another document that stresses needs for more rapid test methods is *TR Circular 386*: *Innovative Contracting Practices*, issued in December 1991 (*64*). The circular reviews existing procedures and certain barriers that may discourage innovation. It also recommends a number of needed short-term and long-term actions. A need for better test methods is stated and a call made for all segments of the highway industry to work together to identify where rapid tests are needed and to develop them.

While there are differences in emphasis and relative priorities, these later reports basically reflect a need that has been emphasized not only in the United States but worldwide over the last decade or more. Of particular interest are *NCHRP Synthesis of Highway Practice 65* on quality assurance (published in 1979) that reviews all aspects of quality assurance from the viewpoint of problems facing highway agencies (*65*). Appendix A of that synthesis reflects the same problems confronted by other countries. Also of interest is *Transportation Research Record 792* on contractual relationships (published in 1981) which discusses overall problems and experiences in several large projects (*66*).

A common thought expressed throughout these documents is the need for knowledgeable personnel employed by all interests (producer, contractor, purchaser) to work together to build optimum quality into our transportation structures at reasonable costs. There is a need to clearly state requirements, to eliminate unnecessary testing, and to develop procedures for determining rapidly that the quality of the product being produced is that which is specified.

As the results of the SHRP program become available, considerable effort will be needed to provide highway agencies, contractors, and producers of asphalt concrete and portland cement concrete with needed information and training to implement new procedures. Such efforts have been organized by SHRP with cooperation of AASHTO, FHWA, and other national organizations and should continue on a nationwide basis. Early implementation of SHRP findings has a potential for providing better transportation facilities at lower costs.

Recommendations

Present emphasis on performance-related specifications and test methods should continue. While rapid test methods are desirable, such methods should be related to performance. Because of the established variability of materials and combinations of materials, new test methods should emphasize continuous read-outs of nondestructive instruments that can be computerized to present both an average of a desired characteristic and its variability around that average (standard deviation) that can be related to performance under expected environmental and traffic conditions.

Continuing consideration should also be given to minimizing the amount of testing based on realistic statistical risks of noncompliance and the criticality of the material or item being tested.

Major efforts should be made to maximize the benefits of the SHRP programs by incorporating new specifications and test methods into standard practices of highway agencies. Worldwide exchange of information should continue.

CHAPTER SIX

REVIEW OF PROGRAMS FOR DEVELOPMENT OF RAPID TEST METHODS

This chapter provides a review and summary of various programs for the development of rapid test methods for quality assurance in highway construction and the relation of such efforts to the broader objective of overall improvements in highway performances. Because of the long-standing interest in rapid test methods covering several generations of engineers and researchers, it is important that those currently involved in developing or implementing rapid test methods have knowledge of the extensive efforts previously made and develop an understanding of restraints that have hindered more universal implementation of a number of these methods.

INITIAL INTEREST

As stated earlier, the need for rapid evaluation of the acceptability of materials and construction has always been a consideration in highway construction. Accelerated efforts to develop rapid test methods date back to the early 1960s and were a part of the overall program initiated by the Bureau of Public Roads (BPR) [now the Federal Highway Administration, (FHWA)] to improve specifications and quality assurance measures for highway materials and construction. That program was begun partly in response to criticism from a congressional committee (the Blatnik Committee) concerning inadequacies in the existing specifications for highway construction and partly from a realization that, with the increasing volume and rate of construction, old procedures and specifications based primarily on establishing target values in specifications without specifically stated tolerances were no longer viable. In many cases where tolerances were stated, they were unrealistic in that normal variability of materials and test results were not taken into account. Traditionally, dependence was placed on the skill of the engineers and builders to provide a finished product "in reasonably close conformance" to the specified value and as a result many decisions as to the acceptability of a product were left to "engineering judgement."

Robert Baker, Director of Research and Development of the BPR started the "revolution," as he put it, in 1965 by a call for the use of statistical principles in highway specifications and acceptance procedures (*67*). He established a special task force to organize and promote a national effort to develop improved specification and quality assurance procedures. This program soon became known as the effort to develop "statistical specifications" and as such it became very controversial in its early stages. The *Proceedings* of the Highway Conference on Research and Development of Quality Control and Acceptance Specifications Using Advanced Technology held in April 1965 provides insight concerning the scope of the early program (*68*). This conference was attended by representatives of the construction materials industry, state highway agencies, agencies of the federal government, universities, trade associations, the equipment industry, consultant firms, and members of county and municipal highway departments. While the need for "statistical specifications" was often debated and the application of statistical principles was controversial, there was unanimous opinion concerning the need for more rapid test methods. Other indications of the scope of the early program and the surrounding controversy are included in *NCHRP Synthesis of Highway Practice 38: Statistically Oriented End Result Specifications* (*69*) and the position paper "SOERS" issued by the Associated General Contractors (*70*). This group objected to some parts of the proposed program but strongly supported the need for more rapid testing that would permit early acceptance or rejection decisions. *NCHRP Synthesis of Highway Practice 65: Quality Assurance* also emphasized the importance of rapid tests as a part of the overall effort to improve the quality of highway construction (*65*).

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

The early and continuing national interest in the development of rapid tests is also shown by a review of the projects funded by NCHRP, a program of research on problems of national concern funded by state highway agencies. The NCHRP program has funded 13 projects related directly or indirectly to rapid testing. The project identification number, project title, and the report number for each of these projects are given in Table 7. Abstracts of these reports, based on the *Summary of Progress* through 1988 for the NCHRP program and the subsequent 1992 *Summary*, are given in Appendix C (*71,72*).

NCHRP Report 103 in this series is of particular interest since it is a comprehensive evaluation of the state of the art with respect to rapid testing and was one of the earliest projects in the NCHRP program (*73*). The relative priorities of rapid tests needed for construction control at that time were established by questionnaires to state highway agencies, and interviews with those involved in the construction of highways or the administration of such construction. The priorities for asphalt concrete were: (a) percentage of asphalt, (b) density, (c) grading, and (d) thickness in that order with the first three being of almost equal concern. For portland cement concrete, strength, air content, water content, and thickness were given top priority. This report provides an excellent evaluation of problems associated with rapid testing in all aspects of highway construction and discusses the principles of tests, some of which are still under consideration 20 years later, as well as some that since have been adopted as standards by AASHTO and ASTM. The report also contains an annotated bibliography of 105 reports published in the 1950s and 1960s. These reports are not referenced individually in this synthesis.

TABLE 7
NCHRP PROJECTS RELATING TO RAPID TEST METHODS

Project No.	Project Title	Publication No.	Publication Date
10-2	Evaluation of Construction Control Procedures	34	1967
10-2A	Evaluation of Construction Control Procedures	69	1969
10-4	Rapid Test Methods for Field Control of Construction	103	1970
10-5	Density and Moisture Content Measurements by Nuclear Methods	14	1965
10-5A	Optimization of Nuclear Density and Moisture Content Measurement Methods	125	1971
10-6	Measurement of Pavement Thickness by Rapid and Nondestructive Methods	52	1968
10-7	Potential Uses of Sonic and Ultrasonic Devices in Highway Construction	25	1966
10-8	Evaluating Procedures for Determining Concrete Pavement Thickness and Reinforcement Position	168	1976
10-12	Acceptance of Aggregates Used in Bituminous Pavement Mixtures	[a]	---
10-18	Specifying and Obtaining Entrained Air in Concrete	258	1983
10-25	Measurement of Cement and Water of Fresh Concrete	284	1986
10-25A	Instantaneous Determination of Water/Cement Ratio in Fresh Concrete	[b]	1990
10-26A	Performance-Related Specifications for Hot-Mix Asphaltic Concrete	332	1990

[a] Not published, available on loan from TRB.
[b] Published as *Research Results Digest 174*, September 1990.

FHWA RESEARCH PROGRAMS

In addition to its cooperation with and support given to the NCHRP, FHWA has conducted research on rapid tests as a major project of its Federally Coordinated Program of Research and Development and later its Nationally Coordinated Program. Studies include direct federal contracts, in-house studies and Highway Planning and Research (HPR) studies conducted by individual highway agencies. The 1990 annual progress report of the Nationally Coordinated Program of Highway Research, Development and Technology states that 80 studies relating to test development and improvement have been completed in the subject area since the early 1970s (*74*). Although speed of testing was not the major objective of all of these studies, it was a significant consideration in many. Present emphasis in this program is to develop and evaluate the components of a performance-related specification (PRS) for hot-mix asphalt concrete and a PRS for portland cement concrete pavement construction. This effort was designated as one of FHWA's High Priority Areas for 1991.

Rapid Test Series

Beginning in January 1971, FHWA issued Technical Notices on various rapid test methods found to be acceptable for process control, monitoring construction progress, or acceptance. They were issued as information to all highway agencies and the agencies were encouraged to use them where appropriate. Close cooperation was maintained with the AASHTO Subcommittee on Materials in an effort to incorporate the appropriate procedures into the AASHTO standards. A total of 15 such notices were issued. The series was discontinued in 1974. Table 8 shows a list of the titles of these notices and the dates issued. All of these methods have been considered by AASHTO and ASTM committees and a

TABLE 8
RAPID TEST NOTICES ISSUED BY FHWA

Report Number	Report Title	Date Issued
1	Sampling Fresh Concrete	January 1971
2	Cement Acceptance Procedure	June 1971
3	Infrared Aggregate Dryers	September 1971
4	Determination of Specific Gravity of Rock in Embankment Compaction Control	September 1971
5	Dry Preparation of Disturbed Soil and Soil Aggregate Sample for Test	September 1971
6	Test Method for Making and Accelerated Curing of Concrete Test Specimens	January 1972
7	Determination of R-Value (Hveem's Resistance Value) pf Aggregate Base Materials	March 1970
8	Mechanical Method of Dry Preparation of Disturbed Soil and Soil Aggregate Samples	May 1972
9	One Point Proctor-Determination of Moisture-Density Relationships Using a Family of Curves	August 1973
10	Determining Percent of Material Passing the No. 200 Sieve (New York Pycnometer Test)	August 1973
11	Rapid Test Method for Earthwork Compaction Control	February 1974
12	Rapid Drying Aggregate and Soil Samples Using a Microwave Oven	April 1974
13	Procedure for Monitoring the In-Place Density of Fresh Portland Cement Concrete	June 1974
14	Procedure for Obtaining Portland Cement Concrete Samples for Chloride Analysis	July 1974
15	Rapid Moisture Measurement Using the 200 gram "Speedy" Moisture Tester	July 1974

number have been included wholly or in part in the standards of those organizations.

Experimental Project

As a means for evaluating the usefulness of rapid tests to the state highway agencies, FHWA established Experimental Project No. 11 on Rapid Testing and Inspection Techniques in 1988. The initial effort included the following studies (the highway agency(s) performing the research is shown in parentheses).

- Ground-penetrating radar (Delaware and Wisconsin)
- Microwave oven (FHWA Western Direct Federal Division)

- Nuclear asphalt content gauge (Oregon)
- Infrared thermography (Delaware and Vermont)
- Thin-lift asphalt density gauge (Oregon)
- Creep and resilient modulus (Iowa)
- Roller-mounted nuclear density gauge (Wisconsin)

Three reports have been issued to date as a result of these projects. These are:

- Field Comparison of Infrared Thermography and Manual Survey Result by the Vermont Agency of Transportation (*75*).
- Evaluation of Ground-Penetrating Radar and Infrared Thermography by the Delaware Department of Transportation (76).
- Thin Layer Asphalt Concrete Density Measuring Using Nuclear Gauges by the Oregon Department of Transportation (*77*).

The reports by Vermont Agency of Transportation and Delaware Department of Transportation on ground-penetrating radar and thermography showed these techniques to be useful for determining the condition of pavement and bridges but both agencies found them to be more expensive than the use of their normal data collection procedures. However, improvements in these techniques are continuing.

The evaluation of the new thin-lift nuclear gauge showed some increase in accuracy for this gauge over those already available for soils or thicker base courses but the Oregon DOT concluded that the slight increase in accuracy was offset by a lack of versatility of the new gauge. More recent evaluations of new nuclear density gauges for asphalt concrete were discussed in Chapter Three.

Experimental Project No. 11 has been discontinued as a separately funded project but work is continuing as parts of other suitable projects.

HIGHWAY AGENCY PROGRAMS

Many state highway agencies have conducted their own programs for the development and evaluation of rapid test methods. Studies are usually made in cooperation with the U.S. Department of Transportation as a part of FHWA's HPR program. Major contributions of the state highway agencies are summarized in the progress reports of FHWA (*66*).

AASHTO-AGC-ARTBA JOINT COMMITTEE

AASHTO, AGC (Associated General Contractors of America), and ARTBA (American Road and Transportation Builders Association) have maintained for many years a joint committee to address problems of mutual concern. In 1972 this committee organized a task force (Task Force 14) with the stated objective "to develop and report rapid sampling and testing equipment and methods for highway materials" (*78*). This task force sent a questionnaire to each of the state highway agencies, all regional and division offices of the FHWA and also to the AGC, National Asphalt Paving Association, American Concrete Paving Association, and National Crushed Stone Association. The major objective of this survey was to identify those job control tests that caused construction delays and that needed improvement.

The questionnaire addressed five construction materials: aggregate, plastic portland cement concrete, hardened portland cement concrete; bituminous concrete mixtures and soils. Under each of these materials the generally accepted controls were listed and the following five questions were asked:

1. Is a more rapid test method needed for this determination?
2. Would a more rapid test method reduce construction delays that are now occurring?
3. Would a more rapid test method tend to improve the contractors quality control?
4. Would a more rapid test method tend to improve acceptance procedures?
5. Is a more rapid test method available that is not published in ASTM or AASHTO? If answer is yes, give reference.

The task force acknowledged that although nothing dramatic or very revealing came from the questionnaire, the responses did identify those areas of concern to the various construction disciplines. Although a few rapid test procedures of which the task force was not aware were reported, most were generally known. After evaluation, the task force referred the procedures considered to show promise of shortening the acceptance time without appreciable detriment to quality, to appropriate AASHTO, ASTM and ACI committees with the approval of the full AASHTO-AGC-ARTBA Joint Committee. This list included 14 of the tests of the Rapid Test series published by FHWA, four concrete strength tests, aggregate washing procedure, nuclear density tests for asphalt mixtures, test for specific gravity of bituminous mixtures, and the vacuum extraction test for asphalt.

The perception of the task force was that this initial effort did not reach the engineering level where knowledge of shortcut procedures was more likely to exist. Accordingly, a second questionnaire was issued and distributed to various organizations involved in highway construction. Replies were received from 231 organizations: 49 from industry, 47 from state agencies and 135 from FHWA offices. This second questionnaire included four questions.

1. What order of priority (1-9) would you assign the following for the development of rapid testing methods? The eight categories were: aggregates, plastic portland cement concrete, cements and admixtures, hardened portland cement concrete, bituminous concrete mixtures, asphalt binders, soils, and others (Specify).
2. What rapid tests would you recommend be given the most effort in order to reduce the time to obtain results?
3. Are there any material characteristics on which you would consider performing research to develop or to provide data to determine its potential for rapid testing?
4. Are you aware of any work going on in the area of more rapid testing (if yes, please identify)?

The major result from this questionnaire with respect to bituminous mixtures was recognition of the need for a faster acceptance sequence for aggregate gradings. Four other items were reported as being under study. These were: (a) the nuclear gauge for asphalt content; (b) a rapid method for separation of ingredients of asphalt mixtures in one operation; (c) the "Puzinauskas" field viscosity test for asphalt consistency; and (d) the pycnometer test for maximum specific gravity and asphalt content.

For freshly mixed portland cement concrete, the main concern was for a quicker method for assessment of potential strength development by determination of the water/cement ratio in the mixture. Items under study were reported to be: (a) the Kelly-Vail procedure for water and cement contents; (b) the Willis-Hime procedure for determining cement content; (c) the Rapid Analysis Machine for cement, water, and aggregate fractions by mechanical separation; (d) the microwave oven for determining the water content of freshly mixed concrete; and (e) nuclear gauges for determining cement content.

Task Force 14 included members representing producer organizations of both portland cement concrete and asphalt concrete, highway agencies, and the FHWA. Its activities consisted primarily of monitoring developments for rapid testing and an exchange of information among its organizational units. This included preparation of a slide presentation on Rapid Sampling and Testing Equipment and Procedures. The task force was abolished in 1990.

STRATEGIC HIGHWAY RESEARCH PROGRAM

The Strategic Highway Research Program (SHRP) is a special program authorized by Congress in 1987 to conduct intensive research in transportation areas considered to be of strategic national importance. This program includes several ongoing projects related to faster testing procedures.

At the time this synthesis was prepared, much of the outcome of this program was unpublished and final accomplishments could not be presented. However, the objectives of several ongoing projects related to asphalt concrete and portland cement concrete are listed as follows.

- Project SHRP-89-IDO21 (The Application of Small Nuclear Magnetic Resonance Spectrometer for Quality Control in Asphalt Processing) This project is studying means to measure asphalt content using Nuclear Magnetic Resonance technology. Such an instrument, if successfully developed, would be installed at the asphalt mixing plant.
- Project SHRP-89-IDO26 (Development of a Prototype Device for On-Line Measurement of Aggregate Gradation in Asphalt Plants) This project seeks to develop a prototype device to measure on-line aggregate grading (at plant) using imaging technology.
- Project SHRP-89-IDO11 (In Situ Determination of Entrained Air in Freshly Mixed Concrete) Using fiber optics, this project will develop and evaluate an instrument for in situ determination of entrained air in freshly mixed concrete.
- Project SHRP-88-C201 (Concrete Microstructure) This project is a study to develop quantitative relationships describing various aspects of microstructure of concrete that relate to its durability through modeling and experimental confirmation. A review of specifications and test methods for hydraulic cement concrete from the viewpoint of the findings of the study is included. Although no new tests have been developed, use of the data and models proposed could lead to future development of new tests and specifications.
- Project SHRP-89-C204 (Nondestructive Testing for Control and Condition Analysis) This project involves a survey of the use and interest of State and Provincial Transportation Agencies in nondestructive testing of concrete for either process control or condition evaluation. Results are discussed in Chapter Four.
- Project SHRP-C206 (Optimization of Highway Concrete Technology) This project includes an evaluation of existing test methods for process control and acceptance of concrete. Special consideration is being given to the rapid determination of water content of fresh concrete using microwave drying techniques. Another effort relates to in situ determination of the degree of consolidation/compaction of concrete prior to hardening using twin probe nuclear density gauge. Results are discussed Chapter Four.

REFERENCES

1. "Acceptance of Materials," FHWA Technical Advisory T5080.11, Federal Highway Administration, Washington, D.C. (1989).
2. D'Angelo and Ferragut, "Summary of Simulation Studies from Demonstration Project No. 74: Field Management of Asphalt Mixes," *AAPT Journal*, Vol. 60 (1991).
3. Kopac, P. A., J. D. Fernandez, S. W. Foster, and T. M. Mitchell, "Aggregate Gradation Control: Part I—An Analysis of Current Aggregate Gradation Control Problems," *Public Roads*, Vol. 46, No. 1 (June 1982).
4. Kopac, P. A., J. D. Fernandez, S. W. Foster, and T. M. Mitchell, "Aggregate Gradation Control: Part II—A Model Aggregate Gradation Control Program," *Public Roads*, Vol. 46, No. 2, Federal Highway Administration, Washington, D.C. (September 1982).
5. *NCHRP Report 34: Evaluation of Construction Control Procedures—Interim Report*, Transportation Research Board, National Research Council, Washington, D.C. (1967).
6. *NCHRP Report 69: Evaluation of Construction Control Procedures*, Transportation Research Board, National Research Council, Washington, D.C. (1969).
7. *The Investigation of Present Aggregate Gradation Control Practices and the Development of Short-Cuts on Alternative Test Methods*, Report No. FHWA-RD-77-53, Federal Highway Administration, Washington, D.C. (1977).
8. Jones, G. M., M. L. Wiley, and R. F. Smith, "Vacuum Extraction of Bitumen from Pavement Mixtures", *Rapid Test Methods for the Determination of Bitumen Content in Bituminous Mixtures*, STP No. 461, American Society for Testing and Materials, Philadelphia, PA (1968) pp. 58-66.
9. *Asphalt Content Determination Manual*, Publication No. FHWA-IP-90-008, Federal Highway Administration, Washington, D.C. (1990)
10. Martinez, J. J., and D. N. Winslow, "A Rapid Test for Asphalt Content of Bituminous Mixtures", *Journal of Testing and Evaluation*, Vol. 14, 1986, pp. 28-32.
11. Steele, G. W., and S. B. Hudson, "A Pycnometer Test Procedure for Determining Asphalt Content of Paving Mixtures", *Rapid Test Methods for the Determination of Bitumen Content in Bituminous Mixtures*, STP No. 461, American Society for Testing and Materials, Philadelphia, PA. (1969) pp. 67-85.
12. Belt, G., N. Santelli, and M. Hansen, *Evaluation of New Nuclear Density Gauges on Asphalt Concrete*, FHWA RD-90-092, Federal Highway Administration, Washington, D.C. (1991).
13. Missouri Highway & Transportation Department Division of Materials and Research, *Density of Thin Lift Bituminous Mixtures by Nuclear Methods*, (FHWA-MO-90-1), Missouri Highway and Transportation Department, Jefferson City (1991).
14. Anderson, D. A., D. A. Luhr, and C. E. Antle, *NCHRP Report 332: Framework for Development of Performance-Related Specifications for Hot-Mix Asphalt Concrete*, Transportation Research Board, National Research Council, Washington, D.C. (1990).
15. Whiting, D. A., A. Todres, M. Nagi, T. Yu, D. Peshkin, M. Darter, J. Holm, M. Andersen, M. Geiker, and G. M. Idorn, *Synthesis of Current and Projected Concrete Highway Technology*, Strategic Highway Research Program C-206. Washington, D.C. (1992).
16. Nasser, K. W. and N. M. Rezk, "New Probe for Testing Workability and Compaction of Fresh Concrete", ACI Journal, *Proceedings*, Vol. 69, No. 5 (1972) pp. 270-275.
17. Nasser, K. W., "New and Simple Tester for Slump of Concrete", ACI Journal, *Proceedings*, Vol. 73, No. 10 (1976) pp. 561-565.
18. Al-Manaseer, A. A., K. W. Nasser, and M. D. Haug, "Consistency and Workability of Flowing Concrete", *Concrete International*, October (1989).
19. Grieb, W. E., *HRB Bulletin 176: The AE-55 Indicator for Air in Concrete*, Highway Research Board, Washington, D.C. (1958).
20. Mather, B. *HRB Bulletin 176: Discussion of paper by W. E. Grieb on the AE-55 Indicator for Air in Concrete*, Highway Research Board, Washington, D.C. (1958).
21. Newlon, H. H., Jr., *HRB Bulletin 305: A Field Investigation of the AE-55 Air Indicator*, Highway Research Board, Washington, D.C. (1961).
22. Sprinkel, M. M., and B. Lee, *The Chace Air Indicator*, VHTRC 81-R37, Virginia Highway and Transportation and Research Council, Charlottesville (1981).
23. Henly, R. G., D. Malkemus, D. W. Fowler and A. H. Moyer, *Evaluation of Chace Air Indicator*, Research Report 363-2F, Center for Transportation Research, University of Texas at Austin (1984).
24. Whiting, D. A., and S. D. Tayabji, *Relationship of Consolidation to Performance of Concrete Pavements*, Report No. FHWA/RD 87/095, Federal Highway Administration, Washington, D.C. (1988).
25. Ozyildirim, C., *Evaluation of a Nuclear Gage for Controlling the Consolidation of Fresh Concrete*, VHTRC-R41, Virginia Highway and Transportation and Research Council, Charlottesville (1981).
26. Mitchell, T. M., P. L. Lee, and G. S. Eggert, "The CMD: A Device for the Continuous Monitoring of the Consolidation of Plastic Concrete", *Public Roads*, Vol. 42, No. 4, Federal Highway Administration, Washington, D.C. (1979).
27. Chapin, C. A. and R. T. Kelly, "The Analysis of Concrete", *Chemistry and Industry*, pp. 1467-1473 (1967).
28. Howdyshell, P. A., *Corps of Engineers Concrete Quality Monitor Operations Guide*, Technical Report M-293, U.S. Army Construction Engineering Research Laboratory, Champaign, IL (1981).
29. Head, W. J., and H. M. Phillippi, *State of Technology for Quality Assurance of Plastic Concrete: Phase 1—Feasibility Study*, Report No. FHWA-TS-80-242, Federal Highway Administration, Washington, D.C. (1980).
30. Head, W. J., H. M. Phillippi, P. A. Howdyshell, and D. Lawrence, "Evaluation of Selected Procedures for the Rapid Analysis of Fresh Concrete", *Cement, Concrete and Aggregates*, Vol. 5, No. 2 (1983).
31. Mitchell, T. M., *A Radioscope Backscatter Gage for Measur-*

ing the Cement Content of Plastic Concrete, FHWA RD-73-48, Federal Highway Administration, Washington, D.C. (1973).

32. Mitchell, T. M., "Measurement of Cement Content by Using Nuclear Backscatter and Absorption Gauge" in *Transportation Research Record 692*, Transportation Research Board, Washington, D.C. (1978) pp. 34-40.
33. Bickley, J. A. and P. R. Muckherjee, "Cement-Concrete Measurements with the Rapid Analysis Machine" in *Transportation Research Record 720*, Transportation Research Board, Washington, D.C. (1979).
34. Roumillac, P., R. G. Hicks, and J. P. Mahoney, *Executive Summary on Evaluation of Rapid Test Procedures for Quality Assurance of Portland Cement Concrete*, Federal Highway Administration, Region 17, Vancouver, WA (1982).
35. Hime, W. G. and R. A. Willis, "A Method for the Determination of the Cement Content of Plastic Concrete," *ASTM Bulletin No. 209,* American Society for Testing and Materials, Philadelphia, PA (1955).
36. Walker, S., D. L. Bhoem, R. D. Gaynor, and J. R. Wilson, "A Study of the Centrifuge Test for Determining the Cement Content of Fresh Concrete", *Materials Research and Standards*, Vol. 1, No. 6, American Society for Testing and Materials, Philadelphia, PA (1961).
37. Nagele, E., and H. K. Hilsdorf, "A New Method for Cement Content Determination of Fresh Concrete", *Cement and Concrete Research*, Vol. 10, pp. 23-34 (1980).
38. Williamson, G., "Methods for Determining the Water and Cement Content of Fresh Concrete", *Cement and Concrete Research*, Vol. 10, July-August, 1985.
39. Hime, W. G., B. R. Buttke, J. C. Synnot, and S. Popovics, *Instantaneous Determination of Water-Cement Ratio in Fresh Concrete*, Preliminary Draft-Final Report, Wiss Janney Elstner Associates, Inc. Northbrooke, IL (1989).
40. Tom, J. G., and A. D. Magoun, *NCHRP Report 284: Evaluation of Procedures Used to Measure Cement and Water Content in Fresh Concrete*, Transportation Research Board, National Research Council, Washington, D.C. (1986).
41. Halstead, W. J. and C. Ozyildirim, *Tests for Early Acceptance of Concrete*, VHTRC 86-R2, Virginia Highway and Transportation Research Council, Charlottesville (1985).
42. Morrison, K. P., "Evaluation of Rapid Test Procedures for Water Determination of Portland Plastic Cement Concrete," Colorado Department of Highways, Denver (1980).
43. Berry, D. H., Jr., "Laboratory Evaluation of Variability in the Kelly-Vail System for Analysis of Plastic Concrete," Illinois Department of Transportation, Springfield (1981).
44. Pederson, C. M., "Portland Cement Rapid Testing, Kelly-Vail," Oklahoma Department of Transportation, Oklahoma City (1982).
45. Beecroft, D. E., and E. L. Dominick, "Rapid Test Methods for Evaluation of Concrete Properties," Oregon State Highway Division, Salem (1982).
46. *Research Results Digest 174*, Transportation Research Board, National Research Council, Washington, D.C. (1990).
47. Naik, T. R. and B. W. Ramme, "Determination of the Water-Cement Ratio of Concrete by the Buoyancy Principle," *ACI Materials Journal*, Vol. 86, No. 1, January-February 1989.
48. Miller, R. W., "Accelerated Strength Testing of Concrete," Report FHWA-NY-78-RR55, New York State Department of Transportation, Albany (1978).
49. "Use of Accelerated Strength Testing," ACI 214.1R-81, *Manual of Concrete Testing*, American Concrete Institute, Detroit, MI (1981).
50. Ragan, S. A., "Concrete Quality Assurance Using Accelerated Strength Testing," Miscellaneous Paper SL-84-4, U.S. Army Engineer Waterways Experiment Stations, Vicksburg, MS (1984).
51. Carino, N. J., "Temperature Effects on the Strength-Maturity Relation of Mortar," NBSIR 81-2244, National Bureau of Standards, Washington, D.C. (1981).
52. Hudson, S. B., F. J. Bowery and F. T. Higgins, "West Virginia Department of Highways. Study to Refine Methods and Procedures for Implementing the Method of Early Prediction of Potential Strength of Portland Cement Concrete," Woodward-Clyde Consultants, Rockville, MD (1976).
53. *Predicting Potential Strength of Portland Cement Concrete*, FHWA-TS-78-212, Federal Highway Administration, Washington, D.C. (1978).
54. Steele, G. W. and F. T. Higgins, "Quality Assurance: A System in Practice that Works," Presented at FHWA, Region 3, Portland Cement Concrete Course, Washington, D.C., April, 1983.
55. Burnside, L. W., "A Ready Mix Contractor's Experience with Innovative Quality Control/Quality Assurance," *Focus*, Strategic Highway Research Program, Washington, D.C. (April 1992).
56. Swamy, R. N. and Al-Hamed, "Evaluation of Windsor Probe to Assess in Situ Concrete Strength," Proceedings of the Institute of Civil Engineers, Part 2, Research and Theory, Vol. 77, pp. 167-194, June 1986.
57. American Concrete Institute, "In Place Methods for Determination of Strength of Concrete," Committee Report 228-1R, *ACI Materials Journal*, Vol. 85, No. 5, pp. 446-472, (1978).
58. Khoo, L. M., "Pull-out Technique—An Additional Tool for In Situ Concrete Strength Determination," *In Situ/Nondestructive Testing of Concrete*, ACI SP-82, American Concrete Institute, Detroit, MI (1986).
59. Johansen, R. "In Situ Strength Evaluation of Concrete—The Break-Off Method," *Concrete International: Design and Construction*, Vol. 1, No. 9, pp. 45-51 (1979).
60. Whiting, D., *Rapid Determination of Chloride Permeability of Concrete*, FHWA/RD-81/119, Federal Highway Administration, Washington, D.C. (1981).
61. Mobasher, B., and T. M. Mitchell, "Laboratory Experience with the Rapid Chloride Test," *Permeability of Concrete*, STP-108, American Concrete Institute, Detroit, MI (1988) pp. 117-144.
62. R. Omran and P. H. Read, *Nondestructive Testing for Quality Control/Condition Analysis of Concrete*, SHRP-88-C204, Strategic Highway Research Program, Washington, D.C. (1990).
63. *Research and Development Program for Highway Construction Engineering Management*, FHWA-RD-90-34, Transportation Research Board, Washington, D.C. (1990).
64. *Transportation Research Circular 386: Innovative Contracting Practices*, Transportation Research Board, Washington, D.C. (1991).
65. Halstead, W. J., *NCHRP Synthesis of Highway Practice 65: Quality Assurance*, Transportation Research Board, National Research Council, Washington, D.C. (1979).
66. "Contractual Relationships: An Essential Ingredient of the

Quality-Assurance System and Other Quality-Control Papers" in *Transportation Research Record 792*, Transportation Research Board, Washington, D.C. (1981).

67. Baker, R. F., "Comes the Revolution," *Proceedings*, Highway Conference on Research and Development of Quality Control and Acceptance Specifications, Volume 1, U.S. Department of Commerce, Bureau of Public Roads, Washington, D.C. (April 1965) pp. 1-4.
68. *Proceedings*, Highway Conference on Research and Development of Quality Control and Acceptance Specifications, Volumes 1 and 2, U.S. Department of Commerce, Bureau of Public Roads, Washington, D.C. (April 1965).
69. Bowery, F. J., Jr., and S.B. Hudson, *NCHRP Synthesis of Highway Practice 38: Statistically Oriented End-Result Specifications*, Transportation Research Board, National Research Council, Washington, D.C. (1976).
70. "AGC Position, Statistically Oriented End-Result Specifications," Associated General Contractors, Washington, D.C. (1977).
71. *NCHRP Summary of Progress through 1988*, Transportation Research Board, Washington, D.C. (1988).
72. *NCHRP Summary of Progress through 1992*, Transportation Research Board, Washington, D.C. (1992).
73. *NCHRP Report 103: Rapid Test Methods for Field Control of Highway Construction*, Transportation Research Board, National Research Council, Washington, D.C. (1970).
74. "National Coordinated Program of Highway RD&T," *Annual Progress Report, 1990*, Federal Highway Administration, Washington, D.C. (1990).
75. Winters, P. C., and R. R. Frascoia, *Field Composition of Infrared Thermography and Manual Survey Result*, Report No. 88-3, Vermont Agency of Transportation, Montpelier (1988).
76. *Pavement Evaluation Using Ground Penetrating Radar and Infrared Thermography*, FHWA-EP 612, Delaware Department of Transportation, Dover (1987).
77. *Thin Layer Asphalt Concrete Density Measuring Using Nuclear Gauges*, FHWA-EP 11-003, Oregon Department of Transportation, Salem (1989).
78. "Development of Rapid Testing Procedures," Report of Task Force 14 Activity, Quality in Construction Conference, University of Texas at Austin (1978).

APPENDIX A
QUESTIONNAIRE

National Cooperative Highway Research Program Project 20-5, Topic 23-02
"Use of Rapid Test Methods for Portland Cement and Asphaltic Concrete"

AGENCY RESPONDING: ______________________
Name: ______________________
Address: ______________________
____
____

Agency Classification:
____ Government
____ Independent Laboratory
____ Producer/Contractor

PERSON TO WHOM QUESTIONS ABOUT REPLY SHOULD BE DIRECTED:

Name: ______________________
Title: ______________________
Phone: ______________________

PLEASE RETURN COMPLETED QUESTIONNAIRE TO:

(Mail) Woodrow J. Halstead
39 Tanglewood Road
Palmyra, VA 22963

(Fax) (804) 293-1990

NCHRP Synthesis Topic 23-02 Survey Agency Reporting: ______________

PART 1 - USE OR EVALUATION OF TESTS

Please indicate which of the listed tests are used or have been evaluated by your agency. For each "yes" reply complete a separate PART 2 for the tests in use, or PART 3 for the tests evaluated but not adopted for use. Also complete a PART 2 or PART 3, whichever is appropriate, for any other rapid tests used or evaluated by your agency but not listed.

ASPHALTIC CONCRETE

	YES	NO
Nuclear density (ASTM D2950)	[ ]	[ ]
Continuous monitoring device (DOR)	[ ]	[ ]
Compaction measuring robot	[ ]	[ ]
Asphalt content nuclear		
(ASTM D4125)	[ ]	[ ]
(AASHTO T287)	[ ]	[ ]
Cold feed gradations (aggregate)	[ ]	[ ]
Dry sieving (aggregate)	[ ]	[ ]
Selected sieves (aggregate)	[ ]	[ ]
Short pulse radar (ASTM D4748)	[ ]	[ ]

PORTLAND CEMENT CONCRETE

	YES	NO
Consistency		
K slump factor	[ ]	[ ]
Air Content		
Chace air indicator (AASHTO T199)	[ ]	[ ]
Fiber optics air void meter	[ ]	[ ]
Air-void distribution with laser	[ ]	[ ]
Quality by pulse velocity (ASTM C597)	[ ]	[ ]
Nuclear density (ASTM C1040)		
Direct transmission	[ ]	[ ]
Back scatter	[ ]	[ ]
Cement Content (ASTM C1078)		
Manual volumetric titration	[ ]	[ ]
Instrumental fluometric procedure	[ ]	[ ]

Part 1. Continued

	YES	NO
Water Content (ASTM C1079)		
Volumetric titration	[ ]	[ ]
Coulometric Reference Technique	[ ]	[ ]

[Note: ASTM C1078 and C1079 incorporate principles of Kelly-Vail, CQM, and RAM.]

	YES	NO
Water in fresh concrete by microwave drying	[ ]	[ ]
Aggregate drying with microwave	[ ]	[ ]
Speedy moisture tester (aggregate)	[ ]	[ ]
Strengths		
Early age tests to predict later strength (ASTM C918)	[ ]	[ ]
Strength estimate by maturity method (ASTM C1074)	[ ]	[ ]
Penetration resistance of hardened concrete (ASTM C803)	[ ]	[ ]
Rebound number - Schmidt Hammer (ASTM C805)	[ ]	[ ]
Pull-out strength (ASTM C900)	[ ]	[ ]
Break-off number of concrete (ASTM C1150)	[ ]	[ ]
Fundamental frequencies (ASTM C215)	[ ]	[ ]
Rapid chloride permeability (AASHTO T277)	[ ]	[ ]
Accelerated curing of compression test speciments (ASTM C684)	[ ]	[ ]
Use of reusable neoprene compression specimen end caps (AASHTO T22 - annex)	[ ]	[ ]

PART 2 - TEST METHODS IN USE

(Please copy sheets as necessary and use a separate sheet for each test method)

Test identification (as in Part 1): ____________________

If test is not listed in Part 1, please provide the following:

Material tested: ____________________

Property tested for: ____________________

Year adopted for use: ____________________

Brief description of procedure and principles involved (published reference if available):

Status of present use (Check appropriate box(es))

A.	Test and limits are specified and materials or products are accepted or rejected based on results.	[ ]
B.	Test used for screening or triggering other tests. Results used only in acceptance and not in rejection. Standard test required for rejection.	[ ]
C.	For process control only	[ ]
D.	Other (state reason for use)	[ ]

Approximate time for a test result: ____________________
Approximate number of results in day: ____________________
Approximate cost per test: ____________________
Approximate cost of unit test equipment:____________________

Part 2. Continued

Advantages of method:

Disadvantages of method:

Other Comments: (Please include any minor deviations or special variations from standard methods)

Part 3 - TEST METHODS EVALUATED BUT NOT ADOPTED FOR USE

(Please copy sheets as necessary and use a separate sheet for each test method)

Test identification (as in Part 1): _______________________________

If test is not listed in Part 1, please provide the following:

Material tested: ___________________________
Property tested for: ___________________________
Year adopted for use: ___________________________

Brief description of procedure and principles involved (published reference if available):

Reason(s) for not using test: (Check appropriate box(es))

A. Insufficient precision or accuracy [ ]

B. Equipment too costly [ ]

C. Reagents or procedures hazardous [ ]

D. Overall time saved not sufficient [ ]

E. Calibration too difficult or time-consuming [ ]

F. Training of operators too difficult [ ]

G. Other (please explain) [ ]

Comments:

APPENDIX B
RESULTS OF QUESTIONNAIRE ON USE OF RAPID TEST METHODS BY HIGHWAY AGENCIES

This appendix summarizes the information supplied by replies to the questionnaire, Appendix A, which was sent to all states of the United States and provinces of Canada. In addition, it was sent to several private laboratories involved in testing or research on materials used in construction of highways or other transportation structures. Replies were received from 45 states, 3 provinces of Canada and 1 private organization.

The summary of the replies from each state and province regarding the procedures evaluated and in use or rejected has been shown for asphalt concrete in Table 2 and for portland cement concrete in Tables 3 and 4. The following, more detailed discussion of the principles of each method and the replies regarding each is provided. Please note that the sum of the agencies making use of the methods or rejecting their use often exceeds the number of agencies because of multiple replies by the same agency.

PART A—ASPHALT CONCRETE

DENSITY OF ASPHALT CONCRETE IN PLACE (NUCLEAR METHODS)

Principle of Method:

Density is determined by measuring the attenuation of gamma radiation with a nuclear gauge. Either the backscatter or direct transmission procedure may be used. Gauge readings must be correlated with density determinations of cores or sections of asphalt concrete cut from the pavement.

Standardization:

The procedure is standardized by ASTM as Method D 2950. AASHTO does not have an equivalent procedure but recognizes D 2950 as an alternative procedure for determining the degree of pavement compaction of bituminous aggregate mixtures in AASHTO T230. A number of states also have their own standard procedures. The principles of these methods are the same as those of ASTM D 2950.

Extent of Use:

Forty agencies report having evaluated the procedures and thirty-eight indicate use in some manner. Two agencies reported that they were not now using the procedure.

Reasons for Use or Rejection:

Twenty-nine agencies indicated use for accepting or rejecting materials or for determining the extent of pay adjustment for deviations from specified tolerances from target percentages of compaction. Three agencies state that the nuclear result was used to trigger another standard test when deviations were large and seven indicated that the gauge was used in process control to indicate the progress in compaction. One agency indicated that use of the gauge had been recommended but not yet adopted. Of the two agencies indicating rejection one indicated that it had not evaluated modern gauges and another indicated that a number of contractors in the state used their own gauges to determine the rolling pattern to meet density requirements but the SHA made no use of the gauges. Both cited lack of precision and accuracy as a reason for rejection.

Advantages Cited:

Even though some cores must be taken for calibrating the instrument, all agencies recognized the great overall advantage of speed of the test compared to the cutting of cores and measuring densities for all lots. The ability to obtain indications of relative density (percentage of compaction) both as a guide to rolling patterns and the opportunity to make corrections while the mixture is still hot was listed as an advantage by most agencies.

Disadvantages Cited:

The special handling and storage procedures for the radioactive materials and the need to monitor personnel for exposure to radioactivity were cited as the major disadvantages. Problems caused by underlying layer density and surface voids, and the variability from gauge to gauge were cited as affecting accuracy.

Time and Costs per Tests:

A relatively wide range of estimates for time and cost of tests were given. Time estimates ranged from 2 minutes per test to 25 minutes with most estimates being about 5 minutes. The number of tests per day ranged from 27 to 50 with a median of about 30. Cost per test ranged from $17 to $100. An estimate of the median is $20. Reported cost of the gauges varied from $2,500 to $7,000, most likely based on the model of the gauge and the time purchased. Most reported costs of $5,000.

CONTINUOUS MONITORING OF DENSITY OF ASPHALT CONCRETE BY NUCLEAR GAUGE

Principle of Method:

The density of asphalt concrete is continuously monitored by a backscatter nuclear gauge during compaction. The gauge is mounted on the roller.

Standardization:

No specific standard by ASTM or AASHTO. The principle of the gauges used is essentially the same as that for ASTM D 2950.

General Summary:

Only two states reported having used this procedure. One indicated rejection because of poor precision, the other recognized the speed and convenience but cited the need for specially trained roller operators. The required paperwork because of the use of the radioactive material was also considered a disadvantage. The recent development of these devices apparently accounts for the lack of evaluation and greater use is expected as newer instruments become available.

COMPACTION MEASURING ROBOT

General Situation:

This is an automated device recently developed in Japan. However, no agency reported evaluations of this instrument in the U.S. or Canada.

ASPHALT CONTENT USING A NUCLEAR GAUGE

Principle of Method:

Asphalt content is determined with a nuclear device that uses neutron thermalization techniques. Calibration curves with samples of known asphalt content must be constructed. A different calibration is required for each source of asphalt or aggregate.

Standardization:

Both ASTM and AASHTO have standard methods. These differ in some respects, but they are both based on the neutron thermalization principle. The ASTM method is D 4125 and the AASHTO method is T287.

Extent of Use:

Thirty-three agencies indicated evaluation with twenty-one indicating acceptance for some purposes and twelve indicating rejection.

Reasons for Use or Rejection:

Fifteen agencies indicate use for acceptance or pay adjustment; one uses it to indicate need for standard tests, and five for process control. One agency has used the method only in a research project and one uses the test for information only. Of the twelve agencies indicating no use at present, four cited the need to run extractions of the mixture for grading anyway; thus, the nuclear result did not save significant time. Two indicated the calibration procedures took too long and four agencies indicated that evaluations were in progress. Two indicated an intention to adopt in the near future.

Advantages Cited:

Twenty-three agencies cited the speed of the determination as a principal advantage. Ten agencies also cited the elimination or significant reduction in the use of toxic solvents as a major advantage. Better accuracy than the standard method was cited by eight agencies. One agency indicated that the use of the nuclear procedure freed a technician for other duties.

Disadvantages Cited:

The time required for calibration and the need to recalibrate if the asphalt or aggregate were changed were cited as disadvantages, as were the problems associated with personnel monitoring for radiation exposure and the licensing procedures for using nuclear material. Problems of inaccuracies when reclaimed asphalt pavement was used in the mixture were reported. Since gauge response is related to the presence of hydrogen, any water in the mixture creates errors. The need for an extraction of the aggregate from the mixture to obtain its grading was also cited as a reason for not using the method because asphalt content could be determined with no extra time.

Time and Cost per Test:

The reported time for testing varied from 5 minutes to 60 minutes, with the consensus being about 10 minutes. Tests per day were often interpreted as being the number of tests actually made by the agency rather than the number possible. Responses varied from 2 to 30 with most indicating about 20 tests being easily run in a day if needed. Reported costs per test varied from \$3 to \$54 with the approximate median being about \$30. Reported equipment costs varied from \$4,500 to \$7,000.

COLD FEED GRADINGS

Principle of Method:

This procedure involves the sampling of aggregate after blending for the mixture production from the cold feed conveyor belt. It often is assumed that the grading so determined is sufficiently precise to represent the grading of the aggregate in the asphalt concrete mixture. Thus, extraction of asphalt from the mixture can be eliminated or used only as occasional "spot checking" for accuracy.

Standardization:

None. Each agency establishes its own sampling procedure to assure a representative sample. Grading is done using standard AASHTO or ASTM methods.

Extent of Use:

Twenty-nine agencies indicated evaluations. Twenty-four reported use and five indicated rejection.

Reasons for Use or Rejection:

Fifteen agencies indicated use for acceptance as grading of the aggregate in the mixture and nine indicated use in process control. Two agencies reported its use for research purposes or information only. Of the five agencies indicating rejection, three indicated insufficient precision and accuracy citing sampling problems or problems relating to break down of aggregate particles during the mixing process. One other indicated that aggregate grading was no longer a requirement for acceptance and another indicated continuing evaluation.

Advantages Cited:

The chief advantage cited was the elimination of the extraction of the asphalt from the mixture and the faster, more timely, results obtained that allowed for faster adjustments when required. The advantage of eliminating or reducing the use of toxic solvents with the accompanying difficulties of disposing of used solvent was also frequently cited.

Disadvantages Cited:

The fact that the sampling of the aggregate occurred prior to the final handling was cited as the principal disadvantage. A number of agencies specifically mentioned that total fines were not always determined, because of possible introduction of bag-house fines in the mixture. Difficulty in obtaining a representative sample, and the inability to use the procedure when reclaimed asphalt is being used in the mixture were also cited.

Time and Costs of Tests:

Reported times for making the test varied from 15 minutes to 2 hours with the average being about 1 1/2 hours. The time was reported as being greatly dependent on the amount of drying required to remove any moisture present. Only a few agencies estimated costs per test. These estimates varied from $15 to $150. The median was about $40. Equipment costs were related to cost for sieves and shaking units. These varied from $300 to $1,000.

DRY SIEVING

Principle of Method:

This method refers to the practice of not washing and drying the aggregate sample prior to sieving. It is used primarily for evaluating stockpiles but may also be used when setting up the JMF.

Standardization:

None. In effect, this procedure represents a shortcut method and its use often depends on the type and source of aggregate involved.

Extent of Use:

Eighteen agencies reported evaluating the procedure with fifteen making some use and three rejecting.

Reasons for Use or Rejection:

Ten agencies reported using this procedure for process control. Three reported use in accepting stockpile material only and four used the procedure to accept materials or to indicate a need for the wet test. Those using the test for acceptance generally established a correction factor for material passing the No. 200 sieve by periodic wet sieving. Three agencies rejected the procedure as inaccurate. The only non-governmental agency replying to the questionnaire reported comparative tests with wet sieving and cited the inaccuracy of the dry sieving, especially with respect to the amount of material passing the No. 200 sieve.

Advantages Cited:

The time saved by not washing and by eliminating the need to dry the aggregate after washing is the sole advantage for this procedure.

Disadvantages Cited:

The failure to provide accurate determinations of the material passing the No. 200 sieve is the principal reason for not using this procedure.

Time and Costs per Test:

The reported time for test ranged from 1 hour to 6 hours, the typical response being 1 hour. The number of tests per day were reported to vary from 2 to 4. This apparently refers to the number of tests normally made rather than the number possible. Cost per test was often not estimated. Generally when estimated, it was given as $25-$50. Estimates of equipment cost varied from $700 to $8,000 with most being in the $1,000 to $4,000 range.

SELECTED SIEVES

Principle of Method:

To shorten the time of test, grading is conducted for critical sieves only.

General Summary:

Three agencies reported some use of this procedure for process control. The advantage cited was the time saved. The disadvantages were that the complete grading is not attained, thus, errors may occur.

SHORT-PULSE RADAR

Principle of Method:

The test determines the thickness of bound pavement layers using short-pulse radar. The layer thickness is related to the time required for the pulse to travel through the layer and be reflected back to the radar equipment. Dielectric constants of the underlying layer must be different from that of the layer where thickness is being measured.

Standardization:

The method is standardized as ASTM D 4748.

General Summary:

No agency reported evaluation of this procedure.

PART B—PORTLAND CEMENT CONCRETE

K-SLUMP FACTOR

Principle of method:

The k-slump tester consists of a hollow tube with standardized holes and slots and a plunger that fits into the tube. To measure the consistency, the k-slump tester is pushed vertically into the concrete, to the depth controlled by a disk attached to the tube. After 1 minute the plastic plunger is lowered slowly until it rests on the surface of the mortar that entered the k-slump tube. The k-slump factor is read from the calibrations on the plunger. Workability is measured from the same scale after the plunger is raised, the tester removed from the concrete and the plunger again lowered to the level of the mortar retained in the tube.

Standardization:

None. Equipment manufacturer's procedures are used.

General Summary:

Only seven agencies indicated having evaluated this method. Five reported rejection because of poor precision and accuracy. One agency reported use as a means of indicating a need for the slump test by testing the material in the truck, the advantage being a rapid indication of acceptability of the truck, with the disadvantage being that the operator had to reach into the truck. One agency indicated recent acquisition of the equipment but no evaluation as yet.

CHACE AIR INDICATOR

Principle of Method:

The approximate air content of concrete is determined by displacing air in a small volume of mortar with alcohol. The change in the level of the liquid in the graduated portion of the indicator is a measure of the air content.

Standardization:
The method is standardized as AASHTO T199 but there is no ASTM method.

Extent of Use:
Twenty-two agencies indicated evaluations. Thirteen reported some use and nine reported rejection.

Reasons for Use or Rejection:
One agency reported use for acceptance of the concrete based on the average of 3 tests and another reported its use in acceptance for Class B or incidental concrete only. One agency indicated it was in the process of evaluation. All others used the test for information only as an indication of the load-to-load uniformity and of the need for standard test (pressure meter or volumetric method). Eight agencies indicating rejection cited poor precision and accuracy as the reason. The other agency indicating rejection stated that the procedure was not used for specification compliance.

Advantages Cited:
Speed of testing was cited by most agencies as the principal advantage. Some referred to the equipment being light and easy to clean with low cost.

Disadvantages Cited:
The possibility of inaccurate results unless standardized and the possibility of erratic results because of non-representative samples were the principal disadvantages cited.

Time and Cost of Tests:
The time for making a test was generally reported as being 5 minutes. Cost per test was given from 5 cents to $1. Equipment cost was estimated as varying from $15 to $200 with most being $20 to $30.

FIBER OPTICS AIR VOID METER

Principle of Method:
Air bubbles are detected by measuring changes in the intensity of light transmitted through a thin optical filter. The changes occur due to difference in the index of refraction between an air bubble and concrete. The apparatus converts the indications of the intensity changes into electrical current and a digital signal. Data are then transferred to a lap-top computer which is programmed to indicate the air content.

General Summary:
Only one agency reported any involvement with this device. That agency worked with the SHRP contractor developing the equipment, but indicated a need for more testing before commenting on its suitability.

AIR VOID DISTRIBUTION WITH LASER

Principle of Method:
A core is drilled from frozen fresh concrete, and a laser beam is bounced off the core surface. Changes in the reflected light provide a measure of the air void distribution.

General Summary:
No agency reported evaluating this procedure.

QUALITY BY PULSE VELOCITY

Principle of Method:
Pulses of compression waves are generated by an electro-acoustical transducer and pulses traversing through the concrete are received and converted to electrical energy by a second transducer. The method is used to assess the uniformity and quality of the concrete.

Standardization:
The procedure is standardized as ASTM C 597. There is no comparable AASHTO standard.

General Summary:
Only five agencies reported evaluating this procedure. Two indicated that use is limited to evaluations where conventional methods cannot be used, and for indicating the limits of poorly consolidated concretes. Three rejected its suitability for acceptance testing.

DENSITY OF HYDRAULIC CEMENT CONCRETE BY MEANS OF A NUCLEAR GAUGE

Principle of Method:
The in-place density of fresh or hardened concrete is determined by gamma radiation. It may be used in backscatter or direct-transmission mode.

Standardization:
The procedure is standardized as ASTM C 1040. There is no equivalent AASHTO standard.

Extent of Use:
Nine agencies reported evaluating this procedure. One reported rejection.

Reasons for Use or Rejection:
Five reported the use for acceptance or rejection of special high density concrete. The other three indicating acceptance did not state the type of concrete for which the procedure is used. The agency rejecting use indicated hazardous materials as the reason.

Advantages Cited:
The speed of the test, which enables determination of the density before the concrete hardens, is the principally cited advantage.

Disadvantages Cited:
The principal disadvantages cited are the high cost of the equipment and the training required for handling the radioactive equipment. Calibration curves also must be frequently adjusted. Gauge variability sometimes affects results.

Time and Cost per Test:
Reported times to make the test varied from 5 minutes to 30 minutes with most being around 15 minutes. Cost of equipment estimates varied between $4,000 and $5,000.

CEMENT CONTENT OF PORTLAND CEMENT CONCRETE

Principle of Method (as adopted by ASTM):
A mass of freshly mixed concrete is washed with a given volume of water over a nest of sieves. The water is agitated so that

the cement and other fine particles washed from the concrete are uniformly suspended. A constant volume representative sample of the suspension is obtained and diluted with a known volume of nitric acid and water. The calcium ion concentration is determined by one of two titration methods and is correlated with the cement content of the sample by means of a previously developed calibration curve.

Standardization:
The ASTM procedure is standardized as C 1078. There is no equivalent AASHTO standard procedure.

General Summary:
Only five agencies reported having evaluated this equipment. One uses the procedure for triggering the need for other tests and four rejected its use. One cited poor precision and accuracy, another indicated the equipment to be too costly, and the third indicated previous evaluation a long time ago but no use.

WATER CONTENT OF FRESHLY MIXED CONCRETE

Principle of Method (as adopted by ASTM):
A given mass of freshly mixed concrete is intermixed with a sodium chloride solution of given concentration and volume. The chloride concentration of the intermixed solution is directly related to the water content of the concrete sample and is determined by volumetric titration or coulometric reference techniques.

Standardization:
The procedure is standardized as ASTM C 1079. There is no equivalent AASHTO method.

General Summary:
Only two agencies reported evaluating this method. Both rejected its use. One indicated that the equipment was too costly and the other cited insufficient precision and accuracy.

WATER IN FRESH CONCRETE BY MICROWAVE DRYING

Principle of Method:
The total water in fresh concrete is determined by drying a known mass of the concrete in a microwave oven. Water cement ratio is estimated by assuming that the mass of cement added is correctly indicated by the recorded amounts.

Standardization:
None

General Summary:
Only two agencies reported evaluation of this procedure. One rejected its use because of insufficient precision or accuracy. The other indicated possible use for determining the need for other tests. The length of time to complete the test, estimated at 30-45 minutes was cited as a disadvantage. Cost of equipment was estimated at $350.

MOISTURE CONTENT OF AGGREGATE USING MICROWAVE OVEN (applies to aggregates for both portland cement concrete and asphalt concrete)

Principle of Method:
Drying is accomplished by heating a given mass of aggregate in a microwave oven in lieu of conventional ovens or hot plates.

Standardization:
Use of the microwave oven is one option given in AASHTO T255. Some agencies have their own standard procedures.

Extent of Use:
Seven agencies reported evaluations. Four make use of the procedure and three indicated rejection.

Reasons for Use or Rejection:
Three agencies report use for process control and one as an indication of need for additional testing. One agency cited poor precision or accuracy as the reason for rejection and the other two indicated the time saved was insufficient to make the use of the procedure cost effective.

Advantages Cited:
All agencies accepting the procedure cited greater speed of drying.

Disadvantages Cited:
The chief disadvantage cited was the danger of disintegration of certain iron-bearing aggregates during the test and the possibility of changing the properties of aggregates from which pore water is removed. The need to exercise care to always assure a clean door closure to avoid microwave leakage was also cited.

Time and Costs per Test:
Time for drying depends on the water content of the aggregate. It was usually estimated at 20 to 30 minutes. Approximately 15 tests per day were estimated. Cost estimates varied from 5 cents to $10 per test. Equipment cost varied from $200 to $1,000, depending on the size and type of microwave used.

SPEEDY MOISTURE TESTER (fine aggregate)

Principle of Method:
The water in aggregate is determined by mixing a mass of aggregate with calcium carbide in a closed system and measuring the pressure created by the acetylene produced by the reaction. The gas pressure is related to the water content by calibration with materials of known water content.

Standardization:
The procedure is standardized as AASHTO T277.

Extent of Use:
Twenty agencies have evaluated the procedure. Thirteen make some use and seven indicated rejection. Use is for water content of fine aggregate for concrete.

Reasons for Use or Rejection:
The test is used exclusively in process control and as an indication of the need for additional tests, usually for fine aggregates

in concrete batching plants. Poor precision and accuracy, costly equipment, hazardous reagents, and insufficient time saved are all cited as reasons for rejecting the procedure.

Advantages Cited:

The speed of the test is the principal advantage cited. The ability to make the test when a hot plate or other source of energy is not available was also cited.

Disadvantages Cited:

Difficulty in selecting a representative sample because of small sample size. The reagent, calcium carbide, may not be readily available in small quantities. The reaction product is a potentially hazardous gas.

Time and Costs per Test:

Estimates of time for the test ranged from 5 to 15 minutes, with an average of about 10 minutes. Cost per test varied from 2 cents to $5 with the median being about $2. Estimates of equipment cost ranged from $180 to $2,000, with a median of about $1,000.

ACCELERATED CURING AND TESTING CONCRETE FOR COMPRESSIVE STRENGTH

Principle of Method:

Any one of four different procedures is used for accelerating the strength development in concrete specimens. Test results must be correlated with strengths of specimens cured under standard conditions.

Standardization:

The procedures are standardized under ASTM C 684.

Extent of Use:

Eight agencies reported evaluations. Four make some use of the procedure and four indicated rejection.

Reasons for Use or Rejection:

Three agencies use the test as an indication of need for standard tests or for process control only. One reported using the procedure only in special cases where project restraints did not provide sufficient time for mixture design acceptance. Results are always followed by standard tests. Agencies rejecting the procedure cited poor precision, costly equipment, and difficulty in calibration.

Advantages Cited:

The tests permit early evaluation of concrete strengths and allow adjustment before large volumes of concrete are placed when potential problems are indicated.

Disadvantages Cited:

Predictions are generally higher than actual 28-day strengths.

Time and Costs per Test:

Estimates provided were 24 hours per test with 4 to 6 tests per day. No estimates of cost were provided.

EARLY AGE COMPRESSIVE TEST VALUES FOR PREDICTING LATER AGE STRENGTHS

Principle of Method:

Predictions of 28-day strengths are made from early-age tests for which the maturity index is calculated. The prediction is based on establishing the "strength versus log maturity" relationship for the specific concrete mixture under test.

Standardization:

The procedure is standardized by ASTM C 918. There is no equivalent AASHTO standard.

Extent of Use:

Seven agencies indicated evaluations. Four indicated some use and three indicated rejection.

Reasons for Use or Rejection:

One agency uses the procedure for concrete acceptance. Two use it for process control and another for triggering the need for further tests. Poor precision and accuracy was cited by one agency as the reason for rejection and the need for special training of technicians as another reason. The other indicated completed research but no use at the present time.

Advantages Cited:

Provides early knowledge of potential problems, and thus, avoids placement of large amounts of unsuitable concrete.

Disadvantages Cited:

Requires calibration for each concrete mixture. Predictions are not 100 percent accurate.

Time and Cost per Test:

Time of test depends on when the agency breaks the test cylinders. This may range from 24 hours to 14 days. Calibration requires at least 28 days. Costs per test are about same as conventional procedures. No special equipment is purchased, so estimates were not provided.

STANDARD PRACTICE FOR ESTIMATING CONCRETE STRENGTH BY THE MATURITY CONCEPT

Principle of Method:

Concrete strength is estimated by the temperature-time factor or in terms of the equivalent age at a specified temperature. The strength-maturity relationship is developed by laboratory tests on the concrete to be used.

Standardization:

The procedure is standardized in ASTM C 1074.

Extent of Use:

Eleven agencies indicated evaluations with four indicating some use. Seven agencies rejected the procedure for acceptance tests.

Reasons for Use or Rejection:

One agency reported use only in a research project and the others use it as an indication of need for further tests. Four agencies indicated poor precision and accuracy as one reason for rejection. Three indicated evaluations were being made but no acceptance to date. Costly equipment and difficult training were also cited.

Advantages Cited:

The possibility of early age acceptance is the major advantage cited. This may have special application for "fast track" construction.

Disadvantages Cited:
Extensive correlations required.

Time and Costs per Test:
The only estimate provided was 6 to 24 hours per test. Cost of equipment was indicated as $5000.

PENETRATION RESISTANCE OF HARDENED CONCRETE (WINDSOR PROBE)

Principle of Method:
The depth to which a probe or pin penetrates into concrete when driven by a known amount of energy is measured. The depth is related to the concrete quality.

Standardization:
The procedure is standardized as ASTM C 803.

Extent of Use:
Fourteen agencies indicated evaluations. Five indicated some use and nine indicated rejection.

Reasons for Use or Rejection:
Test is not used for acceptance. When used, it is usually for information as part of an investigation, often to outline areas of nonuniformity. Insufficient accuracy or precision is the primary reason cited for rejection.

Advantages Cited:
The test provides nondestructive and rapid estimates of uniformity and strength (when comparison with known strength is available).

Disadvantages Cited:
Correlations with compressive strengths are poor. Use of equipment is hazardous. Results are dependent on the type of aggregate.

Time and Cost per Test:
Estimates of time for test varied from 10 to 30 minutes. Eight to ten tests per day were estimated. The cost per tests estimates ranged from $12 to $20. Equipment costs were estimated from $690 to $2000.

REBOUND NUMBER (SCHMIDT HAMMER)

Principle of Method:
A steel hammer strikes a steel plunger in contact with the concrete surface. The amount the hammer rebounds is related to the quality of the concrete.

Standardization:
The procedure is standardized as ASTM C 805.

Extent of Use:
Thirty-three agencies indicated evaluations. Twenty-two cited some use of the method and eleven indicated rejection.

Reasons for Use or Rejection:
Procedure is not used for acceptance. The principal uses cited were for information in investigations to compare different sections of same concrete. The test was reported to be used as a basis for opening new concrete to traffic or removing forms. Poor precision and accuracy as an indication of strength were generally reported as the reason for not using the test for this purpose.

Advantages Cited:
The ability to obtain a quick nondestructive result as a general indication of quality was cited as the major advantage. Comparisons between concretes of unknown quality and those of known quality offer valuable information.

Disadvantages Cited:
Poor correlations with strength if used for that purpose. Aggregate particles can affect results. Calibration of hammer is difficult.

Time and Cost per Test:
Estimates of time per test run from 1 minute to 45 minutes with the median being about 15 minutes. The number of tests to be run was generally indicated to be as needed, or unlimited. The cost per test was not estimated but should be very low. The only equipment cost estimate was $500.

PULL-OUT STRENGTH

Principle of Method:
The force required to pull out a metal insert placed in the concrete at the fresh stage is correlated with other strength test results. Correlation is necessary for each different mixture.

Standardization:
The procedure is standardized as ASTM C 900.

General Summary:
Only two agencies reported evaluation of the procedure. Both indicated insufficient precision and accuracy. Problems with the equipment were also cited.

BREAK-OFF NUMBER OF CONCRETE

Principle of Method:
Tubular disposal forms are inserted in the fresh concrete. During testing the inserts are removed and the concrete is broken off at the bottom by applying a force to the top and at right angles to the axis of the core. The break-off number is related to the flexural strengths of the concrete.

Standardization:
The procedure is standardized as ASTM C 1150.

General Summary:
Two agencies indicated evaluation. Both cited insufficient precision and accuracy and equipment problems as reasons for rejection.

FUNDAMENTAL TRANSVERSE LONGITUDINAL AND TORSIONAL FREQUENCIES

Principle of Method:
A variable frequency audio oscillator is used to create vibrations in the specimen. The fundamental frequencies are determined by

observing the frequency at maximum well-defined peaks on the indicator.

Standardization:
The procedure is standardized as ASTM C 215.

Extent of Use:
Seven agencies reported evaluation. Six indicated use and one indicated rejection.

Reasons for Use or Rejection:
Five agencies reported use for acceptance. Two of these reported that the principal use was for the evaluation of chemical admixtures. The agency reporting rejection for process control indicated some experimental use for problem solving.

Advantages Cited:
Simplicity of operation and speed of results with good repeatability were cited.

Disadvantages Cited:
None.

Time and Costs per Test:
Time of test was estimated as being from 3 minutes to 15 minutes. Most were in the 10 to 15 minute range (3 of 4 replies).

Only one agency estimated cost per test. This was $5. Cost of equipment estimates were $1200 and $2000.

RAPID CHLORIDE PERMEABILITY

Principle of Method:
The relative resistance to penetration of chloride ions into concrete is related to its electrical resistance, as indicated by the coulombs passing through the test specimen in 6 hours at a potential difference of 60 volts DC.

Standardization:
The procedure is standardized as AASHTO method T277 and ASTM Method C 1202.

General Summary:
Twelve agencies reported evaluations. Eight reported some use but only one reported use of the procedure for acceptance testing. The test is used primarily for investigations and information. It is rapid only in that it provides a measure of relative permeability of the concrete in 6 hours. Results with this test have been correlated with the 90-day ponding test but the relationship is not precise. Three indicated poor precision and accuracy as a reason for rejection and the fourth indicated that it was evaluating the procedure for possible future use.

USE OF REUSABLE NEOPRENE COMPRESSION SPECIMEN END CAPS

Principle of Method:
Reusable neoprene caps are used on compressive strength cylinders in lieu of capping specimens with sulfur prior to testing.

Standardization:
The procedure is included in the annex to AASHTO method T22 for 6-in. by 12-in. cylinders. However, use is also being made by a number of agencies with 4-in. by 8-in. cylinders.

Extent of Use:
Thirty-two agencies indicated evaluation with twenty-eight making use of the procedure and four rejecting its use.

Reasons for Use or Rejection:
Essentially all agencies that use the procedure use the results of this test for specification compliance. Two agencies rejected the procedure because the specimens with caps would not fit into their testing machines. Two others noted considerable differences from results obtained with sulfur-capped specimens and rejected use of the pads. One agency is continuing research for possible use and another cited use only in situations where insufficient time was available to use sulfur caps.

Advantages Cited:
Safety from not having to use molten sulfur and faster results are the major reasons cited for use. Increased efficiency of laboratory operations was also cited.

Disadvantages Cited:
Cylinders have tendency to shatter and not have usual type of break. Comparison of results with those for sulfur-capped specimens indicate deviations when strengths are below 2,000 psi or above 6,000 psi. Agreement is reported as good in 2,000-4,000 psi range.

Time and Cost per Test:
Times of tests were reported ranging from 2 to 15 minutes. However, the time saved by not capping with sulfur was reported to be about 2 hours. Tests per day were estimated at 30 to as high as 300, the approximate median being 100. Estimates of costs per test ranged from 11 cents to $23. Thus obviously different bases were used for the estimates. Low costs apparently applied only to the cost of the neoprene pads. Costs of steel caps were estimated as ranging from $50 to $170.

APPENDIX C
SUMMARY OF NCHRP PROJECTS RELATED TO RAPID TEST METHODS

[Abstracted From *Summary of Progress* 1988 and 1992 (*71,72*)]

Project 10-2 FY '64
Report 34: Evaluation of Construction Control Procedures Interim Report (1967)

This research was initiated to obtain basic information for the formulation of standards for evaluation and acceptance of work, materials, and highway construction. Its objectives included a study to determine variations inherent to measurement methods, testing techniques, and sampling methods and procedures. The scope of this study was confined to the examination and investigation of the grading of aggregates. It includes a review of measurement and test procedures to determine those not including precision statements and a study involving statistical techniques for evaluating grading test procedures, sampling methods, and variations inherent in aggregate grading.

Project 10-2A FY '65
Report 69: Evaluation of Construction Control Procedures—Aggregate Gradation Variations and Effects (1969)

This project is a continuation of Project 10-2. The research conducted specifically considered (1) the variations in grading of aggregates including fine aggregates, drawn from the bins of operating hot-mix plants, with sampling error, short and long term variations, and the effect of cold-feed variations to be included; (2) a statistically designed experiment to determine the effect of variation in grading of coarse aggregate, within the range found to be inherent under existent controls, on the strength and workability of laboratory-prepared concrete; (3) the effect of increment size with respect to maximum particle size and accuracy of the results of sampling to provide additional information as to the shape and minimum capacity of tools to be used for sampling coarse aggregates; and (4) further study of the basic pattern of variation of grading.

Project 10-4 FY '64 and FY '65
Report 103: Rapid Test Methods for Field Control of Highway Construction (1970)

The study sought out areas in which rapid test needs are most critical and summarized existing knowledge in these areas with the ultimate aim of accelerating the development of new methods.

Work in the initial phase of this project consisted of a survey of the state of the art in the development, need, and use of rapid test methods for field control of construction.

Emphasis was placed on further development and evaluation of improved test procedures in the areas of asphalt content of bituminous paving mixtures, density of aggregate base courses and bituminous layers, grading of aggregates, and soil compaction.

Project 10-5 FY '64 and FY '65
Report 14: Density and Moisture Content Measurements by Nuclear Methods—Interim Report (1965)

The objectives of this initial research were (1) to review the literature and other available data to determine what has been done by others in the evaluation and correlation of nuclear equipment, (2) to evaluate and analyze assembled data considering such factors as accuracy and precision, and (3) to make recommendations for the development of needed equipment.

Report 43: Density and Moisture Content Measurements by Nuclear Methods (1967)

This report resulted from the continuation of project 10-5. The objective was to investigate, in depth, the promising findings from the initial research. Theoretical investigations were supplemented by field experiments to establish a technique for calibrating nuclear gauges to provide improved accuracy in the measurement of soil moisture content and density. In the pursuit of these objectives, calibration standards were developed which are applicable to nuclear gauges currently in use.

Project 10-5A FY '68
Report 125: Optimization of Density and Moisture Content Measurements by Nuclear Methods (1971)

The essential objective of this study was to optimize nuclear gauge calibration methods and thus improve operational performance of the gauges for control of moisture and density during construction of highway subgrade, subbase, and the base components. The objectives of the research have been met. Procedures have been developed for optimization of nuclear backscatter-type density gauge calibration, a quantity factor approach has been developed for evaluation the over-all performance of density gauges, and a tentative model is available for improved calibration of nuclear moisture gauges. The research has also provided a basis for design of even better nuclear backscatter-type density gauges.

Project 10-6 FY '64 and FY '65
Report 52: Measurement of Pavement Thickness by Rapid and Nondestructive Methods (1968)

Present methods of measuring the thickness of highway pavements are time consuming and generally do not provide data early enough for the contractor to alter operations so as to comply. It is recognized that a nondestructive technique would be advantageous, both cost and time-wise, in comparison to present methods. In initiating this research, four objectives were outlined. They included: (1) a study of all past and present methods of measuring thickness of highway pavements to determine if any existing method may be suitable; (2) a feasibility study of proposed methods now under development; (3) proposals for other feasible methods; and (4) recommendations for promising methods for development of instrumentation.

Project 10-7 FY '64

Report 25: Potential Uses of Sonic and Ultrasonic Devices in Highway Construction (1966)

The use of sonic and ultrasonic devices is well known in some fields. Present practical application of sonic and ultrasonic frequencies and the results of recent experiments indicate a wide range of potential uses of such devices in highway construction. It is felt that possible uses may include pile driving, mixing and compaction of materials, sampling of materials, drilling, cutting, and many other applications. In an effort to evaluate potential uses, this research study was initiated with the objectives of studying available information on present uses of high-frequency vibrations and making a feasibility study of possible applications to highway construction.

Project 10-8 FY '70

Report 168: Rapid Measurement of Concrete Thickness and Reinforcement Location—Field Evaluation of Nondestructive Systems (1976)

The objective of this research was limited to the field evaluation of available nondestructive systems of inspection testing for determining pavement thickness and reinforcing steel position at the construction site, either before or soon after the concrete has hardened, to permit the elimination of, or substantial reduction in, the coring of pavements.

Project 10-12 FY '77

Report: "Acceptance of Aggregates Used in Bituminous Paving Mixtures" - Not published (available from TRB on loan)

The objective of this study was to evaluate currently used methods for the acceptance or rejection of aggregates used in bituminous paving mixtures.

The research was conducted in two phases. Under Phase 1, four overall schemes for evaluating the quality of aggregates to be used in bituminous paving mixtures were formulated, based primarily on various combinations of current state highway department practices. The four schemes were evaluated for their relative usefulness (utility) using a utility decision analysis computer program developed by the researchers. The schemes showing the most utility were comprised of conventional physical and chemical tests of aggregate samples.

Consequently, Phase 2 was designed to evaluate various tests on aggregate samples for their ability to predict bituminous pavement performance. A decision was also made to include some bituminous mixture tests and subjective petrographic ratings and to consider climate or geographic regions.

Project 10-18 FY '81

Report 258: Control of Air Content in Concrete (1983)

The objective of this research was to develop practical guidelines for specifying and obtaining the optimum amount of entrained air in concrete. Consideration was given to interactions between typical concrete constituent materials and various admixtures.

Guidelines for field control of air-entrained concrete were developed in addition to a state-of-the-art report on air-entrained concrete.

Project 10-25 FY '83

Report 284: Evaluation of Procedures Used to Measure Cement and Water Content in Fresh Concrete (1986)

The objective of this research was to establish the applicability and accuracy of test methods for the determination of cement and water content of freshly mixed concrete. The following test methods were investigated: (1) U. S. Army Construction Engineering Research Laboratory/Kelly-Vail (CERL/K-V), Rapid Analysis Machine (RAM), FHWA nuclear device, a centrifuge test, and an x-ray emission spectrometer for determination of cement content; and (2) CERL/K-V, hot plate and microwave oven for the determination of water content.

Project 10-25A FY '85

Research Results Digest 174: Determinations of Water ≠ Cement Ratio in Fresh Concrete

This project investigated the application of analytical instrumentation and procedures to the rapid determination of water/cement ratio of fresh concrete. Attempts were made to develop a single probe that could be inserted into the fresh concrete and uniquely provide its water/cement ratio. The probe involved the use of specific ion electrodes capable of measuring the concentration of ions dissolved from the cement by the concrete mix water. Because of "poisoning" of the electrodes and occasional unexplained variances, this approach was abandoned. The work, however, suggests that such an approach may prove fruitful as instrumentation improves.

Other procedures for the separate determinations of water and cement were, however, pursued and found capable of providing data for calculation of water/cement ratio within ten minutes. Water is determined by a microwave technique employing a special ashing block assemble that allowed a determination of total water in one minute. The water determined includes that due to aggregate absorption, but the sample is chosen to minimize aggregate absorption to a level that can generally be ignored.

A second method involving use of a bromide specific ion electrode does not require a power source and its use could improve the Kelly-Vail procedure often used for water content determinations. This method primarily provides a net water content.

Cement content is determined by a specially developed colormetric procedure for soluble silica.

Project 10-26A FY '84

Report 332: Framework for Developing Performance-Related Specifications for Hot-Mix Asphaltic Concrete

This study identified the relationships between materials and construction test data and the performance of hot-mix asphalt concrete. Causal relationships among performance, design factors, and test data needed verification with the ultimate aim of formulating specifications that directly (or through identifiable indirect means) relate, within acceptable tolerances, to the performance of hot-mix asphaltic concrete in a pavement cross-section. In some cases, this will require establishing the materials and construction tests that will control those design factors. It is noted that all existing materials or construction tests may not be related to performance, and conversely, the present study may identify the need for tests not currently in use.

The report suggests that a promising procedure for establishing performance predictors is to recognize the establishment of design factors as predictors of ultimate performance. Materials and construction testing could then be used as means to ensure adequate compliance with or achievement of the design factors. As an example, for asphalt concrete construction, stiffness (elastic modulus) and tensile strain would be possible design factors, while asphalt content and percent air voids would be possible materials and construction test data.

Project 9-7, FY '93
"Field Procedures and Equipment to Implement SHRP Asphalt Specifications"

This research, which commenced early in 1993, will establish procedures and, possibly, develop equipment for quality control/quality assurance at the asphalt plant and laydown site to ensure that asphalt pavements meet the SHRP performance-related specifications. Rapid test methods to be conducted in the field to meet this objective may result from this research. This will be a major NCHRP research project to be conducted over a time period of 42 months.

THE TRANSPORTATION RESEARCH BOARD is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. It evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce Alberts and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Transportation Research Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

ADDRESS CORRECTION REQUESTED

000021-20
Chief of Highway Operations
~~Idaho Transportation Dept~~
P O Box 7129
Boise ID 83707-1129
MT15