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7. Author(s) J. York Welborn		8. Performing Organization Report No.
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16. Abstract

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EXECUTIVE SUMMARY:
STATE-OF-THE-ART IN ASPHALT PAVEMENT SPECIFICATIONS

I. EARLY DEVELOPMENT OF SPECIFICATIONS FOR MATERIALS AND CONSTRUCTION

This study covers a state-of-the-art in asphalt pavement specifications. To properly cover the development of the specifications, a brief history of the use of asphalt from the beginning to the present is included in the report.

One of the first successful asphalt pavements was constructed in 1876 in Washington, D.C. Up to that time, heavy duty pavements were built with cobblestone, wood block, stone block, brick or stone macadam. One of the earliest references concerning asphalt quality was published in 1892. The report stated:

"The durability of asphalt pavements depends wholly on the suitability of the asphalt for the purpose. It must be of such a nature as to permanently and thoroughly cement together the sand and limestone powder forming the body of the pavement. It must be elastic, independent of the residuum oil required on making the paving cement and in no degree brittle."

Up to 1900, the major source of asphalt was a natural deposit from a lake at LaBrea, Trinidad, known as Trinidad Lake Asphalt. The asphalt was surface-mined from the lake and transported by tramway to a processing plant, where extraneous water and organic matter were removed, and then to a dock where the asphalt was loaded onto ships for overseas shipment.

Asphalt from other natural deposits and from the refining of domestic crude petroleums came into use around 1900.

Subjective evaluations of pavement performance in 1894 showed that the production of paving mixtures up to that time was entirely a matter of rule of thumb. Evaluations also determined that a large part of the success of asphalt pavements was due to the use of proper sands and correct gradings. Thus, simple specifications and relatively crude test methods came into being in the early 1890's. Information became apparent that the time of mixing was important, as well as accurate scales to measure the amount of asphalt in a mixture.

The first specifications included requirements for the amount of matter soluble in carbon disulphide, a melting point, amount of oils lost on heating to 400°F (204°C), and a visual examination of the mineral matter recovered from the natural asphalt.

Requirements on the mixture were that the pavements constructed with the asphalt be solid, durable and capable of withstanding the constant strain of the heaviest and most crowded wagon traffic. One of the advantages of asphalt pavements was that they were less slippery under horses' hoofs than the cobblestone, wood and block, and brick pavements.

Laboratories to control the properties of materials for use in road construction came into more general use during the late 1890's. Beginning about then and later, test methods and test equipment were developed to measure the properties of asphaltic materials, paving mixtures and aggregates.

During 1901, the federal government established the Office of Public Roads in the Department of Agriculture. By 1911, the Office of Public Roads consisted of eleven employees, many of whom are recognized today as pioneers in the development of standard methods for testing of road materials and for the development of specifications.

In 1924, Bulletin No. 1216, "Tentative Standard Methods for Testing Highway Materials" was adopted as a standard by AASHTO and remained a standard until 1931, when the first edition of "Tentative Standard Specifications for Highway Materials and Methods of Sampling and Testing" was published. Since then, new or revised specifications and methods of sampling and testing have been adopted by AASHTO and ASTM. There are about 80 standards on the 1983 books.

II. QUALITY ASSURANCE

RESEARCH AND DEVELOPMENT PROGRAMS

Highlights in the development in quality assurance programs from 1962 to 1982 were as follows:

1962 - Federal Highway Administration (FHWA) launched a comprehensive research and development program on the use of statistical methods for the control of quality assurance in highway construction. This program was necessitated by the tremendous highway construction program underway and the need to provide functional methods of quality control and acceptance of construction.

The program included the following objectives:

1. Awaken the industry's interest in the utility of the statistical approach to quality control and acceptance testing.

2. Develop guidelines for research to establish the statistical parameters needed for writing specifications.

3. Plan and coordinate a nationwide program of research in statisical methods.

4. Gather and analyze research data and disseminate research findings.

5. Design and implement experimental projects to evaluate the findings of the research program.

1965 - The Bureau of Public Roads sponsored a conference on the state-of-the-art in quality control and acceptance specifications, materials and construction. The conference attracted representatives from the highway construction equipment industry, material producers, state highway departments, federal government agencies, consulting firms, universities and local governments. During 1962 to 1965, 28 states had been or were engaged in research to measure the quality of construction.

1969 - FHWA recommended that statistical concepts be incorporated in highway specifications to improve communications between contractors, engineers, lawyers and auditors. To implement the recommendations, the concepts should include the materials and material properties, valid tolerances for materials and construction operations to be measured and controlled, the methods to be used for determining compliance, and conditions under which either full or partial payment will be made.

Based on data received from the states prior to 1969, 50 percent or more of the overall variance from materials, processes, sampling, and testing could be attributed to methods of sampling and testing. The results of studies showed the magnitude of the sampling and testing error and indicated the need for a comprehensive effort to train inspectors and laboratory technicians. To fully implement a statistical approach to end-result requirements, adequate test methods to measure quality and trained manpower must be available to control the processing of materials and inspect the final product.

1971 - Transportation Research Board published a state-of-the-art on the needs of a highway department in the area of quality assurance and acceptance procedures, and on the status of statistically-oriented specifications in bituminous construction. The study pointed out that it was not evident that highway departments were ready to change to statistically-oriented specifications. The particular concern was that the highway industry was reluctant to abandon traditional methods and specifications that were in use for many years. There also was little evidence that contractors saw a need to introduce quality control procedures, mainly because the necessary incentive had not been provided.

An update of the status of quality assurance programs showed that there are generally four steps in implementing statistical specifications:

- o Establish realistic variability by statistical analyses of historical data or from a controlled sampling and testing system. About 25 agencies were working on this step.

- o Use variability to establish tolerances. There were about 12 agencies that had established tolerances for asphalt content and sieve analysis.

- o Use specifications in simulated construction projects. There were about 10 agencies that had or were using this concept.

- o Use specifications as a basis for acceptance. There were about eight agencies that had or were considering using this concept in some form.

The report also enumerated the components more or less inherent in all of the statistical specifications either in simulation stage or actually in use. The specifications include all or part of the following:

1. Lot size

2. Number of samples per lot

3. Acceptance of central tendency - sample average and moving average

4. Acceptance of variability

    a. Limit the amount of variability

    b. Limit the size of standard deviation

    c. Use range to estimate variability

5. Other acceptance criteria, such as:

    a. Defective product

    b. Quality index

6. Adjustment of bid price

7. Use of control charts

8. Retesting and referee procedures

The 1971 state-of-the-art covered the contractor's responsibilities, some of which are:

- Responsible for the complete supervision, performance and completion of all work in accordance with the original approved or revised drawings, specifications, special requirements and contract.

- Provide and maintain an inspection system for the quality control of all materials and construction.

- Perform inspections and tests required to show compliance.

- Provide and maintain test equipment.

- Correct conditions which result or could result in materials, processes or construction that do not conform to the requirements of the specification.

The pros and cons of statistically-oriented specifications were as follows:

Statistically-oriented specifications do not solve all of the engineering or material problems but can solve many of the problems that arbitrary and indefinite specifications have caused in the past. Statistical specifications are being and will continue to be increasingly used because of their clarity and defensibility. The most serious problem is lack of statistical and other training of manpower that faces the contractor as he assumes more control of his process.

1976 - NCHRP Synthesis 38, Statistically-Oriented End-Result Specifications. The purpose of the report was to extend and amplify the concepts and findings of the above state-of-the-art report, published in 1971, with respect to specifications for highway materials and construction, and to show the advantages and disadvantages of statistical acceptance plans. It also was intended to provide contractors with a better understanding of their responsibilities in end-result specifications and the advantages of such a program to them.

The results of the NCHRP survey reported in the synthesis showed that 33 states were using, planning to use or had tried some form of statistically-oriented end-result specification. Seventeen states were not using and were not planning to use this type of specification.

1977 - Methodology to develop price adjustment systems suited for statistically based highway construction specifications. A brief outline included:

- Acceptance characteristics

- Price adjustment schedules

- Operating characteristic curves (o.c. curves)

- Monitoring price adjustment system

1981 - AASHTO Standard Recommended Practice for Acceptance Sampling Plans for Highway Construction. The recommended practice provides guidance in the use and application of acceptance procedures for highway construction materials and items of work. Certain prerequisites were presented for realistic and practical acceptance plans.

SUMMARY - QUALITY ASSURANCE SPECIFICATIONS

The state-of-the-art report shows that substantial progress was made during the past 20 years to develop quality assurance requirements in asphalt pavement specifications. The prerequisites for the proper use of statistical concepts that were essential when the quality assurance programs were first undertaken have been met to various degrees. The accomplishments include:

- Proper allocation of responsibilities of the contractor and agency

- Effective and realistic quality control by the contractor

- Lot by lot acceptance of construction

- Use of random sampling methods

- Selection of effective end-result requirements

- Use of statistically-oriented acceptance plans

- o Use of pay adjustments for non-conforming materials and construction.

Because of the wide divergence in quality assurance and acceptance plans now being used by states and other agencies, more realistic and uniform tolerances for measured characteristics should be determined.

III. PERFORMANCE-RELATED SPECIFICATIONS

The major objective of this study was to develop a system of performance-related specifications and to identify test procedures and construction requirements that would support such a system.

To accomplish this, the specification must provide methods and requirements to measure and control the essential properties that are related to performance. The construction processes also must be controlled to provide pavement surfaces that are resistant to skidding, smooth-riding and durable.

In addition to using performance requirements, the specification must include quality assurance requirements for process control and acceptance. Insofar as possible, the acceptance should be based on end-result requirements. There are standard test methods that can be used to measure end-result requirements, such as density, smoothness, and skid resistance. However, existing new methods of evaluation, such as indirect tension, resilient modulus and creep, should be investigated further to replace conventional or indirect methods currently used. The use of in-place, non-destructive methods also should be expanded.

To develop a realistic performance-related specification for asphalt pavements, the selection of the requirements must be carefully evaluated. First, the decision to write a new specification must be based on the ability to identify the cause of distress resulting from inadequate specifications for materials and construction and to replace, revise or add new, or at times more restrictive, requirements that will assure better performance. The economics of any change in specifications should be recognized and the increase in costs should be offset by improved performance. The addition of quality assurance requirements to the specifications with proper sampling and testing programs should result in lower costs.

To determine the inadequacy of asphalt pavement specifications, the first major undertaking was to evaluate the distress modes that affect performance and select the factors that contribute to the distress conditions. The following information was presented:

- A review of requirements in current specifications for asphalt pavement construction
- An outline of distress modes and contributing factors
- A review of pavement performance studies
- A framework of performance-related specifications

Details of the above items are as follows:

<u>Survey of Asphalt Pavement Specifications</u>

One of the tasks in the study of the state-of-the-art in asphalt pavement specifications was to review existing specifications for dense and open-graded bituminous concrete surfaces and bituminous base courses used by state highway agencies, AASHTO and FHWA.

Representative specifications were reviewed to show:

1. Responsibilities of the agency (engineer) and contractor for materials and construction

2. Job-mix formula, aggregate gradation, bitumen content

3. Quality requirements for density, thickness and smoothness

4. Construction requirements and limitations

5. Quality assurance plans for control and acceptance and for pay adjustment

Distress Modes for Asphalt Pavements

For this study, seven distinct distress modes were selected, together with the material and construction factors that contribute to each type of distress. A distress mode is defined as: "a deficiency in pavement quality and performance shown by reduced serviceability."

The distress modes selected were:

- Cracking - load associated
- Cracking - non-load associated
- Cracking - reflected
- Distortion
- Disintegration
- Skid resistance
- Riding quality - roughness

Factors contributing to each of the distress modes included:

- Pavement design
- Material properties
- Mix design and properties
- Environment
- Construction practices

Mix design is a predominant factor in nearly all of the distress modes. The literature shows that the following properties of mixtures must be considered in mix design:

- Stability (stiffness)
- Durability
- Flexibility
- Fatigue-resistance (cracking under traffic loads)
- Skid resistance
- Permeability (imperviousness)
- Fracture strength (tensile)

Pavement Performance Studies

To properly evaluate the incidence of each of the distress modes, several reports showing the results of surveys on pavement condition were selected. In some instances, both the number of pavements included in the survey and the relative magnitude of the distresses were shown.

FHWA studies showed that the principal types of distress observed in asphalt pavements were as follows:

DISTRESS TYPE	PERCENT OF PROJECTS SHOWING DISTRESS
Longitudinal Cracking	64
Rutting	62
Transverse Cracking	56
Alligator Cracking	16
Edge Cracking	19
Block Cracking	12
Patching	11

Analyses of quality level were made on the basis of conformity to the applicable specification requirements. A 90 percent quality level was chosen on the basis of engineering judgment as the dividing criterion to distinguish between good quality level work and work where improvements are needed. Use of this criterion indicated that quality control problems existed in asphalt pavement construction.

FHWA recommendations for asphalt pavement construction were essentially to improve quality control of density, bitumen content and gradation. Where needed, specifications limits should be adjusted to accomodate normal testing and process variability. This would have to be accomplished on a state-by-state basis.

Overall, FHWA's 1976 and 1979 surveys indicated that there was a decline in quality of construction. No specific causes were found for the decline; however, there were certain general construction practices that were identified in the surveys that may contribute to the overall low quality of construction. These are:

- o The use of specifications that do not allow for normal process and/or sampling and testing variability.

- o The use of conventional practices where acceptance of the work is based on single tests and resampling and/or testing of failing materials is allowed.

The following specific recommendations were offered:

- o Of all construction factors, density control had the greatest degree of non-conformity to specifications. Also, not all states have density requirements for bases, binder and bituminous surfacing. Recommendations include studies to determine whether minimum density requirements are realistic, achievable and represent the desired end result. Also, in those states where there are no density requirements, efforts should be made to develop and implement such specifications.

- o Thickness quality levels were extremely low for the data submitted. A review of specifications indicated that the lack of adequate construction tolerances contribute to the problem. Recommendations were made to develop and implement tolerances that represent actual construction and testing variability.

The literature contains other studies showing the relationship between material properties and distress by type of material. One study indicated that the dependent material properties, i.e., density, aggregate gradation, air voids, etc., were not generally included in the list of properties prepared for most studies. Since the dependent material properties are related to the independent properties, and are more easily and conveniently measured, they can be used in place of the independent material property in an engineering analysis. For example, density, aggregate gradation and type, air voids, etc., are related to the fatigue characteristics of an asphalt concrete mixture.

One study presented an evaluation of the various contemporary mathematic models and selected those that were most capable of predicting distresses in terms of significant material properties. It described briefly the distress models and the material properties considered to affect the occurrence of each distress condition. For asphalt pavements, the types of distress studied and considered for use in the study were rutting, fracture cracking (fatigue), low-temperature cracking, and reduced skid resistance.

A large number of distress models were studied, but only VESYS A, PDMAP, OPAC and WATMODE included models for rutting, fracture cracking, and low-temperature cracking. The Shell Method considered rutting and fatigue cracking. The literature on skid resistance deals mainly with the magnitude of skid numbers for different types of pavements and the change in measured skid numbers over periods of time. A more detailed evaluation of the various models is included in the report.

Information from studies and surveys cited in the report shows a concensus that, of major distresses, the incidence of longitudinal cracking is rated highest; transverse cracking, second; distortion (rutting), third; and the incidence of reflection cracking, fourth. The incidence of disintegration, smoothness and loss of skid resistance varies with the scope of the studies and surveys. However, programs on rehabilitation, resurfacing and reconstruction are of national importance in correcting, reducing or preventing these distresses and providing safe, smooth and structurally sound pavements.

Of particular importance are the short range and long range methods of measuring and evaluating the properties of materials and mixtures and construction requirements. Short range methods include empirical methods that have been standardized and are in current use. Long range methods are those of a fundamental nature, some of which are in use, consisting primarily of new methods that are in the research stage or proposed methods that measure performance-related properties. The development of long range methods are essential to the development of long range specification requirements.

Both the short range and long range methods can be used in performance-related specifications; however, the long range methods are preferred because they can be more readily adapted to pavement design and to quality assurance programs.

ROAD ROUGHNESS AND SKID RESISTANCE

Road roughness is considered to be one of the major elements of performance-related specifications. Measurements of road roughness are of interest to the engineer as a means for determining the acceptance of new or resurfaced pavements. It is of interest to the maintenance engineer in determining pavement safety, serviceability and as a means of assessing pavement distress. The report describes the methods for measuring road roughness.

The literature is replete with information on the various factors that influence skid resistance of asphalt pavements. Skid resistance is included here because of the important role that asphalt pavements play in the design and construction of pavement having high frictional characteristics. Skid resistance is one of the seven distress modes for performance-related specifications. The report describes the distress mode for skid resistance, the controlling factors, contributing material properties and evaluation methods for short and long term use. While there are many aspects of the overall problem, only the contribution of asphalt materials and mixtures to pavement surface texture are discussed in the report.

Microstructure contributes to skid resistance at all speeds with a prevailing influence at speeds less than 50 km/h (31 miles/h). Microstructure depends largely on the mineral composition, rugosity of the aggregate, and the sharp, fine particles that permit intimate contact between the tire and roadway.

Coarse macrostructure is essential to safe high-speed travel under wet conditions. It can be obtained by controlling the gradation of the surface aggregate, which also should be composed of hard, angular, coarse, and polish-resistant particles. Open-graded asphalt friction courses are an example of this type of surface. While the aggregate characteristics are of primary importance in skid resistant surfaces, proper asphalt mixture design also is essential to good performance. Mix properties can be controlled by aggregate, gradation, type and amount of asphalt, void content, and stiffness.

IV. REFLECTION CRACKING AND OVERLAYS

One of the tasks of this state-of-the-art in asphalt pavement specifications is to determine the extent to which the condition of the underlying base, or of the underlying surface in case of an overlay, can influence the properties of a new asphalt pavement or overlay. The seriousness of the problem as it affects pavement performance is substantiated by the extensive amount of laboratory and field research on reflection cracking and overlay construction that has been reported in the literature. A few of the studies are summarized in the report.

The condition of the underlying subgrade, bases and surface courses greatly influences the performance of the total pavement structure. Numerous studies have emphasized the importance of proper moisture and density control of the subgrade during construction. Studies also have shown that the type of subgrade is an important factor in considering low-temperature cracking problems. Subgrades having low swell potential have little effect on the performance of the pavement and subsequent maintenance. However, if the subgrade soil is clay, the designer should carefully consider selecting materials that prevent or resist low-temperature cracking. Water infiltration through the cracks will produce subsequent movements in the subgrade soil through swelling.

Reflection cracking also is predominant in asphalt overlays on cement treated bases, thermal cracking from joints and cracks in rigid pavements. If the cracks are not maintained properly, the surface may develop distresses in the form of raveling and disintegration.

The report presents methods of preventing or correcting reflection cracking. The methods range from the application of fracture mechanics and analytic procedures to provide solutions to reflection cracking through overlays to sealing surface cracks. Numerous methods have been used in experimental studies. They include:

- o Asphalt-rubber membranes
- o Addition of fillers
- o Heater-scarification with reclaimite
- o Soft asphalt in overlay mixtures
- o Stress relief layers
- o Bond breakers

The most reasonable approach to minimizing reflection and cracking appears to be some type of stress-relieving interlayer.

OVERLAY DESIGN METHODS

To properly design asphalt overlays, the condition of the pavement to be overlayed must be determined. Evaluation methods include:

- o Visual condition surveys
- o Structural performance - determine thickness of overlay
- o Analysis of pavement layers to determine stiffness
- o Deflection measurements

The principal functions of an overlay are one or more of the following:

1. Restore the pavement riding quality.

2. Restore skid resistance.

3. Upgrade the load-carrying capacity of the existing pavement.

A number of methods are available that may be used to design overlay thickness. The two basic approaches are categorized as (1) a layer analysis, and (2) use of a mathematical model that assigns a monolithic to each layer and predicts the behavior of the total pavement. The monolithic approach uses the in-place carrying capacity of the existing pavement.