QUALITY ASSURANCE IN PAVEMENT CONSTRUCTION

ASTM STP 709

AMERICAN SOCIETY FOR TESTING AND MATERIALS

QUALITY ASSURANCE IN PAVEMENT CONSTRUCTION

A symposium
sponsored by
ASTM Committee D-4
on Road and Paving Materials
AMERICAN SOCIETY FOR
TESTING AND MATERIALS
Bal Harbour, Fla.
6 Dec. 1978

ASTM SPECIAL TECHNICAL PUBLICATION 709
G. J. Allen, Arizona Department of
Transportation, symposium chairman

04-709000-08

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race Street, Philadelphia, Pa. 19103

Library of Congress Catalog Card Number: 79-56035
ISBN 0-8031-0769-2

NOTE

The Society is not responsible, as a body,
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Printed in Philadelphia, Pa.
April 1980

Second Printing, Philadelphia, Pa.
October 1984

Third Printing, Philadelphia, Pa.
April 1987

Foreword

This publication, *Quality Assurance in Pavement Construction*, contains papers presented at the symposium on Quality Assurance—Who, What, How?, which was held in Bal Harbour, Fla., 6 Dec. 1978. The symposium was sponsored by Committee D-4 on Road and Paving Materials, of the American Society for Testing and Materials. G. J. Allen, Arizona Department of Transportation, served as chairman of the symposium.

Related ASTM Publications

Recycling of Bituminous Pavements, STP 662 (1979), 04-662000-08

Low-Temperature Properties of Bituminous Materials and Compacted Bituminous Paving Mixtures, STP 628 (1977), 04-628000-08

Fatigue and Dynamic Testing of Bituminous Mixtures, STP 561 (1974), 04-561000-08

Viscosity Testing of Asphalt and Experience with Viscosity Graded Specifications, STP 532 (1973), 04-532000-08

A Note of Appreciation to Reviewers

This publication is made possible by the authors and, also, the unheralded efforts of the reviewers. This body of technical experts whose dedication, sacrifice of time and effort, and collective wisdom in reviewing the papers must be acknowledged. The quality level of ASTM publications is a direct function of their respected opinions. On behalf of ASTM we acknowledge with appreciation their contribution.

ASTM Committee on Publications

Editorial Staff

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Introduction

Although the subject of quality assurance in pavement construction has been around for several years and has been batted back and forth considerably, only a few purchasing agencies, to this date, have achieved more than a meager trial application of quality assurance specifications. This symposium was an attempt to present, on one program, a four-sided view of the subject. For this purpose, four individuals known to be knowledgeable in quality assurance procedures were asked to prepare presentations for the symposium. Each was to approach the subject from his own field of involvement and experience. The four viewpoints presented were those of a federal administrator, a state or purchasing authority, a materials supplier, and a contracting firm.

Currently, there seems to be renewed and expanded interest in all aspects of quality assurance. An increasing number of contractors and materials producers are following the lead of those firms that have already realized the benefits of having a competent quality control unit within their own organizations. With each project completed under the quality assurance concept, purchasing authorities are gaining confidence in such specifications and in the ability and integrity of the contractor in providing the quality contracted for.

For anyone wishing an overview, or perhaps insights from different angles of view, of the quality assurance package, the efforts of the four individuals whose presentations make up this publication should provide an excellent reference.

G. J. Allen

Arizona Department of Transportation, Phoenix, Ariz. 85007; symposium chairman.

S. P. LaHue[1]

Quality Assurance and Quality of Construction

REFERENCE: LaHue, S. P., **"Quality Assurance and Quality of Construction,"** *Quality Assurance in Pavement Construction, ASTM STP 709*, American Society for Testing and Materials, 1980, pp. 3–10.

ABSTRACT: Modern quality assurance (QA) systems, including statistically based specifications, are being reviewed and adopted by many states throughout the nation. The U.S. Federal Highway Administration's (FHWA) initial involvement in quality assurance systems started 15 years ago, in 1963. At that time, the Office of Research and Development's efforts were directed toward arousing the highway industry's interest in quality assurance and developing guidelines in this area.

Currently, there are 21 states using quality-assurance-type specifications as their normal specifications for asphaltic concrete construction. In addition, there are seven states that are developing or using QA-type specifications for asphaltic concrete on selected trial projects.

Part of the reasoning for the shift toward the adoption of modern quality assurance systems by state highway and transportation agencies can be attributed to their efforts to apply sound management techniques to the highway industry. The adoption and application of sound management techniques has become essential in this age of increasing costs and reduced revenues and will lead to a better-performing highway system.

KEY WORDS: quality assurance, pavements, management, performance

The quality and durability of our highways has always been a major concern to highway engineers and contractors, as well as to top state highway agency and federal program managers. This concern for quality is the basis for our traditional programs, where quality is primarily attained through the skills and experience of the individual engineers and the highway craftsman. When the proper combination of these skills is applied, satisfactory, and sometimes outstanding, highway quality is obtained.

However, as we are all aware today, there are a number of changing factors which make this traditional system subject to breakdown. Some of these factors are the diminishing numbers of experienced personnel, the increasing speed of construction, and the volumes of materials that must be handled. Also, engineering activities and other duties that are time demanding have

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increased to the extent that our experienced engineers must now delegate many activities to persons whose skills and experience are often inadequate for on-the-spot decisions. These factors have been noted not only by the highway agencies, but also by some practitioners and authors in the management field. Goldhaber, Jha, and Macedo [*1*][2] commented on these factors with the statement:

> As basic as it is, the construction industry is the worst-managed of all industries. In a sense it is still a cottage industry. On top of this, it is presently being plagued by spiraling costs, decreasing productivity, and materials shortages. It is perhaps the last frontier for management thought.

The U.S. Federal Highway Administration (FHWA) maintains that the overall management of the highway industry can be improved by developing and implementing a modern quality assurance (QA) program—which is, in fact, using new management techniques to achieve standards of higher quality.

A modern quality assurance program could be defined as the overall process whereby the joint efforts of industry, state, and federal officials are combined to develop or establish performance-related quality criteria, exercise systematic process controls, establish attainable specification criteria that recognize product variability, and develop unbiased sampling and testing procedures. To put this in the most simplistic terms, modern quality assurance for highway construction is a management tool or process for assuring product acceptance, product sampling and testing, and systematic feedback and evaluation. Quality assurance is basically a management tool that represents management's concern for quality and the efforts to assure quality. The recommended quality assurance program is an effort toward better management of our highway projects, and better-managed projects will ultimately result in facilities of higher quality.

Construction Costs

A press release that was issued by the Federal Highway Administration on 22 Nov. 1978 stated, in part, the following:

> The cost of highway construction during the third quarter of 1978 jumped 14.7 percent above the previous quarter to 296.1 percent of the 1967 average. The 14.7 percent increase follows a 17.6 percent rise for the previous quarter and is the second largest quarterly increase on record. The composite price index for the third quarter is 37.1 percent higher than a year ago.

If the trend that is being established continues, the capital in fixed dollars available for construction and reconstruction will be totally inadequate. The highway budget, as approved by Congress, may seem to be an overwhelming figure, but, in fixed dollars, there is less each year available for capital improvement.

[2]The italic numbers in brackets refer to the list of references appended to this paper.

Many improvements have been made in the highway industry in the last few decades to increase productivity and hold costs down. The current average hourly wage is at an all-time high, but, because of innovations and improvements in production, the labor cost increase per unit of production has actually declined.

We must continue with these innovations and expand upon them wherever possible so that the line can be held on construction costs and on the overall total cost of a highway.

Too often in the past only the initial construction costs have been considered and not the long-term costs, such as maintenance and reconstruction. We can no longer ignore these costs, which is why it is so critical to achieve the highest quality possible without increasing the costs of highways.

Our experience has shown that the adoption of a modern quality assurance program will not increase the overall cost of a project. By overall cost, I mean the total cost of a project to the taxpayers. This total cost includes not only the immediately recognizable costs, such as the contract amount and the state's engineering costs, but also other costs, such as maintenance of the completed facility and the cost of rehabilitating projects that may not have fully provided the anticipated design or service life. These other cost items, which are not normally considered part of the cost of a project, are, at present, one of the biggest drains on the state highway agencies' budgets and are projected to become even greater. Therefore, if the states are going to be able to do any construction in the future, it will be necessary for maintenance and rehabilitation costs to be reduced so that those funds can be funneled back into construction. We believe that the use of a modern QA approach will provide a higher-quality end product that will reduce those costs.

The modern QA concept has been reviewed by the American Association of State Highway and Transportation Officials (AASHTO) in order to determine whether there is a correlation between increased costs and the adoption of QA specifications. A survey was made by the AASHTO Committee on Construction in 1975 in relation to QA specifications and the application of those specifications. Twenty-five states that had used QA-type specifications responded to the question, "Have bid prices been affected and to what degree?" The answers are summarized as follows:

Increase	1 state
Unbalanced bids on items with penalties	1 state
No change	8 states
Too early to tell	2 states
Impossible to determine	3 states
Impossible to determine due to inflation	10 states

These responses are significant since only two states were able to make a determination that higher or unbalanced bids had resulted from the use of QA specifications.

The fact that bid prices have not increased is not the only advantage observed. In addition, the highway agency has the opportunity to realize other advantages through the use of QA-type, or statistically based, specifications. These advantages include:

1. The proper allocation of responsibility for quality between the contractor and the agency.
2. Increased ability to make informed judgments when contemplating changes in quality levels or performance requirements.
3. Defensible project or product acceptance requirements.
4. Savings in engineering costs through reduced testing and inspection requirements.

The ability to realize savings as a result of the adoption of a modern quality assurance program is not limited to the highway agency itself. The advantages of modern quality assurance, or statistically based specifications, observed by contractors and producers include:

1. Cost savings because the most economical mixtures of materials can be chosen to meet the specification requirements, with the corresponding savings due to better use of available materials.
2. Greater latitude in the selection of equipment and work methods.
3. Reduced risk of operations suspension.

Legal Responsibilities

As has been previously stated, engineering activities and other duties that are time demanding have been increased to the extent that our experienced engineers must now delegate many activities to persons whose skills and experience are often inadequate for on-the-spot decisions. The number of inexperienced personnel on current construction projects was shown in the 1976 "Highway Condition and Quality of Highway Construction Survey"[*2*]. This survey indicated that, on a nationwide basis, personnel with two years' experience or less were responsible for 44 percent of the project sampling and testing and 35 percent of the project inspection activities.

This delegation of quality assurance activities has, in some cases, led the state highway agency directly either to an arbitration board or into the local courts. The results of at least one court case have shown that the state highway agency, by explicitly specifying the procedures, found itself party to controls, and, in the court's eye obligated itself to a great degree to accept the end product even though there was no assurance that the end product would meet the performance criteria.

The specific case that I am referring to was decided in September 1973. In that particular case, the state highway agency had proven that a concrete pavement was deficient in cement content by approximately 50 percent. However, even though there was no doubt about the lack of cement in the end product, the case judgment reads in part as follows:

> It strikes the court that it was not the contractor's fault. He mixed exactly what

they told him to and the inspector had to be satisfied. And, I don't think that the ultimate strength of the concrete is the criteria. I think that the thing that we have to determine here today is how much control was retained by the highway department in the mixture of the concrete. I think that they exerted enough influence and had enough control over the project to be responsible for the end results. They had control and retained control all the way through the whole procedure [*3*].

This case was a "landmark" decision that caught the state highway agency somewhat by surprise. However, the case did cause the state officials to take a whole new look at their entire operation and to adopt what they, and we, call a modern quality assurance program.

Program Background

The phrase "modern quality assurance program," or "statistically based quality assurance specifications," has been the cause for expressed apprehension by some, while others have stated that they simply do not understand what the phrases mean. It is unfortunate that the initial promotion of the QA program in the sixties used specific terminology that was not familiar to some contractors, engineers, or administrators. This led to a misunderstanding of the intent and scope of the phrase "modern quality assurance program." This misunderstanding is still around to a limited extent despite the efforts by many state, federal, and private organizations to explain the program and its benefits. The current adoption of modern QA programs, or statistically based quality assurance specifications—whichever you prefer—is not something that resulted overnight from any one person's or any one agency's brainstorm, but is, instead, the end product of a substantial amount of research and work by federal, state, and local agencies and by the contracting industry itself.

Statistically based quality assurance specifications are not requirements for federal-aid projects, even though the Federal Highway Administration is committed to and has been involved, in one form or another, in QA since 1963. This involvement and the results of much research and work have resulted in the issuance of an FHWA policy statement concerning quality assurance programs [*4*]. This policy or directive, as it may be called, was issued to promote and attain the widespread use of modern quality assurance techniques by 1980. However, this policy did not mandate the use of QA, and it did not include guide specifications for the states to adopt. Many states had already adopted quality-assurance-type specifications before the FHWA issued its policy. One state in particular has been working under a QA-type specification since 1964. However, even with that experience, this particular state's specification would not necessarily be applicable nationwide, just as a federal specification would not be applicable. Therefore, any directives that have been issued have been written to promote a program that we firmly believe is in the best public interest and to allow the individual states a "free hand" in the development and preparation of their specifications and methods for implementing a QA program.

Engineering Judgment and Quality Assurance

The adoption of statistically based quality assurance specifications is not a process that is designed to remove engineering judgment from the highway construction industry. Engineering judgment is still very necessary since products are used that have variability. But, this engineering judgment is something that should be applied uniformly and equitably to all contractors. There have been known occasions where the local contractors would add a straight percentage to the cost of a project based on their knowledge of who the engineer would be and how he exercised his particular engineering judgment. Therefore, the best place to utilize good engineering judgment is not in the acceptance of the product, but, instead, in the developing of specifications that are based on achievable requirements. The use of good engineering judgment at this level and providing the field engineers with a basis for determining acceptability will lead to defensible specifications that can be uniformly applied to any project under the supervision of any engineer. Also, the proper application of good engineering judgment in the specifications will provide the contractors and materials suppliers with the knowledge they need concerning acceptance procedures and requirements. With this knowledge, they will know almost immediately whether or not their product is fully or partially acceptable, and they will still have time to make the necessary process adjustments.

Sampling and Testing Responsibilities

One of the concepts embodied in a statistically based quality assurance specification is that the contractor or the materials supplier is the party that is responsible for the actual quality control, or process control sampling and testing. This concept has generated a significant amount of discussion in many states that have adopted, or are in the process of adopting, statistically based quality assurance specifications. This concept and the theory behind it are valid, and we believe that there are a number of advantages for the contractor or materials supplier when he does his own process control testing. Not the least of these advantages is the fact that by having his own testing personnel, the contractor can be constantly more knowledgeable of how his process is running, and he has the prerogative of having as many tests made as he may desire. However, we recognize that there may be instances when a state may wish to retain testing responsibilities for particular contracts for a variety of reasons, or, as some states are currently doing, to retain all testing responsibilities simply because it is their desire to retain those responsibilities. I want to reemphasize that the Federal Highway Administration can see significant advantages to this system, in which the contractor has process control testing responsibilities; however, I want also to emphasize that the FHWA has no objection to a state's retaining any part or all of the testing responsibilities. We consider this item to be a state prerogative that must be determined on the basis of the availability of state personnel, the type and size of the contract, and the abilities and desires of the contracting industry within the state.

The FHWA is not aware of any court test cases to date concerning control responsibilities in which a state is using a statistically based specification but retaining process sampling and testing responsibilities. However, we can envision the possibility that there might be some question as to whether or not the state highway agency is party to the controls and thus obligated to accept the end product if the state's retention of the process control sampling and testing responsibility does, in fact, impose a control on the contractors' process.

National Application in Asphaltic Concrete

The previously noted state that had, in essence, developed a QA system as a result of court actions is only one of a number of states that are either using or experimenting with QA specifications. At our latest count, there were 28 states that were using QA specifications in some form for bituminous concrete projects. This figure will vary to some degree since some states are currently in the transition phase of developing and implementing QA specifications.

However, even within those 28 states, one will find that each specification may be slightly different, since it has been or is being developed to suit the specific needs of the state and the contracting industry. Also, an individual state specification may be different because of the knowledge and innovations that have resulted from the development of QA specifications in other states. The sharing of knowledge and innovations is one of the better attributes of the highway industry. We as a group or as individuals do not mind sharing the results of our failures and our successes so that others can benefit from our hard-earned knowledge. The use of what we call modern quality assurance programs has broadened from one state in 1964 to 28 states today, largely as a result of the sharing of the knowledge of the benefits that can be derived from these programs.

We believe that there will continue to be a broadening of the use of QA specifications as more state highway agencies and the contracting industry become more familiar with QA and its benefits and advantages.

Summary and Conclusions

We at the Federal Highway Administration are aware of some of the benefits and advantages of the program. However, the adoption of a QA program does not guarantee instant success. I am sure that the states that have implemented this program will tell you that they encountered problems during the implementation phase. These problems can, and have been, over-come, but only if the management level of the state highway agency is committed to the success of the program.

There have been instances where the quality assurance programs that were developed within a state have stumbled or fallen by the wayside simply because the people who should have had control did not understand the QA concept or did not take time to make the program work. Any QA concept that is going to be viable in fact must be dynamic. That is, the full circle of involvement of all factions within the highway agency and within the contracting industry must take place, and all factions must have the opportunity to evaluate the process and provide necessary feedback into the process so that remedial action can be taken.

We in the FHWA, and I as an individual, are committed to the quality assurance concept as a management tool. Considerable work by a number of groups has been done toward the development of a dynamic quality assurance system for the highway industry that will be truly responsive to the desires and needs of the taxpayer and provide the most efficient and satisfying mode of highway transportation at the least possible cost. But, we must not quit now since there is still much that can be done.

The complete development of such a system requires a team effort, and the contracting industry, the materials industry, and the local, state, and federal governments are all responsible members of the team. We must all work together if we are to reap the rewards of such a system.

References

[*1*] Goldhaber, Jha, and Macedo, "Construction Management: Principles and Practices," John Wiley & Sons, New York, 1977, p. 7.

[*2*] "Highway Condition and Quality of Highway Construction Survey Report," U.S. Federal Highway Administration, Washington, D.C., July 1977, pp. 5-74.

[*3*] *Donald G. Lambert Contractors, Inc., v. Louisiana Department of Highways*, 19th Judicial District Court for the Parish of East Baton Rouge, La. (1973).

[*4*] *Federal-Aid Highway Program Manual*, Vol. 6, Chapter 4, Section 2, Subsection 10, 27 May 1975.

C. S. Hughes[1]

State of the Art: State Acceptance of Bituminous Concrete Production and Construction Using Quality Assurance Specifications

REFERENCE: Hughes, C. S., "**State of the Art: State Acceptance of Bituminous Concrete Production and Construction Using Quality Assurance Specifications,**" *Quality Assurance in Pavement Construction, ASTM STP 709*, American Society for Testing and Materials, 1980, pp. 11–18.

ABSTRACT: This paper reports on the state of the art, from the standpoint of state agencies, of the use of statistical quality assurance procedures for the acceptance of bituminous concrete production and construction. Information on the procedures being used by the 50 state highway agencies, as of the spring of 1978, was obtained through a questionnaire and is reported. The paper deals with two areas involving bituminous concrete: (1) production, which primarily encompasses determining the asphalt content and gradation of the aggregate; and (2) construction, which comprises the roughness, thickness, and density of the pavement. The responses to the questionnaires showed that 25 agencies have a statistical quality assurance specification for accepting production, although three of these agencies stated that the program was still experimental. For construction, 25 states, coincidently, also reported employing a statistical quality assurance program. Most of these have a specification dealing with density. The estimated annual dollar savings were reported to be from $100 000 to $1 000 000. For those agencies not now using quality assurance specifications, the specifications of most interest were those for production and for the density and roughness of the pavement. Eleven agencies indicated that they are not now using nor are they contemplating the use of statistical quality assurance specifications.

KEY WORDS: quality assurance, pavements, statistical specifications, bituminous concrete specifications

The American Association of State Highway and Transportation Officials (AASHTO) Road Test showed that, even with well-trained inspectors, well-equipped testing laboratories, a competent contractor, and cost-plus financial payments, it was not possible to meet the intuitively based specifications that had been prepared for the experimental installations. Clearly, the intuitive approach to writing specifications and determining compliance that had been used nationwide prior to the AASHTO road test was shown to have

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produced a sense of well-being that, in actuality, was without basis; the agency preparing the specifications often was being provided materials and construction that did not meet its specifications.

The solution was to abandon the intuitive approach in favor of a more scientifically based procedure which included statistically determined tolerances, with "statistics" being defined as that science which deals with the treatment and analysis of numerical data.

Implementation of the statistical concept has not spread quickly, although the concept has been discussed in many highway forums such as those of the American Society for Testing and Materials (ASTM), the Transportation Research Board (TRB), and the Association of Asphalt Paving Technologists (AAPT). A reluctance to abandon traditional methods and specifications, as well as misinformation regarding the statistical concept, has been the major reason for the slow acceptance.

In some instances states appear to be influenced by contractors' objections to statistical quality assurance techniques. Even though those objections are based on conjecture and bias, these states retain the traditional procedures in the interest of state-contractor relations. These states believe that under established traditional procedures they retain greater opportunities for "engineering judgment" decisions, which permit work to progress more smoothly to the benefit of both the state and the contractor.

State-of-the-art reports were disseminated through the TRB in 1971 [*1*][2] and through the National Cooperative Highway Research Program (NCHRP) [*2*] in 1976, and, over the last few years, interest in the application of statistical quality assurance techniques has quickened, particularly in the bituminous paving industry. With the growing popularity of the statistical acceptance approach, much confusion has been generated by the loose terminology employed. The terms "statistical end-result specifications," "statistically based specifications," and "quality assurance programs" have been used interchangeably and improperly. Part of the reason for the confusion has been the evolutionary nature of the growth of statistically based specifications. Following the AASHTO Road Test, several state agencies, and the U.S. Federal Highway Administration (FHWA), began developing statistically based specifications, which generally dealt with only the buyer's role in the acceptance part of what now is often thought of as a system. The evolutionary process eventually added the concept of independent contractor quality control to the system. These two ingredients are now considered essential in a complete statistical quality assurance program. But because such a program is something of an ideal and because of its evolutionary nature, a spectrum of sorts has developed, with some agencies using an early stage of a specification and some having "progressed" through two or more stages. However, for a quality assurance program to be fully effective, statistical concepts must be applied to all facets of the system, including producer and consumer risks, control charts, precise sampling plans, and specific acceptance criteria.

[2]The italic numbers in brackets refer to the list of references appended to this paper.

This paper reports on the state of the art, from the standpoint of state agencies, of the use of quality assurance procedures for the acceptance of bituminous concrete production and construction. As will be noted, it deals primarily with the acceptance portion of quality assurance programs, since this is the most advanced aspect.

Survey

To determine their practices in relation to the use of statistical quality assurance techniques for bituminous concrete, 50 state highway agencies were sent a survey questionnaire. The questionnaire sought information on two facets of bituminous concrete specifications: production, which covers the acceptance of asphalt content and gradation of the aggregate; and construction, which comprises the density, thickness, and roughness specifications. All 50 agencies replied, with many indicating that their specifications were in a state of change. The questionnaire form with the total number of responses shown in the appropriate spaces is given in the Appendix.

Because of previous misunderstandings when the term "quality assurance" was used, the cover letter prefacing the questionnaire established the applicable definition for quality assurance, which was as follows:

> With respect to the questionnaire, a statistical quality assurance program is considered one in which the accepting agency performs tests for acceptance purposes. This is opposed to testing conducted primarily for control purposes and which, ideally, is done by the contractor/producer. Inherent in the definition of acceptance testing is the establishment of a single point of acceptance, lot size, and sample size. It is also assumed that the tolerances on the product are statistically sound.

Responses

General

The responses generally were very complete and many were prefaced by cover letters adding details, comments, and copies of specifications that were very enlightening. It was obvious that many of the agencies using quality assurance specifications were very satisfied with them. Some of the positive comments were:

> construction is better
>
> less administrative costs
>
> overall success was very good; in time it should be excellent
>
> we consider this a much more efficient and logical method than that used previously
>
> we are convinced that [the system] has not caused any increase in cost
>
> several hundred thousand dollar savings based on reduction in legal suits and claims

However, some of the responses also indicated that misunderstanding and mistrust of quality assurance procedures still existed. Here are a few pertinent comments on the question of whether the agency used a quality assurance program:

> not by your definition
>
> we have not seen an improvement in the product and, in fact, could see unnecessary manipulation by contractors, giving us a less uniform product
>
> we do not employ a formal statistically oriented sampling and testing program using rigidly defined lot sizes and sampling locations; however, most of our specifications, sampling frequencies, etc., are statistically sound, but flexible enough to accommodate unique situations
>
> may be forced into this by FHWA

Table 1 lists the states using quality assurance specifications for bituminous concrete production or construction or both.

Production

Twenty-five agencies employed a statistical quality assurance program on either a fully operational or an experimental basis. Of these, 23 did acceptance testing themselves, and the other two supervised the contractor/producer performing the acceptance testing. Twelve agencies stated that contractor/producer control testing predominated in their states, and seven of these twelve required the control testing.

Quite interesting were the specific items in the specifications. For the most preferred location for taking an acceptance sample, 13 agencies took the sample from the truck at the plant, and nine took samples from or behind the paver at the roadway. For lot size, the smallest specified was 500 tons and the largest was 4000 tons. The most popular single lot was a day's production, which was used by eight agencies. The most popular lot size tonnages were 2000 and 2500, with five agencies using the former and four the latter. The number of tests per lot varied from one to seven, with 13 agencies using five tests per lot. West Virginia's system is different in that they start with four tests on the first day of production and decrease to one per day as production continues.

The statistic most often used for tolerances is the average of the tests per lot, which is used by 18 agencies. The range is the next most popular statistic; seven agencies use it as an acceptance parameter. A price adjustment system was used by all of the 25 agencies having a quality assurance program. Incidentally, the price adjustment system is probably the most disliked facet of the quality assurance program from the viewpoint of contractors. Also, in the minds of many people, a price adjustment system is one of the features that distinguishes a statistical quality assurance program from a nonstatistical

TABLE 1—*Response to the 1978 questionnaire on the use of quality assurance specifications.*

		Construction		
State	Production	Roughness	Thickness	Density
Alabama	No	No	No	No
Alaska	Yes	Yes	Yes	Yes
Arizona	Yes	Yes	Yes	Yes
Arkansas	No	Yes	No	Yes
California	No	No	No	No
Colorado	Yes	No	No	Yes
Connecticut	Yes	No	No	No
Delaware	No	No	No	No
Florida	Yes	Yes	No	Yes
Georgia	Yes	Yes	Yes	Yes
Hawaii	No	No	No	Yes
Idaho	No	No	No	No
Illinois	Yes	No	No	Yes
Indiana	Yes[a]	Yes	No	Yes
Iowa	No	No	Yes	Yes
Kansas	No	No	No	No
Kentucky	No	No	No	No
Louisiana	Yes	Yes	No	Yes
Maine	No	No	No	No
Maryland	No	No	No	No
Massachusetts	No	No	No	No
Michigan	Yes[a]	No	No	No
Minnesota	Yes[a]	No	No	No
Mississippi	Yes	Yes	Yes	Yes
Missouri	No	No	No	No
Montana	Yes	Yes	Yes	Yes
Nebraska	Yes	No	No	Yes
Nevada	No	No	No	Yes
New Hampshire	No	No	No	No
New Jersey	Yes	Yes[a]	Yes	Yes
New Mexico	Yes	No	No	No
New York	No	No	No	Yes[a]
North Carolina	No	No	No	No
North Dakota	Yes	Yes	No	Yes
Ohio	Yes	No	No	No
Oklahoma	No	No	No	No
Oregon	No	No	No	No
Pennsylvania	Yes	No	No	Yes
Rhode Island	No	No	No	No
South Carolina	Yes	No	No	No
South Dakota	No	No	No	No
Tennessee	No	No	No	No
Texas	No	No	No	No
Utah	Yes	Yes	Yes	Yes
Vermont	Yes[b]	Yes	Yes	Yes
Virginia	Yes	No	Yes	Yes
Washington	No	No	No	No
West Virginia	Yes	Yes	Yes	Yes
Wisconsin	No	No	No	No
Wyoming	Yes	No	No	Yes
Total number using quality assurance	25	14	11	25

[a] Experimental specification.

program. Actually, this assumption is fallacious because the decision of what to do with nonspecification material depends on engineering judgment, and this holds true for any specification.

Lastly, 14 agencies used control charts for the information of the contractor or the inspectors.

Construction

Twenty-five agencies have either a fully operational or an experimental statistical quality assurance program for the acceptance of density, thickness, roughness or any combination of the three. A density specification based on statistical quality assurance techniques is used by the largest number of agencies, 25, followed by 14 using roughness, and eleven using thickness specifications. Of the 25 agencies using density, 13 employ the control strip approach, which was one of the first statistically oriented specifications implemented in the highway field. One of the reasons this approach has been as widely implemented and accepted as it has is that it is not widely recognized as a statistically oriented specification. (It should be noted that many agencies do not apply a price adjustment to this specification.)

Measures of Success

Two questions were aimed at determining how the agencies viewed the success of their statistical quality assurance programs. The first question asked them to rate the success from excellent to poor. Of the 24 agencies replying to this question, six rated their program excellent, 14 good, four fair, and none poor.

The next question asked whether the program had been cost-beneficial. Of 22 responses, ten replied in the affirmative, six said no, and six were undecided. Of those replying in the affirmative, the estimated annual dollar savings were between $100 000 and one million.

The sources of the dollar savings were stated to be less administration, a reduction in legal suits and claims, and reduced maintenance costs through better construction.

Future Usage

Many agencies indicated that, although they were not using a statistical quality assurance specification, they were interested in applying one or more in the future. Most agencies, 16, indicated that they were interested in a density specification; 15 were interested in one for roughness, 14 in one for asphalt production, and seven in one for thickness.

No Interest

Eleven agencies indicated that they were not then using, nor were they contemplating the use of, statistical quality assurance specifications. Geographically, these states were generally dispersed; three were in the Northwest, two were neighbors in the Southwest, and three were located in the general Midwestern area. The disinterest appeared to be based on local opinions rather than dictated by the materials, operations, etc., employed.

Acknowledgments

The Virginia Highway and Transportation Research Council is a cooperative organization sponsored jointly by the Virginia Department of Highways and Transportation and the University of Virginia.

APPENDIX

Questionnaire

State of the Art of Quality Assurance Programs for Bituminous Concrete

1. Does your agency have a quality assurance specification for the production of bituminous concrete?

   Yes 25 No 25

   If no, please skip to Question 3.

   a. If yes, does your agency perform acceptance testing?

   Yes 23 No 2

   b. Does the contractor/producer do control testing?

   Yes 12 No 10

   (*1*) If yes, is it required 7, voluntary 5?

2. Are the following items specified?

   a. Point of acceptance Yes ___ No ___

   If yes, location Plant (truck) 13, Roadway (paver) 9

   b. Lot size Yes ___ No ___

   If yes, size of lot 2000 T-5, 2500 T-4, Day-8

   c. Number of tests per lot Yes ___ No ___

   If yes, number 4 tests - 6, 3 tests - 4, 5 tests - 13

   d. Are tolerances applied to:

Average	Yes 18	No ___
Standard deviation	Yes 1	No ___
Range	Yes 7	No ___
Quality index	Yes 3	No ___
Other (specify)	___	

   e. Price adjustment Yes 25 No ___

   f. Control charts Yes 14 No ___

3. Does your agency have a quality assurance specification for bituminous concrete *construction*?

   Yes 25 No 25

   If no, please skip to Question 6.

   a. If yes, does your agency have tolerances on:

Roughness	Yes 14	No ___
Thickness	Yes 11	No ___
Density	Yes 25	No ___
Other (specify)	___	

   (*1*) If yes for density, do you use the control strip procedure?

   Yes 13 No ___

4. How would you classify the overall success of your quality assurance program?

Excellent	6
Good	14
Fair	4
Poor	___

5. Do you feel that your quality assurance program has been cost-beneficial?

   Yes 10 No 6 (Undecided 6)

   a. If yes, please try to estimate annual dollar savings.

   $100,000 to $1,000,000

6. If you are not now using a quality assurance specification, are you considering the use of one in the future?

Production	Yes 14	No ___
Roughness	Yes 15	No ___
Thickness	Yes 7	No ___
Density	Yes 16	No ___
Other (specify)	___	

Questionnaire Completed By:

Name ___

Address ___

___

Telephone No. ___

Please return completed questionnaire to:

C. S. Hughes, Assistant Head
Virginia Highway and Transportation Research Council
P.O. Box 3817, University Station
Charlottesville, Va. 22903

References

[*1*] "Quality Assurance and Acceptance Procedures," Special Report 118, Highway Research Board, Washington, D.C., 1971.

[*2*] "Statistically Oriented End-Result Specifications," NCHRP Synthesis 38, Transportation Research Board, Washington, D.C., 1976.

J. T. Molnar[1]

Controlling Aggregate Properties for Compliance with Statistical Specifications

REFERENCE: Molnar, J. T., "**Controlling Aggregate Properties for Compliance with Statistical Specifications,**" *Quality Assurance in Pavement Construction, ASTM STP 709,* American Society for Testing and Materials, 1980, pp. 19–27.

ABSTRACT: The author outlines aggregate process control procedures applicable to both single-plant and multiple-plant operations. The elements in establishing a control program covered here include: the basic plan, the selection and training of technicians, the sampling locations, and rapid testing and reporting methods. The main benefit of an effective control program is that it minimizes the chance of incurring penalties in the form of price reductions when the aggregate is used in products which fail to conform to the requirements of statistical or end-result specifications. Other benefits are also discussed.

KEY WORDS: quality assurance, pavements, aggregates, end-result specifications, aggregate process control, quality control, sampling, testing, control charts

An increasing number of agencies that require specifications—private, state, and federal—are adopting statistically based end-result specifications. The end-result specification—as opposed to the prescription specification—in which the owner specifies what he wants and conducts tests to determine whether he has gotten it, requires the contractor to control the quality of his work by means of an approved program. In most cases, the contractor must also submit the names and qualifications of the personnel conducting his quality control program. Statistical specifications also recognize that material properties vary and that a certain amount of variation must be tolerated. Provisions for variation in excess of that specified for full acceptance are also provided, but usually with a penalty in the form of a reduction from the unit bid price in payment.

For this reason, it becomes most important for the aggregate processor who intends to supply aggregate for such projects to control the variation of properties of his aggregate so that it is within limits which will minimize his chance of incurring costly penalties.

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Since, for an aggregate source of approved quality failure to comply with the specified gradation is the single most frequent reason for rejection, this paper will deal with controlling gradation during production and handling—although the control procedures can be applied to other specified properties as well.

Establishing a Quality Control Program

In establishing an aggregate quality control program, consideration must be given to the size of the operation and the number of operations in the organization—whether it is a single-plant or multiple-plant operation. For a small single-plant operation processing 300 000 metric tons (500 000 English tons) annually or less, sampling, testing, and reporting can be carried out by personnel on a part-time basis. In this case, the materials technician will also perform clerical, management, or other duties and will have a small laboratory equipped for performing gradation and amount tests for material finer than 75 μm (No. 200 sieve). Larger single-plant operations will require one or more full-time technicians and a laboratory equipped for performing at least the tests just mentioned. Tests for sulfate soundness, Los Angeles abrasion loss, and other properties will usually be performed by a commercial testing laboratory periodically. For companies with multiple-plant operations, a quality control department, along with plant laboratories for conducting gradation tests and a central laboratory for conducting more sophisticated tests, should be considered—especially if prospecting is being done for new aggregate deposits.

Since the aggregate technician plays a vital role in a quality control or assurance program, selecting the right person for the position is most important. To be truly effective, the technician must work cooperatively with plant personnel, management, and customers' representatives. In most instances, a person with a good high-school mathematics background and the desire to learn and perform such work makes an excellent candidate. When an individual with a stronger background in engineering fundamentals and higher mathematics, including basic statistics, is needed, colleges and universities which offer degrees in engineering technology should be contacted.

The key to a successful quality assurance program is a combination of total backing by top management and the cooperation of everyone working in the operation. For example, it is impossible for the plant technician to be at all locations where something might go wrong, at the same time. For this reason, he must rely on the plant operator, who may see a section of screen cloth failing and immediately halt production to avoid making a considerable quantity of off-specification material and also to avoid contaminating material of good quality. The technician must also rely on the front end-loader operator, who may notice lumpy material and avoid loading it, as well as notify him immediately so that the cause can be determined and corrected. In short, the quality control program is most effective when all plant personnel take part.

Once the personnel for the quality control program have been selected, they must be trained to carry out their sampling, testing, and reporting duties, using standardized procedures. The most economical training is usually in the form of training programs conducted by state departments of transportation and state and national trade associations. In a large multiple-plant company, annual in-house training sessions can be effectively conducted. Technicians should be kept abreast of recent specification changes and test methods. It is also important that aggregate technicians have a working knowledge of the basic tests conducted upon the end products in which aggregate is used—specifically, those end products which utilize bituminous and cement concrete. With an understanding of such test procedures, the aggregate technician can be knowledgeable about the aggregate properties which have a direct bearing on the test results.

The plant quality control program should, at the very minimum, stipulate:

1. The sampling and testing frequency for each size produced.
2. The sampling locations.
3. The test methods to be followed.
4. The method of reporting test data.
5. The action to be taken when samples fail to comply with the specified properties.

The sampling and testing frequency for a given aggregate size processed will depend upon the variation in gradation encountered in producing that size. Initially, as many samples should be taken as are practical to determine the grading variation to be expected for the process. Once the variation has been determined and has been minimized by reducing the factors responsible, at least two samples per day of each size, ideally, should be selected and tested. One sample per day of each size produced should be the minimum.

The sampling locations will depend upon the plant design. Samples representing current production can be selected from conveyor belts or at transfer points in accordance with the standard set forth in ASTM Sampling Aggregates (D 75-71 [1978]) or by sampling the pile resulting from a dumped truckload. However, the samples that represent current production should only be selected from stockpiles when locations within the process are not available. If radial stackers are used for stockpiling, the stacker can be swung far enough away from the pile to form a smaller pile from which the sample can be taken. Samples that represent material recovered from stockpiles should also be selected and tested to determine whether any change in gradation resulted from segregation or degradation during handling.

Because it is important to determine the test results as rapidly as possible, time-saving procedures should be employed, provided that they do not introduce a significant amount of testing error. For example, sieve analyses of most coarse aggregate sizes can be conducted with the aggregate in a damp condition, provided that the differences between such test results and those conducted on the aggregate in an oven-dry condition are known. However, when the test results are in question, the standard method should always be used. Fine aggregate usually can be quickly dried with a microwave oven for tests on gradation or moisture content. The pycnometer method of determining the amount of material finer than 75 μm (No. 200 sieve) does not require oven drying.

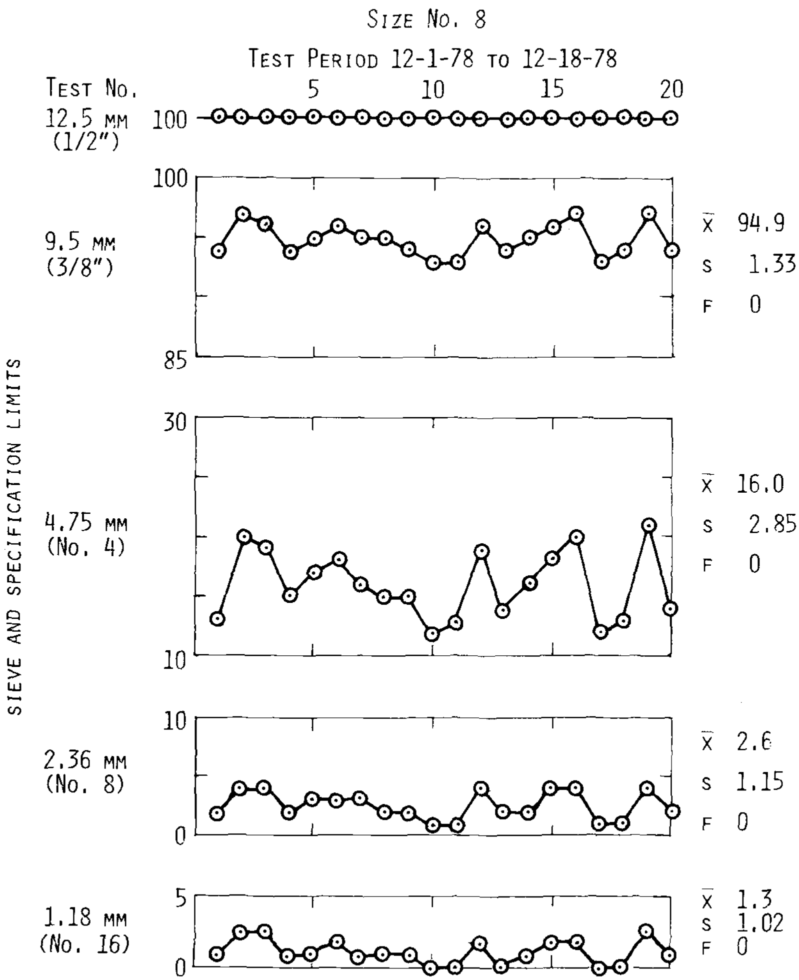

FIG. 1—*Control chart for aggregate gradation.*

The most efficient control program is one which permits data to be rapidly reported to the plant management without delay. This procedure of rapid feedback permits the manager to make any necessary process changes immediately, with little or no material produced out of the gradations specified. Control charts are the best means of reporting data, since each chart contains several test results and permits a rapid comparison of recent data to determine process changes. As illustrated in Fig. 1, a chart permits gradations to be plotted for each size on a single sheet and provides a running account of gradation control. The data in this form indicate trends, and this information, when properly interpreted, allows production changes to be made before the process gets out of control.

As each test is completed, a point is plotted for each sieve which represents the amount that passes. Either the originals or a duplicate set of charts should be kept in the plant manager's office and brought up to date no later than the end of each day. The technician should discuss any trend or obvious change in gradation with the plant manager to determine whether any process adjustments are necessary. As each chart is completed, the average, the standard deviation, and the projected failure, based upon the probability of exceeding the specified limits, are calculated and shown on the right side of the chart.

Figures 2 through 6 are control charts which illustrate common variations in aggregate gradation in relation to the specification limits for a control sieve, determined during production:

Figure 2—The variation is low. However, the average is too close to the lower limit. The result is that 44 percent of the samples fail. The probable reason is either that the wrong screen was used for the bottom sizing of this product, or that the crusher was set incorrectly.

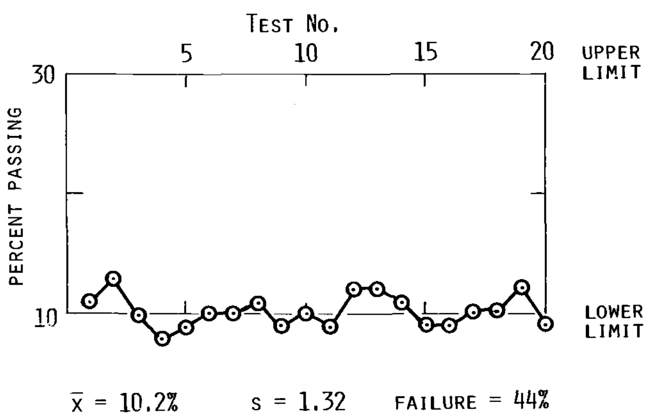

FIG. 2—*Control chart showing that the average results are too close to the lower limit.*

Figure 3—There is the same variation as in Fig. 2, but the average is 3 percentage points greater. The result is that, even though the average is close to the lower limit, only about 0.8 percent of the samples would be expected to fail, because of the low variation. This example proves that it is not necessary to set the average close to the center of the specified limits if the variation is small.

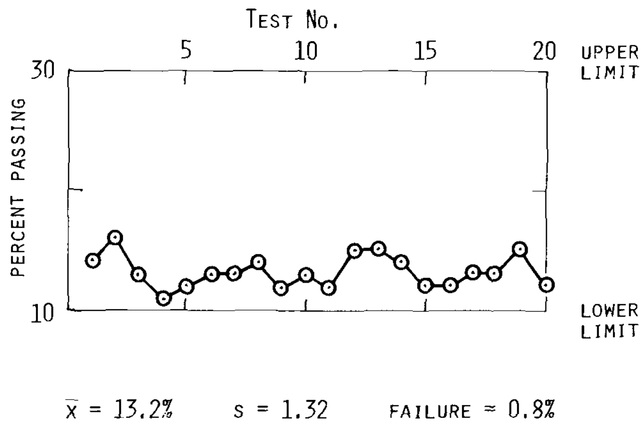

FIG. 3—*Control chart showing that the average results need not coincide with the center of the specified limits provided that the variation is low.*

Figure 4—The variation is moderate, but the expected failure rate is low (5 percent) because the average is near the center of the limits. A shift of the average—either up or down—will result in increased failures.

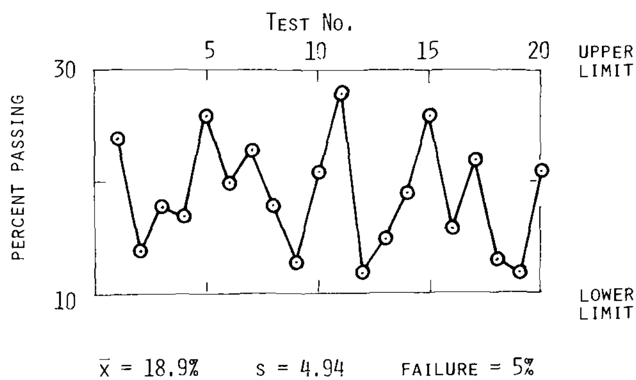

FIG. 4—*Control chart showing the necessity of aiming at the center of the specified limits when the variation is moderate.*

Figure 5—The process is out of control. The variation is too large, resulting in failures at both the upper and lower limits. Action to determine the causes of the large variation and steps to bring the process back into control should have been taken before this chart was completed.

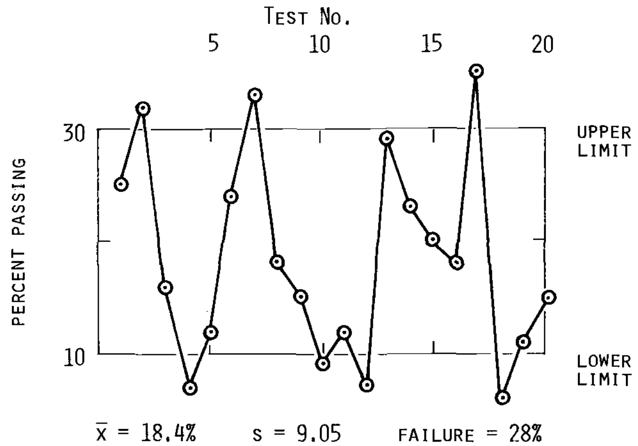

FIG. 5—*Control chart showing that the process is out of control.*

Figure 6—The variation is low, the projected failure rate is low, and the average is near the center of the limits, but the grading is continually getting coarser. The probable cause is that one or more of the production components are wearing down or are out of adjustment. Action should be taken immediately to determine which components are at fault, and these components should be adjusted or replaced, if necessary.

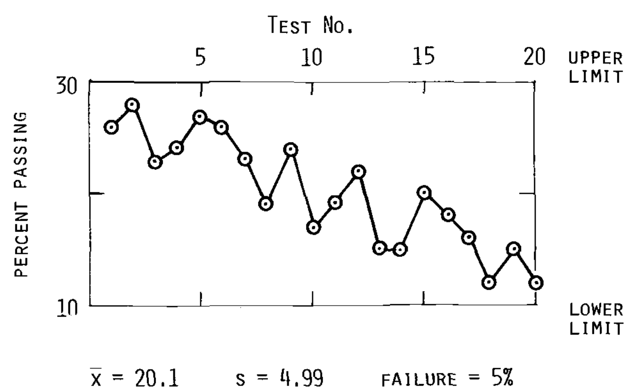

FIG. 6—*Control chart showing that the aggregate is getting progressively coarser.*

These examples should demonstrate the advantages of control charts over other types of gradation reports. In summary, control charts:

(*a*) provide a visual account of the variation, central tendency, and projected failure rate for each sieve and

(*b*) reveal trends which point to problems so that action can be taken to correct a situation before the process gets out of control.

Cost and Benefits

The cost of an effective aggregate process control program will depend upon the size of the production facility. The author's experience is that a viable program can be conducted for between three and five cents per ton.

The main benefit of such a program is that it minimizes the chance of incurring penalties in the form of price reductions when the aggregate is used in products which fail to conform to the requirements of statistical or end-result specifications. Often the attempt is made to pass on to the aggregate producer the penalty applied to the unit bid price of the end product. Unless the producer can prove by documented test results that the variation in the properties of the aggregate was within the limits permitted when the aggregate left his control, he could well incur the total penalty. Further, it is not unusual for such penalties to exceed the production cost of the aggregate by five or more times that cost. It is not necessary to elaborate on the effect such penalties would have upon the potential profit of an aggregate plant. It then can be concluded that effective quality control is inexpensive insurance in terms of minimizing product liability claims.

Other benefits include the additional services which trained aggregate technicians can perform for production management, such as selecting the optimum screen opening sizes, crusher settings and speeds, and sand classifier adjustments for obtaining the most profitable product mix. Technicians also can provide valuable services to customers in helping them to achieve the most effective utilization of aggregates in their projects and products.

When consideration is given to establishing an effective aggregate quality control program, the major emphasis should be placed not upon the projected cost, but on the potential savings.

W. H. Jones[1] *and J. A. Scherocman*[2]

End-Result Specifications— A Contractor's Viewpoint*

REFERENCE: Jones, W. H. and Scherocman, J. A., **"End-Result Specifications—A Contractor's Viewpoint,"** *Quality Assurance in Pavement Construction, ASTM STP 709,* American Society for Testing and Materials, 1980, pp. 28–36.

ABSTRACT: Method-type specifications penalize a competent asphalt paving contractor by requiring the contractor to use prescribed equipment, materials, and methods to construct a particular pavement. End-result specifications, on the other hand, allow the contractor to use his available resources to accomplish the required end product in the manner of his own preference.

The Indiana State Highway Commission let to contract a paving project under end-result specifications. This contract, awarded to Magaw Construction, accepted the asphalt content, aggregate gradation, and pavement surface smoothness on the basis of statistical-type specifications. The quality control exercised by the contractor was excellent, with the penalties assessed being equal to only 1.24 percent of the value of the paving work.

A lack of knowledge by state personnel of the significance of end-result specifications and differences in sampling and testing techniques have, in the past, caused the assessment of many of the penalty points. The differences in the results obtained could be reduced on future projects, however, through the use of a certified asphalt technician approach to end-result specifications.

KEY WORDS: quality assurance, pavements, end-result specifications, full-depth asphalt concrete

For many years, highway pavement structures have been constructed using "method" specifications. This type of specification is a cookbook, or recipe, approach to construction. Under method specifications, the contractor is told how to do the work required—the specifications list the equipment which can be used, the steps to be followed in the building process, and the results which must be obtained when the construction is completed.

Most method specifications have been written because some contractor found a loophole in the existing specifications and tried some new equipment or construction process which did not work out to the satisfaction of the governmental agency's inspector. The agency's reaction in such a situation is

*The original experimental data were measured in English customary units.

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to publish a new special provision or specification to assure that some other contractor does not have the opportunity to use the same loophole. Method specifications require that all contractors, both competent and incompetent, work to the same level, the lowest common denominator. These specifications keep the incompetent contractor in business and prevent the progressive contractor from using his initiative and ingenuity to develop a way that is faster or cheaper, or both, to accomplish the task.

Under method specifications, many governmental agencies attempt to penalize the contractor when the results obtained have not met expectations. A contractor, for example, can have his mix design for an asphalt concrete material written by the agency, his sources of materials sampled and approved, and the mix inspected and tested by governmental personnel at both his plant and the paving site, and still be penalized if some characteristic of the final product does not meet, in the inspector's judgment, the agency's expectation.

It is difficult to understand the reasoning behind the method specifications procedure—which consists of telling the contractor exactly how to do the job, but refusing to pay him the full price for the work if it does not come out exactly right! End-result specifications, on the other hand, allow the contractor to choose his own equipment, materials, and methods, and to accomplish the required end product in a manner determined by his own preference. Each contractor is free to use his available resources to try to maximize his profit on each job he bids and builds.

Bidding on End-Result Specifications Projects

Before any contractor thinks about undertaking an end-result specifications (ERS) project, he should be completely familiar with the requirements of the specifications. The contractor should understand what the governmental agency is trying to accomplish by converting from method specifications to statistical-type ERS. It is also very important that each supplier and subcontractor be cognizant of his responsibilities under the new type of specifications. The potential for a penalty can be greater under ERS than under method specifications, but the possibility of a higher profit level is also greater. A contractor must be able to balance one factor against the other when bidding on an ERS project for the first time.

The Indiana State Highway Commission scheduled its second ERS asphalt paving project for a contract on State Route 1, between State Route 38 and U.S. Highway 35 in the east central part of the state, for bidding on 27 July 1976. The project called for the mixing and placing of 75 871.5 metric tons (83 634 English tons) of various asphalt concrete mixtures. The pavement structure on the two-lane roadway, to be built using full-depth asphalt concrete, was to have the following cross section: 190 mm (0.75 in.) of surface course, 571 mm (2.25 in.) of binder course, 1524 mm (6 in.) of base course, and

1016 mm (4 in.) of bituminous stabilized subbase course. The specifications required the successful contractor to control his own mix production (asphalt content and aggregate gradation) and mix placement (compaction and smoothness).

Magaw Construction, a division of Ashland-Warren, Inc., had a small drum mix asphalt plant located about 11.3 km (7 miles) away from the center of the project. When the sale of the ERS project was announced, Magaw personnel began a series of meetings with the company's traditional suppliers and subcontractors to see if a competitive bid could be submitted for the work.

Several discussions were held with the management of Irving Materials, Inc., an aggregate supplier, to assess potential problems in maintaining strict uniformity of the quality and gradation of the coarse and fine aggregates to be used in the asphalt concrete mixtures. It was stressed that large stockpiles of individual sizes of aggregate were needed at the drum mix plant site in order to provide the Magaw quality control technicians with enough time properly to sample and test the aggregates before they were blended into the mixture. As will be shown, the complete cooperation and assistance of the aggregate supplier is extremely important in producing an asphalt concrete mixture of uniform gradation, one which can be accepted by the inspecting governmental agency without penalty to the mix producer.

Because Magaw is primarily an asphalt paving contractor, the company decided to enter into a joint venture for the project with Rieth-Riley Construction Co., which had the equipment needed to do the required earthwork and drainage structure construction. In meetings with the Rieth-Riley personnel, the need for a consistent subgrade soil quality was stressed—which included a proper grade and cross slope to the subgrade, as well as uniform density. In order for Magaw to obtain 100 percent payment for the compaction of the asphalt concrete layers, it would be necessary to have a subgrade soil which would provide the proper support for the paving and compaction equipment.

The next step in the prebid evaluation process was a review of the production requirements at the drum mix asphalt plant. Magaw's estimators and plant operating personnel got together to discuss ERS and how these specifications would effect normal plant production rates. The laydown operating personnel were then consulted to discuss potential changes in the asphalt concrete paving process caused by the change from method specifications to ERS. Hypothetical plant and paving situations were presented to the Magaw job superintendents; their reactions and the effects of the situations under ERS were considered; and the remedies to possible problems were analyzed.

The prebid preparation work paid off when the bids were opened. The joint venture of Magaw (Ashland-Warren) and Rieth-Riley was the low bidder at $2 447 848.95. The winning bid was only 1.02 percent below that of the second bidder, but 17.23 percent below the state's engineers' estimate.

Preconstruction Preparations

With the ERS project under contract, Magaw purchased and equipped a mobile testing trailer for quality control testing at the asphalt plant. An in-depth investigation was immediately begun to determine the gradation of the stockpiles of the different aggregates to be incorporated into the various asphalt concrete mixtures. In cooperation with the aggregate supplier, Magaw personnel conducted over 200 separate aggregate gradation tests on four different coarse aggregates and one fine aggregate at two separate sites. It was this initial testing which paid off in a uniform mixture produced by the asphalt plant.

The next step in the preparation process was to make some major modifications to the existing drum mix plant. The 1.77 by 9.14-m (5.8 by 30-ft) dryer drum was replaced with a new 2.43 by 10.97-m (8 by 36-ft) Astec drum. A Ramsey asphalt proportioning unit, Texas Nuclear belt scale, and Hayes flow meter were also installed on the plant. The plant was calibrated by Magaw personnel, and the job mix formula for the various mixtures was prepared and tested. The asphalt content and the aggregate gradation of these trial mixes were established and checked by the contractor's quality control technicians.

Job assignments and responsibilities were reviewed with all the Magaw supervisory personnel selected to work on the ERS project. Key operating personnel were given complete authority to stop operations, individually or collectively, whenever anything went wrong which could affect the company's payment or performance on the job. Included in the list of key people were the general superintendent, the plant and paving superintendents, the plant materials technician, and the paving density technician. Each of these individuals had the authority and responsibility to see that his portion of the total project received 100 percent payment.

At this point, discussions were held again with the aggregate supplier to reemphasize the importance of his role in the ERS operation. The availability of large stockpiles of material, careful rehandling techniques, and continual gradation checking were needed to assure process control in producing uniform, consistent, aggregate gradation. A paving contractor must know his material supplier—and that company's equipment, personnel, and capabilities—and bid accordingly; the supplier can make or break the ERS contractor.

Paving Operations

The actual asphalt concrete mix production began on 29 Oct. 1976 on the south 0.8 km (0.5 mile) of the project, so that access could be provided over the coming winter to some residences along the road. The paver used to place the various asphalt concrete layers was a Blaw-Knox 180H. The compaction equipment consisted of a three-wheel steel-wheel breakdown roller, a pneumatic tire intermediate roller, and a tandem steel-wheel finisher roller.

One lot of material on this project consisted of the amount of each type of mixture produced each day. Each lot was divided into five sublots, and the test times and the location for each sublot were chosen from a table of random numbers.

TABLE 1—*The initial mix production.*

Date 1976	Material	No. of Tests	Quantity Placed, tons[a]	Price Adjustment Points[b]		
				Mix	Density	Smoothness
10/29	Subbase	1	1484.1	0	0	...
11/11	Base	1	821.1	0	4	...
11/12	Base	2	1085.3	0	6	...
11/16	Base	3	418.8	0	0	...
11/16	Binder	1	351.1	0	0	...
11/17	Binder	2	360.3	0	0	...

[a]In this table, 1 (English or U.S.) ton = 0.907 metric tons.
[b]Each penalty point is equal to 1 percent of the contract price per ton of mix.

During the fall of 1976, the asphalt concrete mixtures were produced and placed in only six days, in small quantities. Table 1 illustrates the mixtures manufactured and the penalty points assessed. The results for asphalt content and gradation, as tested by the State Highway Commission's inspectors, were perfect. The pavement smoothness, limited by the specifications to the surface course only, was not checked. Penalty points were assessed, and pay was lost, however, on the density of the asphalt concrete base course. The inadequate density was caused by a minor segregation problem in the asphalt concrete base course, which, in turn, affected the level of density that could be achieved in the mix, and which was due to the presence of a localized soft spot in the subgrade soil. In general, the plant ran well, and the mixtures produced met the specifications. The project was shut down for the winter.

Paving operations were resumed on 27 May 1977. Before construction was completed on 30 Nov. 1977, a total of 103 lots had been sampled and tested. Figures 1 and 2 illustrate the consistency of the asphalt concrete extraction testing on this project. In Fig. 1, the control chart for the asphalt content for the asphalt concrete base course for 23 lots (59 individual tests) of material is shown. The job mix formula asphalt content of 4.5 percent is drawn on the control chart, along with the upper and lower limits allowed for one to five tests per lot. In no lot did the average asphalt content go outside of the specification limits for that particular lot. No penalties were assessed for asphalt content for this base course material.

In Fig. 2, the control chart is shown for the amount of aggregate passing the No. 4 sieve for the asphalt concrete base course. The job mix formula for the amount passing this sieve is 30 percent. The control chart illustrates this value, along with the allowable upper and lower limits for one to five tests per lot. Again, no penalties were assessed for this particular sieve since in no lot did the average percent passing the No. 4 sieve exceed the specification limits. In fact, the quality control was excellent, and the average percent passing for each lot was always within ±3 percent of the mix formula value.

Some penalty points were lost, however. On the whole project, for all the mixes (103 lots), nine lots were assessed a total of 52 penalty points for out-of-specification asphalt content or aggregate gradation. Twelve lots out of 103 were assessed 58 penalty points for inadequate density. No penalty points were assessed for smoothness. Table 2 shows a breakdown of the payment deductions lost by item and tonnage.

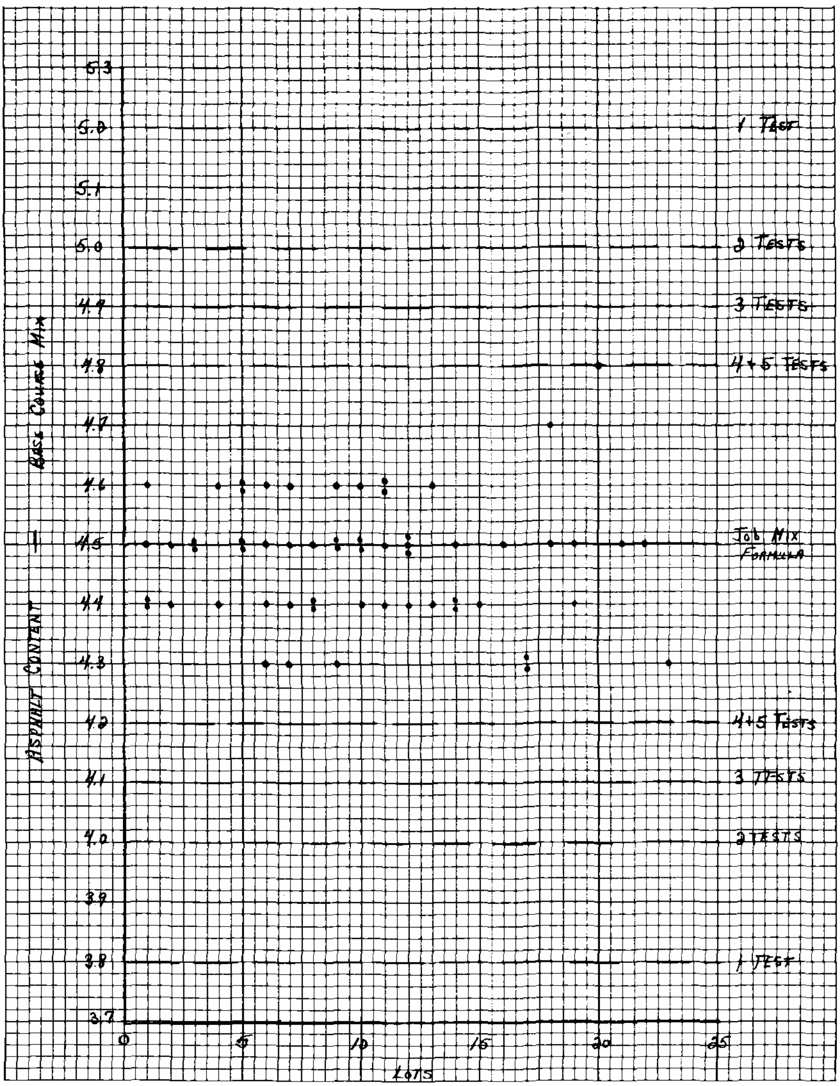

FIG. 1—*Control chart for asphalt content.*

From this table, it can be seen that a total of $12 710.58 in penalties was assessed on deficiencies in 74 154 metric tons (81 741 English tons) of mix. The average price reduction, however, was only 15.5 cents per English ton. The total dollar value of paving in the bid on the project was $1 024 562.37; thus, the amount of money lost in penalties was approximately 1.24 percent of the value of the paving work.

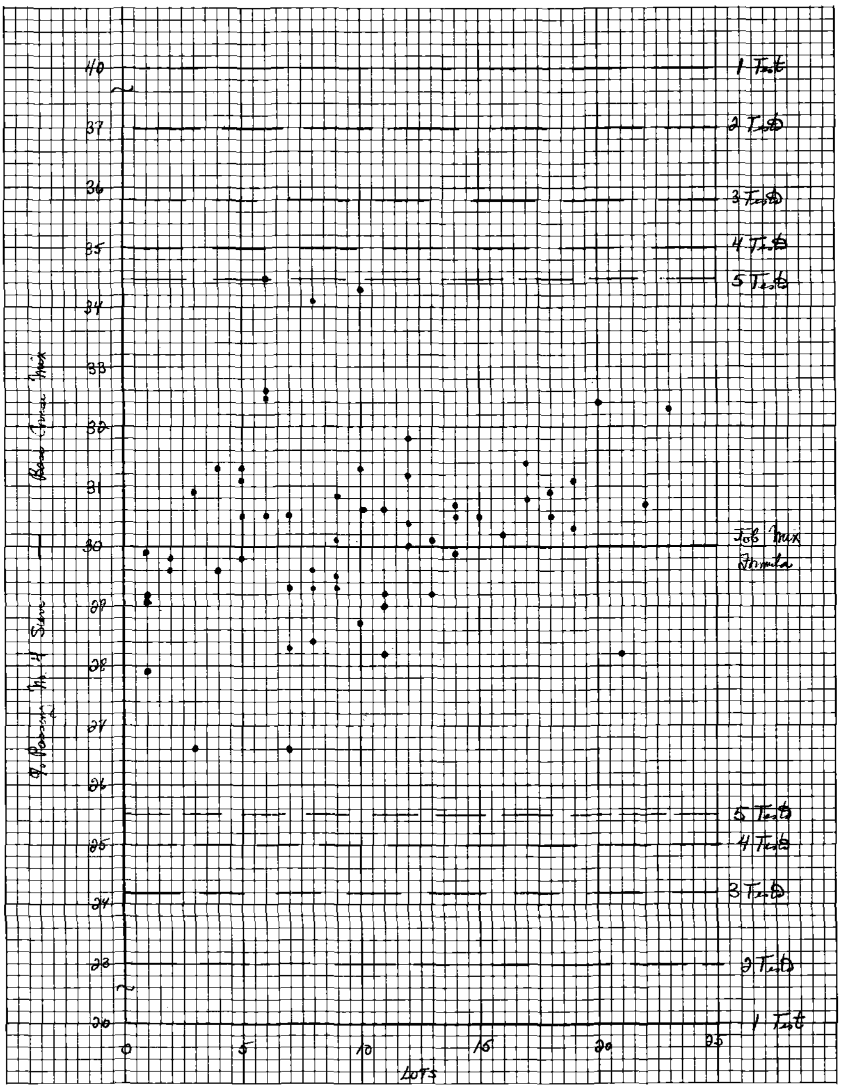

FIG. 2—*Control chart for gradation.*

TABLE 2—*The penalties assessed.*

Item	Tons Assessed[a]	Reduced Price[b]	Amount of Penalty[c]
Subbase	17 535	$0.056	$981.96
Base No. 53B	20 012	$0.227	$4 542.72
Base No. 5	1 507	$0.029	$43.70
	28 827	$0.183	$5 275.34
Binder	11 264	$0.095	$1 070.08
Surface	227	$1.526	$346.40
	2 328	$0.160	$372.48
Approaches	41	$1.900	$77.90
Totals	81 741	$0.155[d]	$12 710.58

[a]1 (English) ton = 0.907 metric tons.
[b]Per English ton.
[c]Per type of mix.
[d]Average per ton on the whole project.

Discussion

The method specifications of the Indiana State Highway Commission are very detailed—virtually every function is spelled out, covering who, where, when, why, what, and how. The project inspectors are taught to monitor and control every aspect of the construction procedure. In addition, most project personnel lack the authority to make any significant decisions—decision-making authority is reserved for the central office (Indianapolis), which causes an automatic delay in the solution to even the most minor problems.

One of the sources of difficulty on this project was a lack of knowledge on the part of the State Highway Commission's personnel of the significance and workings of end-result specifications. The contractor's people were much more familiar with ERS than were the state inspectors—the state still wanted to control the contractor's operations though it no longer had the right to do so. The State Highway Commission should have discussed with its personnel more thoroughly the role of the state inspectors in conducting acceptance testing, as opposed to job control testing; such preparation would have been most beneficial.

Most of the penalty points assessed were the result of differences between different people in sampling, quartering, extracting, sieving, and operating the nuclear density gage. Most of these problems could have been minimized by first adopting a "certified asphalt [and concrete] technician" approach to ERS. On an ERS project, the state and the contractor need to have technicians who have been trained by the *same* instructors, using the *same* equipment and, particularly, the *same* techniques.

Technicians for both the state and the contractor should be required to pass a detailed written test proving their ability and competence in at least the following areas:

1. Aggregate and asphalt sampling and testing.
2. Asphalt concrete mix design.
3. The calibration of asphalt batch and drum mix plants.
4. Nuclear and core density testing.
5. Rolling straight-edge testing.
6. Subgrade soil density testing.
7. Reading, and understanding, project plans and specifications.

Only properly certified technicians should be allowed on ERS jobs (or on any paving projects).

When ERS are used, the project owner benefits by knowing that the products he pays for are what he actually receives. Job and plant delays caused by indecision or by present central office authority procedures are reduced or eliminated. In addition, the contractor gains by being able to use his equipment, materials, and personnel in the most efficient and economical manner. Having an experienced and certified asphalt technician will result in less waste, fewer delays, and better products for the contractor—all of which convert to more dollars on the bottom line.

End-result specifications allow a contractor a degree of independence not possible under method specifications. ERS allow a contractor to participate in the decision-making process on a public paving contract, which is similar to what a contractor does for his private customers. ERS promote good workmanship and quality construction, to the benefit of both the owner and the contractor.