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FINAL REPORT

PERFORMANCE RELATED SPECIFICATIONS FOR BITUMINOUS CONCRETE

by

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ABSTRACT

This report discusses the philosophy and evolution of performance related specifications. The properties of most importance in the construction of asphaltic concrete pavements, as well as the associated specifications, are listed and discussed. The importance of specifications established to control uniformity or to provide a standard basis for bidding is mentioned. Recommendations for making the Virginia Department of Highways and Transportation's specifications for bituminous concrete as performance related as practical are presented.

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INTRODUCTION

Most specifications for bituminous concrete have been developed as particular needs have been recognized and thus do not express a consistent, comprehensive philosophy. For instance, the bituminous concrete portion of the Virginia Department of Highways and Transportation's Road and Bridge Specification includes some method type specifications; e.g., Section 212.11, Bituminous Concrete Mixing Plant, details how the plant scales, drier, screens, etc., shall function, whereas other sections, such as Section 212.07, Acceptance, are oriented to end result specifications. The latter are meant to reflect the philosophy that whenever possible, the characteristics of the mix and pavement that can be measured should be closely related to the ability of the pavement to provide the required performance over its design life.

Although this latter philosophy is easily stated and its validity may be hard to refute, it is also difficult to implement. The many interactive variables in the materials and the construction processes used to build a flexible pavement, as well as the practicality of applying the specifications, make the development of performance related specifications difficult; however, the potential benefits of comprehensive specifications oriented primarily toward assuring that the pavement will be durable should make the effort worthwhile. As Epps and Karis recently stated:

> Because of basic societal changes we have placed ever changing performance demands on paving materials. During the last 10 to 15 years our pavements have been subjected to an increasing number of vehicles. Construction equipment has changed to improve production, improve air quality and workman safety, and material changes have occurred due to crude supply and transportation costs. ... The technologists and practicing engineers must continue their effort to improve the performance based specifications. The need has never been greater. (1)

While this present study is independent of the periodical review and revision of bituminous specifications undertaken by the Department, the findings should assist in these reviews, and the work described here in no way implies criticism of previous efforts.

PURPOSE AND SCOPE

The purpose of this study was to review the Virginia Department of Highways and Transportation specifications for the design, acceptance, and placement of bituminous concrete mixes, and to determine what changes should be recommended for making the specifications as performance related as practically possible. The intent of the study, in essence, was to further the philosophy that, whenever practical, the specifications should be tailored to characteristics of the pavement that enable it to provide the service for which it is designed. While some changes in specification values may be warranted, it was not the intent of this study to tighten the present specification limits.

The study dealt only with the production of asphaltic mixes and their use in construction. It was assumed that pavement design procedures provide the thicknesses of asphaltic concrete necessary to withstand the anticipated traffic loadings.

PHILOSOPHY UNDERLYING PERFORMANCE RELATED SPECIFICATIONS

Prior to an exposition on the values of performance related specifications, a brief contrast of the method and performance approaches to specifications may be worthwhile.

The method specification, which is the oldest type in use, puts maximum control in the hands of the buyer. The seller is required to follow step-by-step procedures using specified materials and equipment. This type of specification has its place, particularly where there is no economically measurable or performance related property that can be specified. Mix segregation, for instance, is undesirable but there is no easily identified procedure for specifying the degree of segregation that is acceptable. Thus, method specifications are often used to specify what a contractor must do to prevent segregation. A disadvantage of method specifications is that they might not allow a contractor to use the most economical or innovative procedures to produce the product sought.

Specifications that require a stated degree or amount of some particular property in a product have been used in lieu of method specifications for years. These have most often focused on such properties as asphalt content, gradation, and density. The manner in which limits for these properties have been derived is of interest, since it has had a direct bearing on the evolution of performance related specifications.

One of the most widespread and most publicized use of "end result specifications" was in the AASHTO Road Test. The limits used at that time had been intuitively derived, and during the road test they were found to be so tight that often a large percentage of the product exceeded them. To overcome this problem revealed in the AASHTO test results, the FHWA promoted studies to determine what process average and variability should reasonably be expected. These studies led to the use of terms such as "statistical end result specifications" and "statistically based specifications." More recently "quality assurance programs" replaced the earlier terms, and now "performance related specifications" seems to be the popular term.

The improper, and sometimes derogatory, use of these terms has resulted at least partially from the gradual evolution of these specifications. The earlier versions of the specifications generally dealt with only the state's role in the acceptance part of what now is often thought of as a system. During the evolution the concept of quality control independently exercised by the contractor became a part of the system, and now both of these ingredients are considered essential in a complete statistical quality assurance program. But because this type of program is somewhat of an ideal, and because of the manner in which it evolved, a spectrum of sorts has developed in which specifications on some items are still in an early stage while some agencies have gone through two or more stages in devising and using performance related specifications.

Virginia has been a national leader in change to end result specifications, and in 1982 the present author undertook an examination of the sections of the state's specifications on bituminous concrete and bituminous concrete pavements to try to develop a consistent philosophy under which the state can require, whenever practical, the properties necessary to provide an asphaltic concrete pavement that will, with reasonable maintenance, perform well throughout its design life. This leaves to the contractor the responsibility of controlling the product so as to meet the specified properties, assuming that practical considerations will be taken into account.

Since this study was begun several changes in specifications have been implemented by the Department, and two of these are noted below.

Section 212.03 — Job-Mix Formula states, "The contractor shall submit, ... for the Engineer's approval, a job-mix formula for each mixture to be supplied ...." The intent of this section has always been to place responsibility for mix design upon the contractor, but in fact mixes traditionally have been designed by the Department. In 1984 the Department turned the responsibility for mix design over to the producers on a limited scale, with total responsibility to be transferred in 1985.

The other major change was the move from voluntary to mandatory use of the Department's quality assurance program, which puts acceptance testing in the hands of the contractor and allows the Department to do much reduced sampling. A vital part of this program is that the Department's inspector has been removed from the plant and inspection is done approximately twice weekly by a district materials technician.

Performance type specifications also require that noncompliance with specifications be addressed. This is often a difficult task and requires careful weighing of the effects of noncompliance on performance. This difficulty has probably been the greatest deterrent to the implementation of performance related specifications by highway departments.

PERFORMANCE RELATED PROPERTIES AND ASSOCIATED SPECIFICATIONS

The properties of most importance in the construction of asphaltic concrete pavements have been enumerated in many publications, (2,3,4,5) and the author has taken the liberty of adding to these in compiling the following list.

Durability
Flexibility
Fatigue Resistance
Stability
Skid Resistance
Impermeability
Workability
Ride Quality
Specified Thickness

These properties are defined below.

- Durability is the ability of the pavement to resist disintegration from the effects of weathering, including aging, and traffic. To minimize these effects, high asphalt contents, dense aggregate gradations, and good compaction are required.

- Flexibility is the ability of the layers to conform to gradual movements of the base and subbase. This property is promoted by high asphalt contents and, probably, by open aggregate gradations.

- Fatigue resistance is the ability of an asphaltic mix to withstand repeated flexing or bending caused by the passage of wheel loads. Asphalt content and density appear to be the two variables that most strongly influence this property.

- Stability is the ability of a mix to resist permanent deformation under loads. To promote this property, the asphalt content must be maintained at a sufficiently low level so that the frictional resistance of the aggregate mass will be effective. Good field compaction is also necessary.

- Skid resistance is the ability of the asphalt surface, particularly when wet, to offer resistance to skidding. High skid resistance is generally provided by the same factors that contribute to high stability, with the additional characteristic of sufficient macrotexture to prevent hydroplaning.

- Impermeability is the ability of a mix to resist the passage of air and water into or through the pavement. For this property, a high asphalt content, dense aggregate gradation, and high density are desirable.

- Workability relates to the ease with which a paving mixture may be placed and compacted. In addition to proper asphalt content and gradation, placement temperature is important.

- Ride quality is the property most noticed by the travelling public and should be adequate at the time of construction and remain that way. It is primarily a construction function, although it can be influenced by the top size aggregate and rate of application of the mix.

- Specified thickness is also primarily a construction function but must be obtained in order to develop the strengths predicted in the pavement design stage.

These properties are listed in column (1) of Table 1. In column (2) are listed the pavement defects which occur when there is an inadequacy of the corresponding property. In some cases the failures may occur after several years; in others, they may be present in the new construction. A property may be associated with more than one failure mode; e.g., a loss of stability may be manifested in stripping that may in turn cause shoving. In most definitions of failure modes, longitudinal cracking is considered a precursor of alligator cracking.

Under the next broad heading, Specification Control Variables, are the direct and indirect means used under the specifications to judge acceptability or, conversely, to minimize the probability of failure. The tests listed in column (3) provide a direct indication as to whether the product is acceptable in terms of the corresponding properties, and the procedures listed in column (4) provide an indirect indication. As can be seen, there are many more indirect than direct procedures.

Durability, flexibility, and fatigue resistance are listed together because they are evaluated through the same indirect measures.

Table 1

Performance Related Specifications for Bituminous Concrete

		Specification Control Variables	
Property (1)	Failure Mode (2)	Direct Measure (3)	Indirect Measure (4)
Durability Flexibility Fatigue resistance	Longitudinal cracking Transverse cracking Raveling	Fatigue test[a] Indirect tension test[a]	Mix design[b] Asphalt film thickness Asphalt grade Asphalt temperature susceptibility Aggregate type and quality Mix temperature Field density Adhesion to underlying layer
Stability	Rutting Shoving Slipping	Stability	Mix design[b] Mix moisture content Asphalt grade Aggregate type and gradation Field density
Skid resistance	Flushing Polishing aggregate	Skid measurement[a]	Mix design[b] Asphalt grade Aggregate type
Impermeability	Stripping Delamination		Stripping test Mix design[b] Field density Mix uniformity
Workability	Poor texture		Mix design[b] Placement temperature
Ride quality	Rough ride Transverse cracking	Straightedge Roughometer[a]	
Specified thickness	Cracking	Tests of cores Application rate	

[a]Test not commonly performed by district labs.
[b]Mix design should consider asphalt content, gradation, filler/asphalt ratio, voids total mix, voids in mineral aggregate, voids filled with asphalt, and flow.

The direct and indirect measures listed are certainly not the only ones used under the specifications to obtain a good asphaltic pavement, and some specifications have been devised to prevent the reoccurrence of a problem encountered one time in one particular mix or on one construction project. Consequently, it is necessary to use engineering experience and logic to specify measures that are necessary and enforceable to the construction of a good asphaltic pavement. However, there is no chance that every eventuality can be covered in the specifications, so the importance of good inspection and common sense cannot be overemphasized, no matter how thorough or logical the specifications may be. Further, compliance with specifications must be achieved through tests that are readily adaptable for use in district laboratories. Fatigue and creep tests, for example, can be very useful in research but at present are impractical as acceptance tests.

The data in Table 2 are from the results of a national questionnaire reported by the Oregon DOT and represent the responses to the question: What properties do you evaluate to establish the acceptability of an asphaltic pavement?(6) While all of the properties cited in Table 2 were covered in Table 1, these responses do provide an indication of the properties that most states place emphasis upon.

Table 2

Properties Most Often Tested to Evaluate the Acceptability of an Asphaltic Pavement

Property	Agencies Testing, %
Mix gradation	96
Asphalt properties	94
Asphalt content	91
Compaction	91
Aggregate quality	83
Smoothness	79
Thickness	66

Source: Reference 6.

CONTRACT RESPONSIBILITY

In the evolution of specifications mentioned earlier, responsibility has gradually shifted from the state to the contractor. Under method specifications, maximum responsibility is in the hands of the state; under performance related specifications, the responsibility is shared and should be well defined. The state is responsible for accepting the product, with as few specific requirements as necessary, and the contractor is responsible for controlling the product so as to meet the specifications.

State's Responsibility

It is the state's responsibility to establish a quality level that is not only desirable but, more important, affordable. To require a quality level greater than necessary is to increase the cost of the product without achieving a commensurate economic benefit. The quality level, ideally, should reflect the design life of the pavement.

All properties cannot be precisely established in terms of quality. For instance, where it might be apparent two contractors have different gradations of aggregates it is possible that one material cannot be judged superior to the other; however, since both contractors propose to enter into a business arrangement with the state, they must produce essentially comparable products that meet the specifications. Thus, many specifications are needed simply to require comparable products from bidders. AASHTO R9-81, Acceptance Sampling Plans for Highway Construction has the following classification system for the criticality of ratings.(7)

Critical — when the requirement is essential to preservation of life

Major — when the requirement is necessary for the prevention of substantial economic loss

Minor — when the requirement does not materially affect performance

Contractual — when the requirement is established to control uniformity and/or provide a standard basis for bidding

The last definition has many applications within highway specifications.

Further, it is the state's responsibility to request the product in precise terms so that all bidders clearly understand what is being required of them. As an example, a specification that requires a 6-in asphalt pavement is not precise, a measure of the central tendency required and an allowable variability must be included to make the specification precise.

The state must also take responsibility for accepting the product that the contractor produces. This can vary from watching the contractor perform the task, as is the case under method specifications, to accepting the product under a sophisticated acceptance plan. Additionally, the state must precisely specify the consequences in the case any product does not meet the specifications.

Contractor's Responsibility

If the state assumes the responsibilities cited above, it leaves the responsibility for product control during production and construction up to the contractor. To allow the contractor to optimize the use of his equipment and benefit from innovations, he should have as much freedom as is practical in exercising this control.

While this responsibility for control can be stated very simply, the implications are quite complex. When a failure such as severe instability occurs within, say 90 days, whose responsibility is it? First, the source of the instability must be identified. Aggregate type, aggregate gradation, asphalt cement, contamination, and inadequate construction procedures are some of the potential sources of instability. Usually, it is a combination of more than one of these factors. Compounding the problem are environmental conditions and traffic that may aggravate the situation.

On the other hand, to state the conditions that must be met to prevent instability would remove all of the responsibility from the contractor and make the specification so cumbersome as to be of little use.

The contractor must assume some responsibility as measured by performance. Reaching a happy medium is difficult.

SPECIFICATION CONTROL VARIABLES

Because so many of the properties sought in an asphaltic concrete pavement are measured by indirect tests, many of which are empirical, any concern as to the ability of performance related specifications to ensure quality is understandable. However, the need for many specifications and for means of achieving compliance from a contractual viewpoint must be recognized. This section is subdivided into direct and indirect tests and procedures for controlling variables, as shown in Table 1, and is further subdivided into materials and design and construction.

Possible revisions of the specifications are mentioned in this section, but any recommended changes will be discussed in a later section.

Direct Measures — Materials and Design

Fatigue Tests

Fatigue tests are run at the Virginia Highway and Transporation Research Council's laboratories for research studies and special projects. They require sophisticated equipment and considerable technical expertise, not only for running the tests but particularly for interpreting the results. The use of these tests in determining compliance with specifications does not appear feasible.

Indirect Tension

The indirect tension test has now been developed to the extent that it can be run in district materials labs as well as in the Central Office Materials Lab and the Research Council lab. The test is used to determine the need for antistripping additives and their effectiveness. However, except for providing an indication of the susceptibility of a mix to stripping, it appears that the indirect tension test gives no more information as to mix design than does the Marshall stability test, which has been used for many years in Virginia.

Stability

The stability value used by the Department is that obtained from the Marshall stability test. The value specified is dependent on mix type. Marshall stability has been criticized as not being a good predictor of rutting and shoving failures. However, it is meant to serve as a guide, and experience with mixes that tend to rut should indicate when a redesign is necessary. A better test for predicting rutting is being considered.

Direct Measures — Construction

Skid Resistance

Skid measurements are made to obtain information for use in pavement management and in safety studies. Because the asphalt film on the surface masks the frictional properties of newly laid plant mix, it is not feasible to use a skid number as a specification requirement. The assurance of adequate skid resistance during construction by indirect measures is discussed later.

Ride Quality

Straightedge

The use of a 10-ft straightedge is specified for determining surface roughness. Any hump or depression exceeding a 1/4-in tolerance is supposed to be corrected. This specification does not appear to be widely used, and additional emphasis may be warranted, particularly in terms of instructions to inspection personnel.

Roughometer

Roughometer tests with the Mays meter are run primarily to obtain information for internal use, although the results often have been used by the Virginia Asphalt Association as the basis for making smooth pavement awards. There is at present no specific roughness requirement, although there does appear to be a need for one. The lack of precision of equipment mounted on vehicles has made previous attempts to establish a performance related specification for roughness unsatisfactory; however, the Council has recently purchased equipment purported to solve this problem. A performance related specification for roughness appears to be more feasible for new construction than for maintenance overlays, since in the latter case the roughness is greatly influenced by the condition of the existing pavement, a factor over which the contractor has no control. If sufficient equipment and personnel were available, it probably would be feasible to run roughness tests before overlaying and base the specification on an improvement of the results.

Specified Thickness

For bituminous base, the thickness tolerance is based on tests of cores. For binder and surface courses the thickness is controlled by rate of application.

The bituminous base thickness tolerance is statistically based, but there is some possibility that the standard deviation used in deriving this specification is now excessive. This specification should be reanalyzed and consideration given to applying a price adjustment system based on performance results obtained from the AASHO Road Test.

The control of the application rate mentioned in the specifications does not address the problem of how to determine the rate. The practice is to measure the thickness every 10 to 20 ft and adjust the paver screed accordingly. This is a very poor practice and one that tends to produce a rough ride. The application rate should be determined on a tons per square yards basis that would give an average rate and not on individual thickness readings.

Indirect Measures — Materials and Design

Aggregate Type and Quality

A recent National Cooperative Highway Research Program study on the acceptance of aggregates in bituminous paving mixes used literature reviews and a national survey to identify the aggregate and mix properties most predictive of pavement performance.(8) Percent crushed particles, water absorption, and sand equivalency were identified as the most important aggregate tests for use in predicting performance. Virginia Specifications (Section 212.02 referencing Sections 201, 202, and 203) appear to be adequate for aggregate type and quality, with the possible exception of those for fine aggregates. The previously referenced NCHRP study states that:

> Sodium sulfate soundness tests were run on both coarse and fine aggregate fractions of the samples and losses were determined after five cycles. It appeared that there is more variability in the results, with the fine aggregate fractions making these results less reliable than with the coarse aggregate fractions. It was also considered that the degradation due to the breaking up of coarse particles will have a greater overall effect on pavement deterioration. Hence the soundness values of only the coarse aggregate fractions (plus No. 4 material) were included in the regression analysis and the discussion here refers to the soundness loss in the coarse aggregate fraction. The soundness losses in aggregates with good performance were less than 4%. (8)

Also, few other states have a requirement on soundness for fine aggregates for bituminous concrete. A soundness specification on this material does not appear logical because the fines are coated with asphalt first, and this combination of fines and asphalt forms a matrix which then helps coat the coarse aggregate. Furthermore, if the fine material is not of sufficient quality to provide durability, the stripping test probably gives a better evaluation than the soundness test. The sand equivalency test should be retained to eliminate "dirty" fine material. A recommendation on this subject will be made.

Aggregate Gradation

Aggregate gradation is an anomaly in that one gradation may not appear to be appreciably better than another until it is evaluated in terms of voids in the mineral aggregate (VMA), which is obtained from the analysis in the Marshall mix design procedure. Once an adequate VMA is obtained in a mix, the uniformity of gradation then becomes more important than the gradation itself.

Aggregate gradation is accepted by determining the average and comparing it to the process tolerance on a lot-by-lot basis and also by determining the standard deviation on each job. The specification appears to be effective for controlling the distribution of the gradation, and no changes in this concept are necessary.

Table II-12 (Section 212.03) in the Virginia Department of Highways and Transportation Road and Bridge Specifications, which specifies the aggregate gradation, needs to be modified. This table contains the design range from which mix gradations are chosen. The gradations for the S-4, S-5, S-8, I-2, B-2, and B-3 mixes should be modified to include a top-size range. For instance,

Figure 1 shows the design range for an S-5 mix as given in the table. At the top of the figure, the design range closes down to a single point. What is needed is a design range, such as that depicted by the dashed line, which has a range of, for instance, 84% to 100% passing the 3/8-in. sieve. Then, the design range could be used to predict the gradation actually produced. This change will be included under Recommendations.

Asphalt Grade

Virginia's specifications cover viscosity graded asphalt cements ranging from an AC-5 to an AC-40. Specifying the grade of asphalt is important to provide flexibility and stability and to prevent flushing. Virginia's specifications generally require the use of an AC-20 cement; however, the S-3 mix requires an AC-10 and the urban mix requires an AC-40. Although, it has become very difficult to obtain any asphalt cements other than AC-20, from a specification standpoint it is advantageous to retain whatever grades the engineer believes will provide good pavement performance, and to require the asphalt mix producer to make an exhaustive effort to obtain the grade specified. A study now in progress at the Research Council is seeking to determine if an AC-20 is providing the best asphalt consistency for Virginia's climate.(9) For the time being, the specifications will be considered adequate and no recommendations will be made.

Asphalt Temperature Susceptibility

This characteristic is probably more important than previously, because of the change in susceptibility resulting primarily from changes in the sources and blending of crudes. (10,11,12,13) The specifications control this characteristic only loosely by requiring a minimum viscosity at 275°F., a minimum penetration, and a plus or minus tolerance on viscosity at 140°F. If any more restrictive requirements on temperature susceptibility are needed, they should be pursued on a national basis.

Mix Design

As shown in Table 1, mix design is an extremely important variable because of its influence on the properties of the mix and those of the pavement.

Typically, for a job mix design, a gradation is selected by the contractor to be within the gradation design range and this is used to select the asphalt content.(14) The determination of the proper asphalt content, because of its correlation with voids total mix (VTM), is extremely important because if the VTM is not within prescribed limits the mix may not reach the proper void content during construction. However, as indicators of VTM, voids mineral aggregate (VMA) and voids filled with asphalt (VFA) are also very important. If the VMA is either too high or too low, the cause is a poor gradation. If the VFA is too high or too low, the asphalt content may be correspondingly high or low or, as has been the case recently, the high VFA may be caused by the amount and fineness of the -#200 sieve material overextending the asphalt. With the increase in the use of the baghouse as a dust collector as opposed to wet wash systems, fines that once were wasted are now being used in the mix. These fines have been termed "super fines." A control is needed to make sure that the film thickness is sufficient to provide durability; however, there is no readily available method for this.

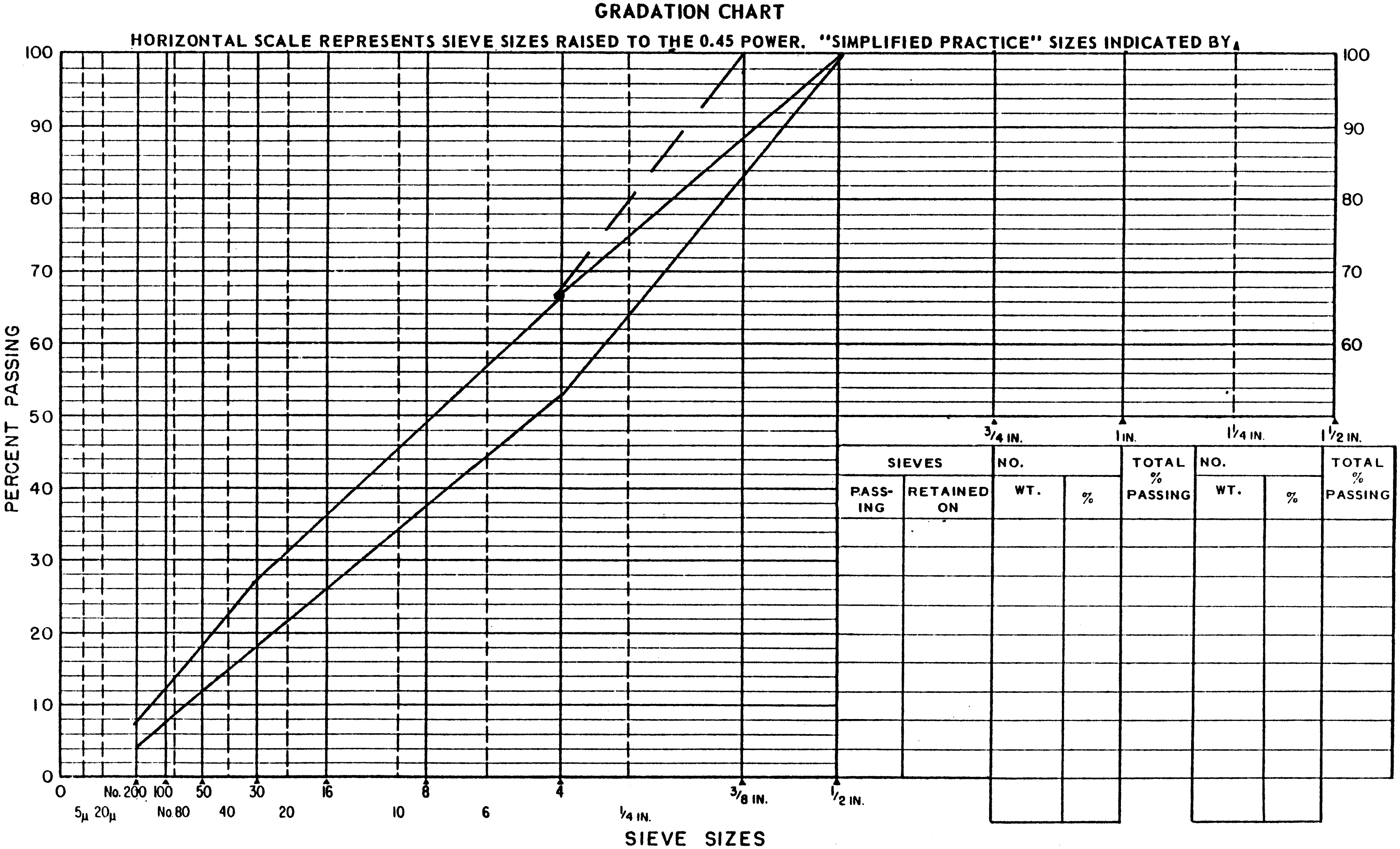
The most expeditious approach to controlling the film thickness is to control the filler asphalt ratio (F/A). The Department has implemented a job mix control on the F/A in which the -#200 aggregate does not exceed the asphalt content for S-4, S-5, and I-2 mixes. While it is not a perfect control in that there is no discrimination between coarse and super fine fillers in the F/A and only the super fines create a problem, the ratio can be quickly and easily determined.

At the time the contractor undertook responsibility for performing the job mix design, changes were made in the void criteria and these should improve the mixes used in the state.

However, as discussed above, it is extremely important that the mix design parameters be well covered in the specifications. While some states use mix design parameters as acceptance tools, Virginia uses them as guides for contractors and engineers. The criteria for accepting gradation and asphalt content are considered controls on the mix design parameters. The present method of determining Marshall values from production samples, i.e., bringing the material into the lab and compacting the briquets, does not lend itself to acceptance testing because of time constraints. Furthermore, the variability inherent in stability and flow determinations would make specification requirements on these properties difficult to administer. Therefore, using the Marshall tests for guidance in mix design and for monitoring production appears to be satisfactory.

Mix Moisture Content

Excessive moisture in a mix can result in instability manifested as a tender mat. This can easily result in low densities, shoving, or both. The specifications allow up to 3% moisture at the point of discharge from the plant. This is much higher than some reports indicate can cause trouble.(15) However, to the author's knowledge Virginia has not had any appreciable problem with excess moisture. Therefore, this specification apparently is controlling the moisture within acceptable limits.



STATE	PROJECT NO.	TYPE CONST; LOCATION ON PROJECT
TYPE, SOURCE, PRODUCER OF AGG.		

SAMPLED FROM	SAMPLED BY	DATE	QUANT. REPRESENTED	SIEVED BY	DATE	SIEVE METHOD ☐ WET ☐ DRY	REMARKS

Existing stocks of PR-1115 (Rev. 10-63) will be used.

Figure 1. S-5 design range.

Mix Temperature

It is very important to control the temperature of the mix to prevent overheating of the asphalt and the resultant premature oxidation and underheating of the mix that leads to problems in compaction, segregation, and placement. It is also important to maintain a uniform temperature throughout the mix to facilitate achieving a uniform density. Table II-12 of the specification book has a master range of temperatures at the plant from which the contractor can choose a single value. Then, a $\pm$ 20^{o}F. tolerance is applied to this job mix temperature. This tolerance is consistent with those used in other states and appears to be quite adequate.

With the implementation of the quality assurance program which resulted in the removal of the state inspector from the plant, it is recommended that the state materials technician monitoring production check mix temperatures periodically.

Mix Uniformity

The lack of uniformity in a mix can cause inadequate coating of the aggregate or poor pavement texture, primarily through segregation of the mixture. The controls required by the specification are determinations of the asphalt content and gradation of the aggregate, with emphasis on the standard deviation. Also, the Ross count procedure assures adequate mixing at the plant. However, these specifications still do not ensure against segregation. Coarse mixes such as the B-3 and I-2 have a greater tendency to segregate than finer mixes. Storage and surge silos have been found to aggravate segregation. This is one problem that requires knowledgeable field inspection to monitor and prevent. The severity of segregation is assessed through judgment, but if the inspector feels that segregation is sufficiently severe, he should bring the problem to the attention of the contractor, who has responsibility to take remedial action. The point to be made here is that preventative measures for every potential problem cannot be spelled out in the specification; in some situations the actions to be taken are solely a matter of judgment.

Stripping Tests

Virginia has done a tremendous amount of work with the tensile strength ratio (TSR) test used to predict the ability of a mix to resist stripping. The specifications require the use of a heat stable additive in all surface courses and in base and intermediate courses, except when carbonate aggregates are used. The author believes the term "heat stable additive" is misleading. What is necessary is an antistripping additive that must be stable under prolonged heating. It may be a subtle point, but the objective is that the additive prevent stripping; that it is heat stable simply means that it will remain effective in storage. The Department's Materials Division, as well as the Council, is doing quite a bit of work that should result in quite a few changes in this part of the specifications.

Indirect Measures – Construction

Adhesion to Underlying Layer

Relatively thin overlays have been noted to crack within the short time of three years in several instances, and investigations have shown this distress to be attributable to a very poor bond between the overlay and the old surface. The specifications cover application of the tack between the old surface and the overlay, but they should be strengthened to cover the amount and uniformity of the application. This may require use of a method specification.

Placement Temperature

Although, as previously discussed, the temperature of a mix is controlled at the discharge point at the plant, the influence of temperature at placement on the road is so important to obtaining proper compaction that a placement temperature is also necessary. The specifications allow the temperature of the mix on the road to be no more than 30°F. below the approved job mix temperatures. Loads of material that do not conform to this tolerance are rejected. The minimum placement temperature is controlled by cessation limits as set forth in Section 320.03 of the Virginia specifications. Although this specification is adequate, additional emphasis should be placed on placement temperatures because with the removal of state inspectors from asphalt plants in the quality assurance program, temperatures may not be checked as often as they have been.

Field Density

In the author's opinion proper field density is the single most important requirement for a pavement that is to give good performance over its design service life. This view is shared by others as evidenced by the number of papers and articles on this subject, a few of which are referenced here. (4, 16,17,18) The durability of the pavement is directly affected by the rate of oxidation of the asphalt, a factor that has been correlated to the percentage of air voids in the pavement.

Virginia has relied on nuclear testing combined with the control strip procedure for years to control density on new construction projects.(19) More recently, a density specification based on removal of 4 in. x 4 in. sawed plugs has been implemented and used successfully.(20) The work in developing and monitoring the maintenance density specification indicates that use of the control strip procedure does not produce the maximum density because of an inability to obtain the needed void content with the materials being used.

Additional Specifications

The above discussion of specification control variables includes most specifications needed in the Virginia Department of Highways and Transportation specification book; however, there are at least a few others that have not been addressed. These are discussed below.

Plant Operation

The question that must be answered in this portion of the specification book is, How detailed must the specification be to obtain a mix that will perform adequately? This means that a critical look should be taken at Section 212.11 Bituminous Concrete Mixing Plant to delete as many method type requirements as possible.

Contamination

The primary contaminant of asphalt mixes appears to be the fuel oil used to coat the bodies of haul trucks to prevent the mix from sticking, and improper use of this oil will make the mix perform poorly. Although the specifications prohibit the use of mixes contaminated with excessive fuel oil, there seems to be some problem in enforcing the specifications. Noncontaminating release agents have been developed.

RECOMMENDATIONS

Listed below by section are recommendations that should be considered by the Virginia Department of Highways and Transportation. The suggested deletions are marked through and the additions are in italic. Some are straightforward and can be implemented very quickly; others will require experimental data, analyses, and, possibly, better test methods. Implementation of the latter probably will be delayed.

Sec. 202 Fine Aggregate

Table II-2 Soundness. Delete Bituminous Surface Courses and Bituminous Bases.

Sec. 212 Bituminous Concrete

Sec. 212.01 Description. Bituminous concrete shall consist of a combination of mineral aggregate and bituminous material mixed mechanically in a plant. ~~Bituminous concrete shall conform to the requirements for the type designated for the work and shall be produced utilizing any of the following procedures:~~

~~(a) Conventional plant with gradation unit,~~
~~(b) Conventional plant using cold feed control methods in lieu of plant screens, or~~
~~(c) Drier drum mixing plant using cold feed control methods.~~

Replace with - *Bituminous concrete shall conform to the requirements for the type designated, the process tolerances, and uniformity requirements contained in Sec. 212.07.*

Sec. 212.02 Materials

h) Additive (Special Provision Copied Note 2-17-84)
i) RAP (Special Provision Copied Note 12-15-83)

Sec. 212.03 Job Mix Formula - (Special Provision 2-3-84)

Table II-12

Add	1"	3/4"	3/8"
S-4			*90-100*
S-5			*84-100*
I-2		*86-100*	
B-2	*76-100*		
B-3	*84-100*		

Sec. 212.04 Certification (Special Provision 12-1-83)

Sec. 212.06 Plant Inspection - The preparation of all bituminous mixtures shall *may* be subject to inspection at the plant. For this purpose the Contractor shall provide a plant laboratory conforming to Section 517. The Contractor shall furnish, maintain, and replace as condition necessitates, the following testing equipment: (and rest of page)

Add - *The contractor shall furnish, maintain, and replace, as conditions necessitate, such equipment as is necessary to run asphalt extraction by the Reflux method (VTM-36), aggregate gradation, and the boiling test (VTM-13).*

Sec. 212.07 Acceptance (Special Provision 12-1-83)

Sec. 212.09 Referee System (Special Provision 12-1-83)

Sec. 212.10 Handling and Storing Aggregates - Aggregates shall be handled, hauled, and stored in a manner which will minimize segregation and avoid contamination. *The different aggregate sizes shall be stockpiled separately and such stockpiles shall be readily accessible for sampling.* Aggregates shall be stockpiled in the vicinity of the plant and on ground that is denuded of vegetation, hard and well drained, or otherwise prepared to protect the aggregate from contamination. Placing aggregate directly from the crusher bins into the cold feed may be permitted, provided the material is consistent in gradation. When different size aggregates are stockpiled, the stockpiles shall be positively separated.

Sec. 212.11 Bituminous Concrete Mixing Plant - Sufficient storage space shall be provided for each of aggregate and the different aggregate sizes shall be kept separated until they are being conveyed to the drier. The storage yard shall be maintained neat and orderly and the separate stockpiles shall be readily accessible for sampling. The plant shall be operated so that the weighing, proportioning and mixing will yield a uniform mixture conforming to the requirements of these specifications. Mixing plants shall be designed and equipped to produce a minimum of 50 tons of mixture per hour. However, this requirement will be waived on the production of mixes used for patching, and for projects or schedules consisting of less than 2,000 tons.

(d) Feeder for Drier: The plant shall be equipped with accurate mechanical means for uniformly feeding the aggregate into the drier so that uniform production and uniform temperature will be obtained. Where different size aggregates are required to meet grading specifications, they must proportioned by feeding into the cold-elevator through a multiple compartment feeder bin (one bin for each size specified) equipped with positive action gates that can be securely locked to maintain desired proportioning.

~~(e)~~ Screens: The plant, except drier-drum mixing plant, shall be provided with screens capable of screening all aggregates to the specified sizes and proportions. The screens shall have sufficient capacity to furnish the necessary quantity of each aggregate size required for continuous operation.

(e) ~~(f)~~ Bins: The plant shall include storage bins of sufficient capacity to supply the mixer when it is operating at full capacity. Bins shall be divided into at least 3 compartments arranged to insure separate and adequate storage of appropriate fractions of the aggregate. Each compartment shall be provided with an overflow pipe of such size and at such location to prevent contamination of the aggregate in adjacent compartments and shall be provided with individual outlet gates which, when closed, will allow no leakage.

The drier drum mixing plant shall include cold feed storage bins of sufficient capacity to supply the mixing operation when the plant is operating full capacity. Hot storage bins will be required on conventional plants only.

Unless otherwise specified, a separate storage compartment shall be provided for mineral filler, and the plant shall be equipped to feed the filler into the mixer.

All plant bins shall be located so as to feed directly into the weighing hopper by gravity and shall be equipped with cutoff gates to stop the flow of dried aggregate.

Adequate and convenient facilities shall be provided to make possible the sampling of representative aggregate material from each hot bin.

(f) ~~(g)~~ Thermometric Equipment: The plant shall be equipped with an approved thermometric instrument so placed at the discharge chute of the drier as to register automatically or indicate the temperature of the heated aggregate or the completed mix if the drier drum mixing plant is used.

(g) ~~(i)~~ Equipment for Preparation of Bituminous Material: Tanks for the storage of bituminous material shall be equipped with a heating system capable of heating and holding the material at the required temperatures. The heating system shall be designed to heat the contents of the tank by means of steam, electricity, or other approved means so *such* that no flame is in contact with the heating surface of the tank. The circulating system for the bituminous material shall be designed to assure proper and continuous circulation during the operating period. Return lines discharging into the storage tanks shall be positioned within 6 inches of the bottom of the tank to prevent oxidation of the asphalt. All pipe lines shall be steam jacketed or insulated to prevent undue loss of heat.

Storage facilities for bituminous material shall be sufficient for at least one day's operation or equivalent means of supply shall be provided which will insure continuous operation. Provision shall be made for measuring and sampling storage tanks. When bituminous material is proportioned by volume, the temperature of the bituminous material in storage shall be maintained uniform ($\pm$20°F) during operation of the plant by means of an approved automatic temperature control device.

(j) Bituminous Control: Bituminous material shall be accurately proportioned by volume or weight. When volumetric measurements are used, they shall be made by means of approved meters or pumps, calibrated for accuracy. The section of the bituminous line between the charging valve and the spray bar shall be provided with an outlet valve for checking the meter.

When proportioned by weight, the bituminous material shall be weighed on scales of the beam or dial type. Beam scales shall be equipped with tare and full capacity beams. Dial scales shall have a capacity of not more than 15 percent of the capacity of the mixer. The value of the minimum graduation shall not be greater than 2-pounds.

Except when drier drum mixing plant is used, the bituminous material bucket, its valves and spray bar shall be steam jacketed or heated by other approved means. The bucket shall have a capacity of at least 115 percent of the weight of the bituminous material required in any mixture and shall be supported on fulcrums.

The bituminous material shall be delivered to the mixer in a thin, uniform sheet of multiple streams for the full width of the mixer.

(h) (k) Proportioning Aggregates: When beam type scales are used, there shall be a separate beam for each size of aggregate and appropriate balancing means. The scales shall be provided with an indicator which will start to function when the load being applied is within 100 pounds of that desired. Sufficient vertical movement shall be provided in the beams to permit the indicator to function properly. Each beam can be suspended or thrown out of action.

Dial scales shall be of such size that the numerals can be read at a distance of at least 25 feet. The dial shall indicate the full capacity of the scale. Dial scales shall be removed and replaced when so ordered. All dials shall be located so as to be plainly visible to the operator at all times.

The weigh hopper shall be of sufficient size to hold the maximum required weight of aggregate for one batch without hand raking or running over. Sufficient clearance between the weigh hopper and supporting devices shall be provided to prevent accumulation of foreign materials.

When using batch plants, the discharge gate of the weigh hopper shall be situated in such a manner that the aggregates will not segregate when dumped into the mixer. Gates on the bins and weigh hopper shall be constructed to prevent leakage when closed.

When using drier-drum mixing plant the aggregate shall be proportioned by a position weight control at the cold aggregate feed, by use of a belt scale which will automatically regulate the supply of material being fed and permit instant correction of variations in load. The cold feed flow shall be automatically coupled with the bitumen flow to maintain the required proportions.

(i) ~~(l)~~ Batch Mixer: The batch mixer shall be of a-twin pugmill or other approved type, steam jacketed or heated-by other-approved means and capable of producing uniform mixtures within the specified tolerances. It shall be equipped with a sufficient number of paddles or blades, operated at such speeds as to produce a properly and uniformly mixed batch. The number and arranagement of the mixer paddles shall be subject to the approval of the Engineer. The clearance of the blades from all fixed and moving parts shall not exceed one inch, unless the maximum diameter of the aggregate particle exceeds 1 1/4 inches, in which case the clearance shall not exceed 1 1/2 inches. Badly worn or defective blades shall not be used in mixing operations.

The mixer shall be provided within an approved time lock which will lock the discharge gate after the aggregates and bitumen have been placed in the mixer and will not release the gate until the specified time has elapsed.

Batch type mixing plants used to produce bituminous concrete shall be equipped with approved automatic proportioning devices. Such devices shall include equipment for accurately proportioning batches of the various components of the mixture by weight or volume in the proper sequence and for controlling the sequence and timing of mixing operations. The automated system shall be designed to interrupt and stop the batching operation at any time batch quantities are not satisfied for each of the materials. A means shall be provided for observing the weight of each material during the batching operation.

Should the automatic proportioning devices become inoperative, the plant may be allowed to batch and mix bituminous materials for a period of not more than 48 hours from the time the breakdown first occurs provided alternate proportioning facilities are approved by the Engineer. Written permission of the Engineer will be required for operation without automatic proportioning facilities for periods longer than 48 hours.

(j) ~~(m)~~ Continuous Mixing Plant: Continuous mixing plant shall include a means for accurately proportioning each bin size of aggregate either by weight or volume. When-gradation control is by volume, the unit shall include a feeder mounted under the compartment bins. Each bin shall have an accurately controlled individual gate to form an orifice for volumetrically measuring the material drawn from each respective bin compartment. The orifice shall be rectangular, with one dimension adjustable by positive mechanical means and shall be provided with a lock. Indicators shall be provided to show the individual gate opening in inches. The plant shall be equipped with a satisfactory revolution counter.

The plant shall include a means for calibrating gate openings by weight. The materials fed out of the bins through individual orifices shall be by-passed to a suitable test box; each component materials confined in a separate section. The plant shall be equipped to conveniently handle test samples weighing up to 200 pounds per bin and accurate platform scales shall be provided for this purpose.

Positive interlocking control shall be afforded between the flow of aggregate from the bins and the flow of bituminous material from the meter of other proportioning device. This shall be accomplished by approved interlocking devices or other approved positive means.

Accurate control of the bituminous material shall be obtained by weighing, metering or volumetric measurement.

The plant shall include a continuous mixer of an approved type which is steam jacketed or heated by other approved means. The paddles shall be of an adjustable type for angular position on the shafts and reversible to retard the flow of the mixture.

There shall be interlock cutoff circuits to interrupt and to stop the proportioning and mixing operations when the aggregate level in the plant or the bituminous material in storage falls below that necessary to produce the specified mixture.

(k) ~~(o)~~ Automatic Printer System: In lieu of providing truck scales, the Contractor may furnish an approved automatic printer system which will print, in digital form, the weights of the ingredients from each bin of aggregate and asphalt in each batch of each load of material delivered, as well as the cumulative total of the batches. The printed weight *shall be shown to the nearest hundredth ton for* each load, *the weigh ticket* of *the* material shall accompany the delivery and such information shall be made available to the Inspector at the project.

(Special Provision 4-9-82)

The equipment shall print the weight of the asphalt dispensed *and such weight shall be* within plus or minus 0.2 percentage points of the asphalt content as shown on the job-mix formula. *If the weight of asphalt is not within 0.2 percentage points, operation of the plant will cease until the problem is solved.*

(i) (p) Uniformity of Mix: The weight of each truck load of paving mixture shall be within plus or minus 3 percent of the total weight of all batches in the load, except that such tolerance will not apply where the automatic printer system is used or where the material is placed in storage bins. Failure to maintain this standard of uniformity will be sufficient cause for rejection of the load.

Sec. 212.12 Preparation of Mixtures - The coarse aggregate shall be separated into appropriate sizes and stored in separate bins. The fine aggregate shall be separated from the coarse aggregate and stored in a separate bin. The dried aggregates shall be combined in the mixer in the amount of each fraction of aggregates required to meet the job-mix formula. The bituminous material shall be weighed or metered, and introduced into the mixer in the amount specified by the job-mix formula.

The bituminous material and aggregate shall be introduced into the mixer at a temperature that will produce a mixture within the requirements of the job-mix formula; however, in no case shall the temperature of the bituminous material exceed 325°F at the time of introduction into the mixer.

After the required amounts of aggregate and bituminous material have been introduced into the mixer, the materials shall be mixed until a uniform coating of bitumen and a thorough distribution of the aggregate throughout the mixture is secured within the requirements of the Ross Count procedure described in AASHTO T195. Wet mixing time, based on the procedures of AASHTO T195, shall be determined by the Contractor at the beginning of production and approved by the Engineer for each individual plant or mixer and for each type of aggregate used; however, in no case shall the wet mixing time be less than 20 seconds. The wet mixing time is the interval of time between the start of introduction of the bituminous material into the mixer and the opening of the discharge gate. A wet mixing time which will result in fully coating a minimum of 95 percent of the coarse particles, based on the average of the 3 samples, and provided that none of the 3 samples result in fully coating less than 92 percent of the coarse particles, shall be the minimum wet mixing time requirement. A dry mixing time of up to 15 seconds may be required by the Engineer to accomplish the degree of aggregate distribution necessary to obtain complete and uniform coating of the aggregate with bitumen.

(Special Provision 2-3-84)

When the paving mixture is produced in a continuous mixing plant, the delivery of the aggregates to the mixer shall be by means of accurately metered gates and at such rate that the composition of the finished mixture shall conform to these specifications and the established tolerances. The volumes per unit of time shall be determined by weight at least once each day and as often thereafter as may be necessary to secure the desired uniformity. The aggregates shall be combined with the required quantity of bituminous material as the materials enter the mixer. The rate of feed to the mixer shall be such that the combination of bitumen and aggregate shall be mixed for a sufficient time to secure a complete and uniform coating of bitumen and thorough distribution of the aggregate throughout the mixture. In the drier drum mixing plant the aggregate and bituminous material shall be weighed and metered into the drier in the amounts specified by the job mix formula.

Sec. 212.16 Type S-4 Bituminous Concrete shall consist of siliceous sand, granite, slag, gravel, gravel screenings, granite screenings or combination thereof, combined with asphalt cement, viscosity grade AC-20 unless otherwise specified, and shall conform to Table II-12.

The combination of aggregate and asphalt shall have a Marshall stability of not less than 1,000 pounds at 140°F. If this value cannot be obtained, the addition-of mineral filler conforming to Section 201, in an amount not to exceed 5 percent by weight of the completed mixture, will be permitted in order to obtain the specified stability. If the mixture still lacks stability, another source of aggregate shall be used.

Sec. 212.17 Type S-5 Bituminous Concrete shall consist of crushed stone, crushed slag, or crushed gravel and fine aggregate, slag or stone screenings, or a combination thereof, combined with a asphalt cement, viscosity grade AC-20 unless otherwise specified, and shall conform to Table II-12.

(Special Provision Copied Note 3-9-84)

The combination of aggregate and asphalt shall have a minimum Marshall stability of 1,450 pounds at 140°F. If the stability and flow values cannot be obtained, the addition of mineral filler conforming to Section 201, in an amount not to exceed 5 percent by weight of the completed mixture, will be permitted in order to obtain this minimum stability. If the mixture still lacks stability, another source of aggregate shall be used.

Whenever the amount of aggregate passing the No. 200 sieve exceeds-5 percent, a minimum of 15 percent siliceous-sand (Minimum Grading B) may be required to be added to the mix.

Sec. 212.18 Type S-8 Bituminous Concrete shall consist of a bituminous porous friction course composed of a mixture of polish resistant No. 8 crushed aggregate, minimum grade B; heat stable additive; and asphalt cement, viscosity grade AC-20. The optimum asphalt content shall be determined by the modified Marshall design method *Engineer*.

At least 90 percent by weight of the aggregate retained on the No. 4 sieve shall have one or more fractured faces. The percent of wear shall not be more than 45 percent as determined by AASHTO T96.

Sec. 212.19 Type I-1 Bituminous Concrete (Local Material) shall consist of local pit material combined with asphalt cement viscosity grade AC-20 unless otherwise specified, and shall conform to Table II-12.

The combination of local pit material and asphalt shall have a Marshall stability of not less than 500 pounds at 140°F. If this value cannot be obtained with the local pit material, the addition of gravel, slag, or stone screenings will be permitted provided the gradation of the final mix is within the limitations provided in Table II-12. If the stability value still cannot be obtained, mineral filler in an amount not to exceed 5 percent by weight of the completed mixture will be permitted in order to obtain the specified stability. If the mixture still lacks stability, another source of local pit material shall be used.

Sec. 212.21 Type B-1 Bituminous Concrete (Local Material) shall consist of local pit material combined with asphalt cement, viscosity grade AC-20 unless otherwise specified, and shall conform to Table II-12.

The combination of local pit material and asphalt shall have a Marshall stability of not less than 400 pounds at 140°F. If this value cannot be obtained with local pit material, the addition of gravel, slag, or stone screenings will be permitted provided the gradation of the final mix is within the limitations provided in Table II-12. If the stability value still cannot be obtained, mineral filler in an amount not to exceed 5 percent by weight of the completed mixture will be permitted in order to obtain the specified stability. If the mixture still lacks stability, another source of local pit material shall be used.

Sec. 212.28 Storage System - In the event the Contractor elects to utilize a storage system, the materials, equipment, and procedures used shall conform to the requirements of Section 212 as amended herein.

The requirements of Section 212.11 ~~(p)~~ *(i)* will be waived when storage bins are used.

The system shall be capable of conveying the hot-mix from the plant to the storage bins and storing the hot-mix without a loss in temperature, segregation of the mix or oxidation of the mix. Storage time duration shall be limited by the ability of the bins to maintain the hot-mix within the quality requirements specified in Section 212 with a maximum time limit not to exceed 10 days. Material may be stored in bins for no more than 24 hours without a heating system.

~~The conveyor system may be a continuous type or skip bucket type. Except when the drier-drum mixing plant is used, continuous type conveyors shall be enclosed and heated to prevent a drop in mix temperature. If the skip-bucket type is used, the bucket shall be of sufficient capacity to transport an entire batch and mass dump into the bins.~~

The storage bins shall be designed in such a manner as to prevent segregation of the hot-mix during discharge from the conveyor into the bins and shall be equipped with discharge gates that will not cause segregation of the hot-mix while loading the mix into the trucks.

Approval for the use of storage bins may be withdrawn by the Engineer in event there is an excessive amount of heat loss, segregation and/or oxidation of the hot-mix due to the use of storage bins.

Sec. 320 Bituminous Concrete Pavement

Sec. 320.04 Equipment -

(a) Hauling Equipment: Trucks used for hauling bituminous mixtures shall have tight, clean, smooth metal bodies equipped with a positive locking metal tailgate. Metal surfaces which are to be placed in contact with bituminous mixtures shall be given a thin coat of ~~fuel oil~~, ~~emulsifiable oil~~, lime solution or other approved ~~material~~ *release agent*, to prevent the mixture from adhering thereto. The presence of ~~excess oil in the mixture or puddles of oil in the truck body~~ *any contaminant in the mix or body of the haul truck* shall be sufficient cause to reject any mixture. ~~hauled therein.~~ Each truck shall be covered with a tarpaulin or other suitable cover which will protect the mixture from moisture and foreign matter and prevent the rapid loss of heat during transportation.

(b) Bituminous Pavers: Bituminous pavers shall be of an approved design, self-contained, power-propelled units, provided with an activated screed to strike-off assembly, heated if necessary, and capable of spreading and finishing courses of bituminous concrete in lane widths applicable to the specified typical cross-section and thickness shown on the plans. Pavers used for shoulders and similar construction shall be capable of spreading and finishing courses of bituminous concrete in the widths shown on the plans. The bituminous paver shall be approved prior to beginning any paving operations.

The paver shall be equipped with a receiving hopper having sufficient capacity to provide a uniform spreading operation. The hopper shall be equipped with a distribution system to place the mixture uniformly in front of the screed.

The screed or strike-off assembly shall effectively produce a finished surface of the required evenness and texture without tearing, shoving or gouging the mixture. The screed shall be adjustable at each end and equipped with a device which will indicate its horizontal position.

Pavers shall be capable of smoothing and adjusting all longitudinal joints between adjacent strips or courses of the same thickness. Joint heating devices shall be used when specified in the contract.

Pavers shall be equipped with mechanical devices ~~such as equalizing runners, straightedge runners, evener arms or other compensating-devices to~~ *that* adjust to grade so that minor changes in elevation will not be immediately reflected in the finished surface and will also confine the edges of the mixture to true lines. Electronically controlled screeds shall be used when specified in the contract.

Pavers shall be operated at ~~forward~~ speeds consistent with satisfactory laying and compaction of the mixture.

(c) Rollers: Rollers shall be of the steel-wheel, static or vibratory, and/or pneumatic-tire type and shall be in good operating condition, capable of reversing without backlash, and shall be operated at speeds slow enough to avoid displacement of the mixture. The number, ~~and~~ weight, *and type* of rollers shall be sufficient to compact the mixture to the required density while it is still in a workable condition. The use of equipment which results in excessive crushing of the aggregate or the marring of the pavement surface will not be permitted.

If, during construction, it is found that the equipment being used mars the surface to the extent that the imperfections cannot satisfactorily be corrected or produces permanent blemishes, the use of such equipment shall be discontinued and replaced with satisfactory units.

For urban mixes, the Contractor shall use a vibratory roller.

(d) (Special Provision 5-24-83) *Rotary saw*

Sec. 320.07 Compaction - Immediately after the bituminous mixture has been spread, struck off and surface irregularities corrected, it shall be thoroughly and uniformly compacted by rolling.

The surface shall be rolled when the mixture is in the proper condition and when the rolling does not cause undue displacement, cracking or shoving.

The number, weight and type of rollers furnished shall be sufficient to obtain the required compaction while the mixture is in a workable condition. The sequence of rolling operations and the selection of roller types shall provide the specified pavement density.

Immediately after the hot mixture is spread, it shall be sealed with the rollers. Thereafter, rolling shall be a continuous process, insofar as practicable, and all parts of the pavement shall receive uniform compaction.

Unless otherwise directed, rolling shall begin at the sides and proceed longitudinally parallel to the center of the pavement, each trip overlapping at least 1/2 the roller width, gradually progressing to the crown of the pavement. When abutting a previously placed lane, the longitudinal joint shall be rolled first, followed by the regular rolling procedure. On superelevated curves, the rolling shall begin at the low side and progress to the high side by overlapping of longitudinal trips parallel to the center line.

Rollers shall move at a slow but uniform speed with the drive roller or wheels nearest the paver. Rolling shall be continued until all roller marks are eliminated and a minimum density of 92 percent of the theoretical maximum density has been obtained. When base and binder course mixtures-are composed of local pit aggregate, the minimum required density will be 85 percent of the theoretical maximum density.

Not more than one sample in every 5 shall have a density less than that specified and the density of such sample shall not be more than 2 percent below the minimum specified.

Field density determinations will be performed with the nuclear field density device, utilizing the density control strip as specified under Section 304 and VTM-10 or in accordance with the requirements of ~~VTM-6~~ *VTM-22*. The method of density determination will be as directed by the Engineer.

(Special Provision 5-24-83)

Any displacements occurring as a result of the reversing of the direction of a roller, or from other causes, shall be corrected at once by the use of rakes or lutes and addition of fresh mixture when required. Care shall be exercised in rolling not to displace the line and grade of the edges of the bituminous mixture.

Section 320.10 Pavement Tolerances -

(a) Surface Tolerance: The surface will be tested using a 10-foot straightedge. The variation of the surface from the testing edge of the straightedge between any two contacts with the surface shall not exceed 1/4-inch. All humps or depressions exceeding the specified tolerance shall be corrected or the defective work removed and replaced with new material.

(An end result specification is desirable for smoothness, but due to equipment and personnel limitations, adoption of this specification may be delayed for some time.)

(b) Thickness Tolerance: It is the intent of these specifications that the base course shall be constructed in accordance with the thickness shown on the plans and the binder and surface courses constructed in accordance with the rate of application shown on the plans. Where any such courses are found not so constructed, the rules for correction provided herein shall govern.

The thickness of the base course will be determined by the measurement of cores taken therefrom as described in VTM-32B.

Acceptance of bituminous concrete base course for depth will be based upon the mean result of measurement of samples taken from each lot of material placed. A lot of material is defined as the quantity being tested for acceptance, except that the maximum lot size will be one mile of 24 foot width base course.

A lot will be considered acceptable for depth if the mean result of the tests is within the following tolerance of the plan depth for the number of tests taken, except that each individual test shall be within ± 0.60 inch of the plan depth:

Mean of two tests	± 0.45 inch
Mean of three tests	± 0.35 inch
Mean of four tests	± 0.30 inch

In the event an individual depth test exceeds a ± 0.60 inch tolerance, that portion of the lot represented by the test will be excluded from the lot. If an individual test result indicates that the depth of material represented by the test exceeds 0.60 inch, the Contractor will not be paid for that material, in excess of the tolerance throughout the length and width represented by the test. If an individual test result indicates that the depth of the material represented by the test is deficient by more than 0.60 inch, correction of the base course represented by the test shall be made as specified hereinafter.

(These tolerances should be examined in view of presently constructed pavements to determine if modifications are needed.)

In the event the mean depth of a lot of material is excessive, the Contractor will not be paid for that material, in excess of the tolerance throughout the length and width represented by the tests.

In the event the mean depth of a lot of material is deficient by more than the allowable tolerance, correction will not normally be required and the Contractor will be paid for the quantity of material which has been placed in the lot.

For excessive depth base courses, the rate of deduction from the tonnage allowed for payment as base course will be calculated at a weight of 115 pounds per square yard per inch of depth in excess of the tolerance. For sections of base course which are deficient in depth by more than 0.60 inch and less than 1.50 inch, the Contractor shall furnish and place material specified for the subsequent course to bring the base course depth within the tolerance. This material will be measured on the basis of tonnage actually placed, determined from weigh tickets and paid for at the unit price bid for the base course material. Such material shall be placed in a separate course. If the deficiency exceeds 1.50 inches, the Contractor shall furnish and place base course material to bring the base course thickness within the tolerance. Corrections for deficient base course depth shall be made in such a manner as to provide an ultimate finished pavement that is smooth and uniform.

(Special Provision 3-20-84)

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