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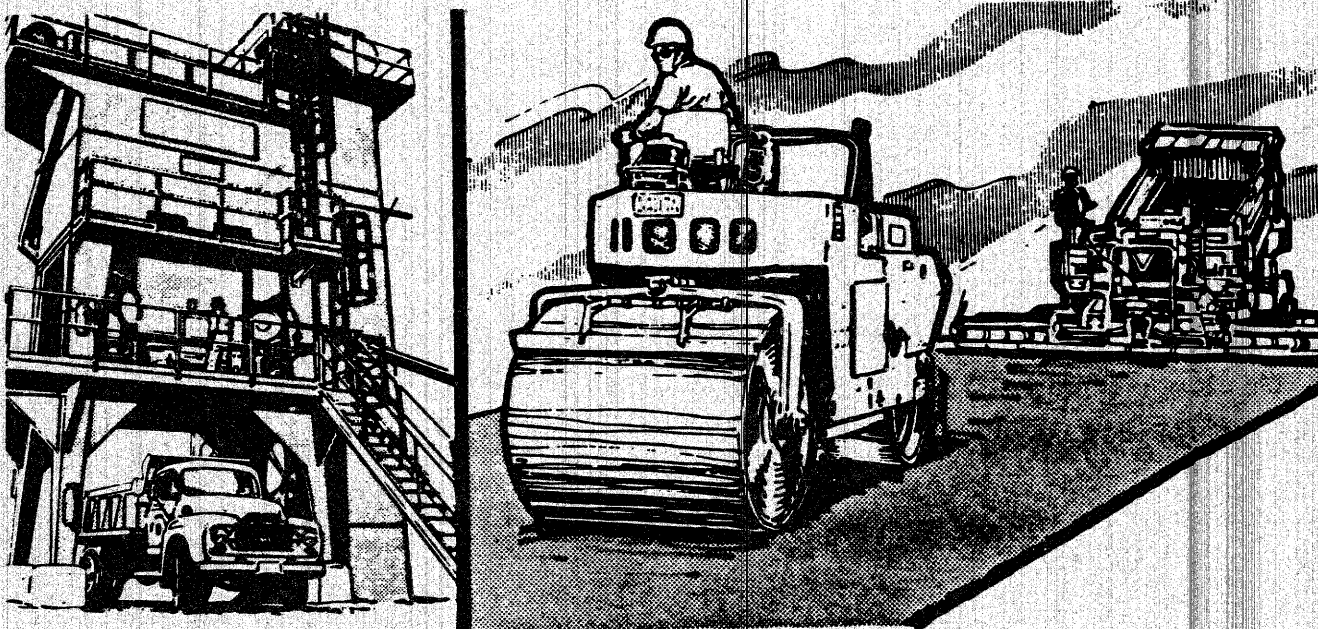
Federal Highway Administration

Construction Inspection Techniques for Flexible Pavements

May 1986

Revised April 1989



Prepared by
Construction and
Maintenance Division

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CONSTRUCTION INSPECTION TECHNIQUES

for

FLEXIBLE PAVEMENTS

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Introduction

The material presented in this workshop is to be addressed as if the Federal Highway Administration (FHWA) field engineer is actually conducting an inspection of flexible pavement construction. It covers the necessary preparation, critical construction inspection points, potential problems, and the solutions to these problems. The workshop is built on training materials and courses dealing with the subject area of flexible pavements which have been presented and/or are currently being conducted.

These materials and courses are entitled, "Asphalt Concrete Mix Design and Field Control" (TA 5040.27) and "Principles of Quality Hot-Mix Asphalt Pavement Construction," the "Materials Course for Area Engineers," and "Hot-Mix Bituminous Paving." Frequent reference is made to these and other basic sources of information throughout the workshop. Active participation, comment, and discussion of experiences and practices is strongly encouraged.

The primary purpose of making detailed inspections of active construction phases is to ensure that a quality product is being produced which should perform according to design expectations and can be accepted for reimbursement with Federal-aid highway funds. This assurance may be obtained by evaluating compliance with contract requirements and good construction practices.

Since it is not feasible nor practical to review all aspects of every operation personally, reliance is placed on verbal feedback from project personnel and the review of the project records. During construction field reviews and day to day contacts with State Highway Agency (SHA) and local engineers and inspectors, the FHWA engineer is expected to develop not only engineering assurances, but also professional working relationships.

While team reviews will occasionally be used, the FHWA area engineer will typically find himself or herself alone in conducting the inspection. Reliance must be placed on one's own training, experiences, and available references for making a creditable evaluation. Some input from others will probably also be available but this must be filtered and evaluated in view of the perspective and interest of the source.

The objectives of this workshop are to

- provide reference materials which should be used in making flexible pavement construction inspections
- discuss how these inspections should be conducted
- provide assistance in the identification, tracking, and solving of problems which may be encountered.

The workshop is not intended to teach the specifics of bituminous mix design, but rather the basics of hot-mix bituminous paving operations and that relationship to mix design. Other training courses are available from National Highway Institute (NHI), the Headquarters program offices, or the paving industry. Attendance at these courses is encouraged where such a training need has been identified.

Most related training courses are arranged in the sequence of project design and development, starting with the composition and characteristics of the various mix constituents and working through the mix design to construction operations. For this workshop, a more logical sequence is to consider the elements in the order in which they would be addressed in making a construction inspection or which they would be considered in solving construction paving problems.

Since there is no ideal nor standardized sequence of activities to be followed in making a construction inspection, some variations in the inspection sequence from those used in this presentation will still be expected.

The normal parts of the active phase of a construction inspection are

- o discussions with project personnel
- o inspection of plant and laydown operations
- o examination of the completed product or parts
- o records review.

Observations made during each part of the inspection should be evaluated as to

- o conformity to plans and specifications and product quality
- o contractor's process control
- o project control and acceptance procedures of SHA's
- o needed improvements.

Areas of concern need to be addressed in terms of

- o the identification of problems
- o the tracing of causes
- o developing and providing solutions
- o undesirable operations which should be pointed out even if product acceptability is not presently a problem.

I. PRELIMINARY INSPECTION ACTIVITIES

Thorough preparation is essential for inspection of flexible pavement construction. Knowledge of the plans, specifications, construction practices, materials control procedures, mix design, and how these various elements fit together is fundamental to an effective inspection. This knowledge can and should be acquired before the actual field inspection so that key questions to ask during it can be formulated and valuable field time can be most effectively utilized.

In addition, it is advantageous to identify and be aware of any areas of known weaknesses in the specifications and/or procedures or in the general performance of flexible pavements in your State or area. Key facts and information to establish before the field inspection are addressed below by category.

A. Plans and Specifications

Thorough knowledge of the plans and applicable specifications is essential to conduct a meaningful and productive inspection of flexible pavement construction. The inspecting FHWA field engineer should be knowledgeable in the following details:

1. **Typical Section of the Pavement** - This includes the mat width, thickness, and cross-slope. Judgments can be made at this point as to the constructibility of the pavement, potential laydown problems, general construction sequences, and potential traffic handling problems if the work is to be done under traffic.

2. **Plan Quantities** - Knowledge of the specific plan quantities allows the inspecting engineer to make subsequent judgments of potential overruns.

3. **Requirements for Contractor Equipment** - General and specific knowledge of the specification requirements for the asphalt plant, the laydown equipment, the hauling units, and the compaction equipment will aid the engineer in (1) assessing the SHA's control of the work, (2) assessing adherence to specification requirements, (3) assessing the contractor's capability to do the work properly, and (4) pin-pointing potential problem areas. References: In addition to the project specifications are AASHTO M 156; **"Requirements for Mixing Plants for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures"; "Asphalt Technology and Construction Practice (E3-1),"** and **"Asphalt Plant Manual (MS-3)"** published by the Asphalt Institute (AI).

4. **Requirements for Contractor Personnel** - Several SHA's have various specification requirements for the contractor's personnel who perform key process functions. These usually fall in the job classifications of asphalt plant operator, batcher, weigh master, and quality control technician. The personnel certification programs of the States of Florida,

Virginia, West Virginia, and Louisiana, and the trade association programs of the National Asphalt Paving Association (NAPA) and The Asphalt Institute (AI) are helpful in gaining a perspective on what these persons should know and be capable of doing. This knowledge is essential for judging the capability of the contractor to do the work and for focusing attention on areas where problems may develop.

5. **Materials Quality and Source Approval** - The quality criteria for source approval of the various materials (e.g., the asphalt cement, the aggregates, filler material, and additives) that go into flexible pavements is usually determined before construction operations start or prior to incorporation in the work.

   It is essential that the inspecting engineer be aware of these requirements and make sure these requirements have been met. Critical quality criteria for each of these ingredients are as follows:

   a. Asphalt Cement - (AASHTO M 20 and/or AASHTO M 226) viscosity at 60°C (140°F) and viscosity at 135°C (275°F), temperature susceptibility, viscosity/temperature relationship; specifically, the temperature ranges relating to the viscosity range of 150-190 centistokes and 250-310 centistokes.

   b. Aggregates -

      (1) Fine Aggregates - (AASHTO M 29) plasticity index, soundness, particle size and shape, origin.

      (2) Coarse Aggregate - (AASHTO M 283) particle shape, soundness, resistance to abrasion, origin.

   c. Filler Material - (AASHTO M 17) plasticity index, mineral origin.

   d. Additives - heat stability, source, effect on asphalt cement and mix.

   Reference is made to the "<u>Asphalt Concrete Mix Design and Field Control" (TA 5040.27)</u> and <u>Hot-Mix Bituminous Paving Manual</u> for more extensive treatment.

6. **Process Control Criteria** - There are a number of requirements and criteria incorporated in most SHA specifications governing flexible pavement construction which are directed to controlling the construction process. These requirements normally take the form of seasonal cut-off dates, paving cessation limits, continuity of operations, sequence or method of construction, and more recently, certain process control sampling and testing. **(Reference: <u>FP-85 and Florida's specifications.)</u>** The process control criteria most critical from a construction inspection viewpoint are delineated as follows:

a. Paving season cut-off dates and/or late season paving controls. The latter is preferred.

b. Paving cessation limits - These should include all principal factors that affect the time available for the compaction process to take place (e.g., mix laydown temperature, mat thickness, base temperature, wind velocity, viscosity of asphalt cement at mix laydown temperature, ambient air temperature, and reasonable time for compactive effort to be applied). **Reference: "Asphalt Concrete Mix Design and Field Control" (TA 5040.27 and NAPA's Superintendent's Manual on Compaction.**

c. Continuity of operations - This is normally imposed by subjective language included in the specifications (e.g., spreading of the bituminous mixture shall be accomplished in a continuous uniform operation with minimal stopping and starting). This is very difficult for SHA's to enforce and requires the contractor to balance his entire paving units, paver speed, number and speed of rollers, mat thickness, and mat width being placed. This is an item that is best addressed at the preconstruction conference or prepaving conference by the SHA project engineer and reinforced during the construction operations as required. **Reference: Dynapac Handbook entitled, "Estimating Net Average Speeds for Pavers and Rollers."**

d. Contractor process control sampling and testing - These specification requirements generally deal with materials control and take the form of number of test per lot or quantity of production. Typical process control tests frequently required include aggregate gradation tests, asphalt content tests, mat density tests, and tests of pavement smoothness and/or ride. Specifications may also require that this test information be presented and maintained in control chart form. **Reference: NAPA's QIP-97, "Quality Control for Hot-Mix Plant and Paving Operations."**

7. **Materials Acceptance Requirements** - These requirements are normally set forth in acceptance sampling plan format wherein specific number of tests per lot or quantity of material are specified, the point of sampling is delineated, and the material's properties and appropriate test procedure are specified. Whether the SHA uses a "method type" or an "end-result type" of specification will greatly influence what these requirements are and how they are incorporated in the specifications. Tables I and II depict in general what is typically required for each of these types of specifications along with pertinent materials properties and test requirements. Full knowledge of these materials acceptance requirements is essential to an effectual inspection and provides a large portion of the basis for determining the acceptability of the project.

Table I. Materials Acceptance Requirements for Method Type Specification

Material	Property(s) Tested	AASHTO Test Method	Point of Acceptance	Typical Testing Frequency
Aspalt Cement	Viscosity or Penetration	AASHTO T 201 & T 202 AASHTO T 49	Hauling Unit or Plant Storage Tank	1 Per Shipment
Aggregates	Gradation and Plasticity Indices	AASHTO T 11 AASHTO T 27 AASHTO T 89 & T 90	Cold Feed or Hot Bins	1 Per 1000 Tons
Bituminous Mix	Asphalt Content	AASHTO T 164	Back of Paver or Hauling Unit at Plant	1 Per 1000 Tons
	Density	AASHTO T 230	Roadway	1 Per 1000 Ft.

Table II. Materials Acceptance Requirements for End Result * Type Specifiction

Material	Property(s) Tested	AASHTO Test Method	Point of Acceptance	Typical Testing Frequency
Asphalt Cement	Viscosity or Penetration	T 201 & T 202 or AASHTO T 49	Feed Line at Hot Point	1 Per 20 Tons
Bituminous Mix	Aggregate Gradation & Asphalt Content	AASHTO T 30 AASHTO T 164	Roadway - Behind The Paver or Haul Unit at Plant	1 Per 1000 Tons
	Stability	AASHTO T 245		1 Per 1000 Tons
	Void Content	AASHTO T 269		1 Per 1000 Tons
	Density	AASHTO T 230	Roadway	1 Per 1000 Ft.

*(Statistically based/performance/modified-end result)

8. **Workmanship Acceptance Requirements** - These requirements are typically more subjective in nature than the materials requirements and require the exercise of engineering judgment in a different vein. These requirements deal with such things as joint construction, smoothness, or rideability of the pavement, pavement texture, and pavement spread or thickness.

   a. Joint construction - Specification requirements governing the construction and acceptability of both longitudinal and transverse joints in flexible pavements typically cover preparation of the joint, joint construction methods or procedures, where they may be utilized, and lastly some sort of straightedge tolerance measure (e.g., 1/8 inch in 10 feet). A general knowledge of these requirements and subsequent checks on joint construction, smoothness, and tightness during the field inspection will help assure a quality end product.

   b. Pavement smoothness and/or rideability - Several SHA's specification requirements governing pavement smoothness are set forth in terms of some tolerance to a straightedge, usually 1/8 inch to 3/16 inch in 10 feet. From a practical perspective this requirement is usually only applied to joints or obvious humps and depressions. Other SHA's use an updated version of the straightedge in the form of a rolling straightedge which allows a more quantitative assessment of the pavement smoothness. Acceptance criteria for this measure is typically set forth in terms of percent of pavement, measured longitudinally, that is within the tolerance limit. More recently SHA's have begun to use profilographs and ridemeters to determine the acceptability of the pavement with regard to ride and/or smoothness. Acceptance criteria for these measures are generally specified in terms of inches per miles or some ride score. **Reference: AASHTO Guide Specifications on Pavement Rideability.**

   c. Pavement thickness - Although project plans and pavement design procedures key on pavement thickness, the preponderance of SHA's do not specify pavement thickness as an acceptance criteria. The typical approach is to check the spread and the loose-lift thickness during laydown with occasional cores taken to insure that adequate finished pavement thickness is being obtained. A few SHA's that pay for flexible pavement on a square yard basis do have pavement thickness acceptance requirements. The acceptance criteria is usually stated in terms of plan thickness and is determined by coring of the mat. The criteria is either applied on an individual core basis or the average of a specified number of core thickness measurements. In view of the criticality of pavement thickness to overall pavement performance, it is essential that the inspecting engineer be fully cognizant of all quality control and acceptance criteria pertaining to pavement thickness.

d. Pavement Texture - Acceptance criteria addressing pavement texture of flexible pavement is generally specified in subjective terms with the bituminous mix design and aggregate type and gradation having the most significant influence on the resulting texture of the pavement. A few SHA's have implemented specification requirements covering segregation which addresses both qualitative and quantitative aspects. **Reference: Colorado-DOH specification requirements 401.16.**

B. Mix Design, Job-Mix Evaluation, and Approval

1. **Mix Design** - Full knowledge and understanding of the SHA's mix design procedures is critical to the conduct of a thorough inspection of flexible pavement construction. The majority of SHA's use the Marshall Method of mix design wherein the parameters of stability, voids in the mineral aggregate, voids in the mix, specific gravity of the mix, and flow are used to establish the optimum asphalt content for a selected aggregate gradation. Ten SHA's use the Hveem Method of mix design. This mix design procedure keys on estimation of asphalt content, the stabilometer tests, density, voids analysis, and swell tests to select the optimum asphalt content. **Reference: "Asphalt Concrete Mix Design and Field Control" (TA 5040.27) and The Hot-Mix Asphalt Paving Manual** gives specific details of each of these mix design methods and discusses the criticality of each parameter and their related effects on pavement performance. Tables III and IV summarize the principal factors which should be taken into account in preparing for an inspection of flexible pavement. Regardless of the method of mix design used, SHA procedures should require that the mix design is made on the materials that are to be used on the project.

2. **Job-Mix Evaluation Factors** - In preparing for an inspection of flexible pavement construction, there are a number of factors that should be evaluated regarding the job-mix established for a project. The factors to evaluate are listed as follows:

   a. Aggregate gradation - A plot of the aggregate gradation raised to the 0.45 power (e.g., see Figure 1) should be made. This will allow assessment of the mix with regard to maximum density attainable, minimum voids, and potential mix stability.

   The applicable gradation tolerance limits should also be plotted so as to give some preliminary assessment of potential problems with tenderness of mix, compatibility, void content, and gradation control. **Reference: Hot-Mix Bituminous Paving Manual - pages 2-11 through 2-14.**

   b. Asphalt cement properties - Preliminary evaluation of the asphalt cement to be used will frequently pinpoint potential construction and pavement performance problems. The key properties to evaluate are the grade of asphalt to

NEW HAMPSHIRE SURFACE MIX

.45 POWER GRADATION CHART

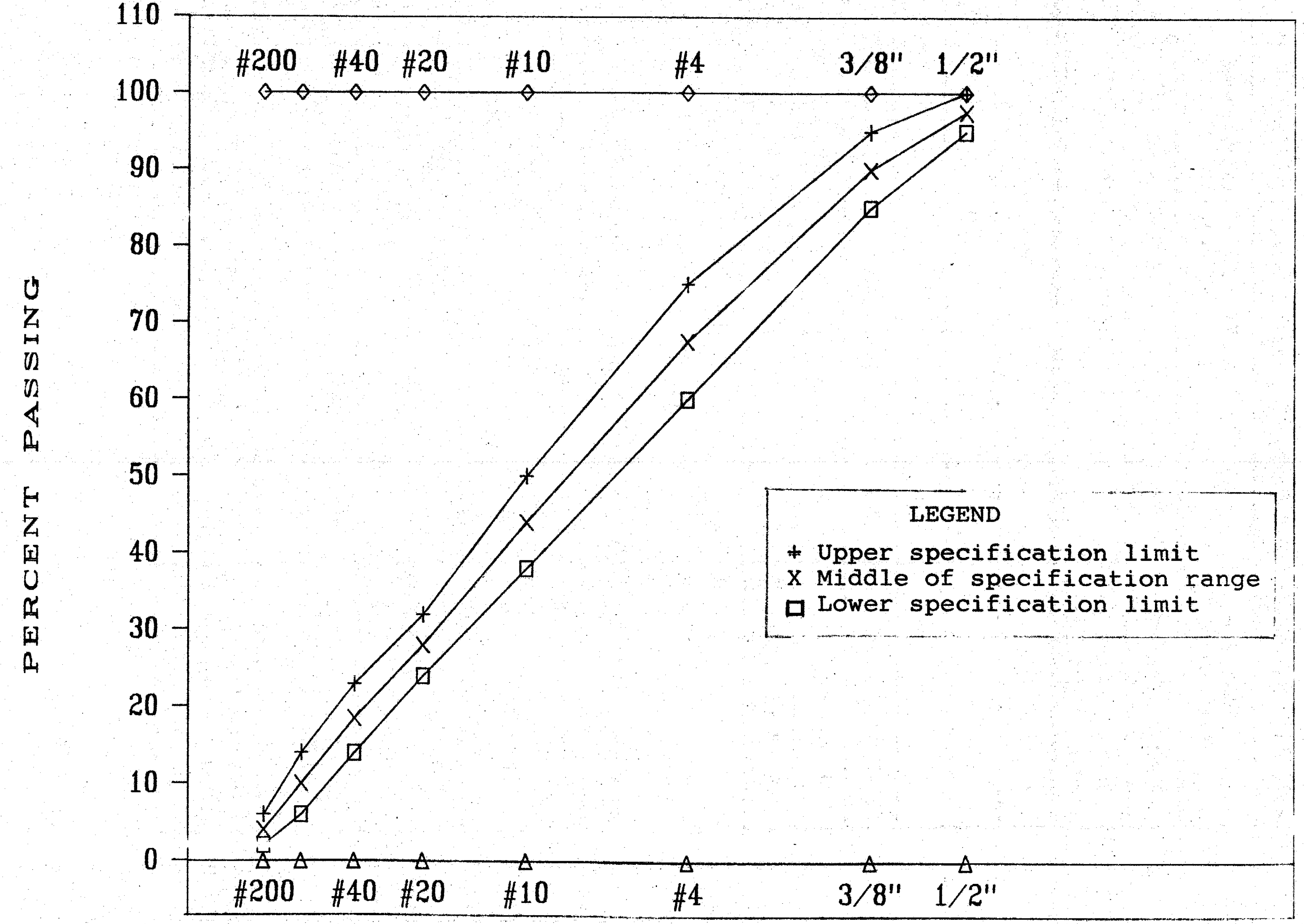


FIGURE 1-RANGE IN MASTER GRADING BANDS FOR NEW HAMPSHIRE

* These particular tables not applicable to all mixes; e.g. -Table III appropriate for surface courses and normal weight aggregates with 1" to 3/8" nominal top size aggregate. Refer to the Asphalt Institute MS-2, Mix Design Methods for Asphalt Concrete, and TA 5040.27, "Asphalt Concrete Mix Design and Field Control."

Table III. Bituminous Mix Design Parameters - Marshall Method *

Mix Parameter	Typical or Recommended Criteria					
Asphalt Content	4.5 to 6.5%					
Voids in Mineral Aggregate (VMA)	13 to 16% (Minimum)					
Traffic	Heavy		Medium		Light	
Compaction Blows	75		50		35	
	Min.	Max.	Min.	Max.	Min.	Max.
Stability (lbs.)	1500	....	750	....	500	...
Flow (0.01")	8	16	8	18	8	20
Air Voids (%)	3	5	3	5	3	5

Table IV. Bituminous Mix Design Paramenters - HVEEM Method *

Mix Parameter	Typical or Recommended Criteria					
Asphalt Content	4.5% to 6.5%					
Traffic	Heavy		Medium		Light	
Stabilometer	Min.	Max.	Min.	Max.	Min.	Max.
	37	....	35	....	30	....
Swell	Less Than 0.030 Inches					
Air Voids	4 or More Percent Air Voids					

be used, the source of the asphalt cement, the temperature/ viscosity curve for the asphalt cement making special note of the mixing laydown, and compaction temperature ranges with associated viscosities. The mixing temperature range specified in the job-mix should correspond to a viscosity of 170 ± 20 centistokes and the cut-off temperature for compaction should correspond to a maximum viscosity of 5000 centistokes. The optimum compaction temperature range, however, is that corresponding to a viscosity of 280 ± 30 centistokes. See Figure 2 for an example of this evaluation. Assessment of the slope of the temperature viscosity curve will also give some indication of the temperature susceptibility of the mix. This will aid in dealing with potential compaction problems that may develop during construction. See Figure 3 for the effect temperature susceptibility has on asphalt performance.

c. Bituminous mixture properties - In addition to the mix design parameters previously delineated for the Marshall and/or Hveem Methods, evaluation of the moisture susceptibility of the mixture is extremely important especially as it affects subsequent pavement performance. "Effect of Water on Compacted Bituminous Mixtures" (immersion compression test) (AASHTO T 165) and "Resistance of Compacted Bituminous Mixture to Moisture INduced Damage" (AASHTO T 283) are currently the only stripping test procedures which have been adopted by AASHTO. The AASHTO T 283, commonly known as the Lottman Test, requires that the test specimens be compacted so as to have an air void content of 7 ± 1 percent, while AASHTO T 165 does not. This air void content is what one would expect in the mat after construction compaction. One of the most promising test procedures is that developed by Tunnicliff and Root as reported in the National Cooperative Highway Research Program (NCHRP) Report 274*. See Table V for a summary of moisture susceptibility tests. **Reference: "Mix Design Methods for Asphalt Concrete" (AI MS-2), and Stripping of Asphalt Pavements: State-of-the-Art, TRB Report.**

Table V. Summary of Bituminous Mixture Moisture Susceptibility Tests

Test Procedure	Test Designation	Test Criteria
Immersion - Compression	AASHTO T-165 (ASTM D 1075)	70 Percent Retained Stability
Static Immersion Stripping Test	ASTM D 3625	95% Coating Required
Dynamic Immersion Stripping Test	Caltrans Test No. 302	75% Coating Required
Lottman Tensile - Splitting Ratio	AASHTO T-283	70 Percent Retained Strength
Texas Pedestal Test	----	Number of Freeze - Thaw Cycles Required to Induce Cracking 725
Coating and Stripping of Bitumen-Aggregate Mixtures	AASHTO T-182	95% Coating Required

* Also the Tunnicliff and Root (NChRP 274 and TA 5040.27); it is similar to Lottman (AASHTO T 283), but has no freeze cycle.

The key point to keep in mind in evaluating the job-mix is that the SHA has evaluated the mix as to its sensitivity to moisture damage and has taken this into account in the job-mix.

The parameters of voids in the mineral aggregate, the voids in the mix, and the influence this method of specific gravity determination has on these parameters should be considered in the preliminary evaluation of the job-mix design. Ideally, the job-mix should produce a pavement with 3 to 5 percent* air voids using the Rice Method (AASHTO T-209) for determining the maximum theoretical specific gravity of the combined mixture. See figure 4 for a plot of pavement durability vs. percent air voids. **Reference: "Hot-Mix Bituminous Paving Manual" - pages 2-18 through 2-20 and "Asphalt Concrete Mix Design and Field Control" (TA 5040.27).**

The parameters of stability, flow, etc., that are inherent in the mix design method used should be evaluated in terms of the class of highway pavement being constructed and the type of traffic being served (e.g., light traffic, medium traffic, or heavy traffic). Tables III and IV should assist in evaluating these parameters and the specific job mix established for the project to be inspected.

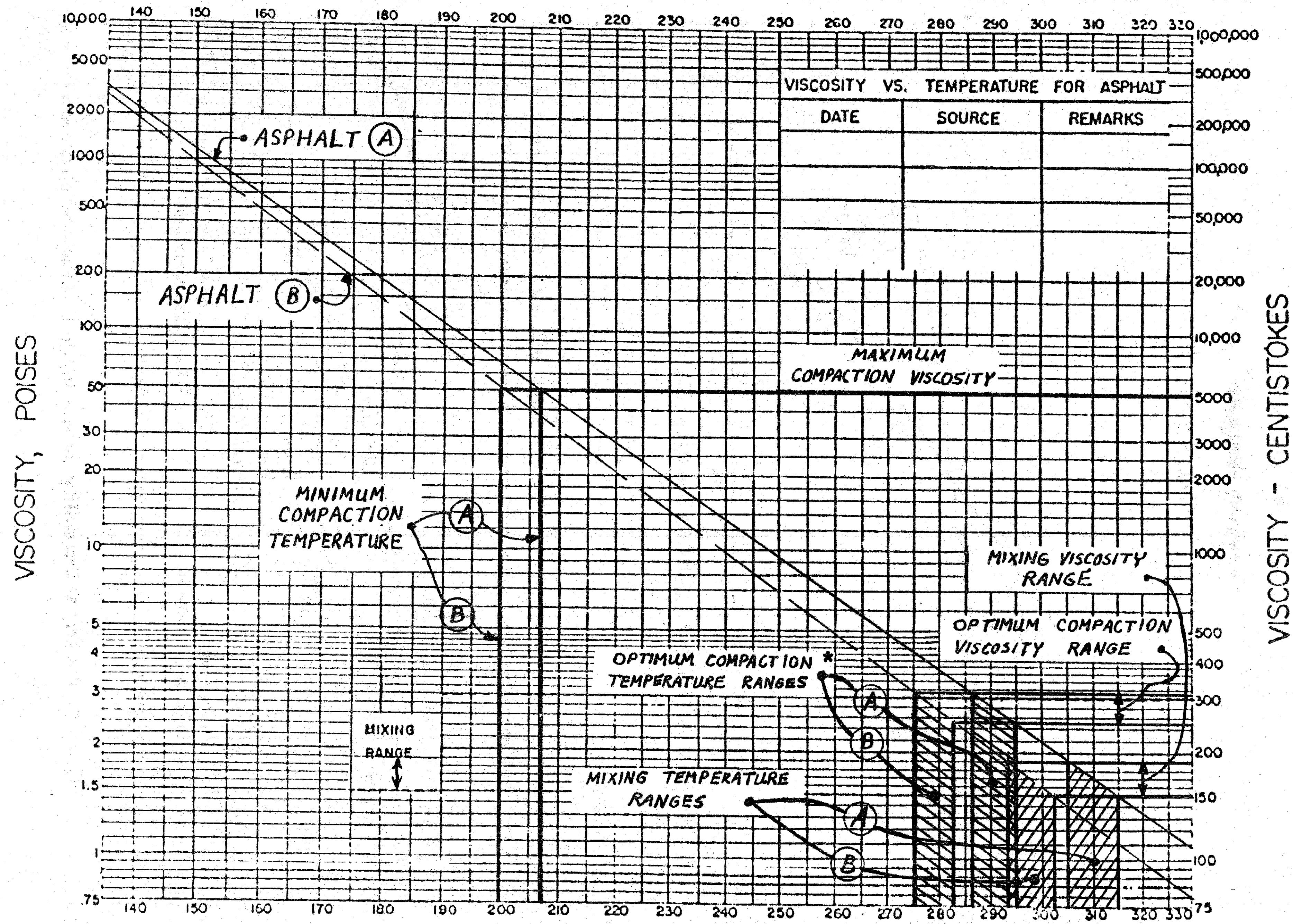
The resulting job-mix is normally set forth with specific target values established for

- mixing temperature
- aggregate grading
- asphalt content
- maximum theoretical density.

In view of the expected variability associated with each of these parameters, it is also beneficial to assess how normal construction variability in any one or combination of job-mix parameters will reflect on the mix design parameters of stability, flow, specific gravity, etc. For example, if the specifications allow a ± 0.5 tolerance on asphalt cement content, a general assessment can be made as to the effect this degree of variability will have on pavement density and/or void content of the pavement, stability of the mix, and flow for the Marshall Method of mix design. Similar assessments should also be made with regard to each job-mix parameter.

3. **Job-Mix Approval** - Currently most SHA's are assuming full responsibility for the development and approval of each job-mix. This responsibility normally rests with the SHA's materials engineer. Under these conditions and from a legal perspective the SHA becomes fully responsible throughout the construction process to see that the contractor adheres to the

* **(As ultimately attained under traffic; see the Asphalt Institute's MS-2, Chapter VI)**



Temperature, Degrees Fahrenheit

*(The optimum compaction temperature is for lab design only.)

Figure 2.

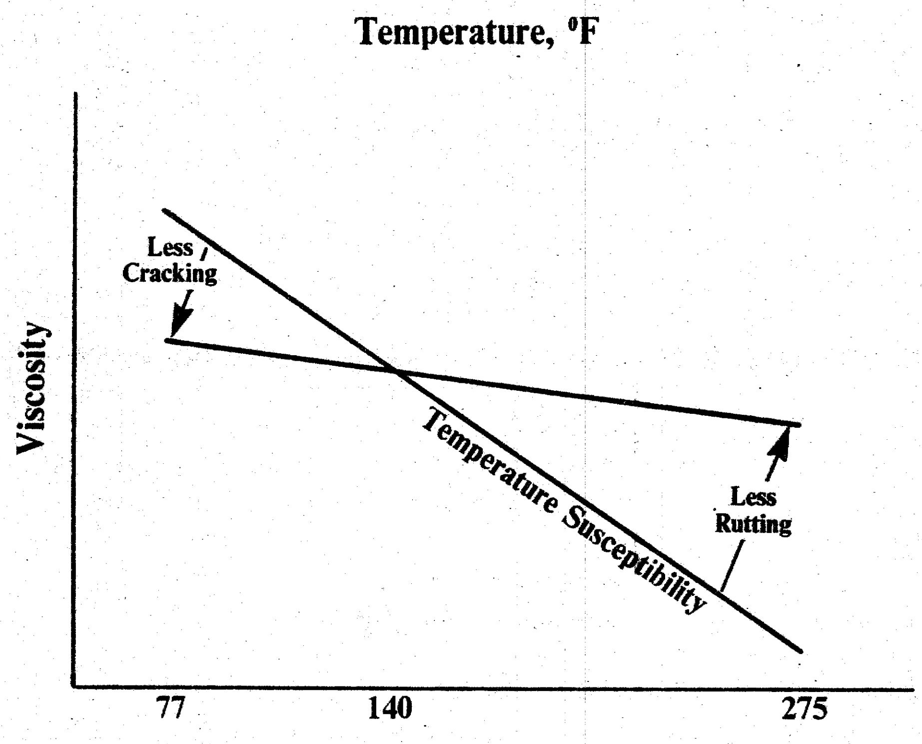


Figure 3. Asphalt Performance

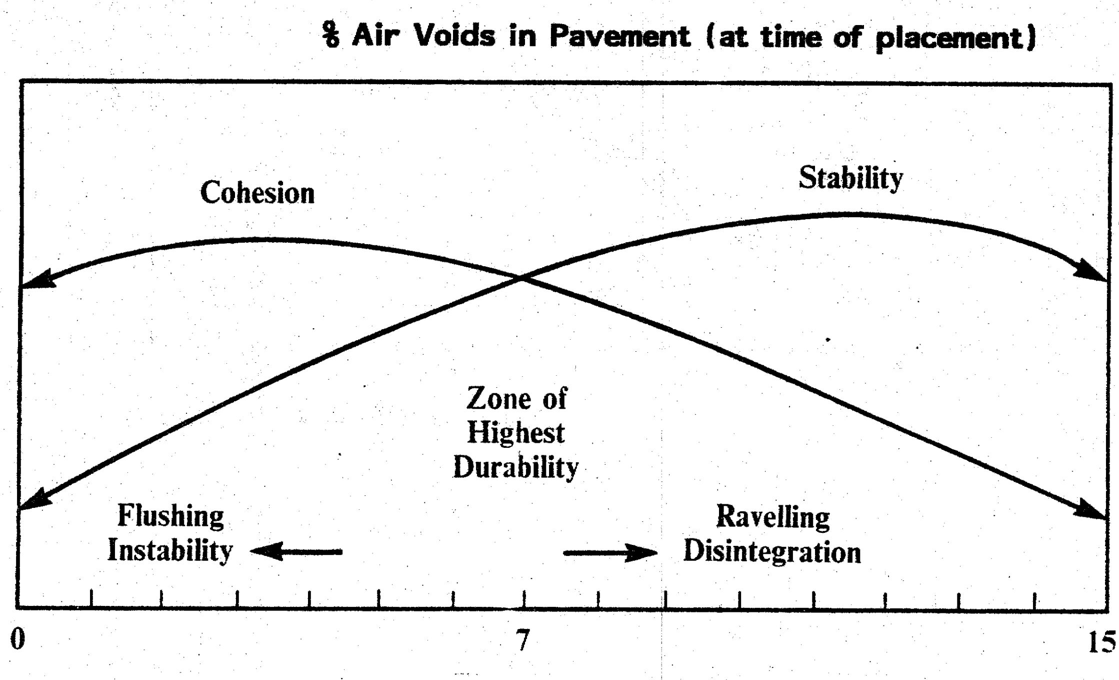


Figure 4. Pavement Durability vs Air Voids (at time of placement)

approved job-mix. From a practical perspective, the contractor and more specifically his individual personnel have the real control of the work. Construction variability introduced by the contractor through his crushing operations, materials supply and handling, and construction operations, can frequently impact the job-mix that is set up for the project. With this in view, a clear understanding of how job-mix changes are to be handled should be established in preparing for the field inspection. Field adjustments to the job-mix for whatever reason should be evaluated by the SHA person responsible for the mix design and job-mix approval before the adjustment is made. This often takes considerable time and can greatly impact the contractor's operations, however, it is a very essential step in assuring good flexible pavement performance.

C. Pavement Construction and Performance Problems

A preliminary review of pavement construction and performance problems will help direct where it is most productive to spend field inspection efforts. Review of previous inspection reports, project materials certifications, pavement condition surveys, and maintenance reports coupled with personal knowledge, observations, and discussions with SHA's construction, materials, and maintenance personnel, as well as other FHWA field engineers will assist in establishing the key element to cover during the field inspection.

Tables VI through VIII provide excellent guidance for determining the root construction and materials causes of flexible pavement deficiencies. Preliminary reviews of these trouble shooting guides prior to the field inspection is highly recommended.

Many of the performance problems associated with flexible pavements can be traced back to deficiencies in materials, construction, and/or design. The Hot-Mix Bituminous Paving Manual on pages 6-1 through 6-18 are recommended for review prior to making the field inspection.

Table VI. Effect of Construction Equipment and Construction Techniques on Asphalt Cement Properties.

Construction Related Factors	Usual Effect On Asphalt Consistency	Mechanism
Drum Mixer Versus Batch Plant	Soften*	Lower Mixing Temperatures Are Utilized in Drum Mixers. Possible Unburned Fuel Contamination.
Vibratory Roller Versus Pneumatic	Harden	Vibratory Equipment May Not Seal Surface and Pavement Is Permeable to Air and Water Thus More Rapid Hardening During Service.
Bag House Versus Wet Washer System	Harden	Baghouse Fines Are Returned to Mix Which may Increase the Apparent Viscosity of the Asphalt.
Transport of Asphalt in Contaminated Transport	Soften	Residual Products in Transport (Often Heavy Fuel Oil or Cutback) Soften Asphalts.
Mixing of Asphalt in Storage	Soften	Blending of Two Crudes of Same Grade May Chemically Interact to Form an Out of Grade Product; Separation of Asphalts Would Also Occur.
Use of Antistrip Chemical in Asphalt	Soften	Chemical Interaction Usually Results in a Softening of the Asphalt.
High Mixing Temperature	Harden	Higher Mixing Temperatures Promote More Rapid Oxidation and Volatilization of Asphalt.
Hot Storage of Asphalt Concrete	Harden	Prolonged Storage of Hot Mixes Will Promote Oxidation and Volatilization of Asphalt.

*Excessive Hardening Can Occur if Proper Flight Maintenance Is Not Practiced and/or Production Quantities Are Low.

Table VII. Mat Problem Trouble Shooting Guide.

CAUSES

PROBLEM	Fluctuating Head of Material	Feeder Screws Overloaded	Finisher Speed Too Fast	Too Much Lead Crown in Screed	Too Little Lead Crown in Screed	Overcorrecting Thickness Control Screws	Excessive Play in Screed Mechanical Connection	Screed Riding on Lift Cylinders	Screed Plates Worn Out or Warped	Screed Plates Not Tight	Cold Screed	Moldboard on Strikeoff Too Low	Running Hopper Empty Between Loads	Feeder Gates Set Incorrectly	Kicker Screws Worn Out or Mounted Incorrectly	Incorrect Nulling of Screed	Screed Starting Blocks Too Short	Screed Extensions Installed Incorrectly	Vibrators Running Too Slow
Wavy Surface — Short Waves (Ripples)	✓	✓	✓				✓	✓		✓									
Wavy Surface — Long Waves	✓	✓				✓	✓	✓					✓	✓					
Tearing of Mat — Full Width			✓						✓		✓								
Tearing of Mat — Center Streak					✓				✓		✓			✓	✓				
Tearing of Mat — Outside Streaks				✓					✓		✓	✓		✓				✓	
Mat Texture — Nonuniform	✓	✓	✓					✓	✓	✓	✓		✓					✓	✓
Screed Marks							✓												
Screed Not Responding to Correction			✓				✓	✓		✓									
Auger Shadows		✓																	
Poor Precompaction			✓					✓											✓
Poor Longitudinal Joint	✓	✓				✓		✓											
Poor Transverse Joint		✓					✓	✓		✓						✓	✓		
Transverse Cracking (Checking)																			
Mat Shoving Under Roller																			
Bleeding or Fat Spots in Mat																			
Roller Marks																			
Poor Mix Compaction																			

PROBLEM	Grade Control Mounted Incorrectly	Grade Control Hunting (Sensitivity Too High)	Grade Control Wand Bouncing on Reference	Grade Reference Inadequate	Sitting Long Period Between Loads	Improper Joint Overlap	Improper Mat Thickness for Max. Agg. Size	Trucks Bumping Finisher	Truck Holding Brakes	Improper Base Preparation	Improper Rolling Operation	Reversing or Turning Too Fast of Rollers	Parking Roller on Hot Mat	Impropor Mix Design (Aggregate)	Improper Mix Design (Asphalt)	Mix Segregation	Moisture in Mix	Variation of Mix Temperature	Cold Mix Temperature
Wavy Surface — Short Waves (Ripples)	✓	✓	✓	✓						X	X			X	X	X		X	
Wavy Surface — Long Waves	✓			✓	✓			X	X	X		X	X			X		X	
Tearing of Mat — Full Width							X							X	X	X	X	X	X
Tearing of Mat — Center Streak																			X
Tearing of Mat — Outside Streaks																			X
Mat Texture — Nonuniform					✓		X			X				X	X	X		X	X
Screed Marks								X	X										
Screed Not Responding to Correction	✓						X											X	X
Auger Shadows														X	X	X			
Poor Precompaction							X			X									X
Poor Longitudinal Joint	✓	✓	✓			✓					X								X
Poor Transverse Joint											X								X
Transverse Cracking (Checking)										X	X			X	X		X	X	
Mat Shoving Under Roller										X	X	X		X	X		X	X	
Bleeding or Fat Spots in Mat														X	X		X	X	
Roller Marks										X	X	X	X					X	
Poor Mix Compaction										X	X	X	X	X	X		X	X	X

1. Find problem above.
2. Checks indicate causes related to the paver.
   X's indicate other problems to be investigated.

NOTE: Many times a problem can be caused by more than one item, therefore, it is important that each cause listed is eliminated to assure solving the problem.

Table VIII. Possible Causes of Imperfections in Finished Pavements.

Types of Pavement Imperfections That May Be Encountered In Laying Hot Plant Mix Paving Mixtures.	Bleeding	Brown, Dead Appearance	Rich or Fat Spots	Poor Surface Texture	Rough Uneven Surface	Honeycomb or Ravelling	Uneven Joints	Roller Marks	Pushing or Waves	Cracking (Many Fine Cracks)	Cracking (Large Long Cracks)	Rocks Broken by Roller	Tearing of Surface During Laying	Surface Slipping on Base
Insufficient or Non-uniform Tack Coat					X				X					X
Improperly Cured Prime or Tack Coat					X				X					X
Mixture Too Coarse				X	X	X	X					X	X	
Excess Fines in Mixture				X				X	X	X				X
Insufficient Asphalt		X				X				X			X	
Excess Asphalt	X		X					X	X					X
Improperly Proportioned Mixture	X		X	X	X	X		X	X	X		X	X	X
Unsatisfactory Batches in Load	X		X	X	X	X			X					
Excess Moisture in Mixture		X							X					X
Mixture Too Hot or Burned		X											X	
Mixture Too Cold				X	X	X	X	X				X	X	X
Poor Spreader Operation				X	X	X	X		X			X	X	
Spreader in Poor Condition				X	X	X	X		X			X	X	
Inadequate Rolling				X	X	X	X	X						X
Rolling at Wrong Time				X	X	X	X	X	X	X		X		X
Over-Rolling				X						X	X	X		X
Rolling Mixture When Too Hot				X	X		X	X	X	X		X		
Rolling Mixture When Too Cold				X	X	X	X	X						X
Roller Standing on Hot Pavement					X			X						
Overweight Rollers					X			X	X	X	X	X		X
Roller Vibration					X				X					
Unstable Base Course					X		X		X	X	X		X	X
Excessive Moisture in Subsoil										X	X			X
Excessive Prime Coat or Tack Coat	X		X											X
Poor Handwork Behind Spreader				X	X	X	X							
Excessive Hand Raking				X	X	X	X		X					
Labor Careless or Unskilled				X	X	X	X	X						
Excessive Segregation in Laying			X	X	X	X	X						X	
Faulty Allowance for Compaction							X							
Operating Finishing Machine Too Fast				X	X								X	
Mix Laid in Too Thick Course									X					
Traffic Put On Mix While Too Hot									X					

II. BASE/GRADE PREPARATION

With today's highway construction program addressing a broader spectrum of activities, new construction, resurfacing, restoration, rehabilitation, and reconstruction, special efforts and attention must be directed during the field inspection of flexible pavements to the preparation, adequacy, and condition of the base/grade on which the pavement is being constructed. The critical elements and factors to cover during the field inspection vary with the type of construction.

A. New Construction

In new construction the elements to cover during the field inspection have largely been addressed under the **Base Course Construction Workshop,** however, they are worthy of brief reiteration.

1. **Thickness and Support** - A check should be made on base thickness and support in conjunction with the field inspection of flexible pavement construction. This check should, as a minimum, include review of the project control and acceptance test results for thickness, density and stability, and/or strength where applicable. A quality level analysis of these test results is suggested for determining conformity to specification and plan requirements. Along with this check, visual observations should be made of the base/grade to determine if any obvious weak spots exist.

2. **Workmanship** - The grade, smoothness, and cross-section of the base/grade will greatly influence what is attainable for the flexible pavement. The use of string lines and automated pavers has led to somewhat of a laxity in the workmanship being achieved for bases. It is not always possible and it is usually not economical to try and level up the grade or cross-section with hot-mix. For these reasons it is imperative that the field inspection include a check on adherence to cross slope tolerances, grade, and smoothness requirements specified for the base/grade.

B. Resurfacing, Restoration, Rehabilitation and Reconstruction

Thorough field inspection of projects involving resurfacing, restoration, rehabilitation, and reconstruction require more engineering judgment and experience than projects involving new construction. Careful and insightful observations should be made during the field inspection to discern if there are any pavement distresses evident that may be related to base or subgrade failure. If these observations detect fatigue or alligator cracking, judgment must then be made as to the adequacy of the rehabilitation or reconstruction treatment. The following offers guidance for making these observations and judgments.

1. **Pavement Evaluation and Current Condition Survey -** There is often as much as a 2-year time lag between the time the pavement evaluation and condition survey is performed for design purposes, and the time the project goes to construction. Further weakening of the base and subgrade can and frequently does take place during this time period. In view of this, the inspecting engineer should review the pavement evaluation and condition survey on which the rehabilitation or reconstruction is based and determine the type and extent of any further distress that may have developed. If the SHA uses a non-destructive test method such as the Dynaflect, RoadRater, or Falling Weight Deflectometer in the pavement evaluation, this data should also be reviewed in conjunction with the field inspection of current pavement conditions. From a review of this data the inspecting engineer can make judgments as to the competency of the underlying base and subgrade.

   If the rehabilitation project involves rotomilling and/or recycling, careful inspection should be made of the rotomilling operation. This will assist the inspecting engineer in determining the extent of stripping that may have taken place, the depth of rotomilling that needs to be done, and whether the rehabilitation treatment will be effective.

2. **Evaluation of the Adequacy of the Rehabilitation or Reconstruction Treatment** - There are a number of rehabilitation and reconstruction treatments being used today which have had limited performance histories. This coupled with the practice of just placing another overlay to appease political pressures has resulted in a number of costly premature pavement failures. Recent failures have also been reported where overlays have been placed on existing pavements with subsequent stripping developing in the existing pavement. This failure has been traced to water entrapment in the existing pavement by the overlay. This coupled with high tire pressures has resulted in hydraulic stripping which has led to early pavement failure.

   Recent guidance has been developed which relates type of pavement distress to appropriate rehabilitation alternative. This guidance is summarized in Table IX and should be used by the FHWA field engineer making the inspection to evaluate the adequacy of the rehabilitation or reconstruction treatment. Steps should be taken to assure that corrections and/or design changes are made if there are apparent inadequacies of which the SHA project personnel are not aware.

Table IX. Pavement Distress - Possible Causes and Rehabilitation Alternatives

Type of Distress	Possible Causes	Rehabilitation Alternatives
Rutting	Structural Deficiency HMAC Mix Design Asphalt Cement Properties Stability of Pavement Layers Compaction (Density) - All Layers	Cold Milling Including Profile Requirements, With or Without Overlay Heater Scarification With Surface Treatment or Thin Overlay Replacement (Particularly Applicable to Corrugations in Localized Areas)
Raveling	Low Asphalt Content Excessive Air Voids in HMAC Hardening of Asphalt Water Susceptibility (Stripping) Aggregate Characteristics Hardness and Durability of Aggregate	Dilute Emulsion or Rejuvenating "Fog" Seal Seal Coat With Aggregate Slurry Seal Thin HMAC Overlay
Flushing (Bleeding)	High Asphalt Content Excessive Densification of HMAC During Construction or by Traffic (Low Air Void Content) Temperature Susceptibility of Asphalt (Soft Asphalt at High Temperatures) Excess Application of "Fog" Seal or Rejuvenating Materials Water Susceptibility of Underlaying Asphalt Stabilized Layers Together With Asphalt Migration to Surface	Overlay of Open Graded Friction Course Seal Coat (Well Designed With Good Field Control During Construction) Cold Milling With or Without Seal Coat or Thin Overlay Heater-Scarification With Seal Coat or Thin Overlay Heat Surface and Roll-In Coarse Aggregate
Alligator Cracking	Structural Deficiency Excessive Air Voids in HMAC Asphalt Cement Properties Stripping of Asphalt From Aggregate Construction Deficiencies	Seal Coat Replacement (Dig-Out and Full Depth HMAC Replacement in Failed Areas) Overlay of Various Thicknesses With or Without Special Treatments to Minimize Crack Reflection Recycle (Central Plant on In-Place) Reconstruction
Longitudinal Cracking	Load Associated Structural Deficiency Excessive Air Voids in HMAC Asphalt Cement Properties Stripping of Asphalt From Aggregate Aggregate Gradation Construction Deficiencies Non Load Associated Volume Change Potential of Foundation Soil Slope Stability of Fill Materials Settlement of Fill or In-Place Materials as a Result of Increased Loadings Segregation Due to Laydown Machine Poor Joint Construction Other Construction Deficiencies	Crack Sealing Seal Coat (Applied to Areas With Cracking) Replacement (Dig-Out and Replace Distressed Areas) Thin Overlay With Special Treatment to Seal Cracks and Minimize Reflection Cracking Asphalt-Rubber Membrane With Aggregate Seal or Thin Overlay Heater-Scarification With a Thin Overlay
Transverse Cracking	Hardness of Asphalt Cement Stiffness of HMAC Volume Changes in Base and Subbase Unusual Soil Properties	Crack Sealing Seal Coat Overlay With Special Treatment to Seal Cracks and Minimize Reflection Cracking Asphalt Rubber Membrane With Aggregate Seal or Thin Overlay Heater Scarification With a Thin Overlay
Roughness	Presence of Physical Distress (Cracking, Rutting, Corrugations, Potholes, Etc.) Volume Change in Fill and Subgrade Materials Non-Uniform Construction	Overlay Cold Milling With or Without Overlay Heater Scarification With Overlay Heater Planning With Overlay (Primarily for Local Areas and Areas With Corrugations) Recycle (Central Plant or In-Place)

III. PLANT OPERATIONS

A. Specifications and Controls

Each of us is probably least familiar with this phase of the hot-mix construction process. We have talked earlier about the mix design and quality of aggregates and asphalts. The SHA/ Contractor operations in aggregate handling and stockpiling, asphalt storage, mixing (batch plant or dryer drum) and hot asphalt mix storage contribute directly to the quality of the finished product behind the paver.

Specifications and controls are probably more generalized and least specific in this phase of operation than any other. The contractor established his plant operation and control to minimize his effort and handling of aggregates and asphalt to make the operation as efficient as possible while still producing the specified hot mix.

Standards, practices and workmanship may vary from State to State, contractor to contractor, and project to project, depending on plant design and equipment variability, materials availability, contractor personnel, and SHA inspectors.

During the inspection of a flexible pavement project most major phases of work involve some review of operations at the hot-mix plant. Since plans and specifications do not normally define the methods and equipment the contractor is to use, we should be aware of "normal" standards of workmanship and acceptable practices by which to judge the plant operations. By being aware of good practice we will be able to determine if a poor mix is being placed on the project.

Some States require that hot-mix plant operations be certified - Plant technicians and operators as well as the equipment, scales and controls have to be tested and periodically certified by the State or other independent agency. Contractor and SHA personnel certification programs usually are based on short courses, and examinations, and renewal of this certification is required periodically. If it is a certified plant, the plant and operators will be required to have current certifications.

Probably the most fascinating (yet least productive) part of the plant to inspect is the control shack. The maze of wires running into that generally "air conditioned" mecca with the board of gauges, dials and recording devices tells us little for the time we have to spend on the job. Key questions to review for this element are

- Is this a certified plant? If so, when was the plant last certified?

- If so, the operator or technician should carry similar certification; does he/she?

- When was the plant last calibrated and by whom?

- Are there signs of control modifications or short cuts added by the contractor?

- And lastly, what is the role and relationship of the SHA Inspector?

In-depth review of the control and operation of a hot mix paving plant and its equipment is largely subjective. Training manuals and courses are available from manufacturers and the industry alike. We will not try to explain the mechanical operation of an automated plant during this short workshop but certainly each field engineer is encouraged to participate in a plant certification review with the SHA materials engineer or certifying authority. (Additional discussion is given under Drum Mix Plants in section E.1.)

The Asphalt Institute's **Asphalt Plant Manual (MS-3)** is one of the best general guides tor FHWA area engineers in preparing for general field inspections of plant operations. Also see **"Asphalt Mix Design and Field Control" (TA 5040.27).**

B. Aggregate

1. Materials Source

The key things to observe and evaluate while reviewing the materials phase of the operation are

- Removal of overburden clay, deleterious material, or other nonspecification material.

- Blending of material from pit or quarry to have desirable or uniform material for the crushing operation.

- Crushing and screening operations:

  - -- scalpers/screens
  - -- excess overflow/reject
  - -- what is being done with reject material?
  - -- does the crushed material meet specifications?
  - -- is the crushed aggregate excessively dirty or dusty?
  - -- does over-sized or foreign material appear on the conveyor after crushing?

These evaluations may require a little closer look at the materials source, the crusher, or the handling of this phase of the operation. Once raw material is crushed from the pit or quarry it is generally sized by use of various screens and stored in 1 to 4 stockpiles. **See TA 5040.27, "Asphalt Concrete Mix Design and Field Control" for more specific information on stockpiles, particularly for drum mixer and screenless batch plants.** The introduction of both white anc black recycling has required additional materials preparation and handling. Requirements are somewhat unique to these types of projects.

Methods of stockpiling used on any operation should insure a minimum of segregation. Sands, single-sized aggregates, and even crushed fine aggregate can generally be handled and stockpiled by almost any method with little worry of segregation. However, material of varying size will most certainly segregate during handling and stockpiling operations. Methods that limit segregation should always be used so that aggregates can be efficiently blended in the hot mix plant to meet the job-mix design.

2. Crushing and Mixing Operations

Signs of segregation and improper materials handling should be monitored during a review of the crushing and mixing operations.

Specific things to look for are

- Gradation and number of stockpiles specified. Frequently the contractor will change the pit source or stockpile. A recheck of the mix design is again necessary when this is done.

- Location and construction of stockpiles:

  - The stockpile should be located on a stable, clean, drainable, working surface.

  - There should be sufficient distance between stockpiles to allow working area for receiving and handling aggregates without contamination or intermingling of materials.

  - Stockpiles should be constructed in layers with limited mechanical movement of each layer. Thick layers may be placed using conveyors with chutes, bulkheads, and etc, to minimize segregation.

When stockpiles are constructed with trucks, clamshells, etc., each layer or thickness should be placed over the entire area before the next layer is started.

Some degradation occurs with all handling. This is generally not significant if care is taken when moving and working material with heavy equipment. If the stockpiled material cannot meet specified gradations it is highly unlikely the final hot-mix can meet the job-mix formula (JMF) either.

C. Asphalt

1. Storage Handling and Sampling

Asphalt storage and handling on the project is critical to the construction of the durable hot-mix asphalt pavement. Asphalt storage capacity at the project plant should be sufficient to maintain a uniform operation while allowing for delays in shipments or time for testing of individual loads. Storage tanks should be insulated and calibrated so the amount of asphalt material remaining in them at any time can be measured. These tanks should also be equipped with a 24-hour recording thermometer.

Storage tanks, transfer lines, pumps and weight buckets should have heating coils or jackets to maintain the asphalt at the required holding temperature (325°F maximum). Heating is generally accomplished by circulating hot oil or steam thru coils in the tank or it can be done using electric resistance coils. In no case should direct heat (flame) be used.

Sampling of stored hot asphalt should be through a spigot or sample valve in the tank discharge line between the pump and the return line discharge. The valve location must be readily accessible and installed in such a way that the valve can be flushed and samples can be drawn slowly and safely at any time.

Protection from contamination of the hot stored asphalt is critical. Contamination may occur from residue of material previously stored in the tank or the solvent used to clean the tank. Water contamination, although not as serious, occurs from condensation from frequent heating and cooling or from leaks in the steam heat system. Contamination from hot oil heating can be determined by a loss of heating oil. Contamination can result from introduction of new shipments of asphalt. Anti-strip additives can also change the characteristics of the asphalt cement.

2. Blending Problems

NCHRP Report 269: Paving With Asphalt Cements Produced in the 1980's does an excellent job presenting the paving and performance problems associated with blended asphalts. Problems occur when asphalts from more than one supplier or source are blended in the same storage tank at the plant. Two asphalts of the same grade can be mixed and produce an asphalt out-of-grade because of the chemical interaction of the asphalts. This practice of blending asphalts from different sources has become fairly common among contractors as they shop for low-priced asphalt. Refer to Figure 5.

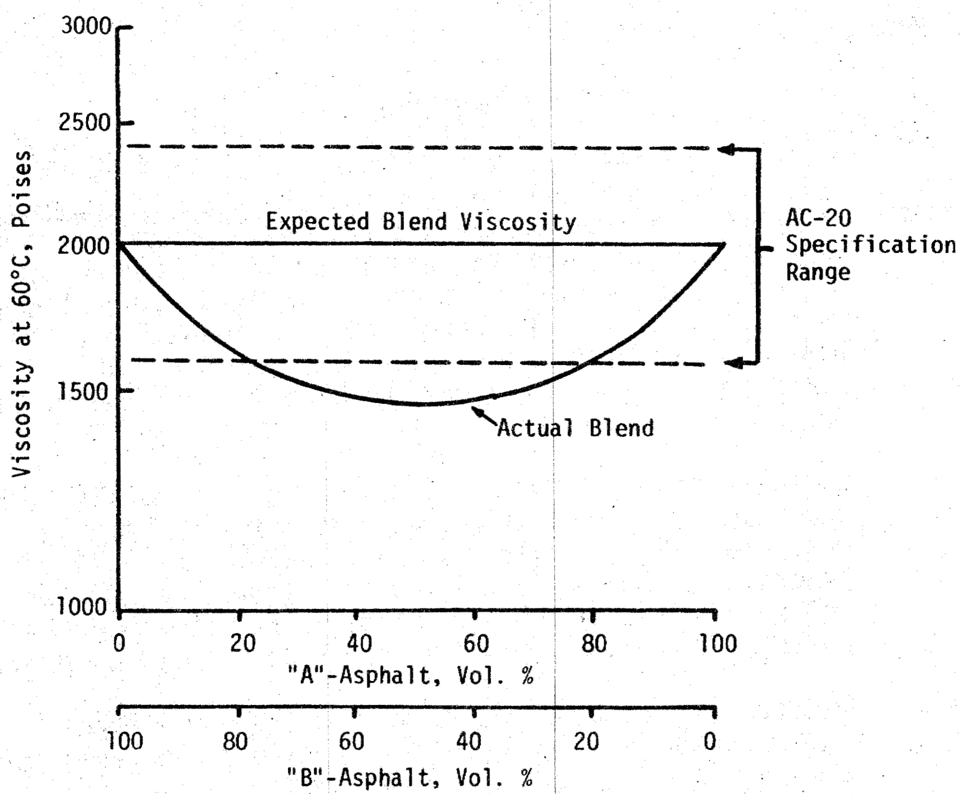


Figure 5. Effect of Chemical Interaction on Blending of Asphalts

It is extremely important that the SHA project engineer and contractor be aware of this blending problem. FHWA strongly advocates that each shipment invoice shows not only the manufacturer's crude source and grade but also includes the appropriate temperature/viscosity curves pertaining to that particular asphalt. By using the information provided on the temperature/viscosity curve the field engineer can determine the differing mixing and laydown characteristics of that asphalt and the subsequent "blended" asphalt and can effect a re-check on the mix design and a change in the JMF as necessary.

Additives introduced into the asphalt at the refinery or the storage tank affect viscosity and penetration and have limited shelf life. The numerous anti-strip chemical additives used to reduce water susceptibility should be tested with the asphalt during the final mix design. Extended heating and storage of the asphalt with such additives can adversely alter performance and durability of the finished product.

The last point to check on with regard to storage of hot asphalt is the effects the method of storage has on oxidation or aging of the asphalt. This is best determined through testing when an apparent problem is evident.

D. Summarizing the Handling, Storage, Crushing, and Stockpiling Operation of Aggregate and Asphalt

We have spent but a few minutes discussing the materials handling, storage, crushing and stockpiling operations with only major points having been made. However, there are many other critical points inherent in each specific operation which must be evaluated. There is no substitute for on-the-job experience. Again as area engineers you are encouraged to participate in inspections-in-depth scheduled at both commercial plants or on the job when conducted by FHWA or SHA materials specialists.

Key features observed in this phase of operation:

- Material source, gravel pit, or quarry should be free and clean of clay and deleterious materials.
- Overburden should be thoroughly removed to provide for crushing operations.
- Materials handling, crushing, and stockpiling should be neat and orderly.
- Watch for screening operations which may be producing excessive waste or overflow.
- Observe the uniformity and cleanliness of aggregates on the feed belt. Are there oversized, foreign material, clays or excessive dust and fines?
- Does the handling and stockpiling cause segregation?
- Is the hot asphalt storage of sufficient capacity and is it properly insulated and heated?
- Where are asphalt samples taken and is the SHA/contractor aware of problems with contamination?

- Does the SHA properly sample asphalt and aggregates and is the information used to adjust the mix design when asphalt sources or materials properties change?

E. Hot-Mix Plants (Batch)

1. Stockpile to Cold Bin

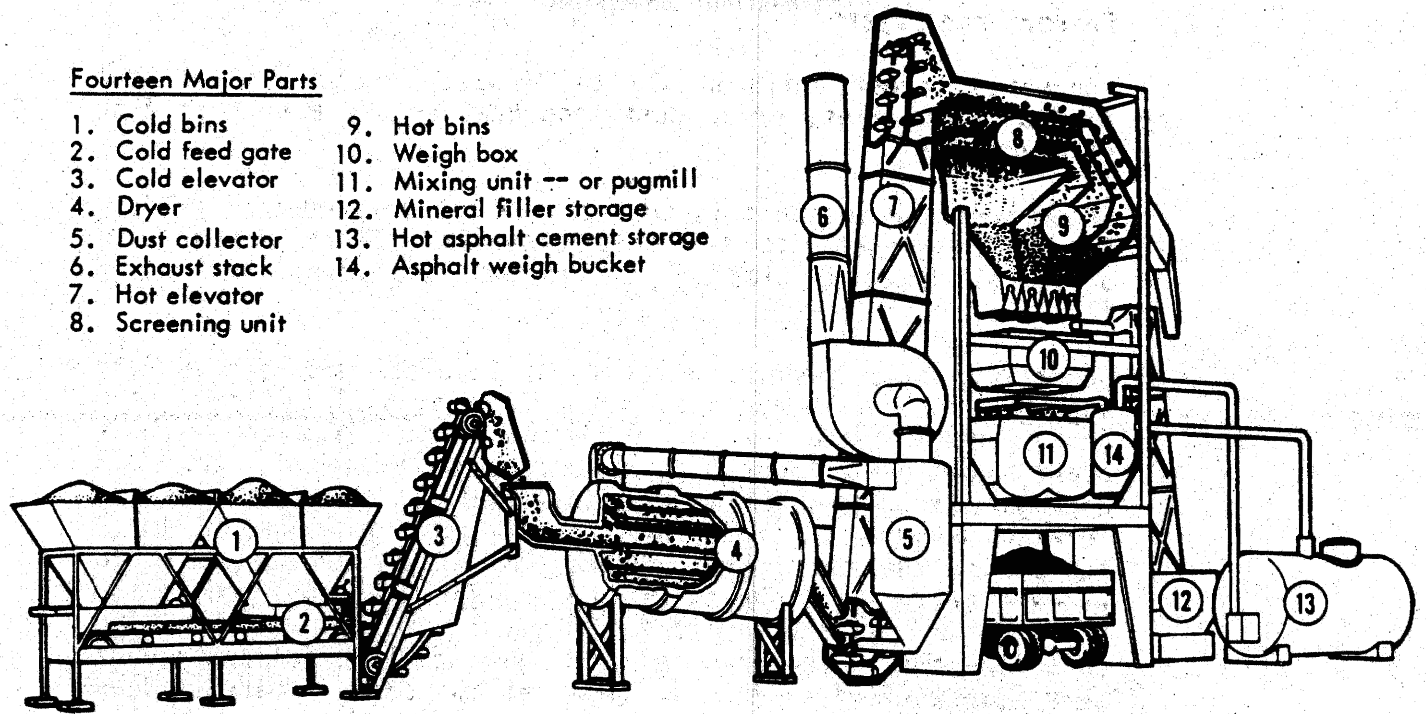
The basic principles of cold feed operations are similar for most types of hot-mix plants, continuous, batch, or drum mixer. Proper cold feed calibration and control is essential to the production of a quality hot-mix. Problems associated with the temperature and moisture control, segregation, aggregate supply imbalance on screens, dryer, or in the pugmill or drum can normally be traced back to the cold feed.

Plants should be equipped with a minimum of four cold feed bins with positive separation. The cold feed bins are charged by material produced and stockpiled using conveyors or front end loaders or both. Care needs to be exercised to balance the aggregate operation with the plant demand. The bins should never be over loaded nor allowed to run low. The same concerns with aggregate segregation and degradation during stockpiling operations exist in the cold feed delivery.

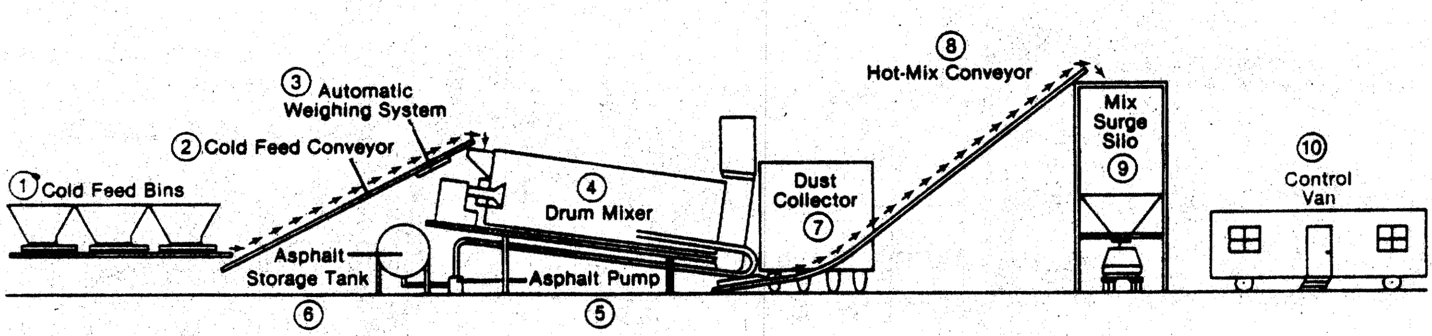
If aggregate is stockpiled over a tunnel and belt, special care should be taken when charging material over the feeders. For example, bulldozers used on stockpiles may cause segregation and degradation. Mud and dirt or other objectionable material should not be tracked onto the stockpile by these machines. Vibration from a bulldozer can cause the fine particles in the coarse stockpile to filter down into a layer that later is pushed to the feeder. The result will be an imbalance of the feed. This may be minimized by varying the path of the feeder. Also, continuous abrasive action by particles being moved about can cause degradation in some types of aggregates.

If the stockpile level above the tunnel is maintained by a dragline or clamshell, the operator must be careful not to pick up material from the same position in the stockpile in successive withdrawals.

Likewise when a front-end loader is used, the operator should not pick up material from the same point in the stockpile. The operator also should not pick up material from the stockpile at ground level. The scoop should be held high enough above the ground to prevent contamination. If trucks are used to charge the bin, they should deposit their loads directly above the feeder. When the stockpile is replenished by overhead belts or elevating conveyors, the flow of materials should be controlled by baffles within the bin.



Major Batch Plant Components. (Modern Plants Also Include a Baghouse in Addition to the Dust Collector Shown in Number 5 Above.)



Basic Drum Mix Plant Components

Figure 6. Batch Plant and Drum Mix Plant Components

2. Feeders and Dryers

Aggregate feeder units should be located beneath the storage bins or stockpiles, or in positions that ensure a uniform flow of aggregate.

Feeder units have controls that can be set to produce a uniform flow of aggregate to the cold elevator. There are several different types of feeds: continuous, vibratory, and apron flow.

Generally, belt feeders are best for accurate metering of fine aggregates. Coarse aggregates usually flow satisfactorily with any of these feeders. For a uniform output from the asphalt plant, cold feed input must be accurately measured. The cold aggregate feeder gates must be calibrated. Manufacturers may furnish approximate calibrations for gate openings of their equipment, but the only accurate way to set the gates is to prepare calibration charts using the aggregates employed in the mix. Refer to Figure 7 for a typical calibration chart for cold feed bins. The importance of feeding the exact amounts of each size aggregate into the dryer at the correct rate of flow cannot be over emphasized.

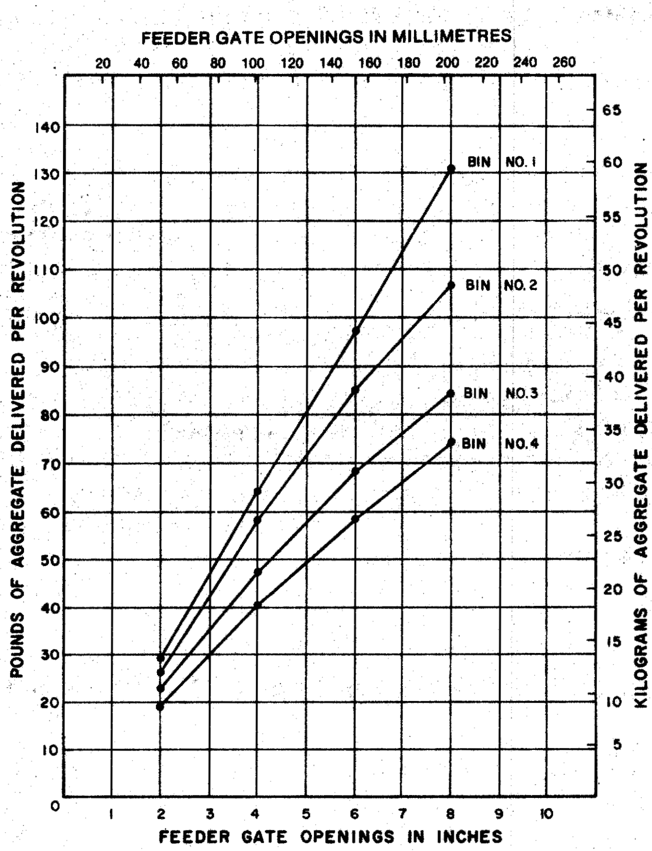


Figure 7. Calibration Chart for Cold Feed Bins

The dryer is a basic unit of an asphalt hot-mix plant either as a separate unit in a batch plant or integral with the continuous dryer drum plants. It is a necessary part of the hot-mix operation for it dries and heats aggregates coming from the cold feed supply making them suitable for mixing with asphalt. To avoid or mitigate unburned fuel oil contamination of the asphalt mixture, the use of propane, butane, natural gas, coal, or No. 1 or No. 2 fuel oils is recommended.

Most dryers are designed to handle aggregate moisture contents in the range of 4% to 8%. Very wet aggregates reduce dryer capacity and require adjustments to be made with regard to either of the following:

- The amount of heat can be increased by burning more fuel while the flow of aggregate remains constant, or

- The flow of aggregate can be reduced.

There is a limit to the increase in heat that is possible without increasing exhaust draft capacity. Beyond that limit the draft must be increased or the rate of aggregate flow must be reduced. In very humid areas, or when aggregates are exceptionally wet, the contractor may operate two dryers in tandem or run the aggregate through the same dryer twice.

Most problems in dryer operations are caused by crowding more material through the dryer than it can properly handle. There are other factors that affect efficient operation. Several factors involve the burner. If an oil burner is used, it is important that the proper grade of fuel oil be used. The oil must be properly atomized by the blower.

The velocity of the draft air, which combines with the atomized fuel oil for combustion, must be in balance with the blower air and the amount of fuel oil being fed into the burner. If the blower air, draft air, and flow of fuel oil are not in balanced adjustment, it may cause incomplete combustion of the fuel, leaving an oily coating on the aggregate particles that may affect the mixture. Black smoke from the exhaust stack indicates that the oil is not being completely burned.

Drying is the most expensive operation in mix production. It is also the most frequently encountered bottleneck in the plant operations. The best dryer is one that meets a desired production level at the lowest investment and operating cost. Improper drying in either batch or drum plants generally leads to poor coating of the aggregate and future stripping or raveling problems with the finished mat.

In general, there are three types of dust collectors: Cyclone collectors, fabric filter collectors, and wet scrubbers. Two or more of these devices may be included in a dust collection system, which then contains a primary collector and one or more final, or secondary, collectors.

The dust collector is generally located adjacent to the dryer, and is necessary for efficient plant operation. The collector eliminates or abates the dust nuisance that might result from exhaust air from the dryer. Modern dust-collection systems are highly efficient. Provisions are usually made in the dust collector to return the collected dust back to the hot aggregate as it emerges from the dryer and is picked up by the hot elevator. If the collected dust is unsuitable for use in the asphalt mixture, it may be removed from the collector and wasted.

3. Aggregate Scales

The aggregate weigh hopper, enclosed by a dust shield, is suspended from a scale beam in such a way as to assure free movement. The lever system, knife edges, and bearings should be checked for cleanliness and to be sure that no moving part is binding against any other part. The dial needle should be free-swinging and register zero at no load.

The weigh hopper scales should be checked with ten 25 kg or 50-lb weights. With the screens running, 250 kg or 500 lbs of weights are attached to the weigh hopper and the exact dial reading recorded. The weights are removed and exactly 250 kg or 500 lbs of aggregate are deposited in the weigh hopper. Check weights are again added, and the procedure repeated until the batch load is reached.

At each 250 kg or 500-lb increment, a test for sensitivity should be made by placing a 2.5 kg or 5-lb weight on the scale and checking for dial movement. Should the scales fail to conform to specification requirements, either in accuracy or sensitivity, plant production should not be permitted until necessary adjustments or replacements have been made. If in doubt the area engineer should discuss such a scale check with the project or district engineer.

4. Asphalt Scales

The asphalt scale is calibrated in nearly the same manner as the aggregate scale, but only one weighing operation is required. Standard weights are placed on or attached to the asphalt bucket; readings are recorded as each weight is added. This is continued until the combined weight is slightly in excess of the pounds of asphalt cement required per batch of paving mixture. Asphalt scales, if in true adjustment, should indicate the same value as the total of the standard weights used. If the weigh scale's error exceeds the margin permitted by specifications, plant operations should not be started until the scales are adjusted or repaired by a qualified scale technician.

The tare weight of the empty asphalt bucket should be watched carefully to see that the bucket is drained completely and to compensate for any asphalt and dust clinging to it. The asphalt bucket should be tared at the beginning of each day and checked after the first few loads are discharged. Quite often, asphalt accumulates on the sides and bottom of the bucket and solidifies overnight. This affects the tare weight and reduces the weight of asphalt actually incorporated in the mix. Have you ever looked into the bucket?

For an accurate zero reading, asphalt scales should not be checked until heating oil or steam is in the jacket around the asphalt bucket and the mixer.

5. **Asphalt Meters**

Asphalt meters are volume displacement pumps, and when used they should be checked for accuracy. Since asphalt content is usually expressed as a percent by weight, a correlation between meter readings and weight should be established.

A simple method to determine the correlation is to read the meter, pump a quantity of asphalt into a tared container, and then read the meter again. The weight of asphalt divided by the difference in meter readings determines the weight of asphalt pumped per division.

The viscosity and unit weight of the asphalt vary with a change in temperature. When the temperature is increased the viscosity decreases. The unit weight decreases about 1 percent for an increase in temperature of 15°C (28°F). Pumping efficiency may be affected by a change in temperature, and it may be desirable to calibrate the pump over a range of asphalt temperatures. Volumes and viscosities can be determined later for calibration and plotting purposes if necessary.

Some asphalt meters have built-in temperature-compensating devices that correct the flow of asphalt when temperature changes occur. When a meter without a temperature-compensating device is used, it is necessary to adjust the delivery setting for each change in asphalt temperature.

6. **Hot Bins**

Accurate proportioning of cold feed aggregates is extremely important. Except for whatever degradation may occur in handling, drying, screening, or the fines that are picked up by the exhaust system, aggregate in hot bins is the same as in the cold feed.

Dried aggregates are generally transported from the dryer by a hot elevator and deposited onto a unit which contains screens, storage bins, and aggregate proportioning devices (Fig. 8).

Screens are used to separate the aggregate into fractions of specified size and deposit each into a separate bin. An imbalance in the hot bins under the screens signals a need for corrective action elsewhere - usually in the cold aggregate feed.

Screen sizes selected are usually based on separating the aggregate into equal percentages of material by weight. The smallest practical size, however is a 3.35 mm (No. 6) screen. To separate aggregate into specified sieve sizes used in testing, screen cloths having slightly larger openings are used.

Hot bins are used to temporarily store heated and screened aggregate in the various size fractions required. Each bin should be large enough to prevent depletion of the material when the mixer is operating at full capacity. Each bin should have an overflow pipe to prevent aggregate from backing up into the other bins. The overflow flow pipe also prevents overfilling to the point where the vibrating screen will ride on the aggregate. Should this happen it would result in a heavy carryover and probable damage to the screens. Many times these overflow pipes are closed by cold asphalt or even welded shut.

Material is withdrawn from the hot bins in predetermined proportions and at a specified rate. If the level of aggregate in hot storage has little variation during plant operation, a balanced flow of aggregate is being achieved.

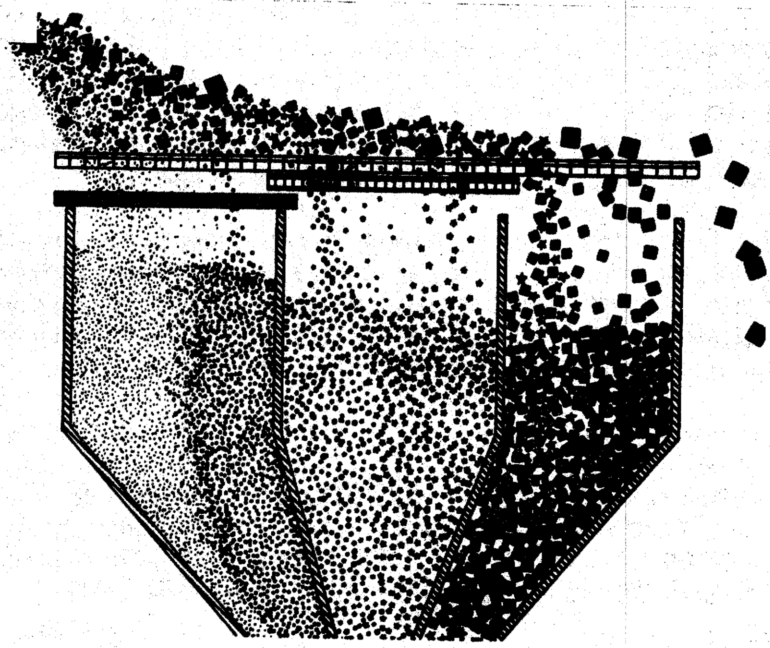


Figure 8. Segregation of Materials in the Hot Bins

7. Collected Dust

If the material gathered in the dust collector is suitable for recombining with the aggregates in the mix, some or all of it may be returned to the plant. Make sure the mix design accounts for the volume of dust being returned to the mix.

A continuously turning worm screw at the bottom of the dust collector removes the dust and fines that have settled in the collector chamber and deposits them at the bottom of the hot elevator where the aggregate emerges from the dryer.

8. Mineral Filler

High-type asphalt plants often have separate feeding systems for introducing mineral filler into the mix. The mineral filler is normally deposited in a special ground-mounted feeder and transported with a screw conveyor, to a dust-tight elevator where it is in turn deposited in a surge hopper. From here it is added to the aggregate as it is drawn from the hot bins for mixing.

9. Charging the Pugmill

Unless the plant is equipped to discharge all bins simultaneously, aggregate should be drawn from the hot bins into the weigh hopper, beginning with the largest size aggregate and progressing down to the finest size. The mineral filler is added last.

This permits some mixing of the aggregate as it discharges into the mixer. The amount from each bin is weighed cumulatively on the scales. The operator carefully marks the scale reading for each size aggregate to be weighed. The asphalt is weighed separately and should be introduced and distributed uniformly and quickly into the mixer. Otherwise, a non-uniform mixture could be produced.

Asphalt cut-off valves should be checked for positive action. They should close tightly so that no asphalt drips after the desired amount has been introduced or discharged from the weigh bucket.

Asphalt is introduced into the pugmill after the aggregate has been deposited from the weigh hopper. Wet mixing time begins when the asphalt is added.

10. The Mixer

All mixer parts must be in good mechanical condition and in proper adjustment. Paddle faces can be set in a variety of combinations. The manufacturer's operation manual gives details on the correct settings of the paddle faces.

Clearance between the paddle tips and liner is governed by the maximum size aggregate and, normally, is less than half the maximum aggregate diameter. Dead spots may develop if the paddles have worn considerably or are broken and have not been readjusted or replaced.

Non-uniform mixing may occur if the mixer is overfilled. At maximum operating efficiency, the paddle tips should be barely visible in the material at the top of their periphery during mixing. Material above this level tends to float above the paddles and is not mixed. On the other hand, an insufficient batch will not be mixed properly because there is not enough material to carry around in the paddle paths. Both conditions can be minimized if the manufacturer's pugmill batch rating recommendation is followed. Normally, this is based on percentage of the capacity of the pugmill's "live zone." When was the mixer last inspected? (See Figures 9, 10, and 11 on page 37.)

11. Mixing Time

Total mixing time begins when all combined mineral aggregates and asphalt are placed in the mixer; mixing time ends with the opening of the discharge gate. Dry mixing is not recommended, therefore the total mixing time will be wet mixing time.

The asphalt film is hardened by exposure to air and heat. Therefore, mixing time should be the shortest time needed to obtain a uniform distribution of aggregate sizes and asphalt throughout the mix.

Mixing time may be established for a particular mix in a plant by the procedure in **AASHTO T 195, (ASTM D 2489)**. This method bases the degree of mixing on the percentage of coarse particles that are completely coated with asphalt. The method is correlated with mixing time.

The test involves separating coarse aggregate particles from the mix on a selected sieve size. About 200 to 300 particles should be examined under strong light. Any speck of uncoated aggregate particle visible to the naked eye classifies that particle as uncoated. Usually, 90 and 95 percent coated particles are minimums for base and surface course mixes, respectively. The least time needed for the pugmill to achieve these minimums is the most desirable mixing time.

F. Drum Mixers

Many of the comments and cautions discussed earlier with batch plant operations are also applicable to drum mixer plants.

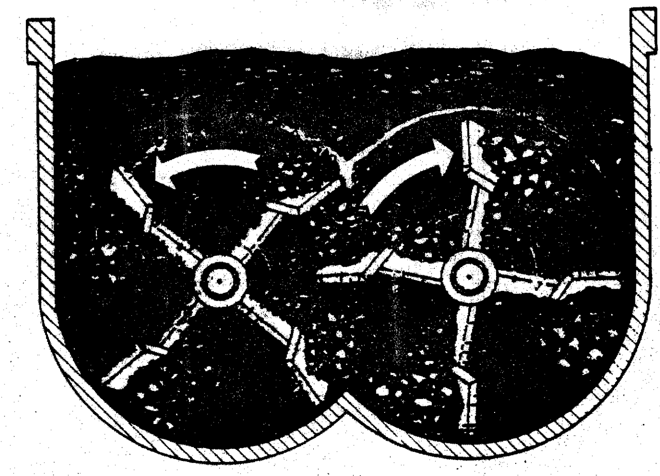


Figure 9. Overfilled Pugmill

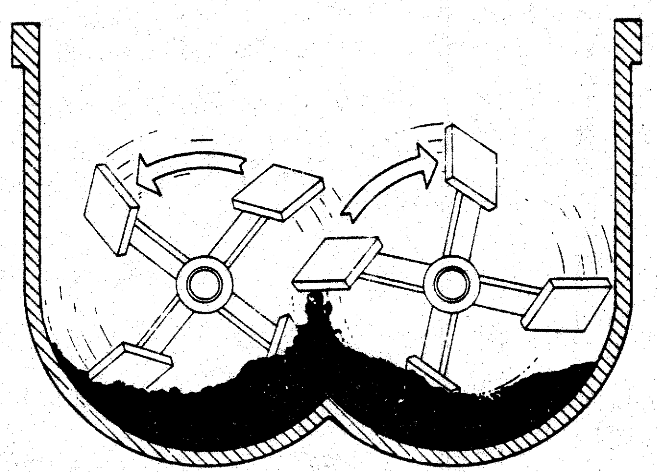


Figure 10. Underfilled Pugmill

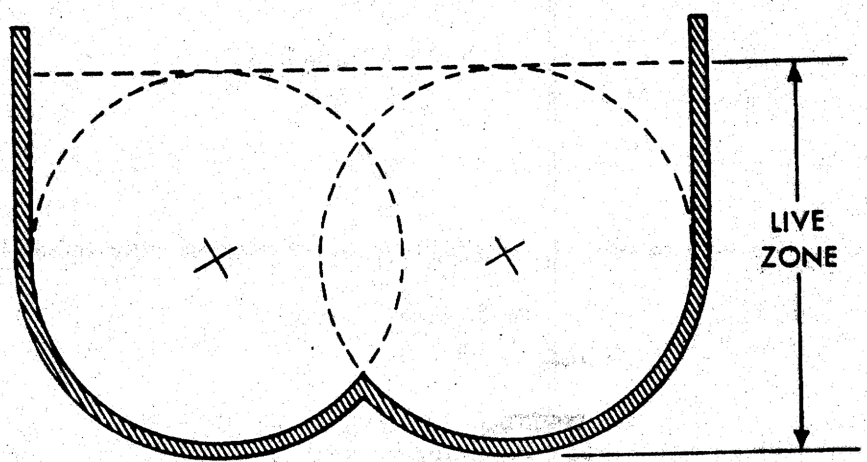


Figure 11. Pugmill "Live Zone"

Simply stated, drum-mixing is a process in which hot asphalt mixtures are produced in a plant without the hot aggregate screens, hot bins, and pugmill mixer. The basic plant consists of a cold feed system, a rotating drum mixer with modified flights, an asphalt proportioning and dispensing system, and a surge bin. The drum mixer plant has also been called a "dryer drum" plant.

1. Plant Control System

Controls at the operator's console permit plant operation from a central location. A typical console includes plant motor controls, automatic blending system controls, digital displays, asphalt volume counters, and burner temperature controls. Recently, computers have been adapted to drum mixer plants. They enable programming at the plant site for changes in the control system, and require minimal training for the operator to run the plant.

Additionally, the following controls and equipment are required for this type of plant to ensure a quality product that meets specifications in all respects:

a. Separate cold feed controls, for each aggregate size,

b. Cold feed flow sensors,

c. Interlocking of aggregate cold feed, and asphalt and mineral filler when used,

d. Sensors to determine the moisture content of aggregate, as well as a moisture compensation to make adjustments in proportions of materials if necessary,

e. Means for sampling all material components while the plant is in full production,

f. Automatic burner controls,

g. Primary dust collector that can feed back collected material, and

h. Sensors to measure temperature of the hot mixture at discharge.

2. Proportioning Aggregates

Aggregate gradation control is achieved in the crushing and stockpiling operations. Accurately controlled feeders proportion the aggregate as it leaves the cold bins. Belt scales that continuously weigh and monitor the combined aggregates are interlocked with a metering asphalt pump to maintain a constant aggregate-to-asphalt ratio. Asphalt is added either at the aggregate entry point, or at variable locations within the drum. The drying and blending of the aggregate, and the mixing of the asphalt and aggregate takes place in the drum. The burner is located at the upper, or aggregate-entry end of the drum. This means that there is a parallel flow of burner gases and asphalt-aggregate mixture toward the discharge end of the drum. Some drum mixer plant variations include counterflow of burner gases and midpoint aggregate entry. Other variations in drum mixer plants are discussed in **Subject L, Hot-Mix Recycling of the Asphalt Institute's ES-1.**

3. Weighing Aggregate

As the aggregate is fed into the drum by the conveyor belt, it passes over the weigh bridge. This is a belt idler, or supporting roller, mounted on a scale. As the aggregate passes over the idler its weight is sensed, and transmitted as a visual display on the control console. The speed of the conveyor belt is also taken into consideration, so that the visual display indicates weight of aggregate per hour. This value is the basis of the asphalt-aggregate blending system.

4. Asphalt Metering and Delivery

A system providing accurate, continuous, proportioning of asphalt to aggregate is required for the successful operation of a drum mixer plant. The asphalt metering and delivery system must be interlocked with the aggregate system to ensure a constant ratio of asphalt to aggregate.

5. Correction for Moisture

The weight of aggregate per hour going into the drum is the basis of the total mix formulation. Since the weight of the aggregate includes moisture, the weight of the moisture must be subtracted to arrive at the true aggregate feed rate. The actual moisture content is periodically determined by moisture extraction tests or moisture probes.

6. Continuity of Operations

One of the essentials for a consistent and high-quality, hot-mix asphalt is a continuous plant and paving operation. Quality of the mix, workmanship, or both, suffer when either the plant operation or actual paving is intermittent. Should the paving operation be unavoidably interrupted for some reason other than plant production, the plant operation will have to be interrupted unless some other provision is made.

With the advent of placing thick-lift asphalt paving courses up to 150 mm (6 in.) thick or more in one operation, the asphalt plant is often taxed to its limit to provide an adequate flow of materials to the paver. In some cases, the plant is unable to produce the mix at the required rate to keep the paver continually supplied. Paving speeds must be adjusted to balance plant output unless other provisions are made.

7. Storage of Hot-Mix Asphalt

Many modern hot-mix asphalt plants are equipped with surge or storage bins. A surge bin is connected to the plant by a conveying system, and is intended to hold mix for relatively short time periods. Generally, it is not insulated because holding time is expected to be only two or three hours. A storage bin is similar to a surge bin except that it is insulated because it is intended for longer storage periods.

The most popular shape of surge or storage bins is cylindrical with a conical section at the bottom. A variety of conveying systems are in use; belt conveyors, bucket elevators, skip hoists, screw conveyors, and slat conveyors. Studies indicate that the bins can be charged without segregation or an appreciable drop in temperature.

Surge systems offer several benefits because stop-and-go operation of the plant is minimized. Variability in mix composition and temperature associated with start up and stopping is reduced by more continuous plant operation. Also the emission of extra air pollutants each time the plant starts up is minimized. Productivity is increased by running continuously during normal working hours and not just when trucks are available for loading.

We have spent but a few minutes discussing a critical phase of the hot-mix operation. Many engineers, technicians and operators spend their whole career on studying, refining, operating and producing the hot-mixed bituminous material that is used on 90% of the Nation's roadway surface.

For purposes of field inspection we have covered the plant site and critical operations which if not properly controlled lead to mix problems and delays which can result in reduced service ability and durability. The following table produced by the Asphalt Institute provides a quick reference for cause and effect problems normally found at the hot-mix plant. Also, refer to the **Technical Advisory (T 5040.27, Mar. 10, 1988) on Asphalt Concrete Mix Design and Field Control** for a model checklist on asphalt plant inspection.

Table X. Possible Causes of Mix Deficiencies in Hot Plant-Mix Paving Mixtures

Aggregates Too Wet	Inadequate Bunker Separation	Aggregate Feed Gates Not Properly Set	Over-Rated Dryer Capacity	Dryer Set Too Steep	Improper Dryer Operation	Temp. Indicator Out of Adjustment	Aggregate Temperature Too High	Worn Out Screens	Faulty Screen Operation	Bin Overflows Not Functioning	Leaky Bins	Segregation of Aggregates in Bins	Carryover in Bins Due to Overloading Screens	Aggregate Scales Out of Adjustment	Improper Weighing	Feed of Mineral Filler Not Uniform	Insufficient Aggregates in Hot Bins	Improper Weighing Sequence	Insufficient Asphalt	Too Much Asphalt	Faulty Distribution of Asphalt to Aggregates	Asphalt Scales Out of Adjustment	Asphalt Meter Out of Adjustment	Undersize or Oversize Batch	Mixing Time Not Proper	Improperly Set or Worn Paddles	Faulty Dump Gate	Asphalt and Aggregate Feed Not Synchronized	Occasional Dust Shakedown in Bins	Irregular Plant Operation	Faulty Sampling	*Types of Deficiencies That May Be Encountered In Producing Plant-Mix Paving Mixtures.*
		A												B	B				A	A	A	B	C	B	B	B		C			A	Asphalt Content Does Not Check Job Mix Formula
	A	A						B	B	B	B	A	A	B	B	B	A							B		B	B	C	B		A	Aggregate Gradation Does Not Check Job Mix Formula
	A	A							B	B	B	A	A	B	B	B	A							B	B			C	B		A	Excessive Fines in Mix
A			A	A	A	A	A																							A		Uniform Temperatures Difficult to Maintain
											B			B	B									B								Truck Weights Do Not Check Batch Weights
														B	B					A	A	B	C	B		B		C				Free Asphalt on Mix in Truck
																		B									B					Free Dust on Mix in Truck
A			A	A	A	A													A		A	B	C	B	B	B		C		A		Large Aggregate Uncoated
									B	B	A	A	A	B	B	B	A	B			A	B	C		B	B	B	C	B	A		Mixture in Truck Not Uniform
																		B			A			B	B	B				A		Mixture in Truck Fat on One Side
					A															A	A	B	C	B				C		A		Mixture Flattens in Truck
		A			A	A	A																							A		Mixture Burned
A			A	A	A	A			B										A			B	C	B				C		A		Mixture Too Brown or Gray
														B	B	B	A			A	A	B	C	B				C		A		Mixture Too Fat
					A	A	A																							A		Mixture Smokes in Truck
A			A	A	A	A																								A		Mixture Steams in Truck
					A	A	A												A										A	A		Mixture Appears Dull in Truck

A — applies to batch, continuous and drum mix plants.
B — applies to batch plants.
C — applies to continuous and drum mix plants.

IV. HAULING AND LAYDOWN

After the bituminous mix is produced at the plant there are a number of factors involved in the transport and laydown of the mix which the field engineer must realize are critical to the workmanship and performance of the finished mat.

The field engineer should be most concerned with the concept of "balanced operations." The production of the plant must be consistent with the length of the haul, the number of haul trucks, the laydown capability of the paver, and the compaction rate of the rollers on the job. From a standpoint of eventual product appearance, rideability, and ultimate performance, optimum hauling and laydown procedures must be adhered to continuously.

A. Haul Trucks

The field engineer will probably not spend a great deal of time on haul truck inspection, but a brief review of vehicle condition, equipment, and operator procedures can be most productive. Haul trucks should be clearly identified (numbered) and checked for safe operating condition and back-up warning devices for the safety of personnel at both the plant and the laydown site. The truck should be clean, with a full complement of operating lights, good tires and suspension, and special attention should be given to assuring no leaks or broken seals are noted. Oil, grease, and hydraulic fluid can cause severe damage to the pavement. Good brakes are critical to the paving operation to assure the desired smooth-quality ride of the finished product and safe operations.

1. Condition/Cleanliness

The haul vehicles need to be completely cleaned before use in hauling bituminous mix to avoid contamination. Hardened mix should be removed from the corners of the bed. This should be routinely checked when haul trucks raise their beds, and is particularly important when mix is being paid for on a tonnage basis.

The field engineer should always check to see that only approved release agents are being used and that they are used as sparingly as possible to prevent damage to the mix.

2. Loading Sequence

An often overlooked factor which can contribute to segregation problems is the proper loading sequence. The field engineer should note that the haul truck is centered under the discharge. The first batch loaded should touch the front wall of the truck bed. The second batch should be made near the rear of the truck and the final drop should be in the center of the truck. Off-center or one-position loading is a common occurrence. Not following standard loading practices can cause segregation problems, and should be discouraged.

3. Weight Restrictions

The maximum allowable gross load is shown on the truck registration and should be spot-checked to prevent overloads. Recent reviews have noted widespread problems with overweight vehicles on construction projects and while hauling from plants to projects.

Haul trucks generally are required to have tarps. Tarps should be checked for adequacy and to insure they are being used when required. Heat retention provided by tarps is particularly important in cold weather, on long hauls, or when rain threatens.

4. Safe Operations

At the paving site, several haul truck-related items need to be reviewed. For safe operation of the truck, make sure that any traffic control plan restrictions are being observed by the drivers and that there are no conflicts with utility lines. If this is not checked ahead of the paving operation, a driver could cause property damage and possibly incur personal injury if the truck is snagged by a raised bed.

Again, back-up warning devices must be working properly and this should be a prime concern of the field engineer because it is often overlooked by the contractor.

When the haul truck backs up to a paver it should always stop several inches short and let the paver engage the truck. This should always be reviewed by the field engineer as truck drivers often bump the paver causing rideability problems. This may happen 50-100 times per day depending on the speed of the paving operation. Also when the truck backs up the rear wheels should contact the paver roller bar squarely to prevent it from jerking and causing waves in the surface.

The field engineer can mitigate segregation in another way by making sure the truck driver first raises the bed before opening the gate high enough to get a large slug of material into the paver when the gate is opened.

5. Truck Types/Integration with Pavers

Constant contact of the truck with the paver is critical to prevent spills and bumps which lead to surface irregularities. This is simple on a level surface but the field engineer needs to keep a close eye on this factor on grades. Truck hitches which tie the paver to the truck's rear axle or through a roller to the rear wheels is an excellent mechanism now being used more frequently to solve this problem.

The field engineer should make sure beds are lowered as soon as they are empty. If the dump body is up, sooner or later an overhead line will be snagged.

End-dump trucks must be inspected to ensure they are compatible with the paver. The rear of the bed has to extend far enough beyond the rear wheels to discharge mix into the hopper to prevent spills in front of the paver. At the same time, the bed must be sized so as to fit in the hopper without pressing down on the paver resulting in workmanship rideability problems.

The previous discussion dealt with all types of trucks with an emphasis on end-dumps. Many portions of the country are more familiar with bottom-dump, haul trucks which have other considerations to be noted.

Bottom-dump vehicles have differing methods for controlling the gate openings. The field engineer should check to see that a unform windrow is being placed. If the windrow is too small, additional material can be added to keep the paver from starving. Likewise gaps can be left in the windrow if it contains too much material. A prime concern of the field engineer is ensuring the windrow length is controlled, particularly in cool or threatening weather. In cold weather the windrow should usually be restricted to a single truckload at a time.

B. Laydown/Pavers

1. Components

The laydown of the bituminous mix is the culmination of all the efforts expended in specification preparation, mix design materials control, and mix preparation. If the mix placement is done improperly, the preceding efforts can go for naught.

In order to get optimum results on a project, it is extremely important for everyone who has a responsibility for placing the hot mix (and inspecting its placement), to have a good understanding of the principles behind the design and operation of the paver.

Pavers have remained essentially unchanged for some 50 years. The basic components are the tractor and the screed. The tractor supplies the power needs of the paver. It moves the paver, and receives and delivers the mix to the screed.

Augers on the tractor keep a uniform distribution of mix in front of the screed. The screed is towed by the tractor and consists of screed plates, screed vibrators (or tamper bars), thickness, and crown controls, and screed heaters.

2. Forces Acting on Screed

The forces acting upon the screed are discussed in detail in the accompanying film which complements the **Barber-Greene** publication, **"Principles of the Asphalt Finisher."** Basically, all pavers operate on tne same principle - as the screed is pulled out into the mix, it seeks the level at which all forces acting on it are in balance. A screed's action can be compared to a water skier with skis tipped up just enough to support the skiers weight. Refer to figure 12.

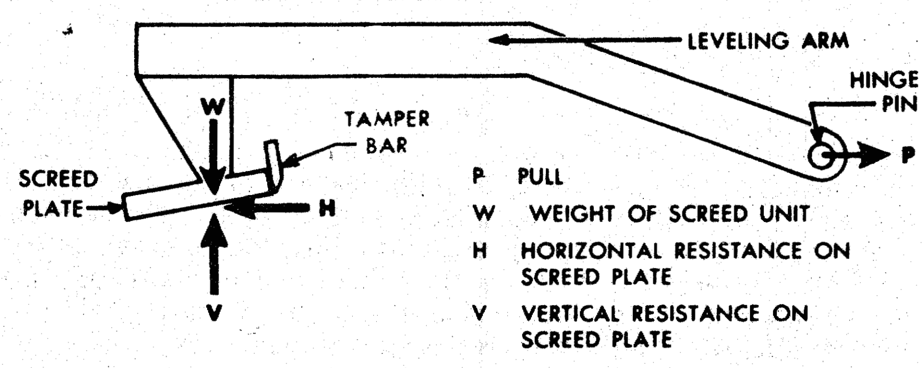


Figure 12. Forces Acting on the Screed During Paving Operation

The screed not only strikes off the mix at the proper elevation to give the correct mat thickness but it also provides initial compaction of some 80 percent of the mat density. The field engineer should be concerned if initial compaction does not meet or exceed this general figure because final compaction will likely be difficult to achieve.

The field engineer must also be aware of the function of proper crown adjustment in the screed. The leading edge of the screed should always have more crown than the trailing edge - this can be checked with a stringline and tape - but too much crown on the lead edge will produce an open mat along the edges. Conversely, too little leading edge crown will cause an open texture in the center of the pull.

3. **Paver Condition Check**

The field engineer should check to see that the paver is in clean operating condition before each day's operation, particularly the screed. The screed assembly is equipped with a heater which serves to prevent sticking and marking of the mat. Use of the heater should be watched by the field engineer. Normally, the heater is only used at the beginning of the day or to compensate for heat loss between loads in cool weather. If it must be run continuously, the burner should be low to prevent warping of the screed. The burner should not be used to compensate for low mix temperatures. This is a problem that needs to be addressed at the plant.

4. **Paver Speed Uniformity**

There are a number of items which the field engineer must review in the laydown operation but perhaps the most important is the uniform speed of the paver and avoidance of starts and stops. Each time the paver has to stop, the screed will settle in the mat. When movement is continued after a prolonged stop the paver will ride up over the cooler material forward of the screed. This depressing and then thickening of the mat translates to poor pavement rideability, and can be avoided with efforts to match the paver speed with the plant output.

5. **Laydown**

During laydown, the field engineer should watch for other practices which can contribute to a poor product. Auger speed and resultant mix delivery to the screed is critical. Too little material ahead of the screed reduces mat density and causes the screed to settle. Too much mix gives the opposite result - increasing mat density and a climbing screed.

A final important reason for the field engineer to be concerned with constant speed on the paver is the fact that mat density is related to paver speed. Slow paver speed allows the paver to impart more densification to the mat causing the paver to rise. Again, the opposite result occurs with higher speeds - the mat density decreases and the screed drops.

If the auger is correctly loaded (mix about the midpoint of the auger) and the speed of the paver is kept constant, the operation has a very good chance of producing a smooth surface. The field engineer should closely observe the personnel on the paver's mat thickness control. This is perhaps the most abused feature of the modern paver, particularly if more than one person is allowed to operate it. It should be understood that constant manipulation of this control will result in an unacceptable product. This is because many contractor employees are not aware of the longitudinal length it takes for the screed to obtain the thickness called for by the thickness control. Then, a "chase" for a higher or lower thickness can occur.

6. Joint Construction

Suitability of the transverse and longitudinal hot mix joints are the final major factor which the field engineer should review in the laydown operation. Cold longitudinal joints should be eliminated where possible because they often crack open allowing water penetration with its resultant problems. This cracking is caused by the lack of confinement and reduced density in the first pull. The reduced density leads to higher voids and higher permeability.

Longitudinal joints have traditionally been built with vertical slopes but a new technique is emerging which has been promoted by the increased amount of resurfacing under traffic. This technique is to lay the initial pull joint with a 4 to 1 side slope, compact this area with a rubber tire roller and then make subsequent pulls. This allows more consistent density across the joint. In either case the field engineer should note that overlap should not exceed 2 inches and that the unrolled mat should be some one-fourth thicker than the rolled mat to provide for consolidation.

The field engineer may see either a "crowded" or a "trimmed" longitudinal joint. In the crowded joint, the excess mix on the rolled mat is pushed back into uniform ridge so that the roller can depress it into the hot side of the joint. The field engineer should understand that excess material is not to be spread across the surface of the unrolled mat. When a trimmed joint is used, the excess material over the rolled mat is wasted or carried back to the hopper. If this technique is used, the field engineer must ensure that the longitudinal joint is compacted first.

Transverse joints for work interruption are constructed in two ways. The field engineer needs to be aware of both because of their importance to pavement rideability and performance. The first method is by bulkheading where the hopper is fed down and the paver travels across a transverse piece of lumber the size of the compacted mat. The remainder of the hopper is feathered out in a ramp. The ramp and lumber is removed when the operation is restarted. Perhaps a more commonly used joint method is where the paver paves over building paper which forms the joint. The paper and tapered mix above it is easily removed when start-up occurs.

Again transverse joints are critical problem areas for roughness. The field engineer should note that these joints are checked for surface tolerance compliance both before and after compaction. Deficiencies should be corrected immediately and the paving operation should not continue until corrections are made.

A final note to consider on laydown is that the paver of today and its ancillary equipment is designed to be less operator dependent than in the past. Equipment operators are generally less experienced and labor is certainly more expensive so their use is being minimized. The training of field engineering and State project field inspection personnel and the proper exercise of oversight is increasingly important in assuring an acceptable laydown operation.

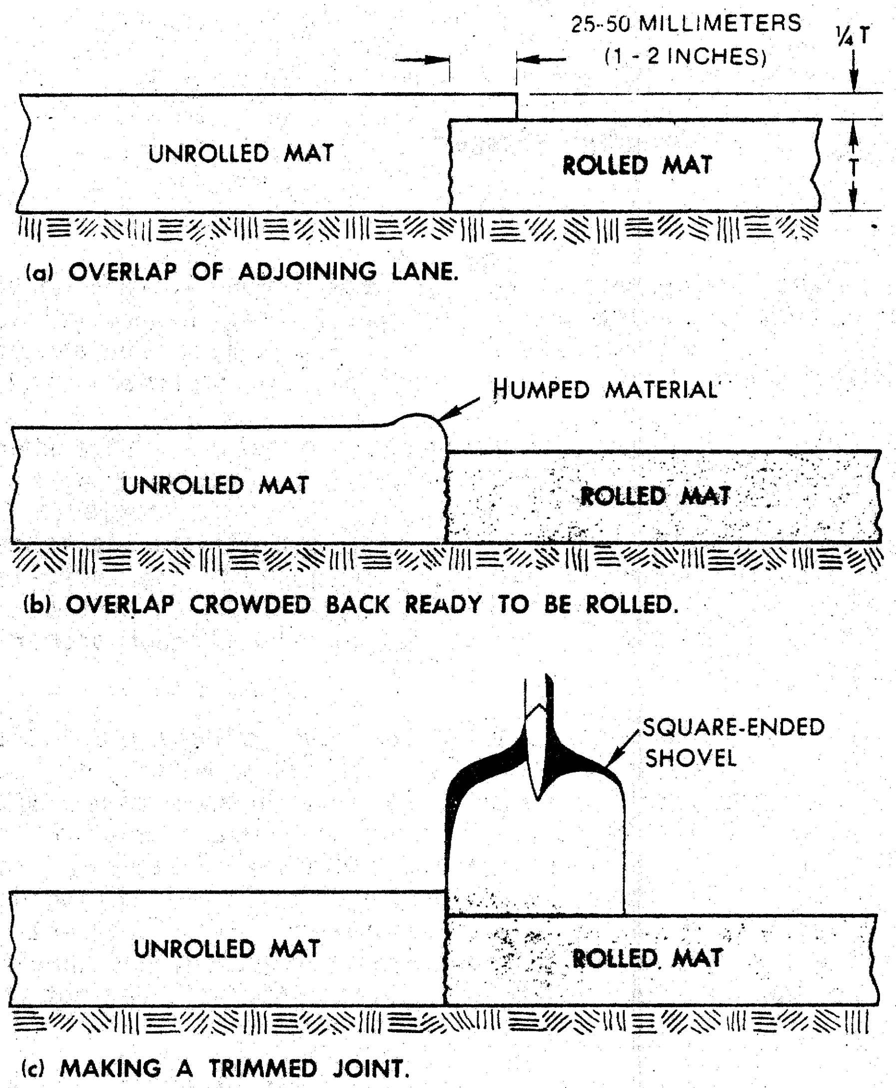


Figure 13. Constructing and Preparing Longitudinal Joints

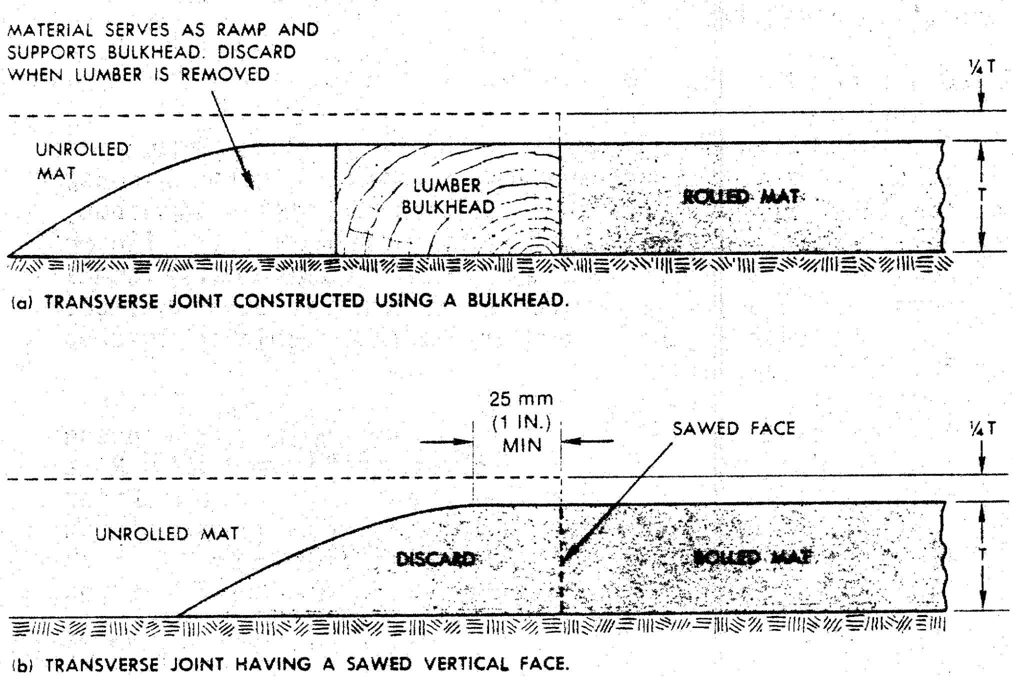


Figure 14. Constructing and Preparing Transverse Joints

V. COMPACTION

A. Purpose

Optimum pavement performance can only be achieved by forcing the aggregate particles into close contact and holding these particles in position with the asphalt binder. The compaction process serves to give the mix stability, cohesion, and impermeability.

Stability is the ability of the pavement to resist displacement when acted on by traffic loads. Cohesion and adhesion work to hold the mix together resisting tensile stresses achieved by effective compaction that binds the particles together. Impermeability is the resistance of the pavement to the intrusion of air and water and is achieved by preventing the connection of voids in the mix through proper compaction and through properly designed mixes.

The field engineer should recognize that the primary reason for compacting the mix is to make it reasonably watertight and reasonably impermeable to air. Most dense-graded mixes with coarse aggregates are reasonably watertight/impermeable if the voids are in the 6-8 percent range. This will also allow for future consolidation under traffic and not result in rutting due to over consolidation. When voids are approximately 3 percent or less the field engineer can expect flushing, rutting, and shoving because the load is being transmitted through the A.C. and not the aggregates.

Compaction involves the compressive force of the roller, the support of the underlying surface, and the forces within the mix resisting the roller force.

1. Compaction Equipment

These are basic types:

a. Static steel-wheeled rollers can vary considerably in size. A standard recommended minimum size for highway construction is 10 tons. Steel wheel rollers (tandems) are generally recommended for breakdown and finish rolling. The field engineer should occasionally check these rollers for wear with a sharp metal straightedge. Scrapers, wetting pads, and sprinklers should be checked for proper operation.

b. The use of a pneumatic roller in the compaction process is strongly encouraged. Pneumatic rollers provide a kneading action on the mat not achieved by the other rollers and can be used on a variety of mixtures (harsh to tender) by varying the tire pressures. This flexibility in contact pressures makes the pneumatic-tired roller popular, but the field engineer should also be aware that such equipment can do a poor job if tire pressure and wheel loads are not properly monitored.

For assured results, the tire pressure and load must be tailored to the particular mix and the support of the surface on which the mix rests. The field engineer should note the specified pressure on the tires and ensure that inflation pressure among all the tires is uniform. Again, the wetting mats and sprinkler system should be checked for proper operation.

c. Vibratory rollers can potentially compact thicker lifts to higher densities with fewer passes than the combined total of steel-wheeled and pneumatic-tired passes but they are also capable of decompacting mixes, providing inconsistent densification, and causing rideability problems. The effectiveness of this roller is controlled by the frequency of vibrations, (2,000 to 3,000 cycles/minute, minimum 10 impacts per linear foot, is usually needed to prevent rippling in the pavement surface) the amplitude of the roller, (use the range recommended by the manufacturer) and roller speed. The slower the speed the smaller the impact spacing and the smoother the surface. Most modern vibratory rollers automatically shut off when they are not rolling but the field engineer should assure this is happening. The field engineer should also note whether the vibration ceases before the roller reverses direction and starts after travel in the new direction begins. If this does not happen indentations in the surface can result.

2. Rollers

All types of rollers have certain requirements in common:

a. speed should never exceed 3 mph to prevent shoving,
b. must comply with established roller patterns to give proper and consiStent densification,
c. no stopping and turning on the fresh mat to prevent indentations, tears, and shoves,
d. use of proper watering systems to prevent pick-up.

3. Sequence of Operation

The sequence of operation is broken down into three phases:

a. Breakdown - where virtually all of the density is achieved,
b. Intermediate Rolling - where some additional density is gained,

c. Finish Rolling - which may impart slight densification but is primarily used to finish the surface and take out previous roller marks.

The field engineer should check to see that all three stages are completed before the mix drops below 175° F. Little or no compaction is achieved below this temperature.

4. Stages of Rolling

a. Breakdown Rolling - is usually accomplished with steel-wheeled rollers. Static or vibratory tandem rollers are often recommended, but occasionally pneumatic-tired rollers with large diameter wheels are used. The field engineer should understand the importance of starting the roller operation on the low side of the spread and progressing toward the high side. This is because the hot mix tends to migrate toward the low side of the spread when rolled.

The same procedures should be followed when more than one lane is placed, but the longitudinal joint should be rolled first. The field engineer should ensure that the drive wheel of the roller is facing the direction of paving, especially during breakdown because more vertical load is applied to the mat by this wheel. The tiller wheel tends to push the material away rather than tuck it under as the drive wheel does. On steep, superelevated or steep grade sections, there may be a need to roll with the tiller-wheel forward but this is not common.

b. Intermediate Rolling - should follow breakdown rolling as closely as possible so that maximum densification can be achieved. Vibratory tandem and pneumatic-tired rollers are usually the choice for this operation. Pneumatic-tired rollers do not usually give a noticeable increase in density over that achieved by static steel-wheeled rollers, but they do reduce the amount of distortion caused by heavy traffic. Vibratory tandem rollers, when properly used, can provide high stability through particle orientation. Static steel-wheeled tandem rollers sometimes are used for intermediate rolling. Regardless of the roller type the field engineer should assure that the roller pattern is developed in the same manner as for the breakdown rolling and that the pattern is followed until the required density is achieved.

c. Finish Rolling - is done almost solely for surface improvement and is usually accomplished with tandem static steel-wheeled rollers or vibratory tandems with the vibration disengaged. The field engineer should ensure that the mat is still hot enough for the removal of roller marks during finish rolling.

B. Conditions and Factors

The field engineer must be aware of the important factors influencing the mix compactability. Special attention is called to (ES-9) publication from the The Asphalt Institute entitled, **"Factors Affecting Compaction."** This contains an excellent dlscusslon of materials properties, course thickness, mix temperatures, weather conditions, compaction forces, and rolling patterns. Another good reference is NAPA's Superintendent's Manual on Compaction.

C. Materials Properties

Aggregates influence compactability through interlock and particle friction. The rougher or more angular particles produce harsher mixes but they generally are more stable when densified. Aggregate soundness is important so that particles are not crushed during compaction. Aggregate gradation is important with excessive coarse aggregate causing harsh mixes. Over-sanded mixes tend to be too tender. Correct aggregate filler amounts affect mix cohesion - too little can cause mix to be coarse and hard to compact while too much can cause a brittle mix.

Asphalt content and viscosity are key factors in compaction. Too little asphalt makes a dry, harsh mix which has a tendency to ravel. Too much asphalt produces an unstable, plastic mix under the roller. The mix is easy to compact, but the result is an unstable pavement. High viscosity asphalt in a normal mix usually makes compaction more difficult for these asphalts. Higher mix temperatures may be necessary. Conversely, low viscosity asphalt allows for easier compaction but can lead to tenderness problems after the mix is compacted.

D. Course Thickness

Simply put, thicker lifts hold more heat than thin lifts and allow more time for compaction. Temperatures are sometimes increased on thin lifts and decreased on thick lifts to provide more compaction time and increased viscosity, respectively.

E. Mix Temperatures

The field engineer should recognize that mix temperature is the single most important factor affecting compaction. Compaction can only occur while the asphalt is fluid enough to serve as a lubricant for the aggregate. Mix temperature therefore must be tied to the viscosity of the asphalt. Higher mix temperatures and heavier rollers can assist in the compaction of harsh mixes. However, caution must be exercised not to overheat asphalt mixes as this can cause premature oxidation and hardening which shortens durability of the mix. The lowest optimum mix temperature that can be compacted to the required density is desirable for reduced aging and energy consumption.

F. Weather Conditions

Ambient temperatures, base temperatures, and wind conditions greatly affect compaction. The mix obviously cools faster in lower air temperatures, but wind can act on a mix like the wind-chill factor does on a person. The stronger the wind, the faster the mix cools and this can become a factor in the formation of a crust on the surface of the mix which can contribute to heat-checking under the compaction of steel-wheeled rollers. The center of the mat can be much hotter and more fluid. than the top of mat. The stiff surface can then slip with cracks opening to the 3/8 inch to 1/2 inch depth in the crust. Heat checking can be cured by 8-10 coverages of pneumatic tired rollers.

Base temperatures also affect the rolling of the mix and the construction time available for compaction. The field engineer is encouraged to review cessation charts which show the expected rolling time available versus mat thickness and base temperature.

G. Compaction Forces

The mixture has to be confined in order for densification to take place. Confining pressure within the mix generally comes from friction between the aggregate particles and the viscosity of the asphalt. Confinement and support are also provided by the surface on which the mat is placed. The subgrade must be firm or confinement of the bottom of the mix cannot be achieved.

For steel-wheeled rollers the overlap of the wheel only needs to be wide enough to confine the mix that is thrust up in the previous pass. This distance is usually no more than 6 inches.

H. Rolling Pattern

A rolling pattern that will provide uniform coverage of the mat has to be established and should be reviewed by the field engineer. It consists of the location of the first pass, the sequence of succeeding passes, and the overlapping between passes.

General roller patterns for various mat thicknesses should be understood by the field engineer and can be found in **"Asphalt Paving Manual" (MS-8), The Asphalt Institute**. In each case, thick or thin lift transverse joints are rolled, tnen longitudinal joints, then breakdown rolling beginning at or near the low side of the mat. Roller overlap generally is no more than 6 inches as previously noted.

I. Control Strip

How does the field engineer know the number of passes required to give the desired density? Control strips are the answer and they are strongly recommended for use on medium and high traffic volume highway projects. Control strips are used to establish a rolling pattern for the type and number of rollers to be used on a project for a particular mix. Control strips help establish the most simple and economical rolling pattern that provides the required density, meets the surface tolerance requirements, and meets production requirements.

Determinations from the control strip should include: approximate temperature of the mix arriving on the project; approximate compaction time, roller vibration, amplitude, and speed; number of roller passes for optimum compaction in the static and vibratory modes; proper lap to match the pavement width; and the approximate rolling zone. **DYNAPAC's Procedures for Rolling a Test Strip** is an excellent reference.

A nuclear gauge is normally used to determine the optimum rolling pattern, however, cores are also taken to assure there is a positive tie to the theoretical maximum density. When density problems develop another control strip should be run. Appropriate changes may include added rollers; higher mix temperature to increase available rolling time; slower rolling speeds and changes in frequency and/or ampitude to increase compaction.

The field engineer should remember one important axiom concerning compaction. A good density specification is one that assures a 6 to 8 percent void range in the compacted pavement. Any mix, regardless of compaction during construction, will continue to densify by consolidation and particle reorientation during the first three summers. The field engineer should be extremely concerned when testing indicates rolling has produced less than 3 percent air voids. The field engineer should suspect too much A.C. or filler in the mix or an error in testing. If there are no testing errors and the density was achieved in 1 or 2 passes the pavement can be expected to rut and/or flush in the future. Redesign of the mix is imperative.

J. Density Tests

Density specifications vary from State to State. Some of the common means of specifying roadway density are: percent of maximum theoretical density; percent of field laboratory density; percent of test strip density; and specified roller passes or roller time. the final method is generally unacceptable because it does not relate to actual in-place densities. The other methods are generally satisfactory provided they are correlated to maximum theoretical density in order to determine the true void content of the mat.

The field engineer should be familiar with the field and laboratory tests for density determination of the finished pavement. Reference is made to **ASTM Method of Test D-2950, Density of Bituminous Concrete in Place by Nuclear Method, AASHTO T 166 (ASTM Methods of Test D-1188 and D-2726), BulK Specific Gravity or Compacted Bituminous Mixtures.**

Nuclear gauges must be calibrated regularly with standard calibration blocks provided by the manufacturer. Pavement cores should be routinely pulled to correlate with nuclear readings. Nuclear gauges must also have compensations for underlying surface densities when new mats are less than about 2 inches thick. However, there are now nuclear guages for thin lifts.

VI. WORKMANSHIP AND PROJECT ACCEPTANCE

A. The Final Judgment

For the most part, this workshop has discussed the "do's" and "don't's," the bad practices to "watch out for," and the ways to "trouble-shoot" construction problems.

All the training and all the background and experience must be boiled down into a "judgment call." The inspecting Federal engineer must make a decision on each and every Federal-aid project. It must be decided if the overall workmanship and quality control of the contractor or SHA has produced the highway product specified and that the project will provide the safe, durable function for which it was designed.

At final inspection, the acceptance of the project should be based on observations of three areas:

1. conformance to specification and design criteria,
2. skid and safety factors, and
3. appearance and rideability.

B. Conformance

It is difficult at times to determine reasonable conformance to specifications and design criteria. If previous inspections of the project have been made, they should be reviewed. Also, weekly reports, diaries, and project test results can indicate construction problem areas. Number and type of construction change orders tend to highlight areas where either the design, the specifications, or the normal construction process cannot be achieved. It is important that the change order, major or minor, does not modify the intended purpose or basic scope of the project nor mitigate the overall performance and product acceptance without proper justification and approval.

That is not to say that we must build what is designed; we must build it as designed and specified, or follow the accepted process to modify both.

C. Safety Factors

A primary objective of any Federal-aid project 3R, 4R, or new construction is one of safety to the traveling public. No project should be constructed (or accepted) with unsatisfactory safety factors. Proper consideration must be given to geometrics and alignment and to current safe design standards and practices during project development. If during construction, design oversights were found, they should be corrected whenever practical.

If items are substandard but are found not to be cost-effective to correct, that decision should be properly supported and documented.

D. Appearance and Rideability

The traveling public judges each project on appearance and rideability. These two factors alone many times will cause a SHA to do more work on a recently accepted project. Final project appearance and rideability reflect on the degree of construction quality control. The area engineer should use his judgment when accepting a poor-riding project. Even if the SHA does not have end-product rideability specifications, emphasis on workmanship and control-of-work should produce a better project next time.

VII. REVIEW OF PROJECT DOCUMENTATION

A. Purpose

The primary purpose of reviewing project files is to verify that the SHA is exercising and documenting quality and quantity control to provide a basis for project acceptance and to support subsequent reimbursement of project costs with Federal-aid funds. A secondary purpose is to ensure that the SHA is inspecting the contractor's facilities, equipment, and operations to assure specification compliance and subsequent product acceptability.

B. Pre-Operation Checks and Materials Approvals

A number of materials approval procedures and quality checks are prerequisite to flexible pavement construction. Checks of these items should be included in the area engineer's review of the project documentation for quality and quantity control. Examples of such records are materials source acceptance, the submission of samples of job mix materials for mix design, mix design calculations, certificates of materials such as additives which may be accepted for use prior to or in lieu of SHA testing, sampling and testing schedules, prequalification of personnel and equipment, and inspectors' reports of checks on the plant, paving machines, and other equipment.

C. Project Quality Control

Evidence of project quality control may be obtained from a variety Of sources including project diaries, inspection reports, materials certificates, test reports, summary books, field books, control charts, and notes on project plans. These records should be reviewed to verify:

- that the SHA is adequately controlling the project through its inspection and testing activities,
- that the contractor is successfully performing quality control activities in accordance with the terms of the contract,
- that materials incorporated in the completed work comply with requirements of the plans and specifications.

D. Materials Acceptance Teeting

In addition to checking materials records for compliance with specifications, the area engineer should seek assurance that the required frequency and distribution of acceptance sampling and testing is accomplished. The field engineer should also check to see what procedures the State follows to assure that sampling will be done when and where needed. Techniques for the selection of random Samples should also be reviewed to ensure unbiased sampling and testing.

Similar procedures for the selecting and obtaining of independent assurance samples is of concern. Scheduling may be critical where sampling personnel must travel a considerable distance to service a number of projects.

Where in-place samples such as test cores are taken, the area engineer should determine if an effort is made to correlate locations with the location of samples taken prior to laydown.

Timeliness in obtaining test results is important since production adjustments or corrective actions may have to be made on the basis of test findings. The relationship between job control and acceptance testing, and procedures for resolving differences between the different test results should be clearly understood. Allowable tolerances between tests and criteria for initiating corrective action should be reviewed.

It is important that project personnel understand the purpose and use of independent assurance samples and tests. They should not be substituted for acceptance samples and tests unless it can be clearly demonstrated that an acceptance test is invalid due to some unforeseen condition such as equipment breakdown or malfunction. The area engineer should check what procedures are used for comparing the results of acceptance and independent assurance tests, who makes the comparison, what deviations between test results are permitted, and what follow-up actions are taken.

The area engineer should review the testing, monitoring tools, and techniques used by the contractor and SHA to control and evaluate the production processes. Control charts, microcomputer control and analysis, and quality levels analyses can be of considerable value. The FHWA engineer should make an independent analysis to spotcheck analysis test procedures and supplement materials test analysis conducted on the project. The reporting of quality levels may be required by the FHWA region or division offices.

Testing of unusual material, or requesting random testing when a process or procedure is in question, is encouraged. The area engineer has the responsibility to ensure that the highest quality product within reason (judgment) is being produced.

E. Pay Quantities

The area engineer should review the SHA procedures used on the project for measuring, checking, and recording pay quantities. Occasional spot checks should be made to verify that field notes are transferred to summary books, which in turn are transferred to progress estimate forms. Identification of nonspecification materials should also be included in the spot check procedure to verify that payment is not made for this material.

F. Critical Items

While occasional checks should be made on a wide variety of items, the area engineer's review of project quality documentation should largely be directed toward those features and characteristics which are the most critical to the quality of the finished product. Gradation checks should concentrate on fines and critical control sieves. Asphalt content and voids are of continuous concern.

Density is the most important item where control needs to be demonstrated during the construction operation. If density is a problem, increased attention should be given to checking such items as temperature, gradation, mix design, etc., which contribute to density. Stability is extremely important during design but will probably not vary much during construction. There is no substitute for the area engineer's good judgment in determining how inspection time should be spent.

Name: ____________________
Office: ____________________
Course Date: ____________________

CONSTRUCTION INSPECTION TECHNIQUES FOR FLEXIBLE PAVEMENT CONSTRUCTION

1. List the principal problems in your State relating to the performance of flexible pavements.

   a.

   b.

   c.

   d.

   e.

   f.

   g.

   h.

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CONSTRUCTION INSPECTION TECHNIQUES FOR FLEXIBLE PAVEMENT CONSTRUCTION
Continued

2. Identify the most likely root cause(s) corresponding to each of these performance problems.

   a.

   b.

   c.

   d.

   e.

   f.

   g.

   h.

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CONSTRUCTION INSPECTION TECHNIQUES FOR FLEXIBLE PAVEMENT CONSTRUCTION
Continued

3. Identify what you are currently doing to affect or cause improvement for each of the above listed performance problems.

   a.

   b.

   c.

   d.

   e.

   f.

   g.

   h.

Name: ______________________
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CONSTRUCTION INSPECTION TECHNIQUES FOR FLEXIBLE PAVEMENT CONSTRUCTION
Continued

4. Identify what the most important thing you could do to affect change or improvement with respect to the previously listed performance problems.

   a.

   b.

   c.

   d.

   e.

   f.

   g.

   h.

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