from John Carroll.

DESIGN AND CONTROL OF SLURRY SEAL MIXES

by

C. Robert Benedict
BENEDICT SLURRY SEAL, INC.
320 Northview Road
Dayton, Ohio 45419
U.S.A.

AEMA

PREPARED FOR PRESENTATION AT THE FOURTH ANNUAL MEETING
OF THE ASPHALT EMULSION MANUFACTURERS ASSOCIATION
PHOENIX, ARIZONA - FEBRUARY 28 - MARCH 2
- 1977-

DESIGN AND CONTROL OF SLURRY SEAL MIXES

INTRODUCTION:

Throughout written history, fine aggregate bituminous mixtures have made their special contribution to the construction arts. Examples are the sand filled mortars used to cement the bricks of the ancient Syrian ziggurats, caulking of papyrus rafts and Phoenician galleys, lake asphalts for floors, roofs and paving down through time to the current hot-mixed sheet asphalts, molten bituminous slurries . . . the German "gussasphalt" . . . the very thin sand-emulsion German "schläme" and the early grout-like California slurries of the 1930's, 40's and 50's.

With the commercialization of the continuous-proportion, continuous-mix and lay slurry machines in 1960, the horizons of fine aggregate mixes expanded to include the more durable, coarser aggregate blends. The slurry seal industry was restricted to the use of slow setting conventional dense mixing grade emulsions until 1966 when the first quick-set systems were introduced.

All these materials have been classified as "Fine Aggregate Bituminous Mixes."

We have come to understand the material called "slurry seal" as a fluid, homogeneous mixture of asphalt emulsion, water, mineral filler and continuously graded fine aggregate which is applied to a pavement surface by means of a bottomless, runner-supported, squeegee-sealed spreader box.

Fig. 1 The continuous slurry seal process precisely proportions the materials, mixes and spreads the mixture.

Fig. 2 The principle materials of slurry seal are aggregate and asphalt emulsion. The aggregate must be clean, crushed, durable, properly graded and uniform. The emulsion is a three-part system consisting of asphalt cement, water and emulsifier. The asphalt emulsions generally conform to the AASHTO "SS" dense mixing types and are made from paving grade asphalts and may be hard or soft. The emulsions may be slow-set or quick-set types made from anionic, cationic, or non-ionic emulsifiers. Sometimes, liquid modifiers are used.

Fillers such as portland cement or hydrated lime are often used in small quantities to stabilize incompatible mixtures or as chemical modifiers of the system. Mix water should be potable and free from harmful salts.

Fig. 3 The International Slurry Seal Association's A-105 guide specification recognizes three basic aggregate gradations:

- Fine Type I (1/8")
- General Type II (1/4")
- Coarse Type III (3/8")

The aggregate gradation selected for use depends upon the objective of a particular treatment:

Type I is used for maximum crack penetration and as an excellent preparation for hot mix overlay or chip seal. It is usually used in low density or low wear traffic areas such as light aircraft airfields, parking areas or shoulders where the primary objective is sealing.

Type II is the most widely used gradation and is used to seal, to correct severe ravelling, oxidation and loss of matrix, and to improve skid resistance. It is used for moderate to heavy traffic depending upon the quality of aggregates available and the design.

Type III is used to correct severe surface conditions, as the first course in multi-course applications, to impart skid resistance and to prevent hydroplaning under very heavy traffic loadings for extended life under these conditions.

The primary uses for slurry seal surface treatments are:

1. Preventive . . . to prevent surface distresses from occurring in newly laid pavements such as the effects of weathering(oxidation, loss of oils, loss of matrix and embrittlement of the structural mix) and to provide special durability and texture not available in the underlying mix.

2. Corrective . . . to correct surface distresses that have already occurred in older pavements such as surface cracking, ravelling, loss of matrix, increased air and water permeability and slipperiness from flushing or aggregate polishing.

Slurry Seal is the most versatile of all pavement surface treatment systems. Because slurry seal is a relatively thin surface treatment, energy requirements are low and it becomes economically feasible to use special imported materials or even exotic materials to provide the desired characteristics.

Fig. 4 Slurry Seal is distinguished from other surface treating systems by its single unique property: its inherent ability to deposit a thin bituminous mixture to pavement surfaces in accordance with the demands of a variably textured surface.

An example is this cross section of an interstate shoulder where slurry will fill the interface crack, deposit a modest wedge, fill ravelled surface voids and transverse cracks, place a skid-resistant weather-tight seal and provide color delineation . . . all in a single pass.

Fig. 5 Consider another example of a pavement cross section where the wheel tracks are compacted by traffic to the point of flushing. The untravelled areas are oxidized and there is a badly ravelled center joint, non-fluid coarse mixes will bridge the cracked and ravelled areas; chip seals will be either too rich or too lean. Many times these treatments merely compound the original problem. Slurry will perform all functions of filling the ravelled joint and oxidized areas and coating the entire areas as required by the demands of the surface . . . in a single pass.

The properties of a completed slurry seal vary with the properties of the materials incorporated into the mix and with the design and construction of the material combinations selected. Slurry Seal is usually considered as having very low permeability (an excellent seal), low tensile strength, high compressive strength, high skid resistance, good macrotexture and high hydroplaning resistance, good stability, excellent bond and appearance.

These properties may be altered by selection of materials such as special aggregates to impart special durability and skid resistance or the use of elastomers impart flexibility and resistance to thermal cracking.

DESIGN OF SLURRY SEAL MIXTURES:

The development of slurry seal design procedures parallels the history of the development of all other paving materials; i.e., trial and error, relating field performance with laboratory experience. In the search for understanding of increased serviceability, all paving arts undergo annual changes of direction and philosophy. For example, the arguments of the proper void contents or penetration of asphalt to be used in a given situation rages unresolved after 25 years of my experience. Each year, the paving industry re-invents ancient knowledge and sometimes repeats errors of the past. The industry understands that all is not known and fully expects to change current notions about design as new insights are gained.

I rely mainly on the design procedures listed in the ISSA A-105 Guide Specification, The Bituminous Surfaces Handbook, Slurry Seal, Inc., Instruction Report S-75-1, U.S. Army Waterways Experiment Station and ASTM publications and ISSA Technical Bulletins and R & D Committee Reports.

The State of the Art does not permit the establishment of universal values for all tests suggested in the following outline procedure. Though I do not speak for the industry here the principles used will be identified in one way or another by the performance of the Mix.

There are three parts to this outline procedure:

- Part 1. Preliminary Considerations . . . pavement condition, statement of objectives, materials evaluation and selection to meet objectives.
- Part 2. Job Mix Formula determined by physical field-simulation tests to laboratory specimens.
- Part 3. Translation of Job Mix Formula to Field Control Data.

The philosophy behind this design approach is pragmatic; that is, the designer should, during his bench work, continually ask these questions:

1. Will this slurry mix well?
2. Will this slurry wear well?
3. Will this slurry be safe?

OUTLINE OF A GUIDE DESIGN PROCEDURE FOR SLURRY SEAL

Part I - Preliminary Design Considerations

1. Describe the Pavement to be treated
   a. Surface condition - macrotexture, absorbtivity, surface and structural cracks, surface contamination, longitudinal and transverse geometry, rutting, vegetation.
   b. Climate and weather conditions - temperature, rainfall, shade, wind
   c. Average Daily Traffic (ADT), speed limits

2. State Objectives of the Treatment
   a. Skid numbers required, surface macrotexture
   b. Sealing, ravelling correction, crack filling, wedging, rut correction, preparation for overlay, slipperiness correction, etc.
   c. Life expectancy requirements
3. Evaluate and Select Materials
   a. Evaluation of proposed AGGREGATE
      1. Field Durability record
      2. Skid Resistance Level (SRL), polish susceptability
      3. Gradation, void content, quality of fines, sand equivalent, particle shape, microtexture
      4. Mechanical properties, resistance to mechanical abrasion, L.A. Rattler, Shaker loss, British Wheel abrasion, hardness, crush resistance, freeze-thaw, friability
      5. Chemical properties, acid insolubility, sodium sulfate soundness, water solubility
      6. Mineralogy/petrology, geology
      7. Economics - location, availability, transportation, cost
   b. Select Aggregate and Gradation to Meet Objectives

   c. Evaluation of proposed EMULSION
      1. Field Durability record
      2. Base asphalt source and type-oxidation/hardening resistance
      3. Emulsion particle size-stability, shear sensitivity, sieve
      4. Climate/penetration-viscosity requirements
      5. Weather-shade, sun, wind, ice, salt, traffic time required
      6. Quick-set/slow-set requirements
      7. Compatibility/adhesion characteristics of the aggregate-filler-retarder-accelerator system, re-emulsification
      8. Economics - location, availability, transportation, cost
   d. Select Emulsion to Meet Objectives

OUTLINE OF A GUIDE DESIGN PROCEDURE FOR SLURRY SEAL (cont.d.)

Part II - Job Mix Formula Procedures

1. Estimate the Theoretical Pure Asphalt Requirement (PAR) or Bitumen Requirement (BR) by Surface Area Method for an 8um coating
   a. Aggregate Sand Equivalent
   b. Aggregate Apparent Specific Gravity
   c. Aggregate Gradation (dry sieving)
   d. Aggregate Centrifuge Kerosene Equivalent
   e. Calculate Total Surface Area
   f. Emulsion percent asphalt residue
   g. Calculate the theoretical PAR/BR for an 8um thickness coating of the calculated surface area and record as
      1. percent asphalt added to dry weight of aggregate
      2. Percent emulsion added to dry weight of aggregate @ % asphalt residue
      3. Percent asphalt of total dry solids

2. System Compatibility Determination
   a. Estimate filler/additive requirements
      1. Run 100-gram trial cup mixes using 100% PAR to estimate optimum water content, filler requirement and mix-set-traffic/cure time characteristics (ISSA TB 102)
      2. Adjust PAR for added filler if required
   b. Cone Consistency Tests run to obtain 2.5 centimetre consistency, ISSA TB 106
      1. Determine optimum mix-water content for three levels of emulsion content; e.g., 100%, 85%, 70% PAR for 2.5 cm. consistency
      2. Adjust filler content, mix-water content and PAR for changes in mix-set-traffic time if required
      3. Construct 3-point consistency/mix-water curve for consistency ranges of 2-3 cm., 4-5 cm. and 6-7 cm. ranges for each of the three PAR levels selected. Air dry at ambient and save each specimen
   c. Compatibility Test
      1. Examine cross-sections of centrally split consistency specimens for evidence of asphalt or aggregate migration or existence of excessively sticky surfaces
      2. If suspicious disuniformity is observed, run Cup Compatibility Test
         a. Mix 100 grams of each formulation in a small, plastic-lined drinking cup, cure in the cup for 12 hours. Separate into upper and lower halves, dry, run asphalt extraction by reflux and split median gradation of extracted aggregate. Substantial variation (10 to 15%) from top and bottom halves indicates an incompatible system.
      3. Wet Stripping Test - 10 grams cured slurry in 400 ml. moderately boiling water for 3 minutes. Decant and place on absorbent paper towel. Low asphalt retention can indicate lack of adhesion, low film coalescence, poor emulsion formulation, re-emulsification or possible false slurry.

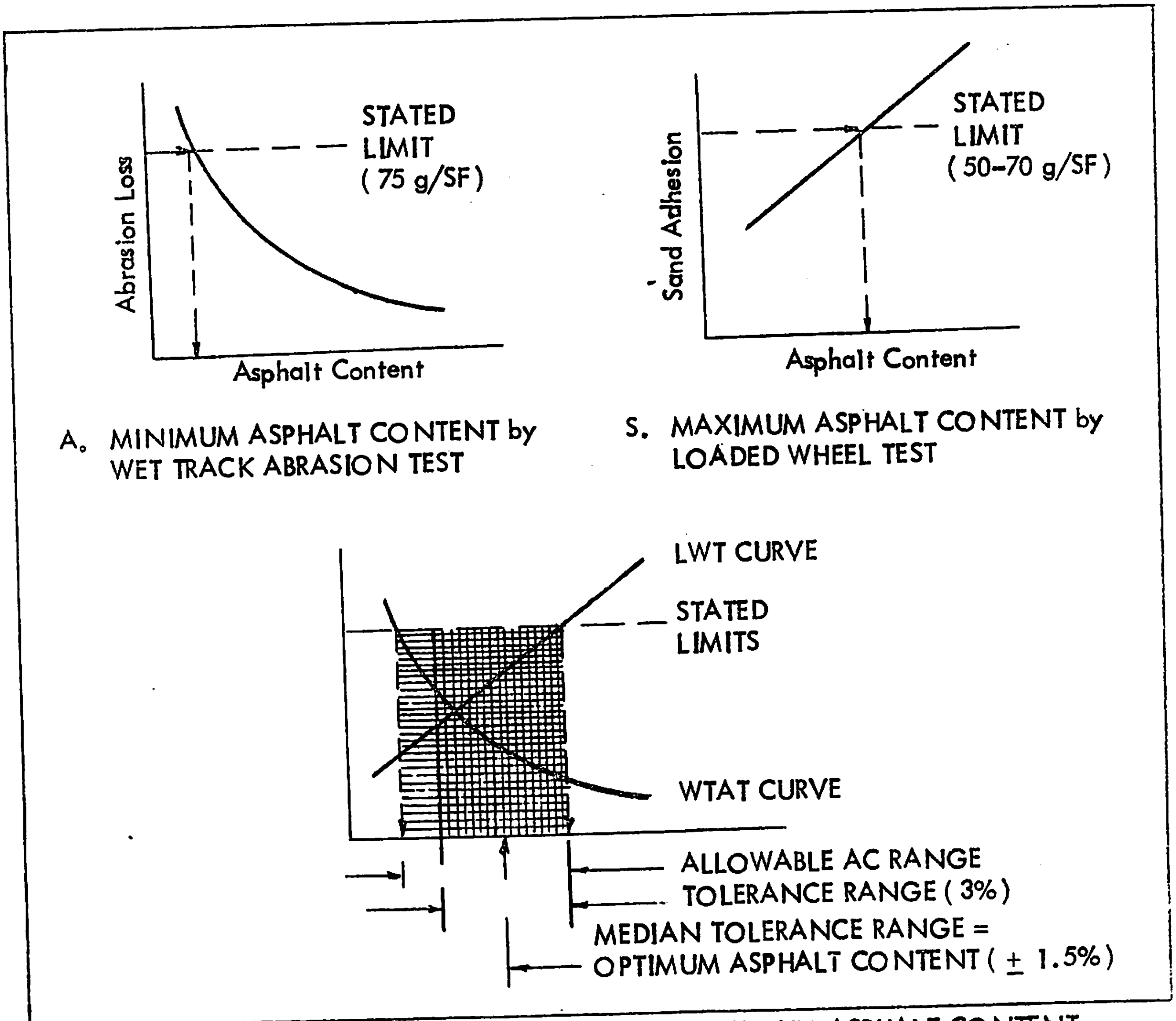
3. Traffic/Cure Time by Slurry Cohesiometer
   a. Mix and set time by ISSA TB 102 at job temperature conditions
   b. Traffic Time by Slurry Cohesiometer at job temperatures, eg. 50°, 80°, & 110°F or 60°, 80°, 100°. (Proposed ASTM D04.24)

4. Physical Tests on Cured Slurry

   a. Wet Track Abrasion Test (WTAT) - measurement of resistance to mechanical abrasion, kick-out, internal mat adhesion
   b. Loaded Wheel Test (LWT) - traffic simulation, measurement of resistance to flushing under heavy traffic loads

5. Selection of Optimum Design

   a. State Maximum limits to WTAT = minimum asphalt content (75g/SF?)
   b. State Maximum limits to LWT = maximum asphalt content or
      State Maximum LWT limits for Traffic Counts
      Light = 0 to 500 ADT (70 g per SF?) sand adhesion, 1000 @125 lbs.
      Medium = 250 to 1500 ADT (60 g per SF?)
      Heavy = 1500 to 3000 ADT (55 g per SF?)
      Very heavy = 3000+ (50 g per SF?)
   c. State Job Tolerance Limits (Contractor Proficiency)
   d. Draw graphs of the physical test data and superimpose the stated limits and read optimum asphalt content.



A. MINIMUM ASPHALT CONTENT by WET TRACK ABRASION TEST

S. MAXIMUM ASPHALT CONTENT by LOADED WHEEL TEST

Figure 6. GRAPHICAL DETERMINATION OF OPTIMUM ASPHALT CONTENT

CONTROL OF SLURRY SEAL CONSTRUCTION:

After the optimum design suggested is established, it is necessary to translate this design into field control quantities. One suggested method is described in ISSA Technical Bulletin #107, "A Method for Unit Field Control of Slurry Seal Quantities." The objective of this method is to aid operators and inspectors to control the field material quantities and application rates so that design results are obtained. The method is essentially to translate laboratory design into field units of gallons, tons and bags and to measure these during application.

The following is an <u>example</u> of the laboratory design translation into the essential field control quantities:

LABORATORY DESIGN FOR FIELD CONTROL

— EXAMPLE —

	Optimum Lab Design	Control Quantities	Tolerances
a) Aggregate	100.0%		
b) Filler* Type PC-II	1.0%	2-bags/10 tons	± 1/2 bag
c) Mix Water*	12.0%	29 gals./ton	± 2.3 g/t
d) Cone Flow Consistency	2.5 cm.		± .75 cm.
e) AC Target Extraction	10.5%		± 1.5%
f) Emulsion* @ 61.0% Res. AC	17.2%*	41.0 gals/ton	± 4.0 g/t
g) Design Width	20.0 Ft.	2 lanes x 10 ft.	± .5' OA
h) Spread Rate	15.0 lbs/SY		± 2.0 Lb/SY
	133 SY/ton	118 to 154 SY/ton	
i) Lineal Ft./ton @ Lane Width	120 LF/ton	106 to 138 LF/ton	

j) Aggregate Specific Weight vs. Moisture Content:

Moisture Content	Moist Lbs/ CF Loose	Dry Lbs/CF of Moist Ag.	% Dry/Wet	Machine Setting At Design
0%	96.4	96.4	100.0	____
1	95.4	94.5	98.0	____
2	83.6	81.9	84.9	____
3	79.7	77.3	80.1	____
4	79.0	75.8	78.6	____
5	78.0	74.1	76.8	____
6	77.9	73.2	75.9	____

* Per Cent added to the dry weight of the aggregate

Figure 7. Example of Laboratory Design For Field Control

Spread rates shown in Figure 7 are estimated from the charts in Figure 8.

Reduction in loose unit weights due to increase in moisture contents is determined by using ASTM C-29 "Test for Unit Weight of Aggregate" at various moisture levels likely to be encountered in the field, such as 0% to 6%. Some contractors relate the various wet weights directly to machine calibrations and settings.

Calibration of each machine to be used on the job is essential, and is normally done by the contractor in accordance with the manufacturer's instructions. The procedure involves weighing each material as it is discharged at either a unit time per RPM and setting, or unit number of revolutions of the drive at various settings. The results are then plotted on a reference chart. Calibrations for aggregate delivery should be related in some way to moisture content/unit weight of the aggregate.

Inspectors and engineers should be well schooled in the particular control techniques selected for use. The presence of the inspector in the laboratory during the design process, particularly the consistency testing, is helpful to develop understanding of the process.

There are at least five (5) methods of field proportion control which have been suggested. They are:

1. Calibration according to manufacturer's instructions
2. Batch Unit Control by measurement of batch weights and net liquid usage as described in TB #107
3. Field consistency tests vs. gross RPM and water flow meter
4. RPM, emulsion flow meter and water flow meter ratios versus field consistency measurements
5. Continuous measurement by emulsion flow meter and aggregate weigh meter ratios versus field consistency measurements

There are four (4) important factors involved in the construction of the optimum laboratory design that should be emphasized here.

1. Field changes in the aggregate specific weight (pounds per cubic foot) due to the bulking effect of moisture in the aggregate are critical. Operators must be made aware of this critical variation and trained how to recognize changes and to compensate for them by adjustment of machine settings. Four methods are suggested to recognize these changes and to relate them to machine settings:
   a. Direct percentage moisture analysis of the job with the soil test carbide-acetylene bomb versus a machine setting chart
   b. Unit weight of specific container filled with the job aggregate versus a machine setting chart
   c. Continuous moisture content by electronic probe versus a machine setting chart
   d. Aggregate color-moisture content comparison specimen versus a machine setting chart

2. Control of materials at the source can alleviate many problems in the achievement of the optimum design. Aggregate gradation changes such as over-size or under-size contamination can radically alter the asphalt requirements. These changes are most economically controlled at the source. Subtle changes in emulsion formulation and manufacture can

play havoc with mixing and setting characteristics. Measures should be taken at the source to assure delivery of emulsion as specified such as the mixing profile with the job aggregate. Changes in the residual asphalt content should be noted on the delivery tickets so that field adjustments can be made to insure application of optimum design.

3. Operating crews must be trained to understand acceptable operating procedures. Each contractor must develop his own operator training program to best suit his local situation. Film and manuals may be most helpful. We find that actual laboratory bench experience in making proper and improper mixes, learning the "feel" of the mix and the hand-eye association to be the most expedient training technique.

4. The achievement of steady state operations: i.e., uniformity equals the best chance of success. Operators should seek the steady state.
   a. Maintain constant mix consistency
   b. Maintain constant mixer speed, output, slurry mixer depth
   c. Maintain constant forward speed
   d. Maintain uniform, constant depth of slurry in the spreader

The control or elimination of the following list of pernicious problems and variables is essential to the achievement of successful slurry construction:

1. Aggregate moisture content
2. Varied aggregate compaction on the metering belt
3. Fine aggregate build-up on metering gates or screws
4. Erratic loading of the mixer
5. Temperature-viscosity variations of emulsions
6. Pump slippage and clutch slippage
7. Air leaks from worn packings, grease fittings, seals, hoses and pipe threads
8. Positive and negative pump heads
9. Surging or rough running drive engines
10. Sudden changes in drive engine speeds
11. Partially plugged nozzles, valves and screens, lines
12. Variable mix consistency due to indiscriminate use of water
13. Variable depth and quantity of slurry in the spreader
14. Improper mix sampling and laboratory extraction technique

Generally, results of laboratory extractions of mixer samples have been erratic and unreliable. Variations thus obtained have not been observed in the field. ISSA Technical Bulletin #101, "Guide for Sampling of Slurry Mix for Extraction Tests" may prove helpful when this test is performed. Reflux extractions are generally more reliable than centrifuge extractions.

I have attempted to present a brief history of slurry seal and offered a definition of the material, a description of the process, properties and uses, a rational design method, and have reviewed control problems and methods. Also included is a basic Slurry Seal technology reference list for use in your researches.

Hopefully, the information contained here will assist AEMA in its current project to develop performance specifications for slurry seal emulsions. As always, I will appreciate your discussion.

I wish now to praise the emulsion industry for its past contribution and encouragement to the slurry seal industry. At the same time it would be unfair to neglect mention of the Slurry Seal contractors who have invested in the order of $50,000,000 to sell your products for you. The industry now has at hand the tools for design and the tools for the economical, competitive production of 10 to 15 lane miles of heavy slurry per day. We have technically outrun our ability to control traffic with the so-called quick-set slow-curing emulsions you now produce.

We need your help . . . desperately . . . to develop a quick-cure slurry seal system. We cannot achieve--nor can you--our enormous potential without your help.

I challenge you to return to your laboratories and to take new approaches. Don't let your past experience say "it can't be done." The rewards are incentive enough. You can serve yourselves, your customers and our taxpayers.

Thank you.

REFERENCES:

Flock, J. F. — "Moisture Content and Specific Weight Characteristics of Slurry Seal Aggregates", Excerpt from 7th Annual Convention ISSA Proc. Jan. 1969

Godwin, L. N. — "Instruction Report S-75-1, Slurry Seal Surface Treatments", Soils and Pavements Laboratory, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. June 1975 - 62 pp.

Young, R. T., Province, R. J., Flock, E. F. — "Bituminous Slurry Surfaces Handbook", Completely Revised, Slurry Seal, Inc., P.O. Box 7677, Waco, Texas, 1973 - 116 pp.

Kari, W. J., Coyne, L. D. — "Emulsified Asphalt Slurry Seal Coats", Proceedings AAPT, Volume 33, 502-537 pp. 1964

Harper, W. J., Jimenez, R. A., Galloway, Bob M. — "Effects of Mineral Fillers in Slurry Seal Mixtures", Highway Research Board Record #104, 36-59 pp. 1965

Rogers, E. D., Goodrich, J. L., Schmitz, C. G. — "Practical Quick-Set Slurry Seal Coats (Cationic Emulsion Type)" Proc. 7th Annual ISSA Convention, Miami, Jan. 1969, 36 pp.

Goodrich, J. L., Ferm, R. L., Rogers, E. D. — "Practical Quick-Set Slurry Seal Coats (Anionic Emulsion Types)" Proc. 7th Annual ISSA Convention, Miami, Jan. 1969, 33 pp.

Benedict, C. R. — "An Introduction to the Potential Uses of a Loaded Wheel Tester (LWT) for the Traffic Count Design of Slurry Seal", Proc. 13th Annual Convention ISSA, 1975, 23 pp.

ISSA Publications: A-105 Guide Specifications, Technical Bulletins #101, #102, #106, #107, #108, #109, #T-100; Drawer "F" St. Louis, Mo. 63044.

ASTM — Annual Book of Standards, C, D, & E Sections. Part 14 and Part 15 - American Society for Testing and Materials. 1916 Race Street, Philadelphia, Pa. 19103.

California DOT test methods 355-A, and 303, Kansas DOT and Virginia DOT "Special Provisions for Design and Application of Slurry Seal".

Dougherty, H. D. "Servicing Slurry Seal Construction Using Bitumuls Anionic Quick Set Emulsified Asphalt", Chevron Tech. Paper #159, Jan. 1970.

Skog, J. "Wet Track Abrasion Testing", Proc. 8th Annual ISSA Conv., San Diego, Feb. 1970.

Landise, C., Jr., ed. Armour Takes a Scientific Approach to Slurry Seal, Highway Chemical Newsletter, Spring 1971.

Harkness, L. "Laboratory Tests for Slurry Seal", Proc. 9th Annual ISSA Conv., El Paso, Feb. 1971.

Flock, E.F., McAtee, L. "A Shaker Method for Evaluating the Quality of Cured Slurries", Proc. 10th Annual ISSA Conv., New Orleans, Jan. 1972.

Benedict, C.R. "Machine Laid Travel Plant Emulsion Mixes--Applications and Uses", Proc. 1st Annual meeting AEMA (Asphalt Emulsion Manufacturers Assn.) Jan ?74

"Redi-Cote Reference Manual", Armak Highway Chemicals Dept., P.O. Box 1805, Chicago, Ill., 1974.

Roberts, James M., Gotolski, Wm. H. (Pen DOT) "Pavement Asphalt Properties and Pavement Durability", pres. to TRB, Jan. 1975.

Kandhal, P.S., Wenger, M.E. "Paving Asphalt Properties in Relation to Pavement Performance", Proc. TRB, Jan. 1975.

Eggleston, H.K., et al. "Blast Furnace Slag Slurry Seals", National Slag Assn., Alexandria, Va., Bulletin MF-175-3, 1975.

Irick, Paul E., et al. "Bituminous Emulsions for Highway Pavements", National Cooperative Highway Research Program, Synthesis of Highway Practice No. 30, 1975--Transportation Research Board, National Academy of Sciences, 2101 Constitution Ave., N.W., Washington, D.C. - 1975

Pinilla, A., Agnusdei, J.O. "The Influence of Temperature in Rate of Setting of Cationic Emulsions",(Laboratorio de Ensayo de Materiales e Investigationes Technologicas de la Provincia de Buenos Aires), Proc. 49th Annual Meeting AAPT, Feb. 1975.

Harkness, L.M. "Aggregates and Slurry", Conf. Paper pres. @ Waco, Tex., Mar. 1974, Dist. 14th Ann. ISSA Conv., San Diego, Feb. 1976.

McLeod, Norman W.	"Basic Principles for the Design and Construction of Seal Coats and Surface Treatments with Cutback Asphalts and Asphalt Cements", Supp. to Vol. 29, Proc. AAPT, Jan. 1960.
Zube, E.	"Studies on Water Permeability of Asphalt Concrete Pavements", Proc. 4th Annual Highway Conf., University of the Pacific, Mar. 1961
Skog, J. Zube, E.	Proc. of AAPT, Vol. 32, pp. 380-411, 1963
McCoy, Paul Coyne, L. D.	"The Wet Track Abrasion Test", Chevron Asphalt Technical Paper #125 pres. to Road and Paving Materials Session, ASTM, Chicago, June 1964.
Clifton, D.J.	"Chemistry of Slurry Sealing". 1966.
Huppi, P.	"Recent Progress of Slurry Sealing in Switzerland and Austria". 1966.
Hawken, N.	"Slurry Seal—Practical Application and Current Use". 1966.
Hiscock, W.J.	"Slurry Sealing--A Road Maintaining Process". 1966.
	"Slurry Sealing". 4-part Slurry Seal Symposium spon. by Armour-Hess @ Olympia, Nov. 66. Rep. in Roads and Road Const., vol. 145, No. 531, Mar. 1967.
Hutchinson, John W. Rose, Jerry G. (UK)	"Skid Resistant Slurry Seal", pres. to ISSA Workshops, Hershey, Pa., Washington, D.C., Columbus, Ohio, Apr. 1968.
Rankin, W. D.	"What's New in Testing", Proc. 6th Annual ISSA Convention, San Francisco, Feb. 1968.
Gardner, James	"The Promise of Slurry Seal", Proc. 7th Annual ISSA Convention, Miami, Jan. 1969.
Flock, E.F.	"Laboratory Experience with Asphalt Slurries and Their Constituents", Proc. 7th Annual ISSA Convention, Miami, Jan. 1969.
	"Asphalt Surface Treatments and Asphalt Penetration Macadams", The Asphalt Institute, College Park, Md., Manual Series No. 13 (MS-13), Nov. 1969.
Rogers, E. D. Schmitz, C. G.	"Servicing Slurry Seal Construction Using Bitumuls QS-Kh Emulsified Asphalt", Chevron Asphalt Tech. paper #158, Jan. 1970.

Landise, C. C., Jr. "Some Mineral Fillers Used in Slurry Seal", ISSA R & D Comm. Report, Aug. 1975, and Proc. 14th Annual ISSA Conv., San Diego, Feb. 1976.

Dybalski, Jack N. "The Chemistry of Asphalt Emulsions", Proc. 55th Ann. TRB, Jan. 1976.

Benedict, C.R. "An Introduction to Elements and Uses of Slurry Seal Systems", pres. U.S. Air Force Institute of Technology, WPAFB, Ohio, Apr. 5, 1976.

Dahir, S.H. "Characteristics of Bituminous Aggregate Combinations to Meet Surface Requirements—State of the Art", Inf. pres. TRB Comm. A2DO3, Jan. 1976.

Dahir, S.H. "Friction and Wear Properties of Bituminous Surface Aggregates", TRB Comm. A2DO3 Inf. Report, Jan. 1977.

Young, R.T. et al. "Shaker Wear and Acid Insolubility Tests", pres. 15th Annual ISSA Conv. and Ist World Congress of Slurry Seal, Madrid, Spain, Feb. 1977.

Whitehurst, E.A. "Aggregates, Skid Resistance and Slurry Seals", Proc. 15th Annual ISSA Conv. and Ist World Congress of Slurry Seal, Madrid, Spain, Feb. 1977.

Harkness, L.M. "Slurry Sealing—The Total System", Proc. 15th Annual ISSA Conv. and Ist World Congress of Slurry Seal, Madrid, Spain, Feb. 1977.

Landise, C.C., Jr. "The Chemistry of Slurry Seal Components", Proc. 15th Annual ISSA Conv. and Ist World Congress of Slurry Seal, Madrid, Spain, Feb. 1977.

Benedict, C.R. "Laboratory Tests and The Design and Control of Slurry Seal", "Introduction to a Study for the Prediction and Maintenance of Slurry Seal Spread Rates", "An Interim Report on the A-B Road Test Project and the Loaded Wheel Test", Proc. 15th Annual Conv. ISSA and Ist World Congress of Slurry Seal, Madrid, Spain, Feb. 1977.

Huffman, John E. "Successful Slurry Sealing—By Plan and Not Chance", Proc. 15th Annual ISSA Conv. and Ist World Congress of Slurry Seal, Madrid, Spain, Feb. 1977.

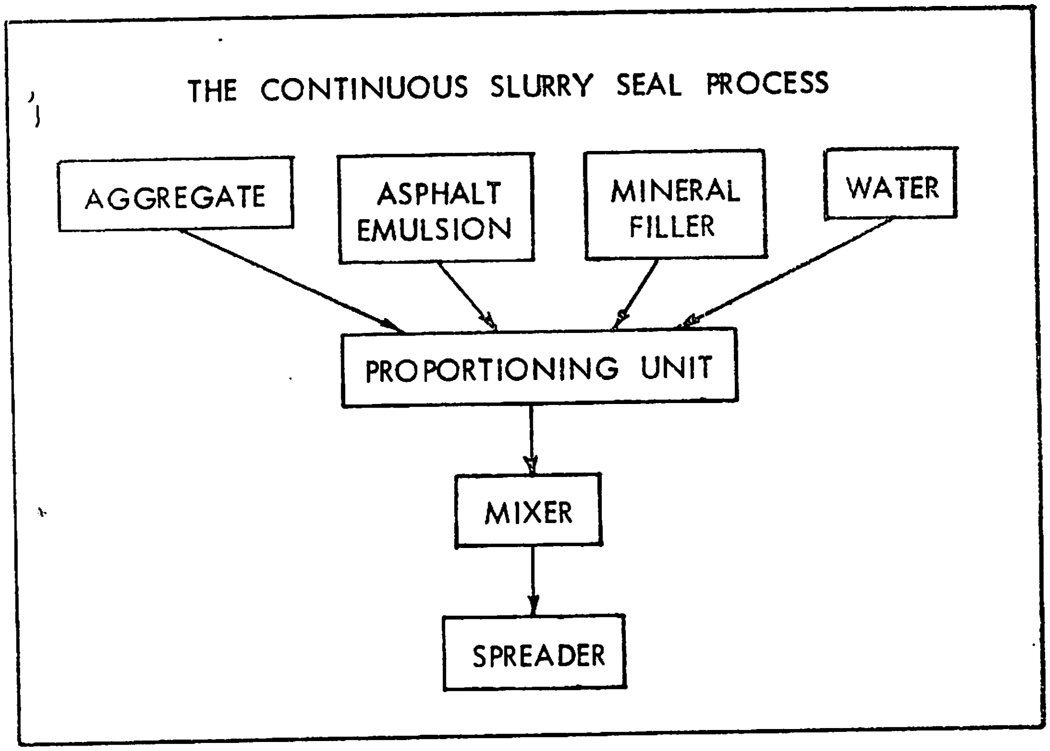


Figure 1

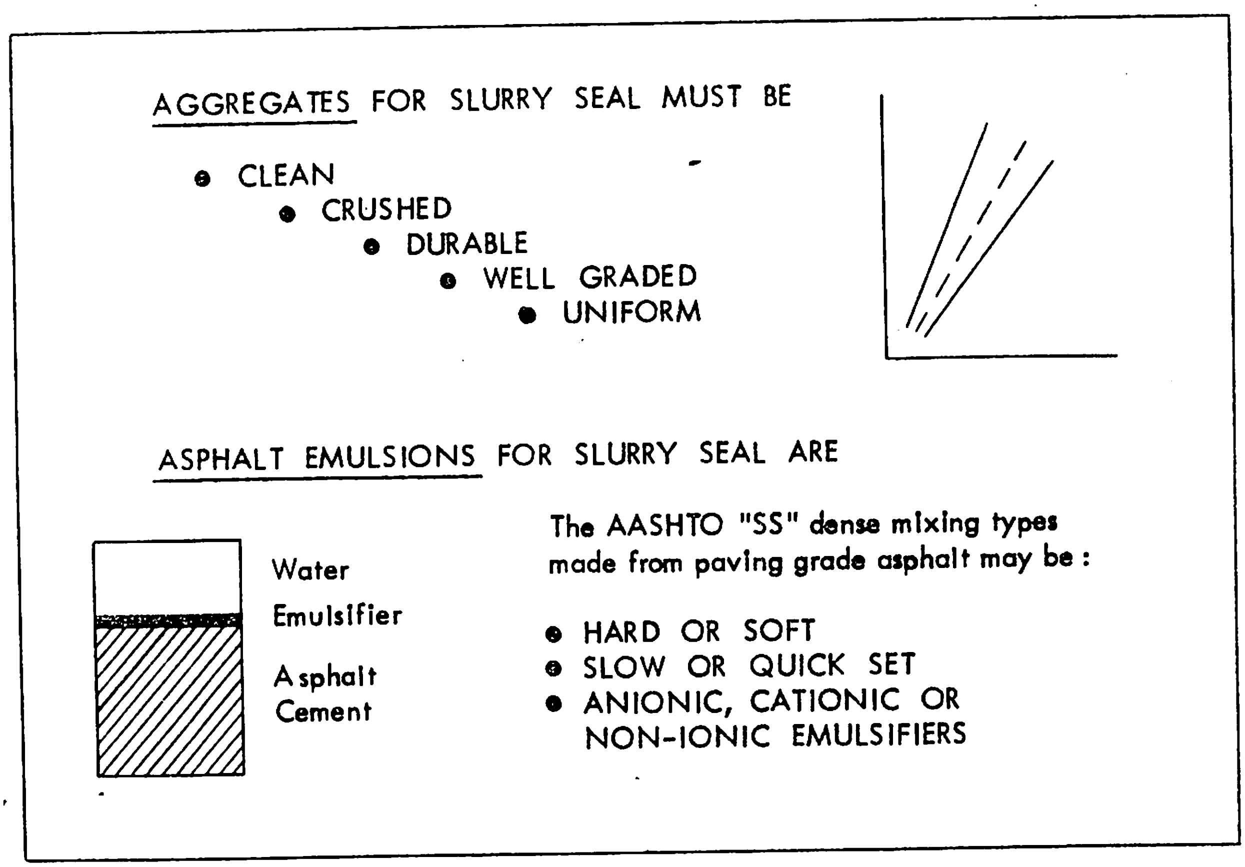


Figure 2

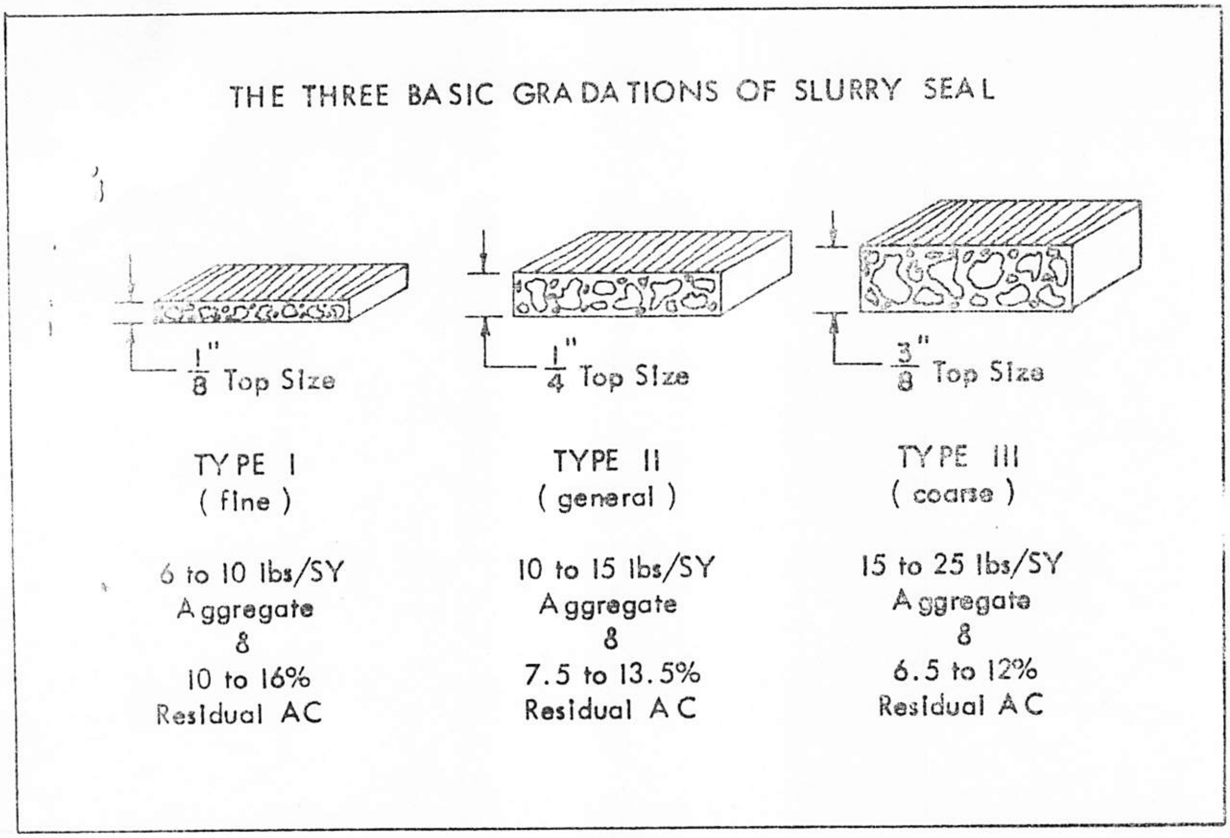


Figure 3

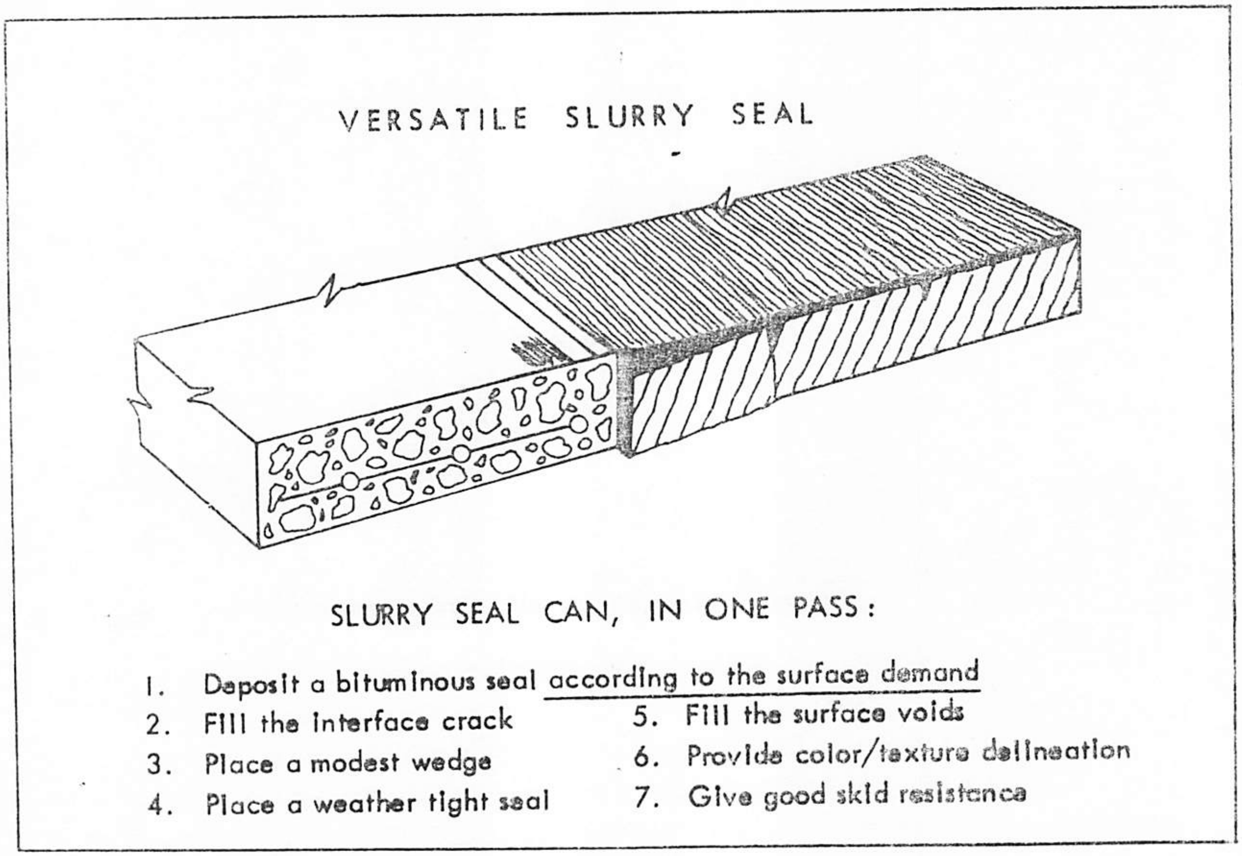


Figure 4

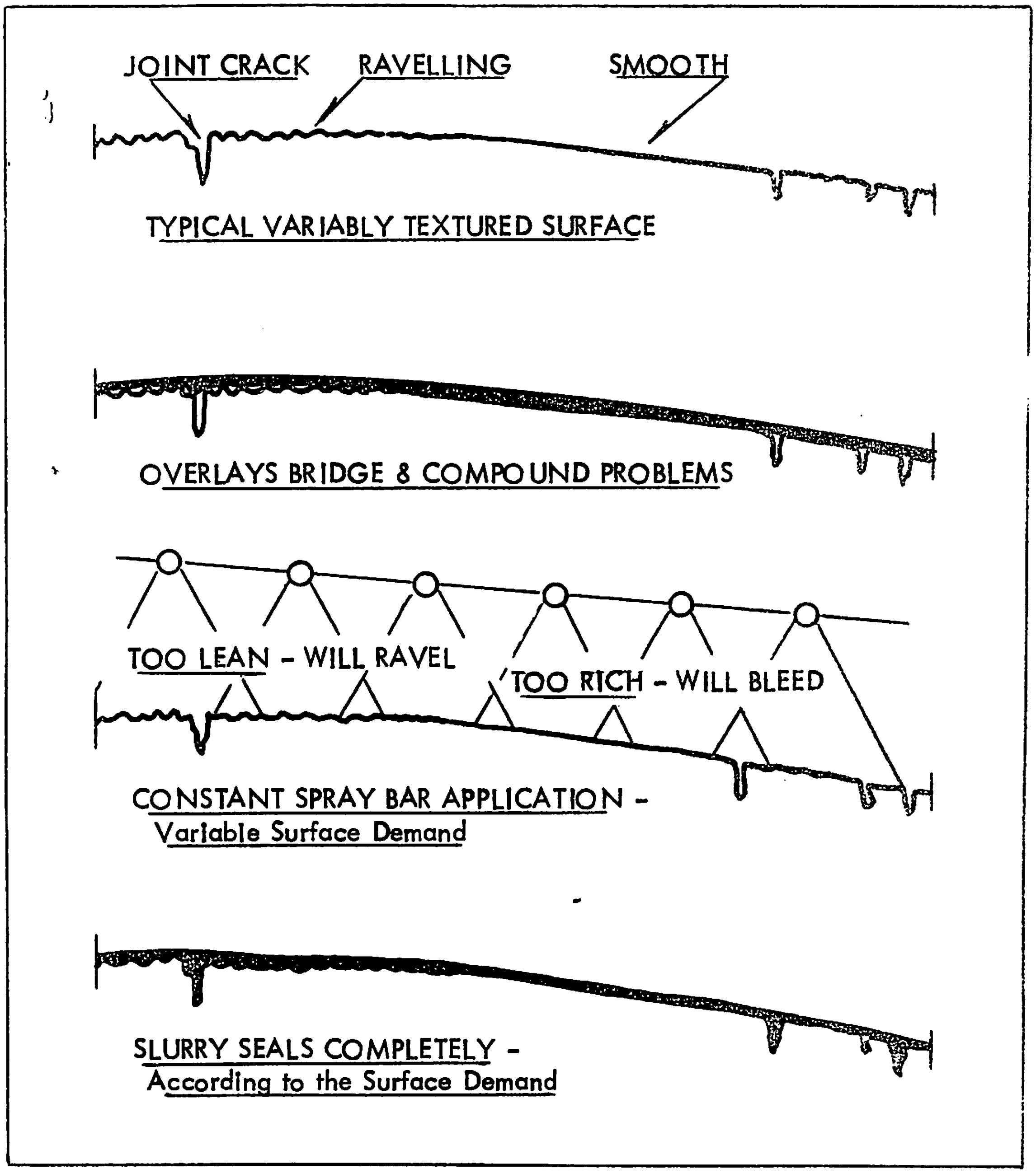


Figure 5. Effectiveness of Surface Treatments Applied to a Variable Cross Sectional Surface Texture.

APPROXIMATE SPREAD RATE CALCULATION*

(Under study in 1977...Subject to revision)

BASIC MONOLAYER SPREAD RATES FOR SMOOTH SURFACES (McLeod "S" or 60cc Sand Box Spread of 16-18'- ASG=2.65)						
GRADATION	TYPE I		TYPE II		TYPE III	
	%+16	lb/SF	%+16	lb/SF	%+16	lb/SF
FINE	10	5	30	9	50	14
MEDIAN	22.5	6	42.5	10.5	61	15.5
COARSE	35	7	55	12	72	17

FACTORS:	McLeod Rating	Sand Box Texture	Add lb/SY	TOTAL
BASIC RATE	S	16-18'		
ADD FOR SURFACE TEXTURE	H-1	10-12'	1	
	H-2	8-10'	2	
	H-3	5-7'	3	
		2-4'	4	
ADD FOR CROSS SECTIONAL IRREGULARITY	Nominal - 3/8"		1	
	Moderate - 1/2-3/4"		2	
	Severe - 1-1-1/2"		3	
ADD FOR JOINT CRACKS & LAPS (Calculate)				
APPROXIMATE SPREAD RATE - TOTAL				

* Variables of Particle Shape, Dimensions, Matrix Volumes, Void Content, Screen Ratios, All Affect the Spread Rate. Use these tables as a GUIDE only.

Figure 8. Spread Rate Calculation

SLURRY SEAL MIX DESIGN CHECK LIST

PART I BASIC MATERIALS TESTS

- EMULSIFIED ASPHALT SPECIFICATIONS ASTM D977, D2379, LOCAL
  - [ ] STABILITY, VISCOSITY, SIEVE, ASPHALT RESIDUE, PENETRATION &c. ASTM D244
  - [ ] SLOW-SET, QUICK-SET IDENTIFICATION ASTM D244 & ISSA TB102
- AGGREGATE SPECIFICATIONS, ISSA A-105. LOCAL
  - [ ] SAND EQUIVALENT ASTM D2419
  - [ ] DURABILITY - L.A. RATTLER ASTM C131
  - [ ] SODIUM SULFATE SOUNDNESS ASTM C88
  - [ ] ACID INSOL ASTM D3042, LOCAL
  - [ ] SHAKER WEAR TEST ISSA R&D Note 1.
  - [ ] GRADATION (DRY) ASTM C136
  - [ ] WET SIEVE -200 ASTM C117
  - [ ] UNIT WEIGHT ASTM C29
  - [ ] WET UNIT WEIGHT ASTM C29 @1-6% Note 2
- FILLER SPECIFICATION ASTM D242, LOCAL
  - [ ] FILLER SIEVE ANALYSIS ASTM D546

PART II JOB MIX FORMULA

1. ESTIMATE THEORETICAL BITUMEN REQUIREMENT (BR) or (PAR)

- [ ] SURFACE AREA METHOD WES S-75-1, CalDOT 355-A & 303-F
  - [ ] AGG. GRADATION (DRY) ASTM C136
  - [ ] APPARENT SPECIFIC GRAVITY ASTM C128
  - [ ] ABSORPTION ASTM C128
  - [ ] CENTRIFUGE KEROSENE EQUIVALENT Cal. DOT 303-F
  - [ ] CALCULATE TOTAL SURFACE AREA WES S-75-1
  - [ ] CALCULATE BR FOR 8um COATING WES S-75-1
- [ ] ALTERNATE METHOD - ESTIMATE BY EXPERIENCE e.g., 20%AE/Type IIC

2. SYSTEM COMPATIBILITY

TRIAL MIXES (50, 100 or 200g) TO ESTIMATE REQUIREMENTS FOR FILLER, MIX WATER, ACCELERATOR, RETARDER & BR ADJUSTMENTS

CONSISTENCY TESTS @ 100, 85, 70% BR, ISSA TB106

COMPATIBILITY TESTS

- SPLIT CONSISTENCY SPECIMENS Note 3
- SPLIT CUP TEST Note 4
- WET ADHESION Note 5

3. TRAFFIC & CURE TIME

MIX AND SET TIME ISSA TB102

TRAFFIC TIME AT JOB CONDITIONS BY COHESIOMETER ASTM D04.24 prop.

4. PHYSICAL TESTS ON CURED MIX SPECIMENS

WET TRACK ABRASION TEST ISSA T-100

LOADED WHEEL TEST ISSA TB109

OPTIMUM DESIGN BY GRAPHICAL SELECTION

PART III TRANSLATION OF OPTIMUM DESIGN TO FIELD CONTROL QUANTITIES

ISSA TB 107 "UNIT FIELD CONTROL"

- OPTIMUM DESIGN DATA (Above)
- SPREAD RATE ESTIMATE ISSA R&D Note 2
- WET UNIT WEIGHT @ 0-6% MOISTURE ASTM C29 Note 2

ALTERNATE METHODS

- CALIBRATION / MFR. & EXTRACTION
- CONSISTENCY VS. WATER FLOW METER
- CONTINUOUS AGG. & AE METERING

Note 1. May be used to estimate gradation for durability (R&D Committee).
Note 2. Required for unit control data.
Note 3. Consistency specimens are cast on paper at 3 levels of mix water and A.E. and are centrally split and examined for asphalt and aggregate migration. (In committee)
Note 4. A 100g mixture is cured in a 6oz. paper cup. Upper and lower halves are analyzed.
Note 5. 10g cured mix three minutes in boiling water, decant and examine coating.
Note 6. Dashed boxes indicate tests not suggested in ISSA A-105 Guide Specification.