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SLURRY SEAL & MICROASPHALT DESIGN: WHERE WE ARE, WHERE WE ARE GOING

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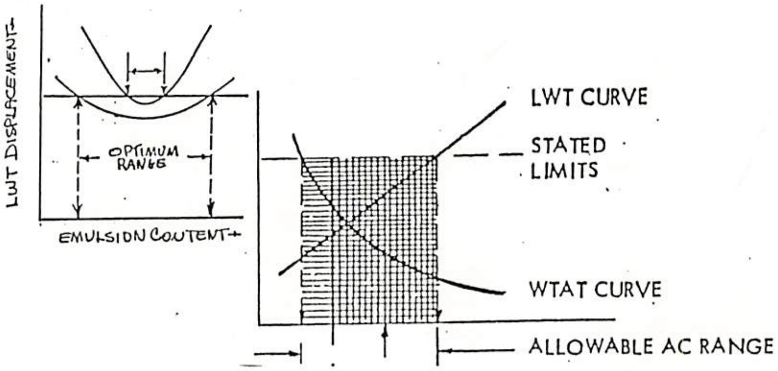
SUMMARY

Principles of current design methods and tests are reviewed. The importance of careful, thorough materials combinations evaluation is stressed. An actual design is "walked through" including materials analysis, trial mixes, compatibility, field simulation tests, interpretation of test results and job mix formula recommendation. Results of the design tests are then compared with other tests to show a range of typical results or test responses. Finally, the distinguishing differences between conventional slurry seal and polymer modified micro-asphalt are compared.



INTRODUCTION:

Some 12 years ago at the 4th annual meeting of the Asphalt Emulsion Manufacturer's meeting in Phoenix, and at the ISSA 1st World Congress on new Slurry Seal, and 15th annual meeting, Madrid Spain, we presented a slurry design method which remains essentially unchanged. The first ISSA Design Technical Bulletins-1978 detailed the procedures used in Technical Bulletin #111. Since that time many new technologies have been field proven in the U.S. and abroad which require definition. Many new technical bulletins have been published in the 1980 and 1984 editions of Design Technical Bulletins as well as ASTM D3910-1980a Standard Practices for Design, Testing and Construction of Slurry Seals.

A completely revised edition of Design Technical Bulletins is planned for publication in February 1990 and will include several new advanced test methods which are applicable to conventional slurry as well as the new polymer modified technologies.

Here we want to :

1. Review the current design method(s);
2. Examine an actual slurry design;
3. Compare a variety of abnormal test results and their interpretation;
4. Discuss the differences in test response between conventional Slurry Seal and Polymer modified micro-asphalt as well as some of the new tests which are required.

PART 1 REVIEW THE CURRENT SLURRY SEAL DESIGN METHOD

Emulsion mixes currently represent considerably less than 2% of all bituminous mixes. Great confusion arises among 98% of the paving technologists when their hot mix design experience attempts to explain slurry design. The main differences are:

1. Accounting for the presence and effects of water in the mix (usually there is more water than bitumen);
2. Considerably more aggregate fines (0/#200) are present. Maximum fines in hot mix is about 5% or the minimum which is allowmed in Slurry and Micro-asphalt. Typical Slurry gradations have 2 or 3 times more fines than hot-mix;
3. Presence of emulsifier residues, in quantity, in the bitumen and at the bitumen-aggregate interface;
4. A much wider range of field variation in aggregate gradation and bitumen content;
5. Comparatively much thinner layers than in normal hot mixes.

The slurry seal micro-asphalt designer accepts the materials submitted and may not alter the emulsion qualities nor the aggregate gradation. The designer must do his best with the materials submitted to him.

The variables are astronomical: At any one moment any one of 1,300 different chemical types of aggregates, 400 different chemical types of bitumens, ten different chemical classes of emulsifiers and 350 emulsion plants may be submitted. There are 1,820,000,000 simple possibilities which gives rise to Benedict's law: $C=V_n{}^2$.

If there is one fact we've learned through our experience it is that "EACH SYSTEM IS ITS OWN THING". Change any single element and it becomes a whole new ball game.

Though we are beginning to gain a better understanding of the "chemical porridge" called slurry seal, the astronomical variables, requires an empirical or experimental approach rather than a scientific approach to slurry and microsurface design: i.e. construct a series of laboratory specimen mixes, subject them to simulated field condition tests and compare the test results with known successful field results.

The primary tests are the Wet Track Abrasion Test which establishes the minimum bitumen or emulsion content and the Loaded Wheel Sand Adhesion Test which establishes the maximum emulsion content. Plots are made of the WTAT loss-emulsion curve and the LWT Sand adhesion-emulsion curve and an optimum emulsion content selected between the 2 values at the stated limits as close to the maximum emulsion content as realistic field tolerances will allow.

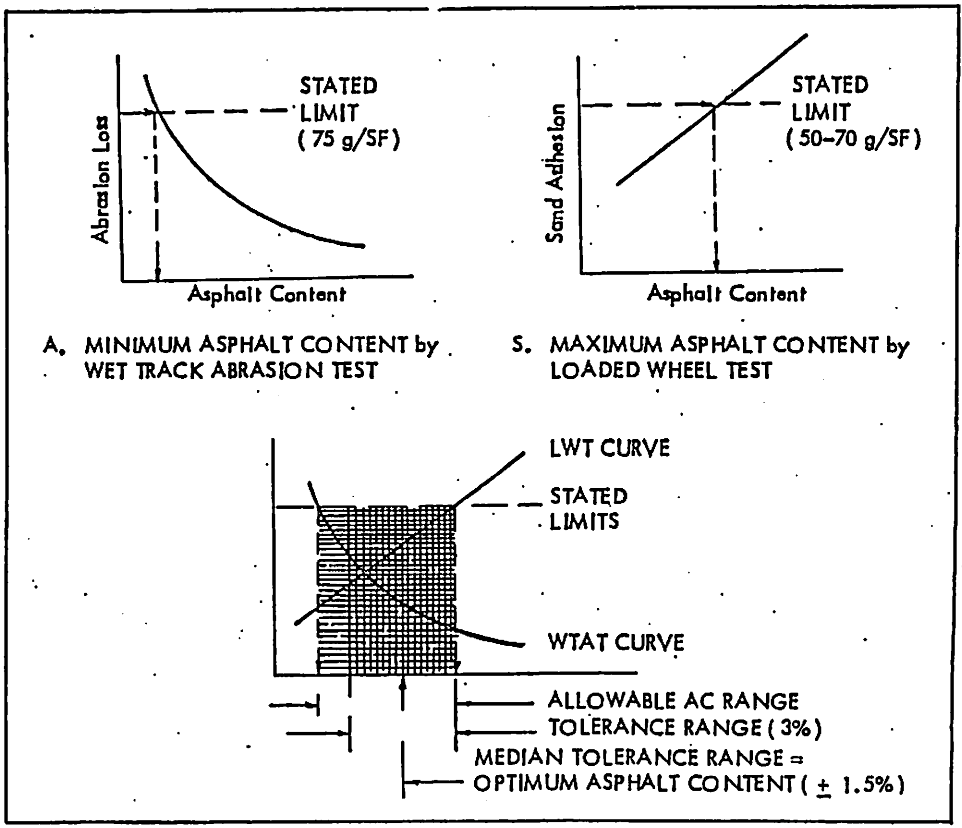


FIGURE 1 — GRAPHICAL DETERMINATION OF OPTIMUM ASPHALT CONTENT

Other methods are:

Surface area design for 8.0 or 6.5 micron bitumen film thickness;
Minimum 50g/SF WTAT loss/AEMA;
Voids analysis;
Marshall stability and flow.

Most design work is performed for and paid by the contractor. Most contractors have little interest in all the details of the test results, they simply want a system that "WORKS".

Consequently, the designer, during the course of his work, must answer these contractor (client) questions:

1. Will "it" mix? - Working time;
2. Will "it" set? - Rain resistance time, traffic time;
3. Will "it" last? - Kick-out & wet abrasion loss;
4. Will "it" be safe? - Retain texture, no bleeding;
5. Will "it" perform? - Customer satisfaction.

PART II CONVENTIONAL SLURRY SEAL-A LABORATORY DESIGN EXAMPLE
(PRELIMINARY DESIGN EVALUATION)

This particular design involved the use of all new materials with no previous field experience. Because of this, considerable preliminary evaluation work was undertaken to assure that these new materials combinations would be compatible and would have a good chance of success in the field. Three emulsion formulations were mixed with 0/#4 aggregate using no chemical filler, portland cement and hydrated lime as well as three other chemical additives.

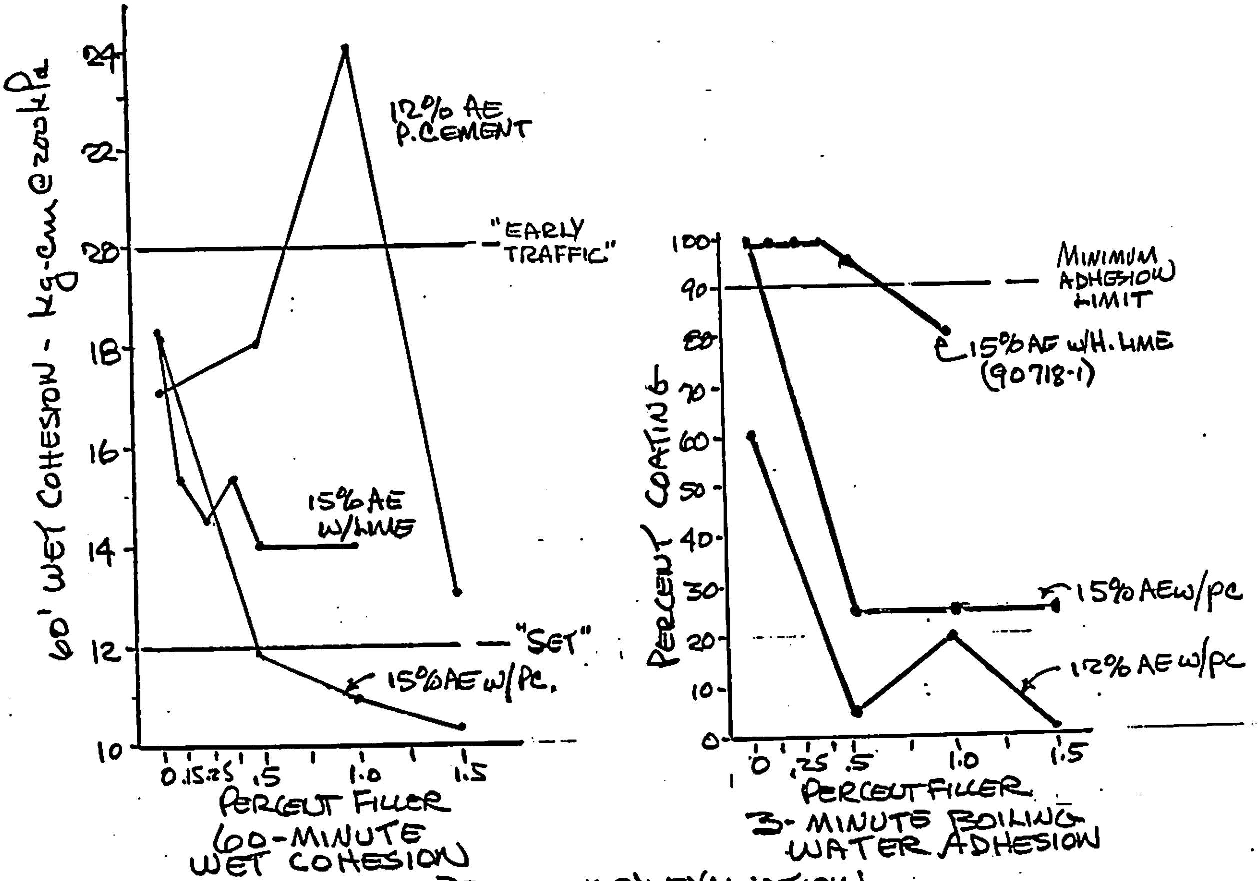


FIGURE 2. PRELIMINARY EVALUATION (90718-1 AE w/ #230 AGG.)

60' Wet Cohesion Test Patties were evaluated (figure 2). Cohesion with the initial emulsion formulation best at 15%AE and no filler at 12% AE and 1% cement did quite well. Mix times were lengthened by the use of lime or cement. However, the boiling water adhesion was unacceptably low with portland cement. The initial materials would tolerate up to .5% lime.

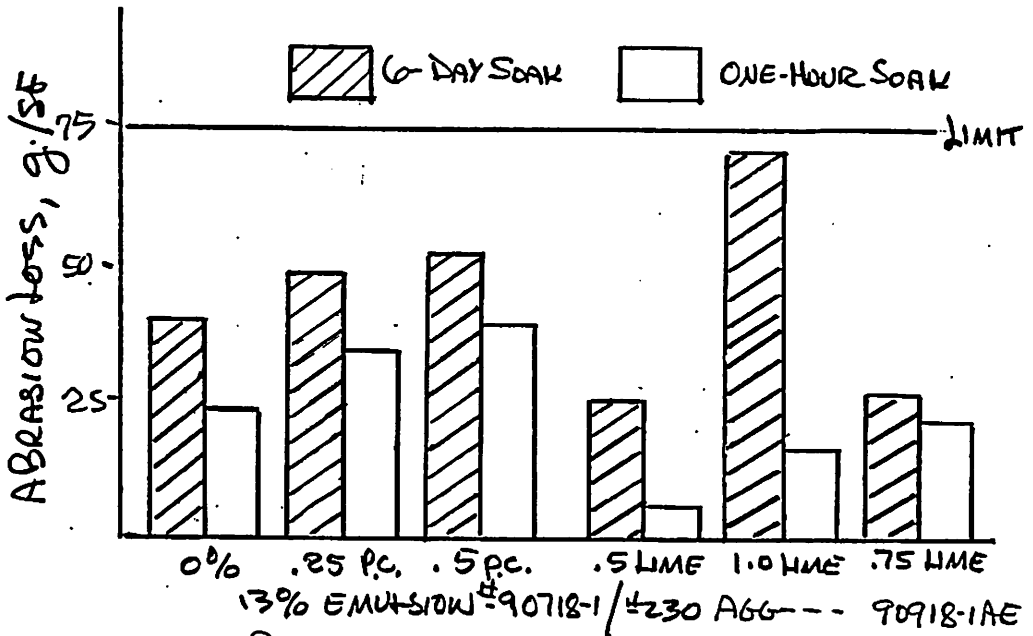


FIGURE 3. PRELIMINARY MATERIALS EVALUATION
6-DAY SOAK WET TRACK ABRASION TEST

Single 13% AE One-hour and 6-day soak Wet Track specimens (fig. 3) were tested with relatively good results, with .75% or less lime out-performing cement.

SCHULZE-BREUER-RUCK COMPATIBILITY TEST
C/#10 STANDARD GRADATION
#90718-1 AE VS. #230 AGG.

MIX FORMULA			ABSORB-TION, g.	ABRASION LOSS, g.	COATING, %	INTEGRITY %	GRADE RATING
FLR	H2O	AE					
0	17.5	12.5	.95	2.24	90+	97.6	OAA=8
.5pc	15.0	12.5	1.06	6.09	90+	0	OAO=4
.5hl	16.0	12.5	1.00	3.98	90+	25.5	OAD=5

– FIGURE 4 –

Schulze-Breuer-Ruck Compatibility Tests (fig. 4) were not stellar but indicated that the most compatible combination with the initial emulsion formulations was with no filler.

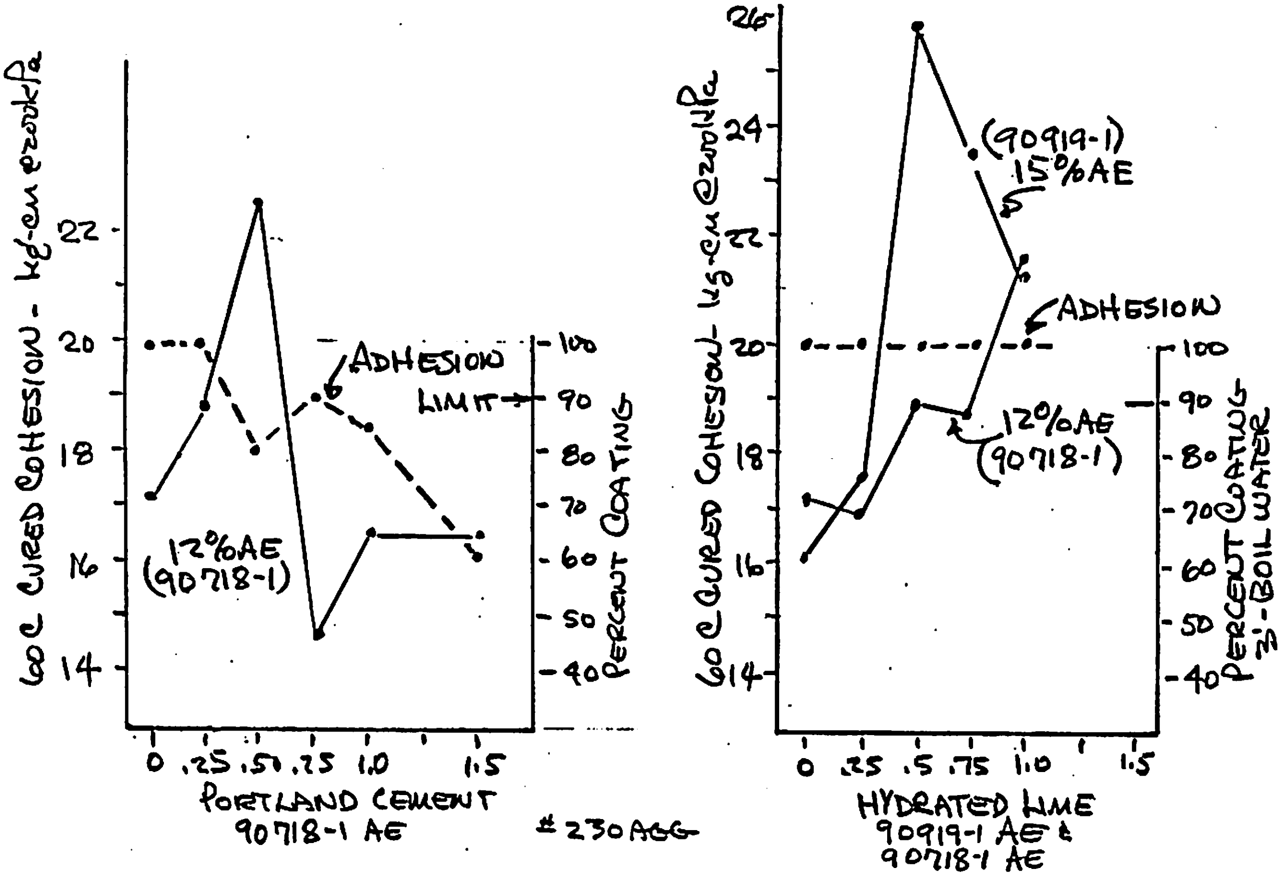


FIGURE 5. PRELIMINARY EVALUATIONS
#230 AGG + 90718-1 AE

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Results from the 60C Cured Cohesion Tests (fig. 5) suggested that .5% cement was optimum at 12% AE (with poor adhesion) while 1% lime yielded an equivalent cured cohesion with 100% adhesion. Later formulation modifications yielded excellent 60C cured cohesion at .5% lime.

Initial field trials with a slightly altered emulsion (90907-1) showed that the materials combination was too water sensitive to control segregation in the field, without the use of lime. Further formulation modifications (90919-1) produced a very workable and attractive field slurry with no kick-out, quick-sets, good early traffic times and no surface richness. The tests performed for this design used both of the emulsions.

DESIGN PROCEDURES AND TESTS

A. MATERIALS ANALYSIS

1. The first step in a design, of course, is to test the aggregate and emulsion submitted to make sure that the specification requirements are met. The aggregate tests we perform are usually:
    - Gradation (dry and wet), (we add the 1/4" or 5/16" and #325 screens)
    - Sand Equivalent, Simple surface area calculation
    - Methylene blue absorption, mg/g 0/#325
    - Blue factor
    - pH 10:1
    - Specific gravity (dry)
    - Specific gravity SSD
    - Absorption
    - Bulk specific gravity & compacted and loose unit weights
    - Voids, compacted and loose
    - Acid Reaction

2. Emulsion Tests are minimal:
    - Sieve%
    - AC Residue%
    - pH
    - R & B softening point

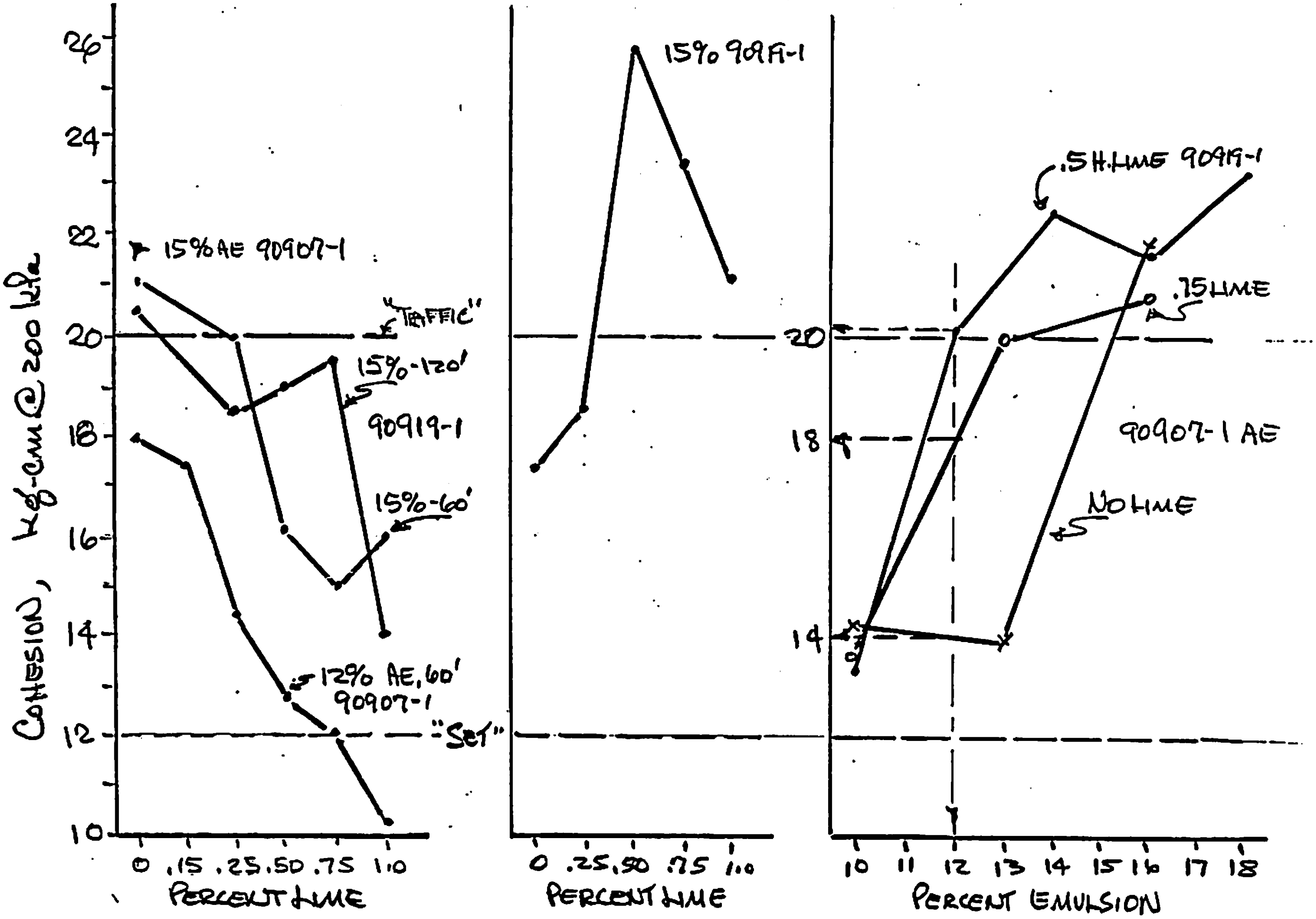
3. Chemical Fillers are usually local sources and from current production.

4. Water is usually our softened tap water.

TRIAL MIXES

B. Our standard trial mixes use initially 100% 0/#4 with the +4 discarded. Both the Sand Equivalent and ASTM WTAT Tests require 0/#4. We also use 12% AE contents as the initial standard for comparison with all other work. After this work is completed we may use different emulsion contents or gradations.

Trial mixes are made to determine:
- Mix time
- Clear water set time
- 30' & 60' wet cohesion
- Optimum filler contents
- Total liquids requirement
- 2-day air dried subjective analysis:
    - Color, appearance
    - Toughness
    - Wet adhesion
    - Susbtrate adhesion
    - 3' boiling water adhesion
    - 60' Cured cohesion for filler content confirmation and system classification.



WET COHESION
12 & 15% AE

60C CURED COHESION
15% EMULSION

60C CURED COHESION
CLASSIFICATION CURVE

- FIGURE 6 -

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Figure 6 plots the cohesion test results at .25% increments of filler contents. Here the 60-minute wet cohesion tests do not clearly indicate the optimum filler content. The best wet cohesions are at no filler. The 60C cured cohesion clearly shows that .5% lime at 15% AE gives by far the best high temperature cohesion.

The 60 cured cohesion curves show the 90919-1 AE @ 12% have a rating of 20 kg cm while the 90907-1 AE has ratings of 18 and 14 kg cm at .75 lime and no lime respectively.

.5% hl at 15% AE is selected as the optimum filler content. Mix time is 180"+, clear water set time is 45' and traffic time is between 2 and 3 hours. This is a Quick-Set, Slow-Cure system.

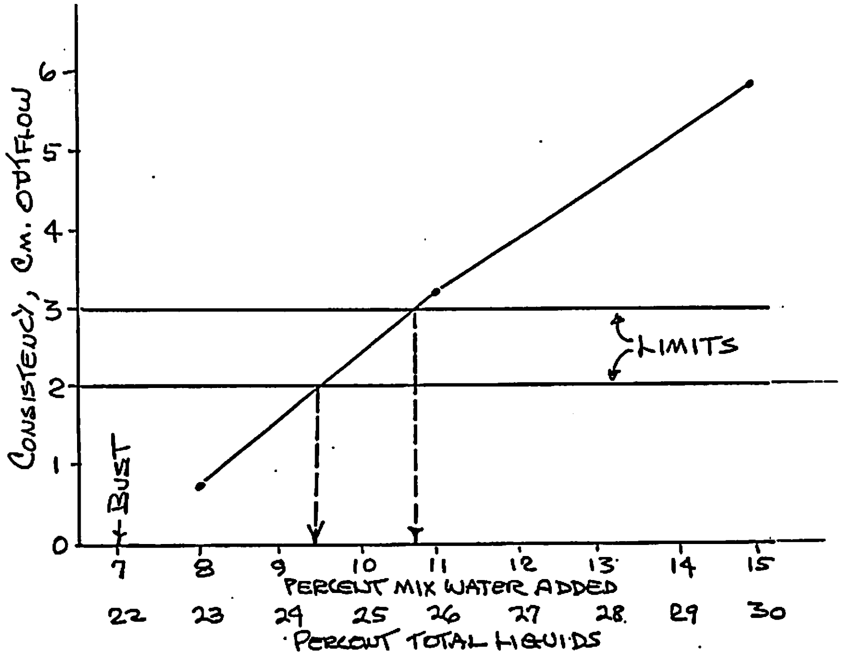


FIGURE 7. CONSISTENCY TEST - OPTIMUM LIQUID CONTENT #9099-1 @15% vs. #234, 0/#4

C. CONSISTENCY-COMPATIBILITY TESTS

Complete Consistency Tests to determine optimum water and total liquid content were not completely run in this design because of a shortage of materials. However, consistency tests at 15% AE, fig 7 , show that 9.5 to 10.75% mix water added (24.5 to 25.75% total liquids) is required to give the required 2 to 3 cm, consistency. This consistency is normally used for making the field simulation test specimens. Cured consistency specimens may be split in half to observe possible segregation.

100-gram Split Cup Compatibility mixes were cast at 23 of 26, and 30% total liquids. The 30% total liquids mix overfilled the voids or space available for liquids and floated a thick, sticky film of pure asphalt to the surface while the lower liquid contents did not. Our "Kleenex" Test failed on the high liquids mix. It is noted that the best surface coatings in this test were at the lowest total liquids.

		TOTAL LIQUIDS	REMARKS	"KLEENEX" TEST	DEPTH, mm
.5HL	8 - 15	23	No segregation*	PASS	26.38
.5HL	11 - 15	26	No seg., sl. rich	PASS	26.35
.5HL	15 - 15	30	Excess surface AC	FAIL	26.41

*best surface adhesion

D. COMPATIBILITY.

Since homogeneous non-segragating slurries can be made which have 90%+ coatings and have adequate mix times as well as good 6-day Soak Wet Track Abrasion Tests, the system is judged "compatible".

FIELD SIMULATION TESTS ARE:

The WET TRACK ABRASION TEST which simulates wet abrasive conditions found in wet weather while cornering, braking or accelerating.

THE MONOLAYER LOADED WHEEL SAND ADHESION TEST measures surface asphalt film thicknesses (excess asphalt) after the compactive effort of about 1 million vehicles.

THE MULTILAYER LOADED WHEEL DISPLACEMENT TEST measures the stability or resistance to flow or rutting and corrugating tendencies of multilayer slurries.

E. WET TRACK ABRASION TEST (fig. 8). 1/4" x 11" (800 grams) diameter specimens prepared in triplicate at each of 3 emulsion contents; in this case 10, 13 and 16%. After drying to constant weight in a forced draft oven. 2 sets are soaked for one-hour and scrubbed with a weighted hose for 5 minutes. The abraded specimens are washed, dried and weighed to determine the amount of aggregate lost during the test. 75 grams per square foot is the maximum allowable loss. This value establishes the MINIMUM emulsion content.

We then soak the remaining set of specimens for six days and then perform the test. Though no standard value has been determined, we believe that 75 grams is also a valid number for the 6-day soak.

In this design, all Wet Track Abrasion Test losses were below the 75 gram loss limit. No minimum value could be established with the submitted materials.

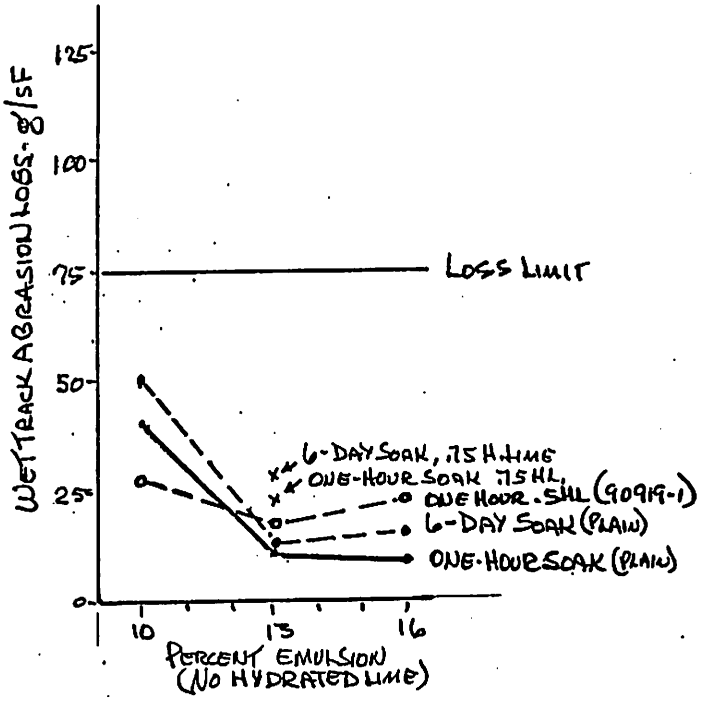


FIG. 8 - WET TRACK ABRASION TEST
#90907-1 NA, #230 AGG

9/29/89-CRB

F. MONOLAYER LOADED WHEEL SAND ADHESION TEST specimens (fig. 9) (1/4" x 15" 300 grams) were prepared in duplicate at 10, 13 and 16% emulsion contents, the same as with the WTAT's. One set was fully compacted with 1,000 125 lb cycles of the Loaded Wheel Test machine. During the runs, no tackiness was observed.

ASTM C-109 (fine 30/100 mesh Ottowa Sand) calibrated sand at 180F was applied to the compacted surface and the amount of adhered sand measured and reported as grams per square foot.

The second set is tested for sand adhesion without compaction. The difference between compacted and uncompacted sand adhesion values is usually about 12 grams per square foot.

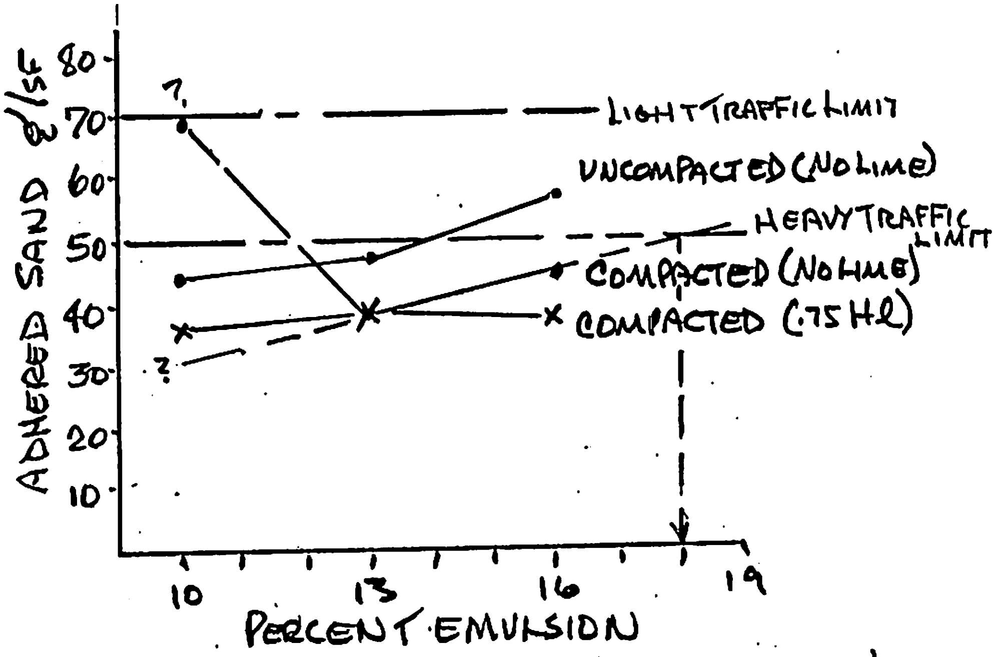


FIG.9 LOADED WHEEL C-109 SAND ADHESION
#9D907-1 NO. #230AGG.

9/29/89-CRB

In these tests an error occured in the compacted 10% AE specimen. The result was corrected by reducing the uncompacted result by 12g/SF to give 32g/SF.

Though no final correlations or values have been set, the original estimated values of 50 and 70 g/square foot for heavy and light traffic appear to be valid if not slightly high.

Here 16% AE sand adhesion was 44.6 g/SF indicating a wide margin of safety. If projected, the maximum emulsion content becomes 18%.

G. THE MULTILAYER UNCONFINED LOADED WHEEL DISPLACEMENT TEST (fig. 10) uses 1/2" or 13 mm x 15 specimens which are measured before and after 1,000, 125 lb. LWT cycles at ambient for vertical and lateral displacements (compaction). Without lime very high values were found expecially the lateral displacements. With lime a peak stability was found for both vertical (25.4%) and lateral (5.0%) displacements at 16% emulsion.

The system is unsuitable for multilayer application under heavy traffic. Our maximum multilayer criteria for vertical and lateral displacement is 10% and 5% respectively.

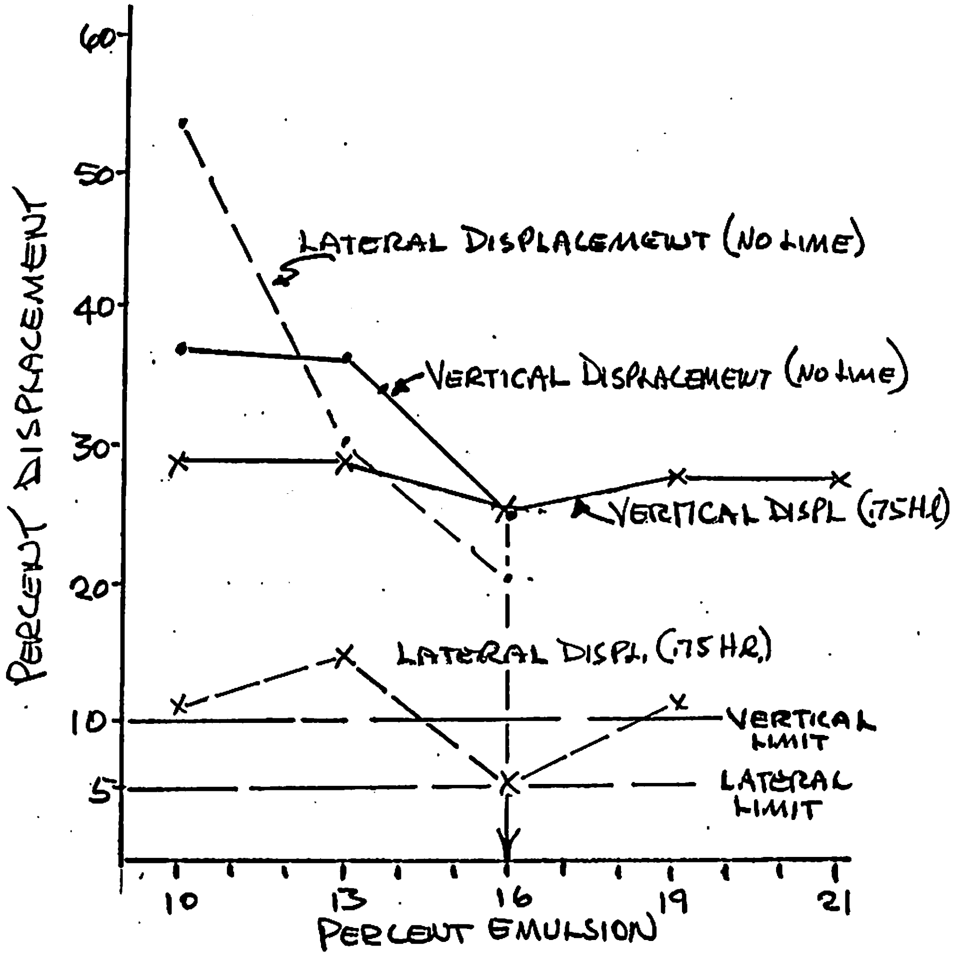


FIG. 10- MULTILAYER UNCONFINED LOADED WHEEL TEST DISPLACEMENTS
#90907-1 AE N3, #250 AGG.

9/29/89 - CRB

H. Thus far, our tests have told us that we have a compatible mixture, that is mixable and will set quickly and have good high temperature cohesion at .5% lime, but that no clear minimum emulsion content can be established and that the maximum AE might be 18% AE which seems a little high and that this material should not be used for multilayer application under heavy traffic but that maximum resistance to flow was at about 16% AE.

SURFACE AREA ANALYSIS.

To check our results we calculated the surface area of the aggregate and the bitumen required for an 8 micron bitumen coating of this surface area. (We are very leary of surface area design which is faulty in our opinion with high fines aggregates.) Additionally, we calculated the voids in the compacted aggregate and the extent to which they would be filled by the bitumen required for 8 micron coatings.

The surface area calculations here were based on a dry gradation, estimated bitumen specific gravity and aggregate CKE all of which introduce a small error. At any rate our calculations indicate a 15% emulsion content or 9.57% AC added or 8.65% AC extracted.

VOIDS ANALYSIS

At this amount of Bitumen, voids in the total compacted mix would be 12.0% and the percent of total voids filled would be 58.8%. These values are right in line with data from previous successful designs of this kind.

To check our liquid contents, we calculated the dry aggregate loose voids and the total liquids required to fill these voids our results were 26.3% total liquids which squares with our split cup "Kleenex" test and at 3.5cm consistency. Excessive total liquids are one cause of bleeding surfaces and create excessive "hydraulic" voids which separate the aggregate or prevent contact and thus excessive "kick-out".

I. In the formal design report the data is summarized in a DISCUSSION AND INTERPRETATION SECTION with comments on the various test results. Finally the JOB MIX FORMULA recommendation is given along with an estimation of the spread rate.

In this design we allowed for field application precision of +/-1.5% Our optimum recommendation was 15.5% +/- 1.5% or a range of 14.0 to 17.0 % AE with the upper limits suggested for very light traffic and the lower limits for heavy traffic.
.5% +/- .25% hydrated lime was recommended.

PART III COMPARISON OF TEST RESULTS WITH OTHER CONVENTIONAL SLURRY DESIGNS.

In the following comparisons, example "A" is the plot of the foregoing design test results.

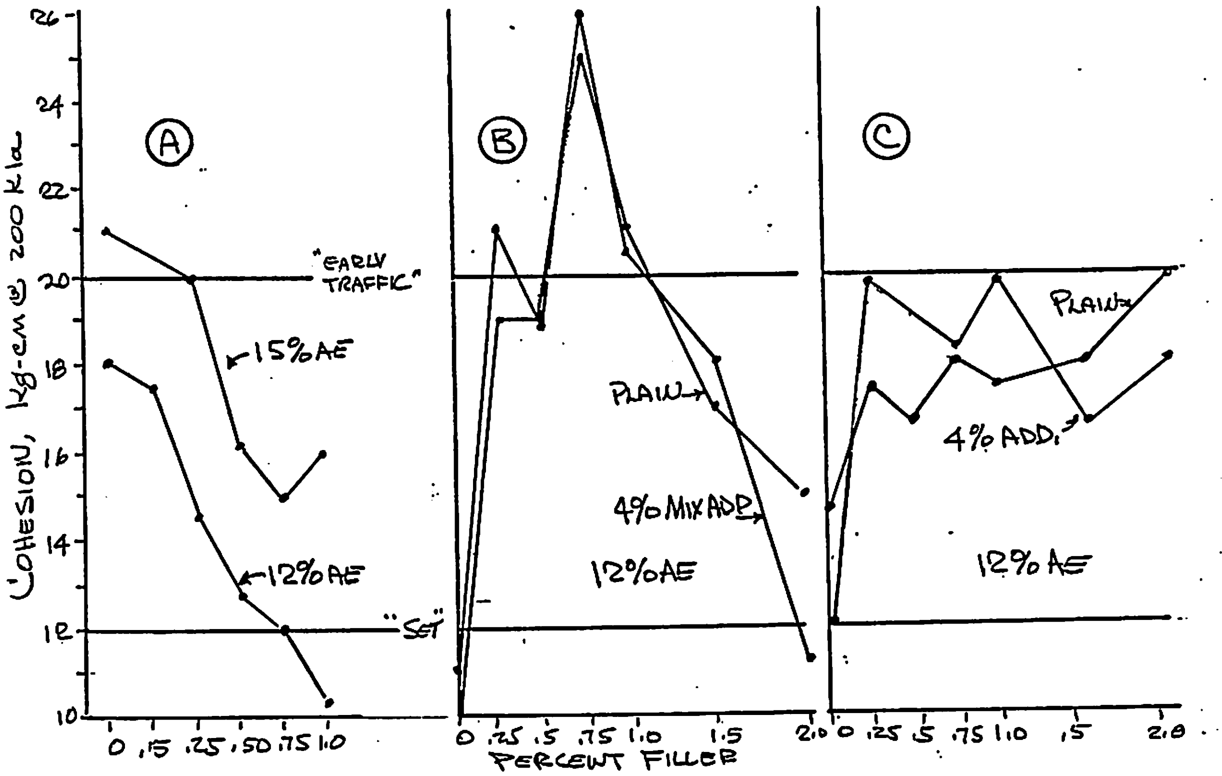


FIGURE 11. 60' WET COHESION TEST-EXAMPLES

Fig. 11 60' WET COHESION.

A. As filler increases, Wet Cohesion decreases until there is no set at 60' 15% emulsion though parallel to the 12% curve is 2 or 3 points higher.

B. A definite peak occurs at .75 filler regardless of mix additives. QT systems achieved at .6 to 1.1% filler. Additional filler reduces 60' wet cohesion to the "SS" level of below 12 kg cm/60'. This curve is typical of high quality carefully formulated systems. We call this the "Benedict curve".

C. Here there is a single (point) with the addition of .25% filler where the 20 kg cm traffic cohesion is found. Increases in filler only flatten the curve irrespective of the filler or additive content.

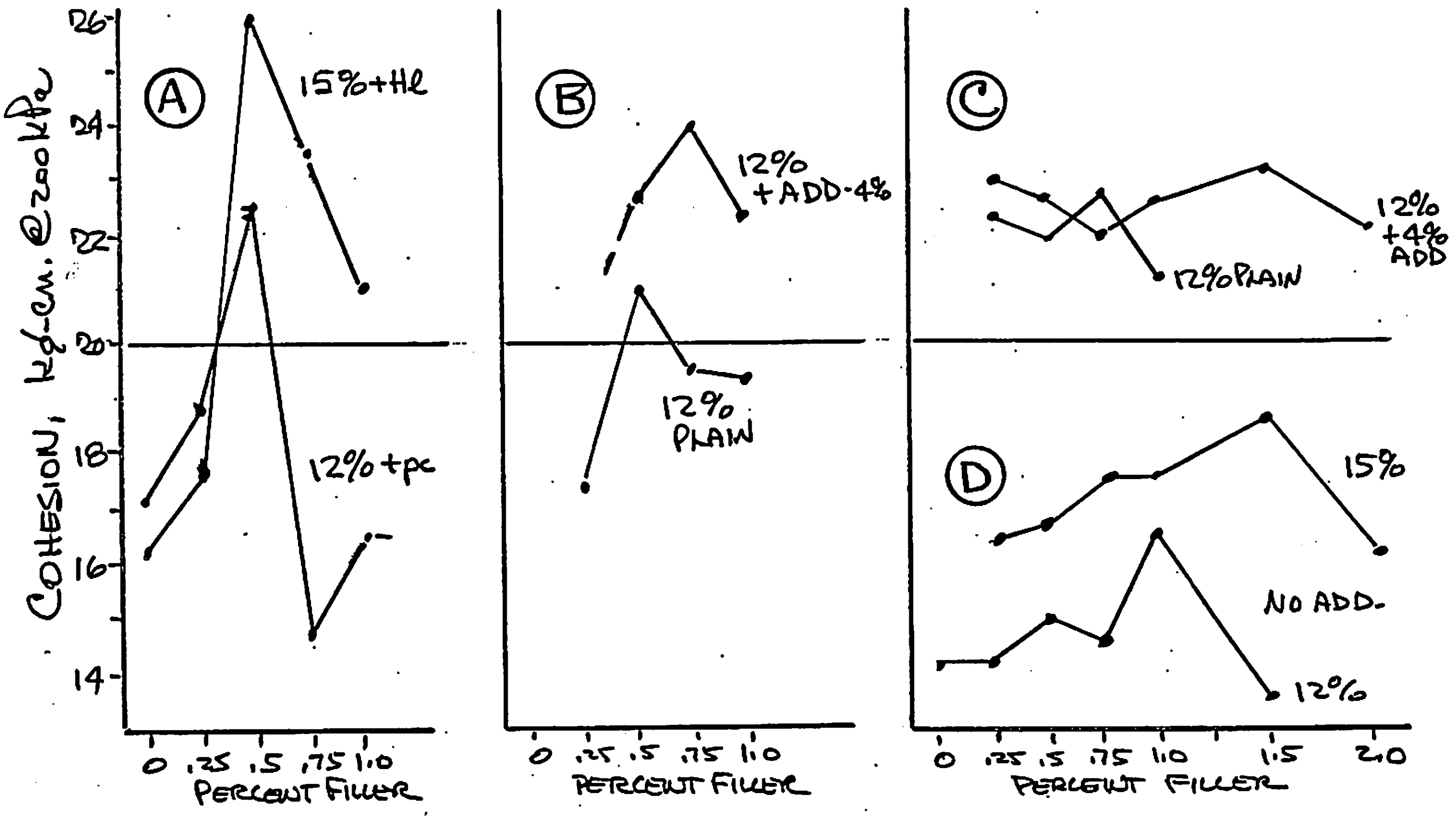


FIGURE 12. 60C CURED COHESION - EXAMPLES

Fig. 12. 60 C CURED COHESION.

In these examples the 60C Cured cohesion is used to determine the filler content for high temperature cohesion.

A. Both cement and lime at either 12% or 15% AE give optimum peaks at .5% filler, while the wet cohesion gave no optimum. The cured cohesion does do so.

B. This is a confirmation of example B Wet Cohesion Peak. Note the .25% filler shift when additive is used.

C. Nearly flat peaks require .75% and 1.5% filler depending upon the use of a mix additive.

D. The requirement for filler also shifts from 1.0 to 1.5 as the emulsion content increases from 12% to 15%.

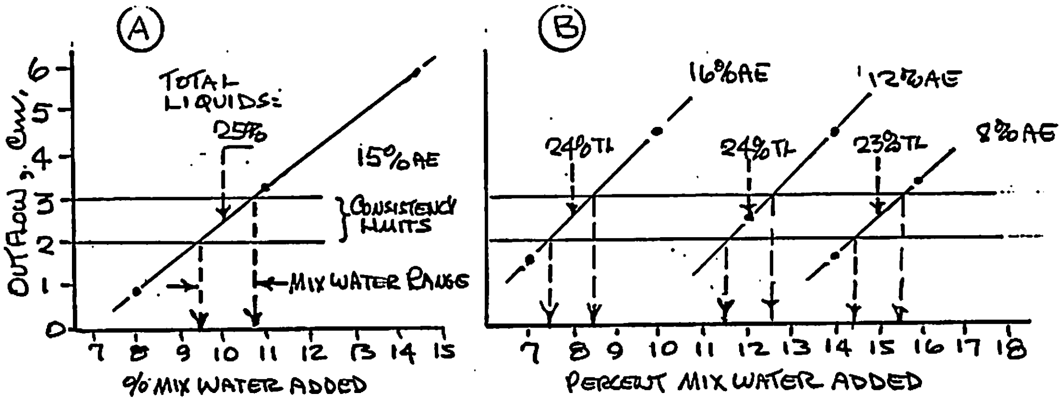


FIGURE 13 CONSISTENCY TEST - OPTIMUM TOTAL LIQUIDS AND MIX WATER
— EXAMPLES —

Fig. 13. CONSISTENCY TEST optimization of mix water and total liquid contents is a straight forward procedure. The primary purpose of the test is to determine the mix water added or total liquids required to produce the same mixture viscosity or consistency at each level of emulsion content to enable casting of uniform WTAT and LWT specimens. Between 2 and 3 centimeters average outflow has been considered optimum; our preference however is 3 to 3.5 cm.

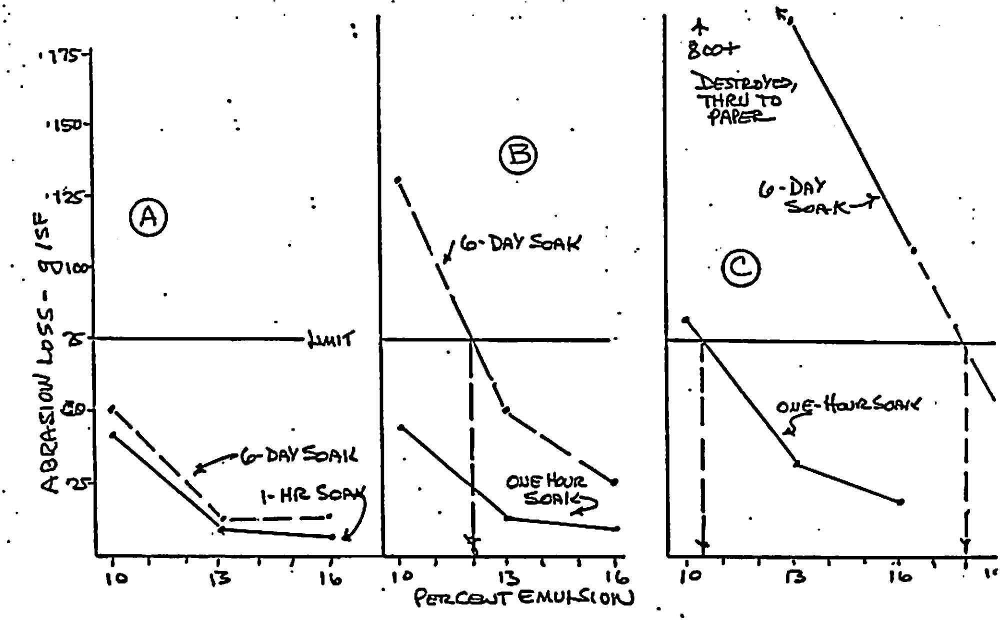


FIGURE 14. WET TRACK ABRASION TEST - EXAMPLES

Fig. 14. One-hour and 6-day Soak WET TRACK ABRASION TESTS shows 3 rather typical kinds of results, Example A shows the WTAT one-hour 6-day curves as essentially the same. With a reasonable amount of emulsion, the 75g/SF loss limit is not found and no minimum emulsion content can be established from either soak period. Example B's one-hour soak is also too good to establish a minimum emulsion content while the 6-day soak curve does establish a minimum AE content at 12%.

Example C tells two stories: The one hour peak is rather typical and suggests a 10.5% minimum emulsion content; but the 6-day soak specimen is quickly and completely disintegrated at 10.5% AE and is only saved at 18% AE. We are inclined to look at this result with a jaded eye.

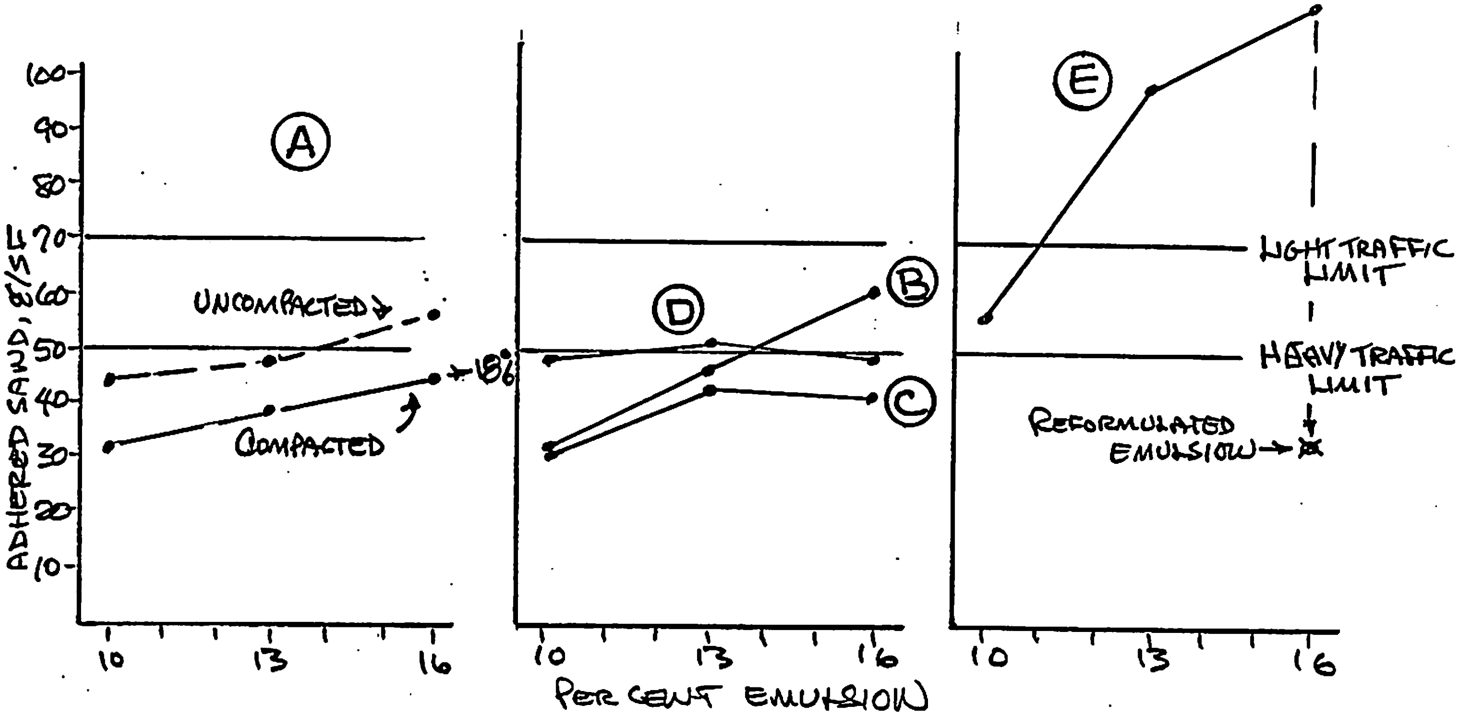


FIGURE 15 MONOLAYER LOADED WHEEL SAND ADHESION TEST
- MEASUREMENT OF EXCESS SURFACE ASPHALT
- EXAMPLES -

Fig. 15. MONOLAYER LOADED WHEEL TEST SAND ADHESION TEST is a measure of the thickness of the surface films of asphalt. Example A shows a very typical sand adhesion curve though the 18% emulsion indicated at 50 grams/SF may be too much for heavy traffic. Example B shows a film thickness increase in proportion to emulsion content. C shows an initial increase and then no increase with emulsion content. D shows a high initial film thickness which is constant regardless of emulsion content. We suspect that the ability of the emulsion to plate out onto the aggregate surface to the extent that the aggregate is "satisfied" or the emulsion was "exhausted" on the aggregate surface and any remaining unreactive emulsion simply drains into the loose void space. The B case appears to not only plate out on the aggregate but then continues to plate out, build or layer out upon itself.

Example E is a clear case of asphalt floatation due to either rejection of the emulsion by the aggregate, excessive total liquids in a low void gradation or a combination of both.

These phenomena bear investigation. Whatever the cause, with E example we can guarantee very greasy wheel tracks, a likely hazardous situation and likely a poor substrate adhesion. This situation clearly shows an incompatible system.

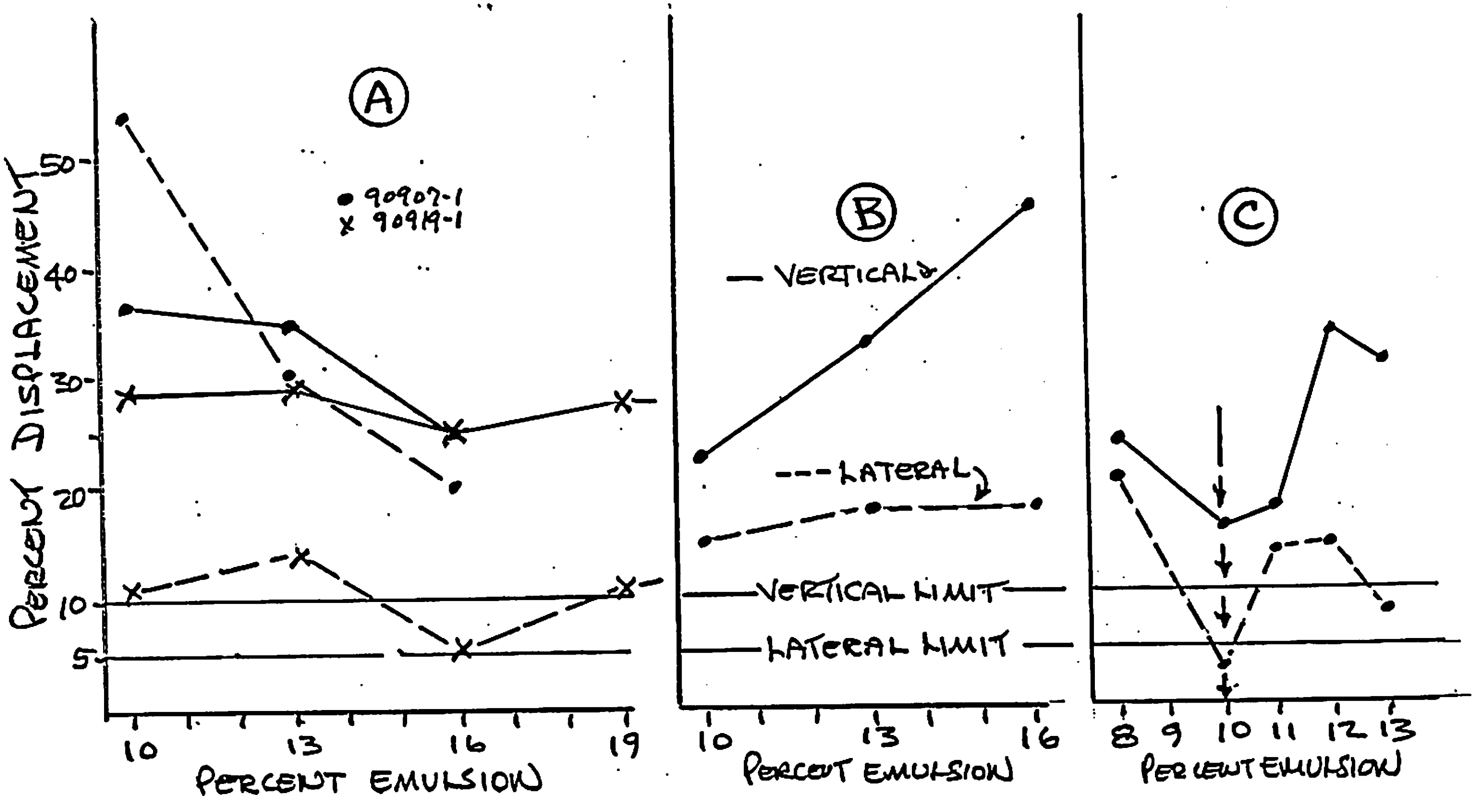


FIGURE 16. MULTILAYER UNCONFINED LOADED WHEEL DISPLACEMENT TEST
1000, 125 LB CYCLES @ 75F
- EXAMPLES -

Figure 16. MULTILAYER UNCONFINED LOADED WHEEL DISPLACEMENT TEST is used to determine the resistance to flow or stability of multilayer as in the case of rut filling or wedging where stability over a range of thickness is desirable. Though no criteria has been established, we observe that slurries which displace less than 10% vertically and 5% laterally are highly satisfactory for multilayer application. In small increments of emulsion content, it is usually possible to find a peak stability which resembles an inverse Marshall curve.

Examples A and B indicate a peak resistance to vertical displacement (maximum stability) at 16% emulsion. The 25% displacement is a value too great for multilayer application.

Example C becomes proportionately less stable with increasing emulsion content. Example D is a classic inverse Marshall curve both vertically and laterally where the optimum emulsion content is 10%. However, the 14.5% vertical displacement does not meet our multilayer criteria even though the results are considerably better than typical slurries.

PART IV SLURRY SEAL AND MICROASPHALT PROPERTIES COMPARED

In the previous Parts II & III we've fairly well described the response of a good QS Slurry Seal to laboratory tests. The distinguishing feature of slurry seal is that there is little resistance to rolling compaction and that in time slurry will "flatten" and become smooth, sometimes smoother than desired; ie, macrotexture is substantially reduced.

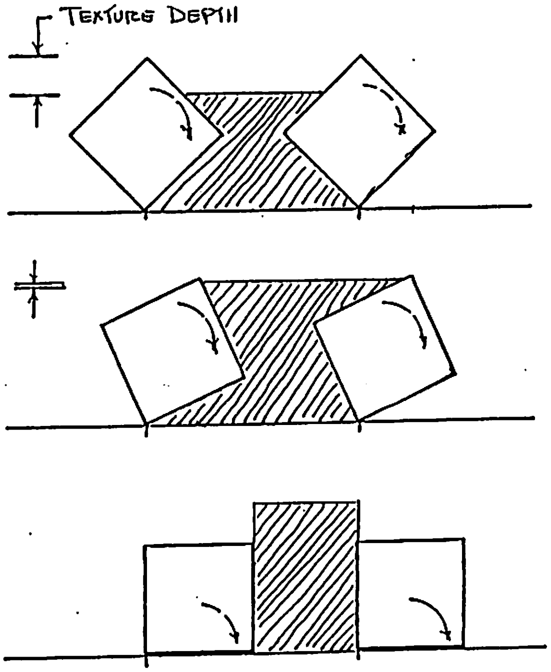


FIG.17- EFFECT OF TRAFFIC COMPACTION ON MACROTEXTURE (MATRIX EXTRUSION)

Figure 17 illustrates the mechanism that takes place under traffic compaction. The matrix or mastic portion of the mix is plastic and allows the larger aggregate particles to roll over into their most comfortable position while closing the void spaces by extruding the plastic matrix into and filling the space available for macrotexture.

Polymer Modified Microasphalt responds to the compactive effort of rolling traffic by resisting compaction in this way. This single property is THE difference between conventional slurry seal and Polymer Modified MicroAsphalt. The microasphalt matrix is very stiff and essentially non-plastic.

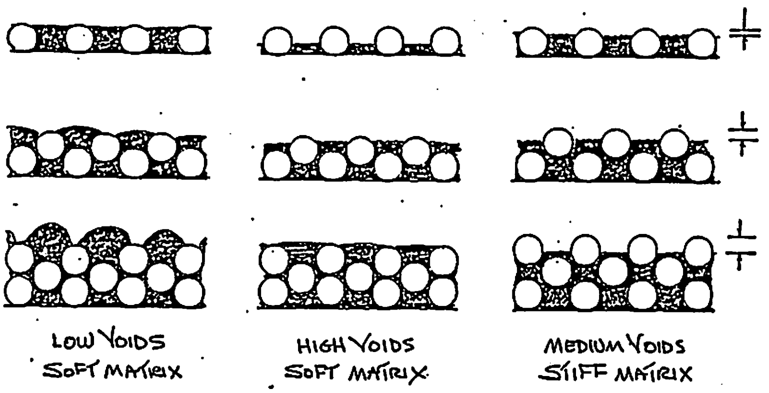


FIG.18 - EFFECT of LAYER THICKNESS & MATRIX PROPERTIES ON MACROTEXTURE DEPTH

Figure 18 illustrates the traffic response differences between low and high void gradations with a conventional soft matrix slurry and a medium void stiff matrix modified microasphalt. As layer thickness increases, voids are closed and the "matrix" is extruded to the surface resulting in a loss of texture with the soft matrix conventional slurry. With the stiff matrix mix the REVERSE is true; texture INCREASES with layer thickness!

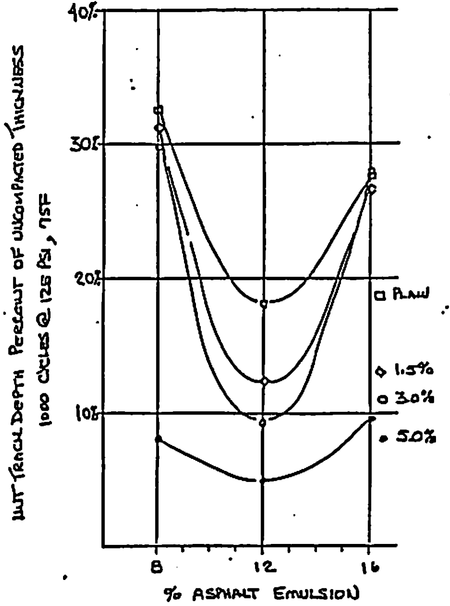


FIGURE 19A. POLYMER "F"
G1201-1 @ 5%; G1201-2 @ 3%
G1201-3 @ 1.5%; G1201-3. PLAIN
VS. SAND 2 AGG. + KA ADD.

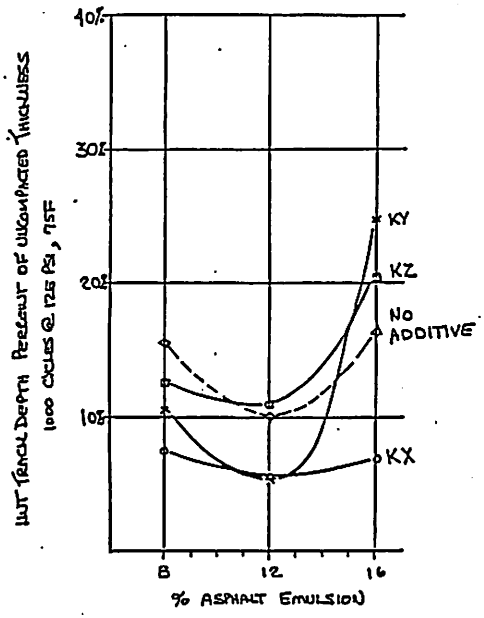


FIGURE 19B. EFFECT OF MIX ADDITIVES
POLYMER "A" - 3%
VS. SAND 2 AGG.

Laboratory tests to determine the property of resistance to compaction is already at hand, the Multilayer Unconfined Loaded Wheel Test at ambient temperatures. Figure 19 shows the effects of polymer content, additive type and emulsion content on the resistance to compaction of multilayered specimens. First, the maximum resistance to compaction or vertical displacement occurs at about 12% emulsion without regard to formulation. Secondly, as polymer content increases, the resistance to compaction at optimum emulsion increases. Thirdly, by "tailoring", the "U" or "V" shaped curve metamorphosizes into a flat, saucer-shaped displacement curve; i.e., displacement is uniform or unaffected by a wide range of emulsion content. ("ISOPAC" or "UNIPAC").

When a "Unipac" response is achieved there is room for error in field proportioning without sacrifice of product quality. It then becomes possible to use more emulsion or thicker bitumen coatings which should increase the service life of the microasphalt. This "UNIPAC" response also suggest that a new design method which uses the 10% vertical displacement value to establish both the maximum and minimum as well as the range of emulsion content as shown in fig. 20.

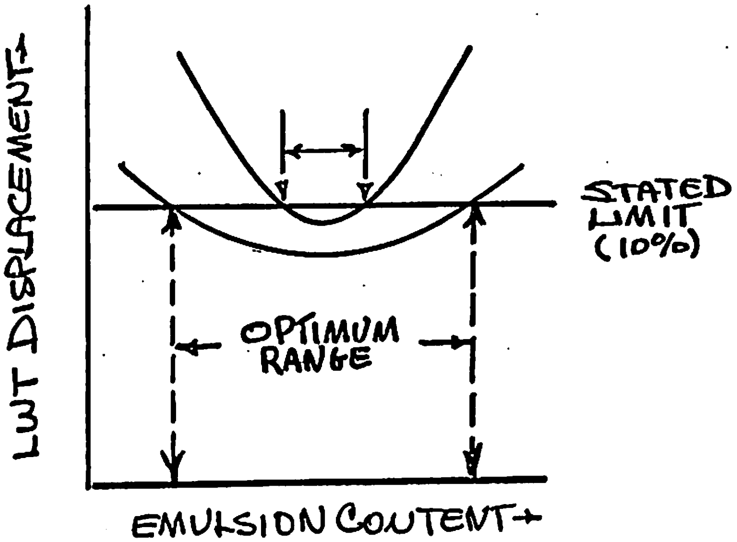


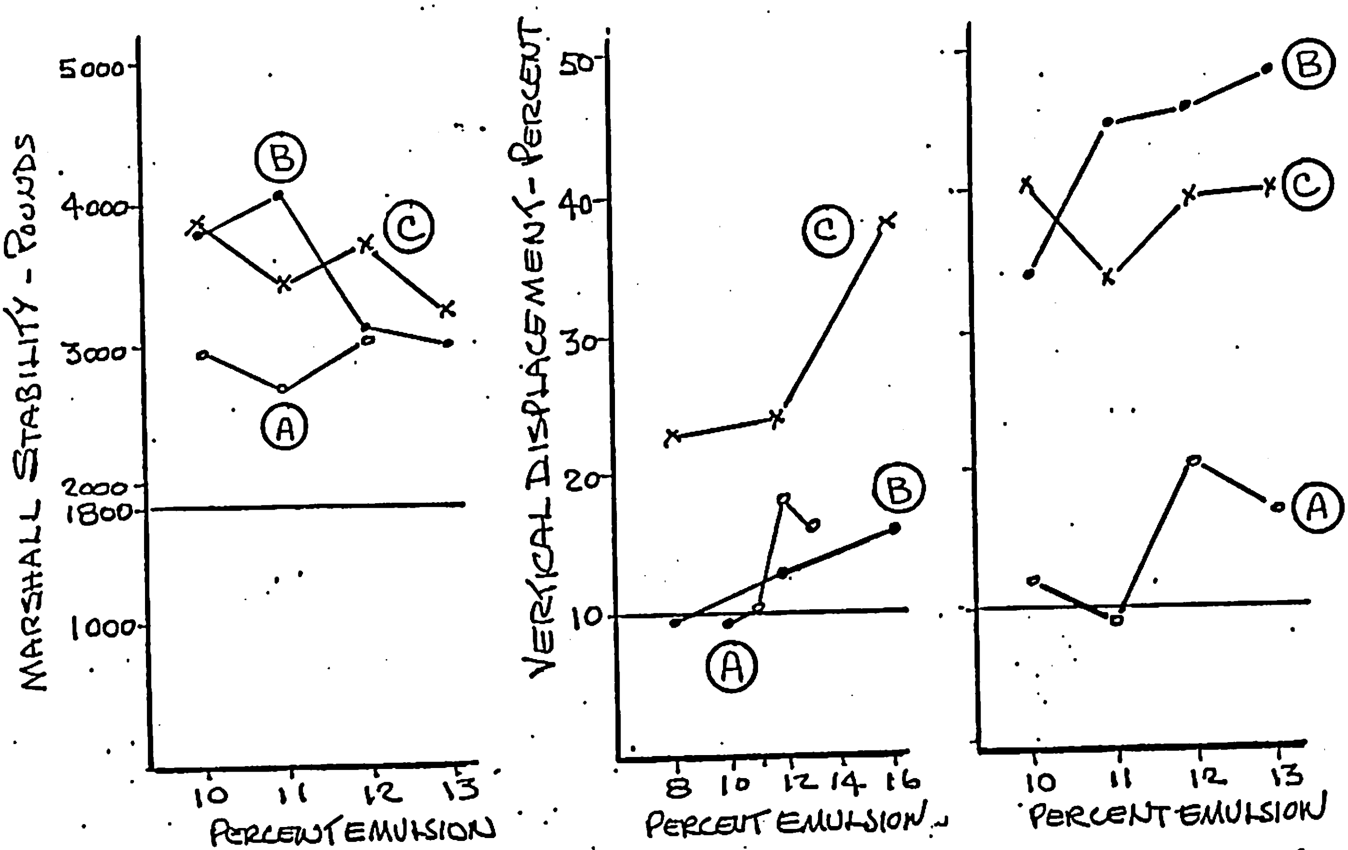
FIGURE 20. DISPLACEMENT DESIGN

What about the Effects of Temperature?

The previous discussion about design tests has said nothing about the effects of high summer and low winter temperatures. All previous tests were performed at the somewhat idealized laboratory temperature. In summer, pavement temperatures can be 35 to 40 F higher than the air temperature so that frequently the pavement temperature is above the softening point of the bitumen. Normal slurries literally melt and, in multilayers, will quickly displace, rut, shove and corrugate. In monolayers, large aggregate is kicked out and the slurry destroyed with heavy loading at intersections or curves.

The Loaded Wheel Test has been run at elevated temperatures (105F) but the LWT, in the normal configuration is too harsh at elevated temperatures. We prefer to use the British Wheel Tracking Machine for elevated temperature work where the wheel is stationary, the work moves, the wheel loads are about half the LWT loading and the machine is more adaptable to attachments. The British have done considerable work in correlating Wheel Tracking Rates of vertical displacement at 45C (115F) with field results and, in fact, the WTT is an integral part of their hot mix design procedure.

Rates of vertical displacement at 45C truly separates polymer modified microasphalt from conventional slurry. Figure 21 shows the comparative test results of 3 emulsion-aggregate systems (A,B,C) subjected to the 1) Marshall Stability Test, 2) Multilayer LWT at ambient and the 3) Wheel Tracking Test at 45C.



MARSHALL STABILITY
@ 140F
-POUNDS-

LOADED WHEEL TEST
@ 75F

WHEEL TRACKING TEST
@ 115F

- PERCENT VERTICAL DISPLACEMENT -

FIGURE 21 MARSHALL, LOADED WHEEL & WHEEL TRACKING TESTS COMPARED

System A is a polymer modified microasphalt; System B is a high quality slurry while System C is a commodity grade slurry.

In the ambient Multilayer LWT displacement test, A & B at 10 & 11% AE are equal at 10% vertical displacement. However, in the 115F Wheel Tracking Test System B melts into plastic putty at 45% vertical displacement while system A remains unaffected at the same 10% LWT displacement.

We note that the very best Marshall Stability (System B at 4,100 lbs.) had the very worst high temperature displacement.

Comparative low temperature properties are measured by the flexural tension test where the compacted LWT or WTT specimens are chilled to 4°C and arched upwards at 20mm per minute until cracking across the wheel path is noted. The mm travel at cracking is recorded as the test result.

Polymer modified microasphalt is touted as having greater low temperature flexibility. None of our testing has confirmed this assertion.

Our philosophy is to test only the cured mix for its special properties since it is the mix, not the individual materials, which will be applied to the road. While normal AC may have a 4°C ductility of 5 cm and the Polymer Modified bitumen may have low temperature ductilities of 12 cm or even 120+ cm, the effect of the aggregate and aggregate fines can actually make the MIX more brittle with polymers than without polymers.

CONCLUSION.

We have reviewed a conventional slurry seal and the attendent design test comparisons have been made with a variety of conventional slurry systems. The primary differences between conventional slurry and polymer modified microasphalt is shown to be the high temperature displacement or resistance to compaction when tested by the Wheel Tracking Test at 115F.

Finally we suggest that Polymer Modified Microasphalt could be described as meetin the following criteria:

The Microasphalt surface should be - - -

- - - capable of being spread in variably thick cross sections (wedges, ruts, scratch courses) which,

- - - after initial traffic consolidation, does not further compact (resists compaction) throughout the entire design tolerance range of bitumen content and variable thicknesses to be encountered, and

- - - maintains high macrotexture (high wet friction coefficient) in variably thick sections throughout the service life of the microsurface.

And the laboratory properties should meet or exceed the following suggested test values:

Mix time @ 75F. ISSA TB 113	120' min.
Wet cohesion @ 60'. ISSA TB 139	20 kg-cm. min.
60C Cured Cohesion @ 12% AE ISSA TB 139	24 kg-cm. min.
Classification compatibility, Schulze-Breuer-Ruck ISSA TB 145	(AAA, BAA) 11 grade points min.
Wet Track Abrasion Test 1 hr. soak ASTM D3910, ISSA TB 100:	24.5 grams max. (75g/SF at optimum)
6-day soak	24.5 grams max.
Monolayer Loaded Wheel Test Sand Adhesion ISSA TB 109	50 g/SF max.
Multilayer Loaded Wheel Test displacement @ ambient and optimum Bitumen ISSA TB 147A	10% vertical, 5% lateral
Multilayer Wheel Tracking displacement @ 45C ISSA TB 147B	10% vertical, 5% lateral
Multilayer Wheel Tracking Macrotexture	1 mm min.
(?)Low Temperature (4C) Flexural Tension Test ISSA TB 146	8 mm min.

SLURRY SEAL DESIGN FOR

1989 PROJECT

PREPARED FOR:

PHONE:
FAX:
ATTN:

PREPARED BY:

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FAX: 513-426-3368

DATE: SEPTEMBER 29, 1989 (FINAL)

CONTENTS:

MATERIALS

AGGREGATE: Granite, Our lab
#230 7/24/89 and #243 9/14/89

GRADATION:

SIEVE#	PERCENT PASSING (DRY) #230	X SAF	= SA	#243	ISSA SPECS TYPE 2
3/8"	100	.02	2.00	100	100
1/4"	100	--		100	--
#4	99.9	.02	2.00	97.0	90-100
8	78.2	.04	3.13	71.3	65-90
16	56.6	.08	4.53	50.8	45-70
30	39.7	.14	5.56	35.8	30-50
50	24.7	.30	7.41	23.3	18-30
100	12.7	.60	7.62	12.7	10-21
200	6.9	1.60	11.04	6.5	5-15
325	3.2	--		3.6	--

SIMPLE SURFACE AREA, SF/LB	43.29		
CORRECTED SURFACE AREA (2.65/2.57) =	44.64 SFPP		
SAND EQUIVALENT	75.8	67.9	45 MIN.
METHYLENE BLUE ABSRB. 0/#325	10.5 MG/G	10.5	
BLUE FACTOR	33.6	37.8	
PH 10:1	7.22 - 7.33	8.05 - 7.97	
SPECIFIC GRAVITY (DRY)	2.568	2.581	
UNIT WEIGHT, LOOSE	(1.532) 95.6 PCF	(1.558) 97.2 PCF	
UNIT WEIGHT, COMPACTED	(1.821)113.6 PCF	(1.769) 110.4 PCF	
VOIDS	29.1	31.5	

ASPHALT EMULSION Received about 1/2 gallon, identified as 8/21/89 (1.8:1; 2.2 pH, 62.6 AC)
Our lab No. 90907-1

TEST	FOUND	SPECS
SIEVE, %	.06	.010
AC RESIDUE, %	63.8	57.0 MIN
pH	3.44	--

CHEMICAL FILLERS Hydrated Lime, National Lime & Stone Co.,
Marion, Ohio

WATER Softened Well Water
556 N. Valley Rd., Xenia, Ohio

TRIAL MIXES FOR MIXABILITY, ADDITIVE OPTIMIZATION, SET & TRAFFIC TIMES BY WET COHESION, 60C CURED COHESION CLASSIFICATION, ADHESION & COMPATIBILITY

WET COHESION (90907-1) VS. #240 0/#4

MIX FORMULA						WET	COHESION Kg-cm			ADHESION
#	FLR	H20	AE	MIX"	SET'	30'	60'	120'	APPEAR.	(1)(2)(3)
35	0	12	12	29	BUST	-				
36	0	18	12	TOO	WET	-				
37	0	15	12	100	3	17.0	18.0	--	RCH TF	FF 95+
38	.15HL	16	12	29	BUST					
39	.15HL	18	12	110	3	16.5	17.5	--	GREY TF	PF 85+
40	.25	18	12	35	20	13.5	14.5	--	BL TF	GF 95
44	.5	13	12	150	30	9.5	12.8		DL BL	GG 99+
43	.75	13	12	160	30	9.5	12.1		DL TF	GG 99+
41	1.0	18	12	TOO	WET					
42	1.0	15	12	180	30	8.5	10.3		DL TF	GG 97
45	0	15	12	90	5		18.5	20.8	BL TF	GF 90
46	0	12	15	170	30+	SL.WET	20.0	20.0NS	GREY TF	GG 90
47	0	10	15	165	30+		20.1	21.8	GREY	GG 90

90919-1 (Field formulation) vs. #243 0/#4

237	0	12	15	120	22'	-	21.1	20.5	RCH TF	GG 98+
238	.25hl	13	15	85	20	-	20.0	18.5	BL TF	FG 98+
239	.5 hl	15	15	180+	45	-	16.1	19.0	BL TF	GG 98+
240	.75hl	14	15	180+	45	-	15.0	19.5	BL TF	GG 98+
241	1.0hl	12	15	180+	45	-	16.0	14.0	DL BL TF	GG 97+

WET COHESION: 12.0 Kg-cm. = "set", 20.0=Early Rolling Traffic
ADHESION: (1)=Wet Adhesion; (2)=Substrate Adhsn; (3)=3' Boiling Water Adhesion

60C CURED COHESION (90907-1) FOR CLASSIFICATION

				(1)	(2)	(3)	AVERAGE
140	0	16	10	13.2	12.2	14.2	13.2
141	0	13	13	15.0	15.3	13.7	14.7*
142	0	8	16	19.2	18.9	21.8	20.0
143	.75HL	13	10	13.2	13.2	14.3	13.6
144	.75HL	11	13	19.2	20.0	20.8	20.0
145	.75HL	9.5	16	19.8	21.0	21.2	20.7

60C CURED COHESION (90919-1) FOR CHEMICAL FILLER OPTIMUM

242	0	12	15	17.0	16.1	16.1	16.4
243	.25	13	15	15.9	17.0	20.0	17.6
244	.50	13	15	24.9	27.3	25.2	25.8*
245	.75	12	15	22.0	24.3	24.1	23.5
246	1.0	11	15	22.0	22.5	19.0	21.2

60C CURED COHESION (90919-1) FOR CLASSIFICATION CURVE

18	.5HL	17	10	14.0	13.0	14.3	13.8
19	.5	16	12	24.0	19.3	17.0	20.1
20	.5	15	14	23.4	22.0	22.0	22.5
21	.5	13	16	24.0	20.3	22.2	22.2
22	.5	11	18	20.8	25.1	24.0	23.3

CONSISTENCY - Optimum liquid determination consistency tests were not initially run in order to conserve materials. The results of an abreviated series follows:

		TOTAL LIQUIDS, %	OUTFLOW, CM.
.5 HL	7 - 15	22	0.0 - BUST
.5 HL	8 - 15	23	.72
.5 HL	11 - 15	26	3.2
.5 HL	15 - 15	30	5.8
.0	12 - 15	27	4.1 (liquid sep.)

SPLIT CUP COMPATIBILITY

Three, 100 grams mixes were placed in 6 oz. dixie cups. After 2 days curing the specimens were exposed by opening the cup at the seam. The following observations were made:

		TOTAL LIQUIDS	REMARKS	"KLEENEX" TEST	DEPTH, mm
.5HL	8 - 15	23	No segregation*	PASS	26.38
.5HL	11 - 15	26	No seg., sl. rich	PASS	26.35
.5HL	15 - 15	30	Excess surface AC	FAIL	26.41

*best surface adhesion

FIELD SIMULATION TESTS

WET TRACK ABRASION TEST; ONE HOUR SOAK/ASTM D3910 (90907-1 AE)

				BEFORE, g.	AFTER, g.	LOSS,g.	LOSS, g/SF
1A	0	17	10	816.5	803.7	12.8	
1B	0	17	10	806.7	793.2	13.5	
					Average	13.2	40.2
2A	0	14	13	807.8	805.6	2.2	
2B	0	14	13	876.7	871.8	4.9	
					Average	3.6	10.8
3A	0	9	16	797.1	793.0	4.1	
3B	0	9	16	758.6	756.5	2.1	
					Average	3.1	9.5

WET TRACK ABRASION TEST; SIX DAY SOAK/ISSA TB100 (90907-1 AE)

1C	0	17	10	787.0	760.3	16.7	51.1
2C	0	14	13	868.2	864.0	4.2	12.9
3C	0	9	16	755.9	750.7	5.2	15.9

NOTE: Segregation was noted during specimen preparation. Fines were separated at one side of specimens. With hydrated lime no fines separation or segregation was noted. A single WTAT specimen was prepared with lime at 13% emulsion with the following results:

ONE HOUR SOAK (90907-1 AE)

A4	.75HL	6	13	835.0	827.6	7.4	22.6

SIX DAY SOAK

A4	.75HL	6	13	835.0	826.5	8.5	26.0

ONE HOUR SOAK (90919-1)

1	.5HL	6.5	10	840.9	831.8	9.1	27.5
2	.5HL	9.5	13	782.4	776.7	5.7	17.4
3	.5HL	6.5	16	762.4	754.6	7.8	23.8

MONOLAYER LOADED WHEEL TEST; C-109 FINE SAND ADHESION

COMPACTED/ISSA TECH. BULL. 109 (90907-1 AE)

				TACKINESS POINT.	BEFORE g.	AFTER g.	SAND WT.,g	f=6.6 SAND g/SF
1E	0	15.5	10	1000+	350.06	360.52	10.46	69.0(32.0?)
2E	0	12.5	13	1000+	383.21	389.05	5.84	38.5
3E	0	7.5	16	1000+	340.10	346.06	6.76	44.6
UNCOMPACTED								
1D	0	15.5	10	1000+	356.63	363.43	6.80	44.9
2D	0	12.5	13	1000+	366.94	374.04	7.10	46.9
3D	0	7.5	16	1000+	388.05	396.65	8.60	56.8
COMPACTED WITH HYDRATED LIME:								
A1	.75HL	8	10	1000+	379.41	384.91	5.50	36.3
A2	.75HL	6	13	1000+	376.07	382.03	5.96	39.3
A3	.75HL	4	16	1000+	356.16	361.92	5.76	38.2

MULTILAYER, UNCONFINED LOADED WHEEL DISPLACEMENT TEST/ISSA TB #147, METHOD A.

				PERCENT DISPLACEMENT		
				VERTICAL	LATERAL	REMARKS
90907-1 AE						
1F	0	15.5	10	36.9	53.8	SEVERE EDGE & END
2F	0	12.5	13	36.6	30.9	END & SL. EDGE SPLITS
3F	0	7.5	16	25.1	21.2	END SPLITS
90919-1 AE						
1	.75HL	13	10	28.6	11.3	SEVERE EDGE & END SPLIT
2	.75	11	13	28.6	14.7	END SPLITS
3	.75	9.5	16	25.4	5.0	OK
4	.75	7	19	27.4	10.9	OK
5	.75	6	22	27.3	4.0	OK

NOTE: Criteria for multilayer application is maximum 10% and 5% vertical & lateral displacement.

SURFACE AREA CALCULATIONS

The formula used here for emulsion added requirement is from ISSA Tech Bull No. 118 and the U.S. Army, Waterways Experiment Station Instruction Report S-75-1:

BR=(CSA x tc x SGB x 0.02047) + KA

Where: BR = Total Bitumen Required (% added)
CSA = Corrected Surface Area (SF/LB)
t = Design Bitumen film thickness in Microns (8.0)
SGB = Specific gravity of Bitumen (Assume 1.02)
KA = Kerosene absorbtion (Assume 2.00)

BR = (44.64 x 8 x 1.02 x 0.02047) + 2.00
= 7.47 + 2.00
= 9.47% Bitumen added to AGG Dry weight
or 14.84% emulsion added (9.47/63.8)
or 8.65% Bitumen extracted from total mix. Use 15% emulsion added (9.57% AC).

VOIDS ANALYSIS

Aggregate specific gravity	2.568
Compacted Bulk Specific gravity	1.821
Voids, volume %	29.1%
Bitumen added, 15% x 63.8% = 9.57% AC	
x Compacted unit weight of 113.6 PCF	
= 10.87 lbs. volume/1.02/62.4	
= 10.87 lbs./1.02 = 10.67 corrected SG 1.0	
= 10.67/62.4 = 17.1 Volume %	17.1%

VOIDS TOTAL MIX	12.0%
PERCENT VOIDS FILLED	58.8%
COMPACTED UNIT WEIGHT, TOTAL MIX	124.5 PCF

Aggregate specific gravity	2.568	(160.24 PCF)
Loose bulk specific gravity	1.532	(95.6 PCF)
Loose voids (Sp. Gr. = 1.0)	40.3%	(25.15 PCF)
TOTAL LIQUIDS TO FILL LOOSE VOIDS	26.3%	

NOTE: No corrections made for lime content or aggregate absorption

DISCUSSION

Preliminary materials and mix evaluations reported August 11, 1989, were performed and suggestions presented for initial field trials and emulsion formulation modifications. The initial field trials were performed at 15% +/- 1% emulsion with 0 to .75% hydrated lime. Though the initial formulations did well in the laboratory with no filler, hydrated lime additions were required to improve workability in the field. Portland cement was ruled out because of poor adhesion and loss of early cohesion. Emulsion formulation modification improved test results as well as field results. Further emulsion formulation modifications continued to improve results. This design uses two field samples: Our lab numbers 90907-1 and 90919-1.

The materials submitted by the client met the ASTM and ISSA specifications for Type 2 slurry aggregate gradation and for CSS1h emulsion.

Trial mixes to determine mixability, set and traffic times, compatibility and optimum additive contents were performed at 12 and 15% emulsion contents with hydrated lime contents ranging from 0 - 1.0% in .25% increments. Mix times were adequate to give time for hand work and still allow early rolling traffic in about 2 - 3 hours and rain resistance in about 1/2 to 3/4 hour as determined by the 30' and 60' Wet Cohesion Test. Adhesion met the 90% minimum requirement for the 3' Boiling Water Test but was 95 to - 99+% when hydrated lime was used. Fast sets or early high cohesion was best at 0 to .25% lime. The optimum lime content for maximum high temperature stability was .5% at 15% emulsion as determined by the 60C Cured Cohesion Test. The system is Quick-Set, Slow-Traffic, or in the case of zero to low filler, Quick-Set, Quick-Traffic.

Mix segregation is difficult but barely controllable without filler. Workability and adhesion is very good. The 6-Day Soak Wet Track Abrasion Test results were also very good. The system is compatible.

Because of the QS-QT characteristics with no filler, our initial design work was done with no filler, with no filler, there was a tendency for segregation, water content sensitivity and slight greasiness. Later work with a modified formulation emulsion used .5% hydrated lime. The One-hour and Six-day Soak Wet Track Abrasion Test results were all too good with either emulsion to clearly establish a minimum emulsion content, with or without hydrated lime.

The Monolayer Loaded Wheel Sand Adhesion Test results did not clearly determine a maximum emulsion content. By projecting the test results, up to 18% emulsion could possibly be used without bleeding.

The Multilayer Unconfined Loaded Wheel Displacement Tests are improved by the addition of lime. A peak resistance to both vertical and lateral displacement occurs at 16% emulsion content. This system, while suitable for monolayer applications, is not suitable for multilayer applications such as rut filling or wedging.

Since no clearly defined optimum emulsion content was established by the field simulation tests, we performed surface area calculations for eight micron bitumen coatings as well as voids analysis for comparison with other system design tests.

Surface area calculations indicate an optimum of 15% emulsion content or 9.5% bitumen added (8.7% extracted). At 15% emulsion content, voids in the total compacted mix would be 12.0% with 58.8% of the voids in the mineral aggregate filled. These results are quite in line with our experience as well as performing well in laboratory tests.

Additionally, loose voids analysis show a maximum of 26.3% total liquids to avoid excess liquids and the creation of "hydraulic voids". Laboratory mixes required 24 - 26% total liquids or less than this critical 26.3%. 100 gram split cup compatibility specimens clearly confirmed this fact.

Based on the above information, we recommend the use of .25% to .75% hydrated lime and 15.5% +/- 1.5% emulsion added to the dry aggregate. The upper limits should be used for very low traffic while the lower limits would be used for heavy traffic.

JOB MIX FORMULA RECOMMENDATION:

Aggregate	100.0%
Hydrated Lime	.5% +/- .25%
Asphalt emulsion @ 63.8% residue	15.5% +/-1.5% (37 gal/ton)
Target AC extracted	9.0%
Water	To suit field conditions

SPREAD RATE.

In accordance with ISSA Tech. Bull #112, the estimated spread rate for the submitted aggregate would be 14.0 +/-2 lbs/SY for normal surfaces. Very course surfaces would require 16.0 lbs/SY.

Should questions arise, please feel free to call.

Respectfully submitted,

C. Robert Benedict, Consultant
(513)298-6647

Assuming a moderate squeegee contact pressure, a slurry consistency of 2.5 to 3 cm. and a slurry depth of 5 to 6 inches, basic spread rates applied to smooth surfaces may be selected from the 1st table. The quantity of slurry required to fill surface texture may be added to the basic rate along with an estimate of requirements due to cross sectional irregularity and for joint cracks and laps. These increments may be added to give an estimate of the spread rate.

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/SY	%+16	lb/SY	%+16	lb/SY
FINE	10	5	30	9	50	14
MEDIAN	22.5	6	44.4 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'	▨	10.5+
ADD FOR SURFACE TEXTURE	H-1	10-12'	1	-2.0
	H-2	8-10'	2	
	H-3	5-7'	3	
	▨	2-4'	4	
ADD FOR CROSS SECTIONAL IRREGULARITY	Nominal - 3/8"		1	1.0
	Moderate - 1/2-3/4"		2	
	Severe - 1-1-1/2"		3	
ADD FOR JOINT CRACKS 8 LAPS (Calculate)				.5
APPROXIMATE SPREAD RATE - TOTAL				14.0 ±2.(1.

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

TABLE FOR UNIT FIELD DETERMINATION OF PERCENT OF ASPHALT CEMENT IN DRY SLURRY MIXES

AE GALS PER TON	AE % ADDED	% ASPHALT CEMENT IN THE DRY SLURRY (% ADDED TO AGG)								
		Per Cent Asphalt Residue in the Emulsion								
		57	58	59	60	61	62	63	64	65
25	10 5	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8
26	10.9	6.2	6.3	6.4	6.6	6.7	6.8	6.9	7.0	7.1
27	11.3	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.3	7.4
28	11.7	6.7	6.8	6.9	7.1	7.2	7.3	7.4	7.5	7.6
29	12.2	6.9	7.1	7.2	7.3	7.4	7.6	7.7	7.8	7.9
30	12.6	7.2	7.3	7.4	7.6	7.7	7.8	7.9	8.1	8.2
31.	13.0	7.4	7.6	7.7	7.8	7.9	8.1	8.2	8.3	8 5
32	13.4	7.7	7.8	7.9	8.1	8.2	8.3	8.5	8.6	8.7
33	13.9	7.9	8.0	8.2	8.3	8.5	8.6	8.7	8.9	9.0
34	14 3	8.1	8.3	8.4	8 6	8.7	8.9	9.0	9.1	9.3
35	14.7	8.4	8.5	8.7	8.8	9.0	9.1	9.3	9.4	9.6
36	15.1	8.6	8.8	8.9	9.1	9.2	9.4	9.5	9.7	9.8
37	15.5	8.9	9.0	9.2	9.3	9.5	9.6	9.8	9.9	10.1
38	16.0	9.1	9.3	9.4	9.6	9.7	9.9	10.1	10.2	10.4
39	16.4	9.3	9.5	9.7	9.8	10.0	10.2	10.3	10.5	10.6
40	16.8	9.6	9.7	9.9	10.1	10.2	10.4	10.6	10.8	10.9
41	17.2	9.8	10.0	10.2	10.3	10.5	10.7	10.8	11.0	11.2
42	17.6	10.1	10.2	10.4	10.6	10.8	10.9	11.1	11.3	11.5
43	18.1	10.3	10.5	10.7	10.8	11.0	11.2	11.4	11.6	11.7
44	18.5	10.5	10.7	10.9	11.1	11.3	11.5	11.6	11.8	12.0
45	18.9	10.8	11.0	11.2	11.3	11.5	11.7	11.9	12.1	12.3
46	19.3	11.0	11.2	11.4	11.6	11.8	12.0	12.2	12.4	12.6
47	19.7	11.3	11.4	11.6	11.8	12.0	12.2	12.4	12.6	12.8
48	20.2	11.5	11.7	11.9	12.1	12.3	12.5	12.7	12.9	13.1
49	20.6	11.7	11.9	12.1	12.3	12 6	12.8	13 0	13.2	13.4
50	21 0	12.0	12.2	12.4	12.6	12 8	13 0	13.2	13.4	13 7
51	21.4	12.2	12.4	12.6	12.9	13.1	13.3	13.5	13.7	13.9
52	21 8	12.4	12.7	12.9	13.1	13.3	13.5	13.8	14.0	14.2
53	22.3	12.7	12.9	13.1	13.4	13.6	13.8	14.0	14.2	14.4
54	22.8	12.9	13.2	13.4	13.6	13.8	14.1	14.3	14.5	14 7
55	23.1	13.2	13.4	13.6	13.9	14.1	14.3	14.6	14.8	15.0
56	23.5	13.4	13.6	13.9	14.1	14.3	14 6	14.8	15.1	15.3
57	23.9	13.6	13.9	14.1	14.4	14.6	14.8	15.1	15.3	15.6
58	24 4	13.9	14.1	14.4	14.6	14.9	15.1	15.3	15.6	15.8
59	24.8	14.1	14.4	14.6	14.9	15.1	15.4	15.6	15.9	16.1
60	25.2	14.4	14.6	14.9	15.1	15.4	15.6	15.9	16.1	16.4

Note: A. E. weight is taken at 8.4 lbs. per gallon. Figures are to the nearest tenth.
Make corrections for emulsion temperature and aggregate moisture.