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LAB NOTES ON EFFECTS OF TOTAL MIX LIQUIDS AND AGGREGATE VOIDS ON SLURRY SEAL AND MICROASPHALT TESTS

BY

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INTRODUCTION

After preliminary materials analysis, the first step in the design of slurry seal is to make a series of 100-gram trial mixes in which emulsion filler, additives and water contents are varied. Observations are made on mix time, set time, wet cohesion, compatibility, consistency, free liquids, etc.

Mix water and emulsion (plus aggregate moisture) combine to lubricate the mixture. When the emulsion content is held at a constant 12%, which is our standard starting trial mix emulsion content, we have previously used up to a maximum of 18% mix water or 30% total liquids in order to get an adequate mix time of 90" to 180+". The emulsion is rejected if more than 30% total liquids is required.

The amount of mix water added becomes quite critical at some low amount where only .5% increase or decrease in water content is the difference between no mix and good mix. In many material systems, mix time will increase with the increase of mix water added above the critical minimum amount of mix water.

The critical minimum mix water varies widely with the type of emulsion and type of aggregate, percent and rate of absorbtion of the aggregate. With most CSS1h and SS1h superstable systems, the mix water requirements are usually very low, ranging from as low as 3 to 4% or 7 to 8%. With QS systems however, mix water requirements may be much higher; up to 18 to 20% or more.

We have observed that better systems usually require about 12% or less mix water or 24% total liquids and that when this value is exceeded, the cured mix properties may suffer.

It is only recently that we have begun to look at the **volume** of total mix liquids in relation to the space between the aggregate particles that is available to be filled; i.e., aggregate voids. If there is more total liquids than there is space available for these liquids, the aggregate particles may be pushed apart by the liquids (creating hydraulic voids), the aggregate may fall to the bottom of the mix as the liquids rise to the top, or the liquids may drain out of the mix.

The cone consistency test as described in ISSA Technical Bulletin 106 is used to determine mix water or total liquids required to produce a 2 to 3 centimeter outflow or "consistency". Our preference is slightly higher than the presently established 3 cm limit. While the test does very well for most slow setting systems, it is not applicable or reliable for use with many Quick Set or Quick Traffic systems.

Developement of a method for determination of the proper amount of total mix liquids for these QS systems is the purpose of this report.

SERIES 1 EXPERIMENTS

1. EFFECT OF GRADATION ON LIQUID VOIDS

Sandusky Dolomite was regraded to the following A, B, C & D gradations corresponding to ISSA Type 2 and Type 3, fine and coarse. Using a machined metal cup 3.1" ID x 3" deep which contains 370.93 grams of water, and an ASTM C-28 tamp, loose and compacted bulk specific gravities were determined. The dry aggregate specific gravity was determined using 500 grams of aggregate and a 500 ml. volumetric flask. Voids and the weight percent of liquid to fill the voids were calculated. The results follow:

SANDUSKY DOLOMITE

	A 2f	B 2c	C 3f	D 3c
GRADATION U.S. SIEVE NO.	PERCENT PASSING (DRY)			
3/8"	100	100	100	100
5/16"	100	100	100	100
1/4"	---	---	---	---
#4	100	90	90	70
8	90	65	70	45
16	70	45	50	28
30	50	30	34	19
50	30	18	25	12
100	21	10	18	7
200	15	5	15	5
325	--	--	--	--
APP. SPECIFIC GRAVITY	2.77	2.77	2.77	2.77
BULK SP.GR., COMPACT	1.96	1.91	1.98	1.85
UNIT WEIGHT, COMPACT	122.3PCF	119.2	123.6	115.4
VOIDS, COMPACT	29.2	31.0	28.5	33.2
LIQUID VOIDS, WT.%AGG.	14.9	16.2	14.4	17.9
BULK SP.GR., LOOSE	1.63	1.64	1.67	1.62
UNIT WEIGHT, LOOSE	101.8PCF	102.3	104.2	101.1
VOIDS, LOOSE	41.2	40.1	39.7	41.5
LIQUID VOIDS, WT.%AGG.	25.2	24.4	23.8	26.2

2. <u>EFFECT OF GRADATION ON CONSISTENCY</u> and water - total liquid content required for 2.5 cm CONSISTENCY:

Consistency tests for each gradation were made using 400 gram mixes, 1% Portland cement and 10, 13, & 16% CSS1h emulsion with the the following results.

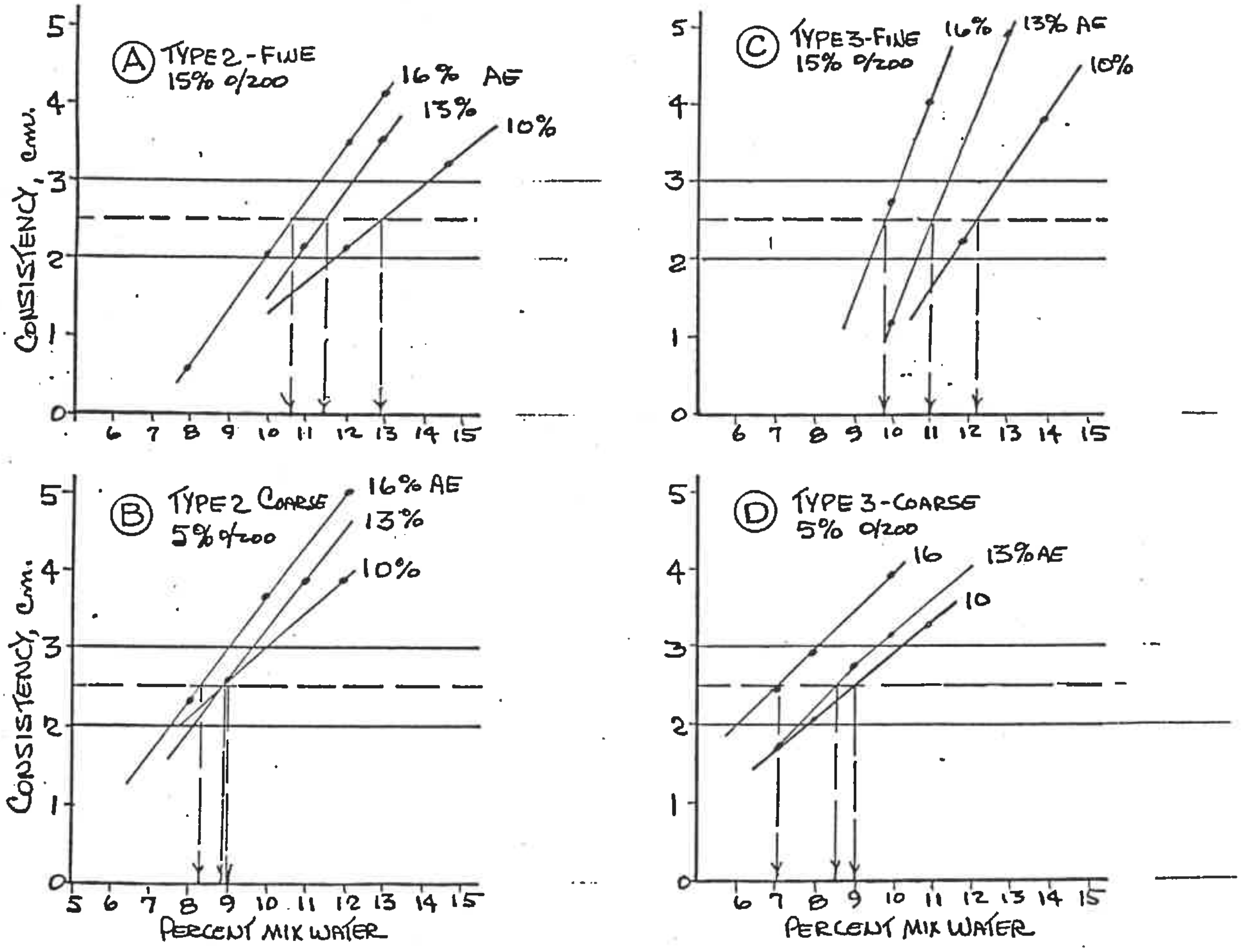

FIG. 1 EFFECT OF GRADATION ON SLURRY CONSISTENCY

As expected, the coarser low-fines gradations, B & D required less mix water and less total liquids. At 13% emulsion content, about 24.5% total liquids were required for the A & C Type 2 & 3, 15% fines gradation which correlated with loose voids. At 16% AE the loose voids are OVERFILLED with all gradations but "D".

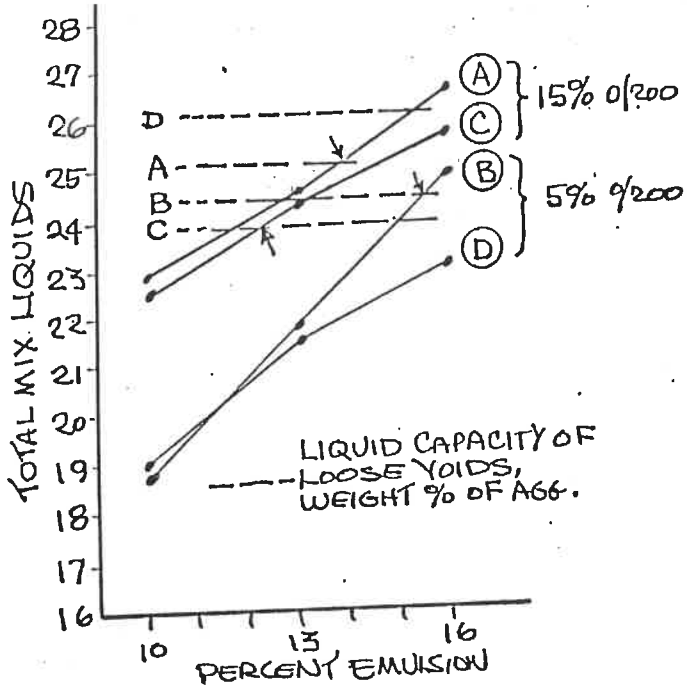

FIG. 2 TOTAL LIQUIDS (AE+ WATER) REQUIRED FOR A 2.5 cm, CONSISTENCY

3. EFFECT OF TOTAL LIQUIDS ON THE LOADED WHEEL FINE SAND ADHESION TEST.

LWT sand adhesion specimens were prepared at 10, 13 & 16% AE with 1% Portland cement and at 2 total liquids contents; 24 and 28%. There was essentially no difference in sand adhesion at either the 24 or 26% total liquids with hi fines A gradation. However, there is a significant difference with the lo fines "B" gradation.

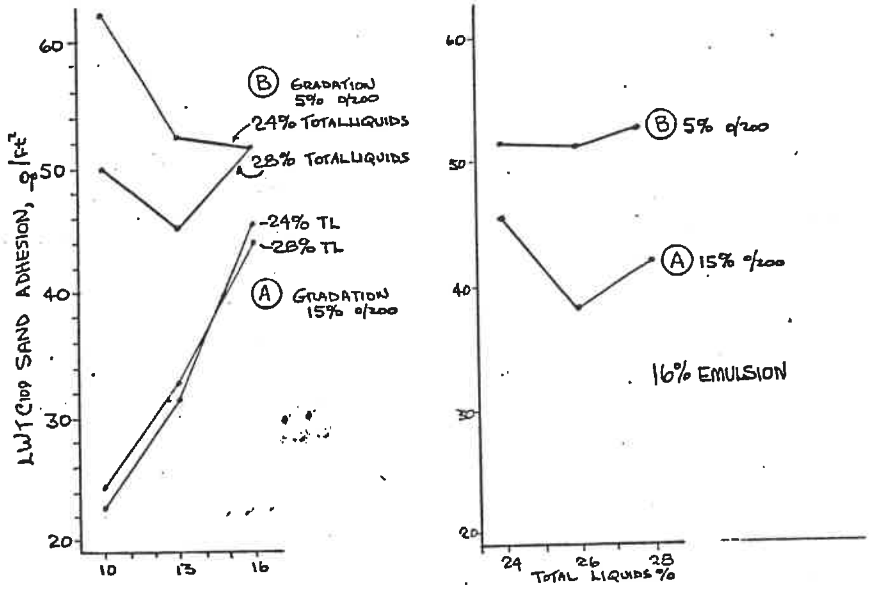

FIG. 3 EFFECT OF GRADATION & TOTAL MIX LIQUIDS ON LWT FINE SAND ADHESION

At 16% emulsion, total liquids of 24, 26, and 26% had no effect on the lo fines (coarse) B gradation but there was an apparent effect on the A gradation. Note the "V" shape.

4. EFFECT OF TOTAL MIX LIQUIDS ON CURED MIX DENSITY

100 gram mixes for A,B,C, & D were mixed with a constant 16% emulsion but at total liquids of 24, 26 & 28%. The completed mixes were poured into clean 6 oz. paper cups and allowed to set and air dry for 2 days. The cups were split open and then oven dried at 60°C for 2 days. The dried samples were then weighed in air and in water and the specific gravity determined. The results ranged from 1.69 to 2.00 indicating a substantial effect on uncompacted mix voids due to both gradation and total mix liquids. The high fines A & C gradations formed a "V" shaped curve while the low fines B & D gradations were more linear (compare the sand adhesion curves).

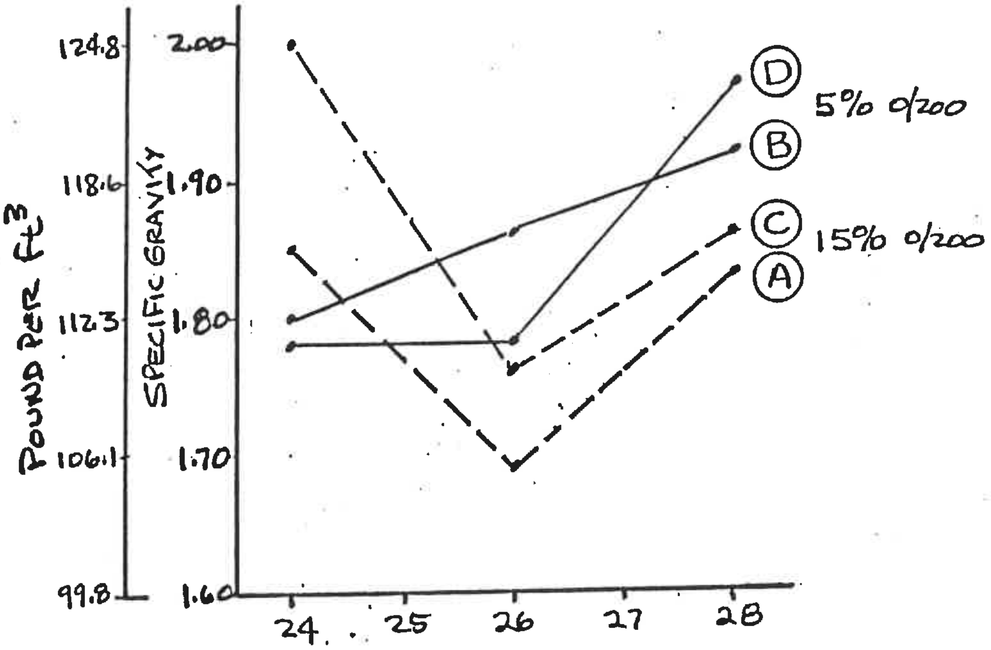

FIG. 4 EFFECT OF TOTAL MIX LIQUIDS & GRADATION ON DENSITY

SERIES 2 EXPERIMENTS:

Another aggregate, Latham Dolomite, was used for the remainder of our experiments:

GRADATION:

SIEVE #	PERCENT PASSING (DRY) AS REC'D	PERCENT PASSING (DRY) USED IN TEST	ISSA TYPE 2 SPECS.
3/8"	100	---	100
5/16"	100	---	---
1/4"	100	---	---
#4	95.4	100	90-100
8	71.0	74.4	65-90
16	50.2	52.6	45-70
30	36.2	37.9	30-50
50	26.5	27.8	18-30
100	20.0	21.0	10-21
200	12.3	12.9	5-15
325	6.5	6.8	---

AP. SPECIFIC GRAVITY	2.75
BULK SP,. GRAV.,COMPACT	2.03
UNIT WT., COMPACT	126.4PCF
VOIDS, COMPACT	26.2
LIQUID VOIDS, WT.% AGG.	13.0
BULK SP. GRAV.	1.70
UNIT WEIGHT, LOOSE	106.0PCF
VOIDS, LOOSE	38.2
LIQUID VOIDS, WT.% AGG.	22.5

This aggregate was chosen because it has lower void content for comparison. Also a very slow setting emulsion (Our #91226-2) was used.

These results were somewhat surprising to us. First we see an extremely wide variation caused by the total liquids content. At 16% AE the difference between 26 and 20.5% mix liquids was 51 to 18 grams/square foot or <u>280%</u> (!) while at 13% AE, the difference between 26 and 19.5% total mix liquids was 142 to 33 g/SF or <u>430%</u>.

The consistencies are shown on the WTAT plots. We note that none were within the recommended 2 - 3 cm outflow. A 4.0 cm. consistency was found at 22.5% total liquids; the voids capacity of the aggregate gradation. We also note that as liquids contents decrease and consistencies approach the ideal 2 - 3 cm., that WTAT losses increase dramatically, indicating perhaps, that a 2 - 3 cm consistency may be an incorrect standard, at least for this gradation and materials system.

It appears that as density increases WTAT losses decrease. It may be that increased density due to increase total liquids contributes to some fines and bitumen crusting and toughening the surface.

7. EFFECT OF EMULSION FORMULATION ON DENSITY, SERIES 3

Four emulsions were prepared at 1.1 and 1.8% emulsifier each at 1.4 and 2.2 pH. 100-gram cup mixes were made at 10 and 16% and tested as previously described.

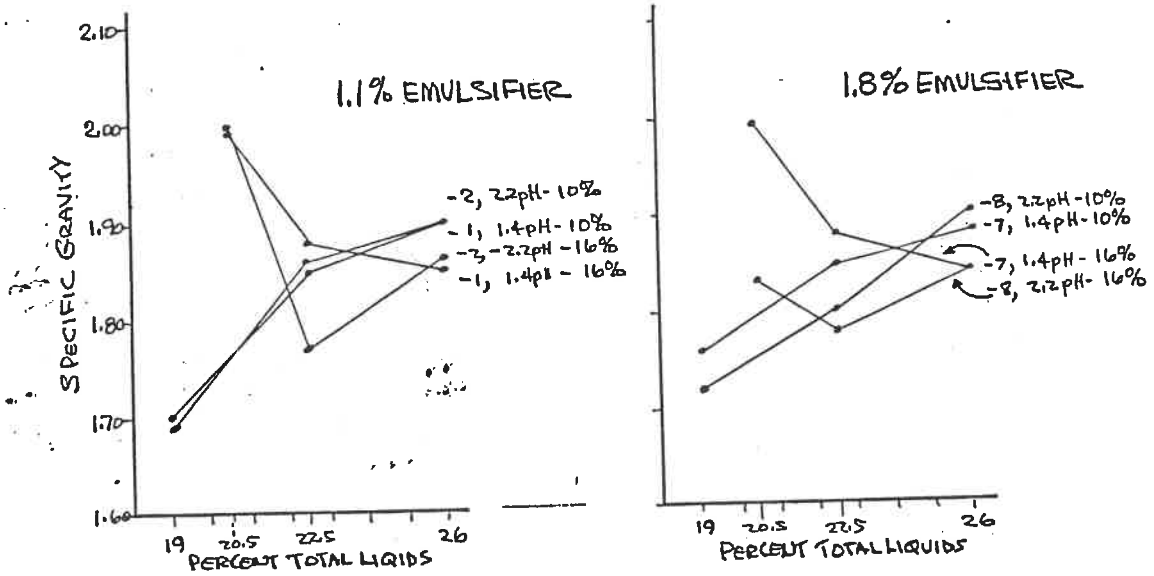

FIGURE 8 EFFECT OF TOTAL MIX LIQUIDS, EMULSIFIER CONTENT & pH, & EMULSION CONTENT ON CURED MIX DENSITY (00122AE SERIES - J. LATHAM 0/84)

At low emulsion content (10%) cured mix density increases linearly with an increase in Total Liquids. All 4 emulsions performed essentially the same.

At high emulsion content (16%) cured mix density is reduced as Total liquids increase though not linearly.

There seems to be little to no effect of either % emulsifier or pH on density.

8. EFFECT OF EMULSION FORMULATION, TOTAL LIQUIDS AND DENSITY ON WET TRACK ABRASION

The previous 4 emulsions, made at 1.1 and 1.8 emulsifier, each at 1.4, were used to prepare WET TRACK ABRASION specimens. After curing and 2.2 pH, and a one-hour soak, the specimens were abraded for 5 minutes in a C-100 WTAT machine. The results were plotted as follows:

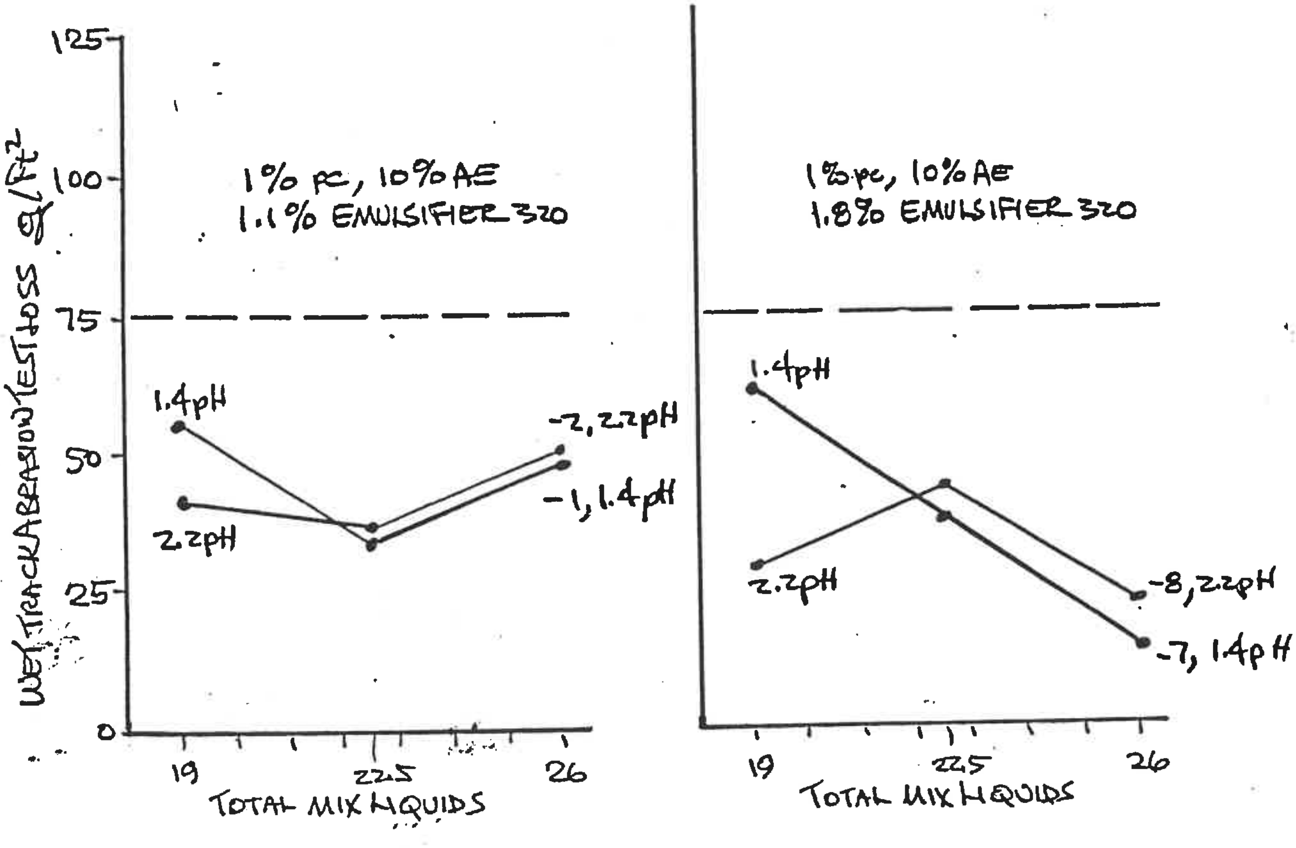

FIGURE 9 EFFECT OF TOTAL MIX LIQUIDS ON WTAT LOSS
HIGH & LOW EMULSIFIER & pH. OC122AG SERIES
WITH LATHAM 0/#4, - LOOSE VOIDS LIQUID CAPACITY 22.5%

First, we see that, at low soap, WTAT losses increase with total mix liquids above the loose voids liquids capacity of 22.5% as does the density of the uncompacted mix: the reverse is true when total mix liquids are less than the liquid capacity.

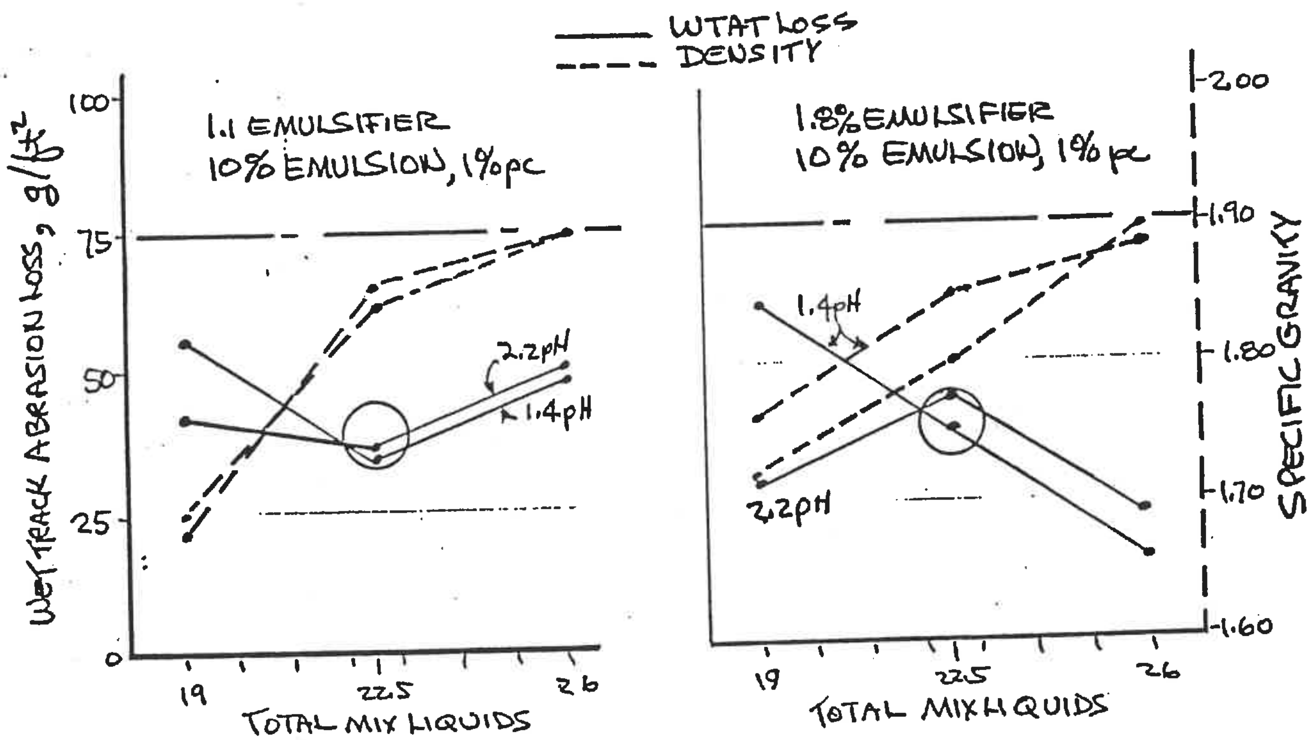

FIGURE 10. EFFECT OF TOTAL MIX LIQUIDS, EMULSIFIER CONTENT AND DENSITY ON WTAT LOSS AT 10% EMULSION— CQ122 SERIES W. LATHAM 0/#4 ; LOOSE LIQUID CAP'Y=22.5%

At high soap, density increases with <u>increase</u> in total mix liquids while the WTAT loss is <u>decreased</u>.

Low pH, with both low and high soap, seems to increase WTAT loss at total liquids less than liquids capacity of the aggregate voids.

Of interest is how WTAT results are essentially the same, irrespective of emulsifier concentration or pH, when the liquids capacity of the aggregate is just filled.

Note the extreme variation in WTAT losses even though all 12 samples had the identical emulsion content! Losses range from 14 to 61 g/sft or a 435% variation in results!

9. EFFECTS OF CURED MIX VOIDS ON MULTILAYER LOADED WHEEL VERTICAL DISPLACEMENT

An extensive series of several polymer modified emulsions were used with two slightly different gradations or void contents of 0/#4 Latham Dolomite. Cement contents for each mix were optimized by 60′ wet cohesion. 13 mm LWT specimens were cast cured, specific gravity determined, bulk measurements made, then subjected to 1,000, 125-lb. LWT cycles and remeasured. The percent vertical displacement was applied to calculate a PROJECTED COMPACTED SPECIFIC GRAVITY.

Plots were made to try to correlate percent compaction with compacted and uncompacted specific gravity, sample net weight and the projected compacted specific gravity. Correlations were found only in the projected gravity-percent compaction curves as follows:

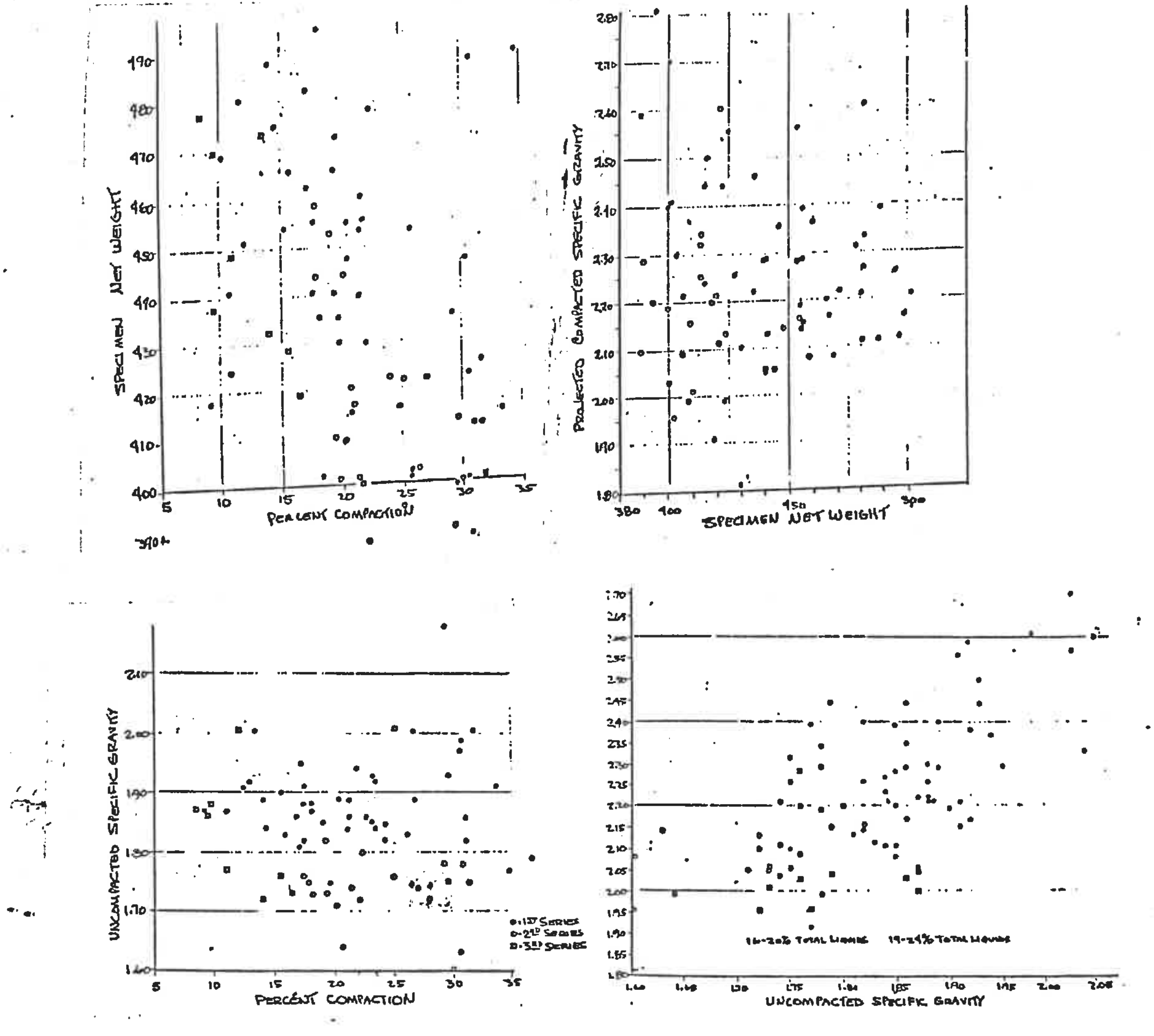

Figure 11 MULTILAYER LOADED WHEEL TEST VERTICAL DISPLACEMENT CORRELATIONS

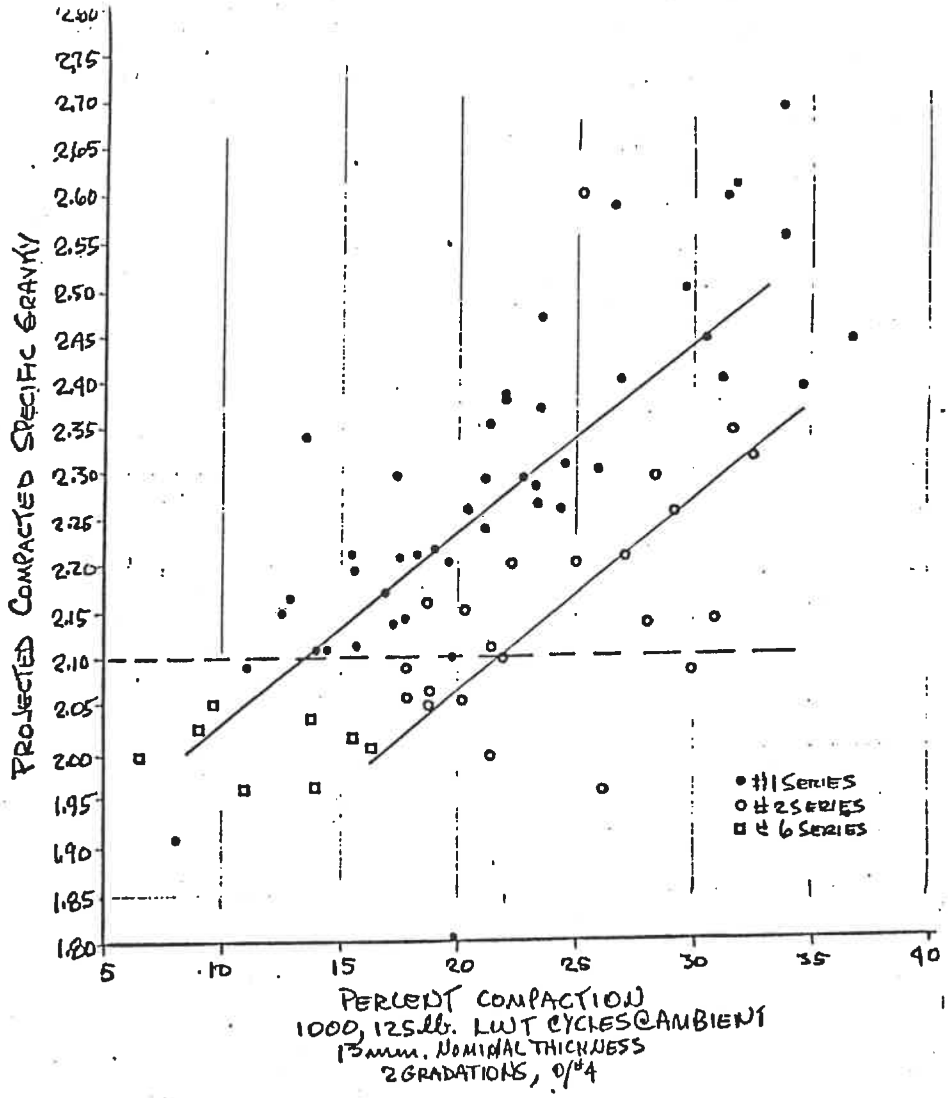

Figure 12 PERCENT COMPACTION (VERTICAL DISPLACEMENT) CORRELATION WITH PROJECTED COMPACTED SPECIFIC GRAVITY.

Our criteria for percent compaction or vertical displacement has been maximum 10% vertical and 5% lateral displacements. Recent work by Koch Materials has shown surprisingly high void contents, and low density of field samples of polymer modified rut mixes; in the order of 2.10 - 2.15 (130-134 lbs/ft^3).

These limits, superimposed on the figure 12 correlation plot shows that vertical displacements can be as high as 25-30% and still give a realistic compacted density of 2.10 or 130 lbs./ft^3!

One reason for the high percent compactions is very likely the TOTAL MIX LIQUIDS in relation to the loose voids space, and that some high compaction rates are due solely to high mix voids.

We theorize that resistance to vertical displacement is ultimately due to emulsion and mix formulation when gradation is constant.

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10. A FINAL NOTE ON LWT SAND ADHESION IN RELATION TO MIX VOIDS.

The monolayer Loaded Wheel Sand Adhesion test measures, primarily, the relative thickness of the asphalt film on the surface of a slurry specimen. ASTM C109 fine Ottowa sand is heated and compacted onto the surface of a LWT specimen. The grams per square foot of adhered sand is calculated. Tentative limits were first suggested in 1975 as 50 grams per ft^2 for very heavy traffic and 70 grams per ft^2 for very lite traffic.

Considerable variation in results have been found which has been related to hi and low fines gradations. An analysis from our 1989 Kona paper on effects of gradation variation shows clearly the effects of compacted voids on the sand adhesion:

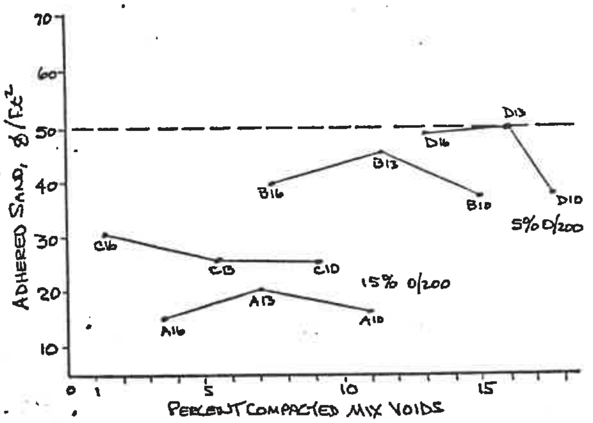

FIG. 13 MIX VOIDS vs. LWT SAND ADHESION

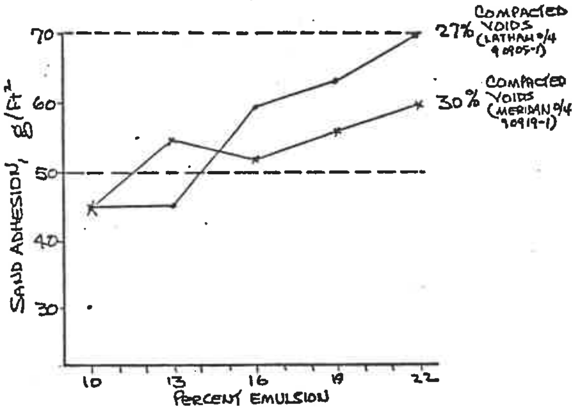

FIG. 14 EFFECT OF COMPACTED VOIDS ON LOADED WHEEL SAND ADHESION TEST

Figure 14 extends the asphalt content beyond our normal design limits and relates the sand adhesion to compacted voids where lower voids give higher sand adhesion. Figure 15 shows a range of sand adhesion curves for a series of field designs. 4 Typical "classes" of curve shapes are shown in Figure 15.

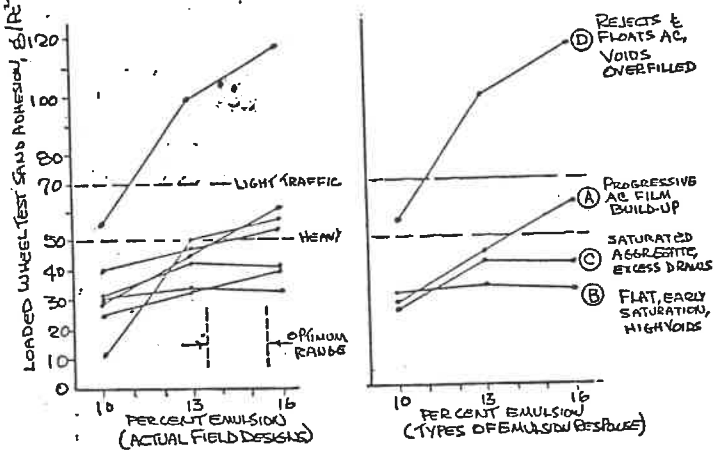

FIG. 15 CLASSIFICATION OF SAND ADHESION CURVES BY EMULSION DEPOSITION CHARACTERISTICS

What we think we are seeing is a maximum, a film thickness capacity of the particular aggregate-emulsion system.

System A	builds film thickness in direct proportion to the asphalt present.
System B	builds film thickness up to a maximum or "saturated" state. No more bitumen is deposited on the aggregate. The excess unadhered emulsion runs off into the space available (voids). When those voids are filled, the "surplus liquids" are deposited on the surface and adhered sand resumes an increase in proportion to bitumen present.
System C	initially deposits all asphalt available with no run-down. The system is "saturated" at that point and no additional bitumen is deposited on the aggregate but runs off into the voids until saturated.
System D	is an incompatible system which rejects all bitumen which is floated to the surface of the specimen.

We also theorize that there are several very different classes of emulsion response to a given aggregate to help explain some of the test results we see.

1. Water wet emulsion (non-ionic, quats, etc.) systems which really do not want to break or plate out on an aggregate surface. With hi voids they drain freely to the bottom of the mix. With lo voids they may float to the surface or be easily displaced by the heavier aggregate.

2. Thixotropic systems which are mobile only under shear or agitated conditions. These emulsions do not migrate in the mix, however they may or may not adhere to the aggregate (larger fractions).

3. Film Stacking or Layering emulsion-aggregate systems which "adhere" well to the aggregate and "coheres" within itself during a rather quick and complete coalescence; i.e., stacking infinitely until all bitumen is plated out of the emulsion on to the mix aggregate and substrate. Many times, these systems are "clear water poppers" i.e., clear water flows from the mix. This stacking characteristic is relatively independent of the mix water present. The bitumen particles so love the aggregate surface and itself that the mix water is ostracized!

A good deal more research should be done in this area. Coalescense mechanics or chemistry, inversion points dilution effects and incomplete release of water should be studied in relation to layering and mix performance.

SUMMARY

SOME RATHER CLEAR, IF NOT STARTLING, EFFECTS OF TOTAL MIX LIQUIDS IN RELATION TO AVAILABLE VOIDS HAVE BEEN DEMONSTRATED. RESULTS FROM MANY OF OUR ISSA DESIGN TESTS HAVE BEEN SHOWN TO REQUIRE INTERPRETATION IN LIGHT OF THE FINDINGS PRESENTED HERE. PERHAPS WE HAVE FOUND AT LEAST ONE REASON FOR WIDE VARIATIONS FOUND IN TEST RESULTS AMONG LABORATORIES.

WE ENCOURAGE OTHERS TO CAREFULLY REVIEW THE WORK PRESENTED IN THE LIGHT OF THEIR EXPERIENCE AND TO VERIFY BY EXPERIMENT TO DEFINE MORE PRECISELY THE EFFECTS WE HAVE SEEN.

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