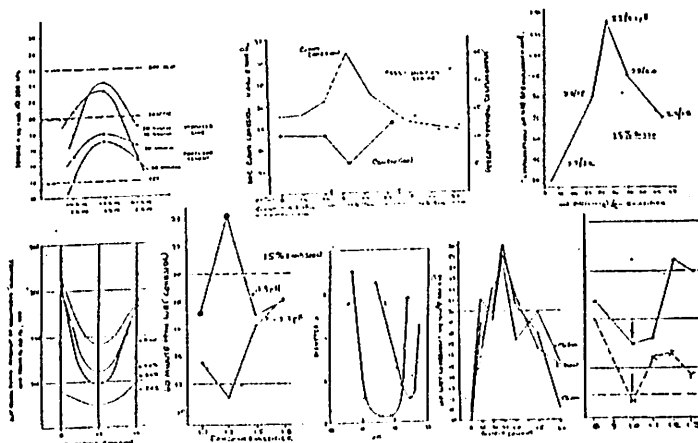DRAFT - NOT FOR PUBLICATION

OPTIMIZATION OF PERFORMANCE

SLURRY SEAL AND MICROASPHALT SYSTEMS

BY

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OPTIMIZATION
GETTING WHAT YOU PAY FOR

1. INTRODUCTION

The manufacture of asphalt emulsion is rather well understood.
It is one thing, however, to make "an emulsion" to meet an
particular ASTM specification and quite another thing to make an
emulsion that functions in the field with a particular aggregate
as advertised.

The emulsion manufacturer's all important customers (contractors
and consumers) have none to little concern with the
specifications for "SS1h", "CSS1h", etc., The customer is only
concerned with an emulsion's **FUNCTIONALITY**; i.e.,:

<div align="center">

WILL "IT" MIX?

WILL "IT" SET?

WILL "IT" LAST?

WILL "IT" BE SAFE?

WILL "IT" PERFORM?

</div>

FUNCTIONALITY and the ultimate performance of the total mix
system requires "tailoring", "cutting-to-fit" or, in a word,
OPTIMIZATION.

Our industry has expended a great deal of energy developing
laboratory tests which attempt to relate to or simulate field
performance and give objective numbers to measure the degree of
performance. Examples of these tests are:

<div align="center">

WET TRACK ABRASION - WET PAVEMENT SCRUBBING

COHESION - POWER STEERING

LOADED WHEEL - ROLLING TRAFFIC

</div>

Here we will report some of the ways that slurry systems may be
optimized in order to give our customers a quality product and
the best chance of success.

2. OPTIMUM ASPHALT EMULSION STABILITY

The first concern with an emulsion is its storage stability.
Barth relates storage stability or "settlement" stratification,
sedimentation to Stokes Law:

$$V = \frac{2r^2(S - S')g}{9n}$$

where V = rate of fall of the particle, r = radius of the
particles, S = their specific gravity, S' = the specific gravity
of the liquid, g = gravitational constant, and n = viscosity of
the dispersion medium.

Practically, Stokes Law says that the smaller the asphalt
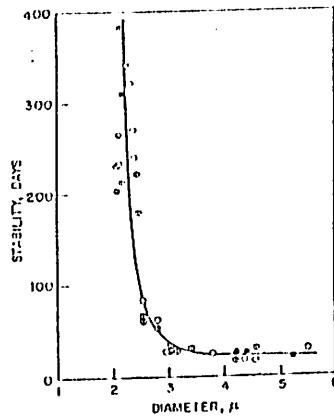particle size, the slower the settlement rate as illustrated
below:

FIGURE 1. RELATION OF PARTICLE
SIZE TO STABILITY
(BARTH)

Particle size is not only dependent on bitumen crude source, mill
setting, emulsifier type, activity, solubility, HLB and
concentration, (see: A.M. Ajour) but also on interfacial tension
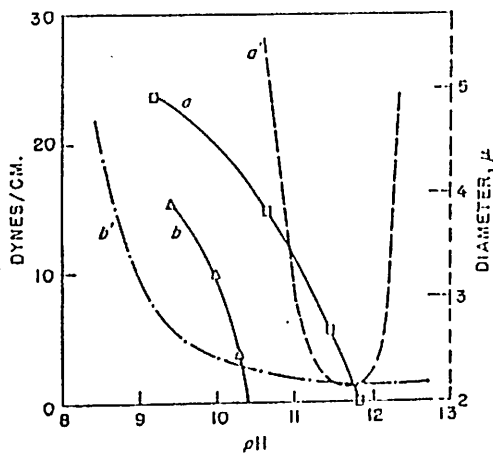and pH as illustrated (Barth) below:

FIGURE 2. RELATION OF pH TO INTERFACIAL
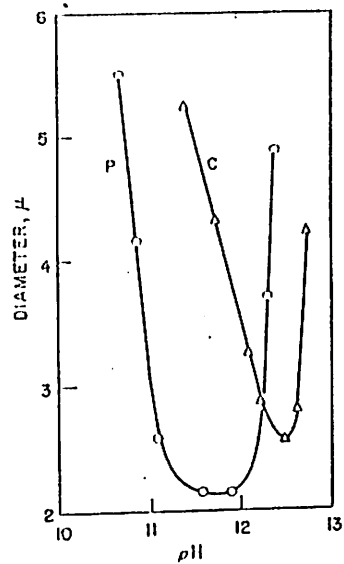TENSION & PARTICLE SIZE (BARTH)

FIGURE 3. PARTICLE SIZE
vs. pH (BARTH)

From these curves it may be inferred that in a given system,
there is an OPTIMUM pH, which gives the smallest particle size
distribution which in turn gives OPTIMUM STABILITY.

3. OPTIMUM CHEMICAL FILLER CONTENTS

At the 1985 AEMA meeting, we introduced the use of the cohesion tester to optimize the setting and curing characteristics of slurry systems. Among the uses discussed was optimization of mix time and chemical filler contents (dubbed the "Benedict Curve"). Shown below where the optimum cement or lime content is clearly defined:
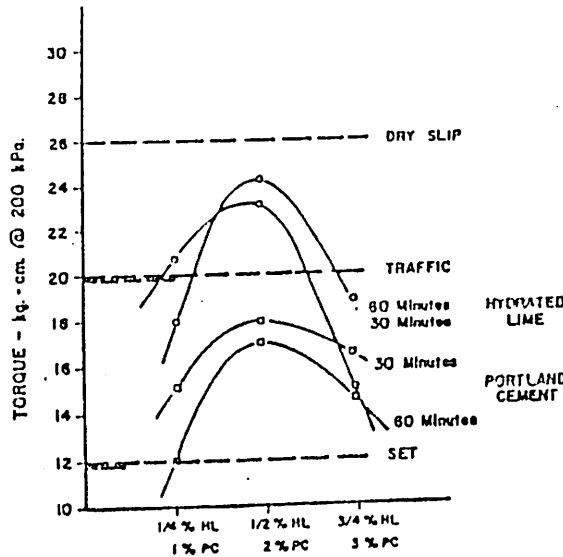

FIG. 4 FILLER CONTENT OPTIMIZATION

Figure **5** shows another example of Cohesion Tester use for optimization of both Filler Content <u>and</u> Retarder Content by 60' wet cohesion. Also shown, is the effect of emulsifier concentration (content) on Traffic time. Here an increase in emulsifier content from 1.2 to 1.4% destroys traffic time.
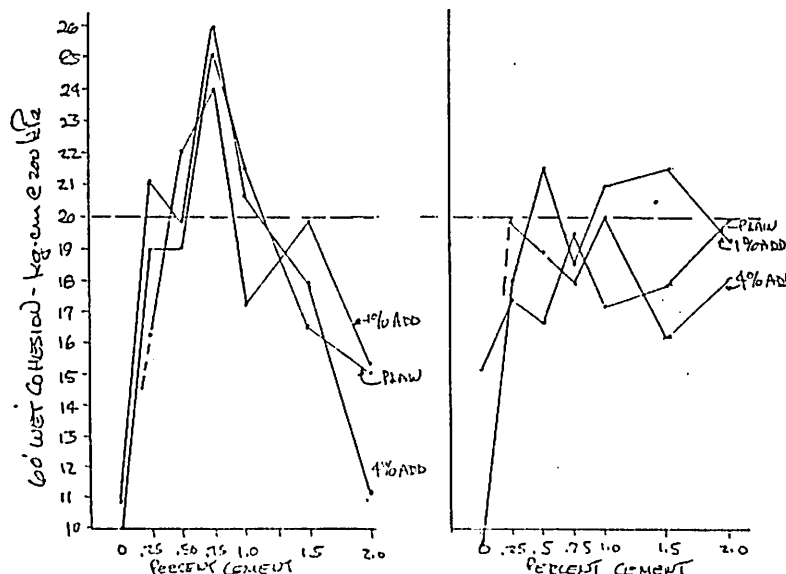
60°C Cured Cohesion may be used not only to CONFIRM the Optimum peak WET COHESION but also to OPTIMIZE HI TEMPERATURE COHESION OR RESISTANCE to plastic deformation as shown in figure 6.
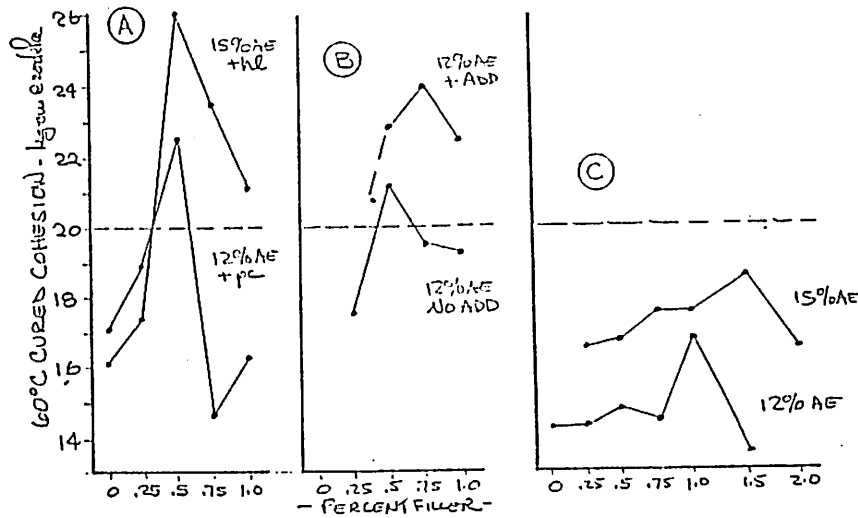

FIG. 6   HIGH TEMPERATURE 60°C CURED COHESION.
FILLER OPTIMIZATION & 60° WET COHESION
CONFIRMATION

Example A shows a peak Cohesion at .5% pc at 12% AE while .5% lime is required at 15% AE.   Example B shows a shift or increased cement requirement from .5 to .75% when 4% retarder is included. Example C also shows a shift in filler requirement from 1% to 1.5% cement with an increase in emulsion content from 12 to 15%.

4.   OPTIMUM POLYMER CONTENT AND OPTIMUM ADDITIVE CONTENTS

Optimum polymer and additive contents for maximum resistance to vertical displacement by traffic are clearly shown by curves generated by the the following Multilayer Loaded Wheel Displacement tests:
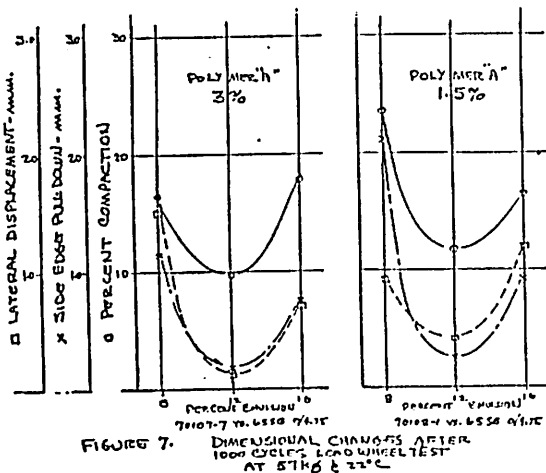

FIGURE 7.   DIMENSIONAL CHANGES AFTER
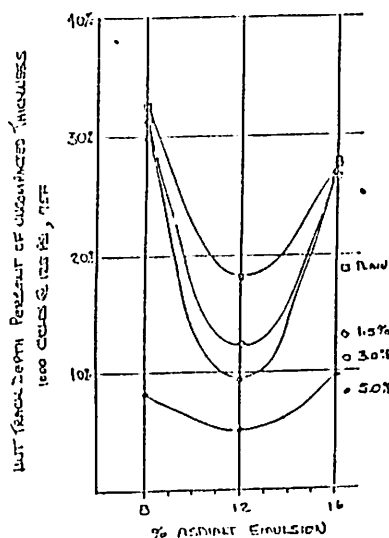1000 CYCLES LOAD WHEEL TEST
AT 57kg & 22°C
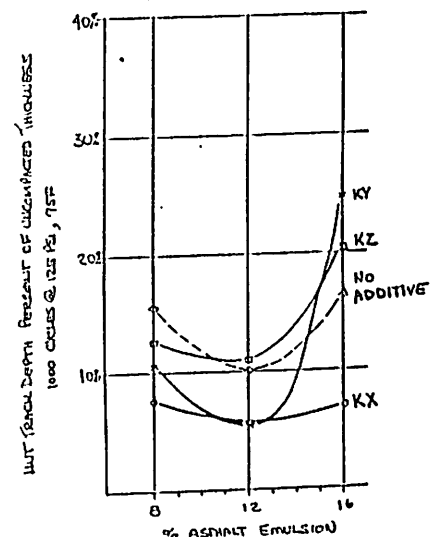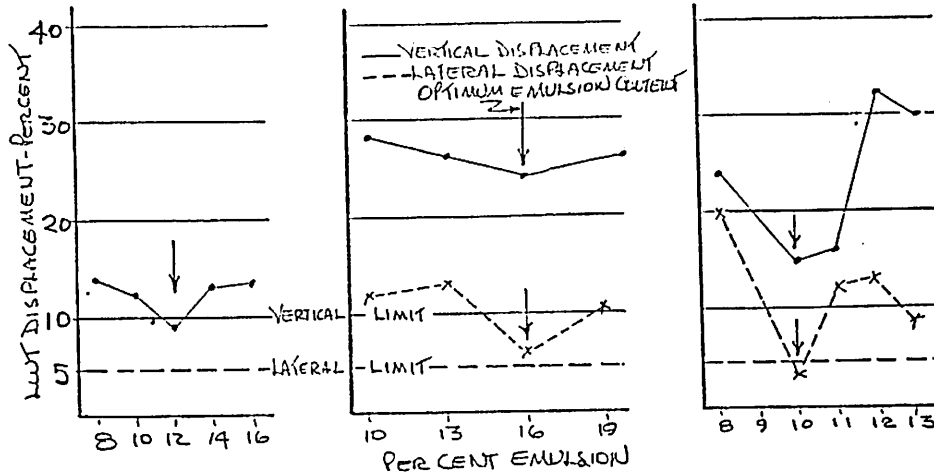
FIGURE 8.   POLYMER "F"

FIGURE 9.   EFFECT OF MIX ADDITIVES
POLYMER "A" -3%
VS. SAND 2 AGG.

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5. OPTIMUM BITUMEN CONTENT

The Loaded Wheel Test may also give simulated traffic compaction curves similar to inverse Marshall curves to establish peak or OPTIMUM emulsion content in the following examples:

FIGS. 10 & 11 OPTIMUM EMULSION CONTENT FOR MAXIMUM RESISTANCE TO TRAFFIC DISPLACEMENT DETERMINED BY THE MULTILAYER, UNCONFINED LOADED WHEEL DISPLACEMENT TEST

6. OPTIMUM MINERAL AGGREGATE FILLER & CHEMICAL FILLER CONTENT
may be determined by 60°C Cured Cohesion or by Loaded Wheel Test displacement curves. In this example from our 1989 Kona paper on FODless airfield slurries, the optimum mineral aggregate filler is 12% 0/200 and the OPTIMUM CHEMICAL FILLER is .8% Portland Cement when 12% synthetic latex emulsion is used. Notice how the 60°C Cured Cohesion and LWT Displacement Tests compliment or confirm each other.
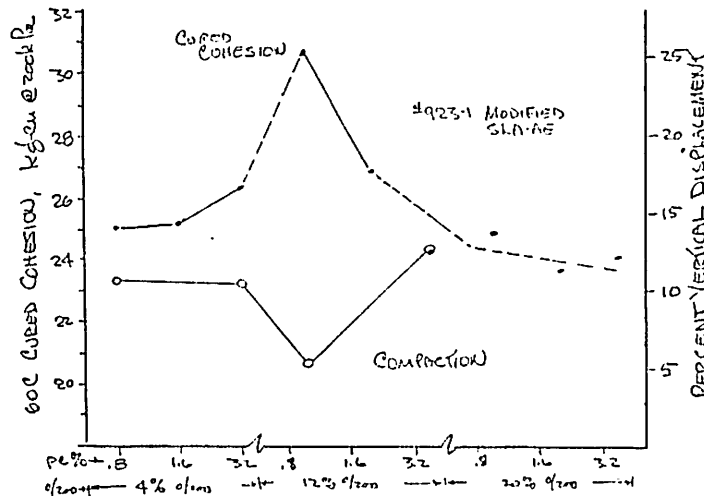

FIG. 12 60C CURED COHESION & LWT VERTICAL DISPLACEMENT VS. 0/200 & CEMENT %

7. EMULSION FORMULATION FOR SLURRY SEAL AND MICROASPHALT SYSTEM PERFORMANCE OPTIMIZATION BY USE OF THE MODIFIED COHESION TEST

24 laboratory emulsions were prepared using one emulsifier at 4 use levels, 2 pH levels and 3 asphalt cements from different crude sources. Each emulsion was cup-mixed with 100 grams of a dry reference 0/#4 dolomite at 12% and 15% emulsion contents and 0, .5, 1.0 & 2.0 Type 1 cement mix time, clear water set time and 30' and 60-minute wet cohesions were determined by the ISSA Technical Bulletin 139 procedure.

For clarity only the results from one base asphalt is reported here. Total liquids contents for all mixes ranged from 19-23%, sufficiently less than the total liquids capacity (22.5%) of the loose aggregate voids. Mix times were all near 180 seconds or more. Clear water set times were generally 10 minutes or less except for the highest emulisfier content at the higher pH.

Normally, chemical filler (type 1 Portland cement) would be used in .25% increments for better precision, but time and money restraints dictated an abbreviated "screening" procedure. No retarders were used nor were they required for the laboratory conditions.

The ISSA Technical Bulletin No. 139 Modified Cohesion Tester is the primary laboratory instrument used in this study.

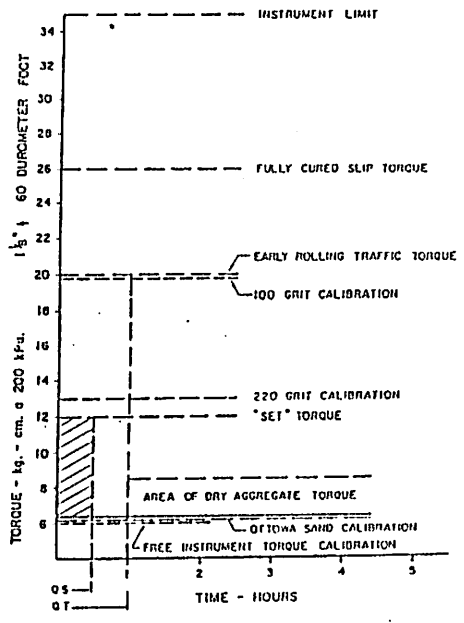Fig. 13 Cohesion Tester   Fig. 14 Tested Specimens

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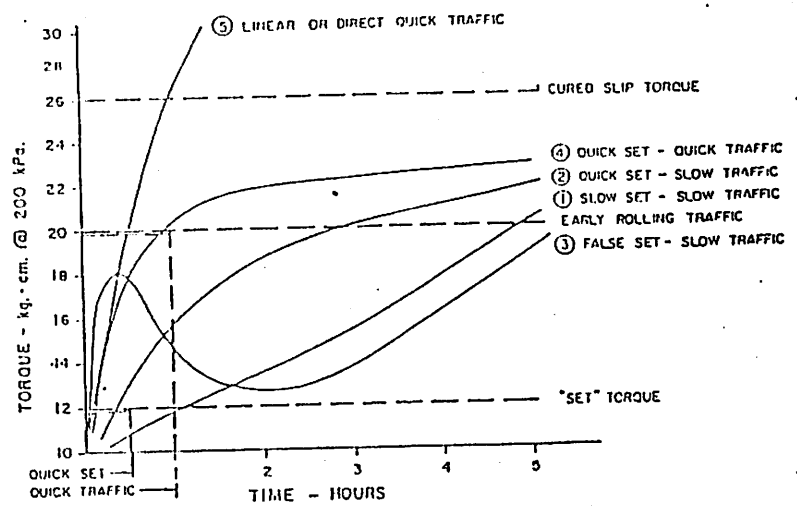FIGURE 15. COHESION TESTER TORQUE LEVELS

FIGURE 16. CLASSIFICATION OF MIX SYSTEMS BY MODIFIED COHESION TEST CURVES

Fig. 15 Quick Set &
Quick Traffic Definition

Fig. 16 Mix System
Classification

The cohesion value reported is the torque required to "rupture" or fail the specimen. Torques of 12.0 kg cm or more in 30 minutes or less indicate "Quick-Set" systems while torques of 20.0 kg-cm or more indicate "early rolling traffic" or "Quick Traffic" systems. For most field situations, "Quick Traffic" systems (20 kg-cm/60) are desirable.

Figure 17 plots the 60 minute cohesion test torques for the emulsion aggregate system using the AC #C100 base asphalt.
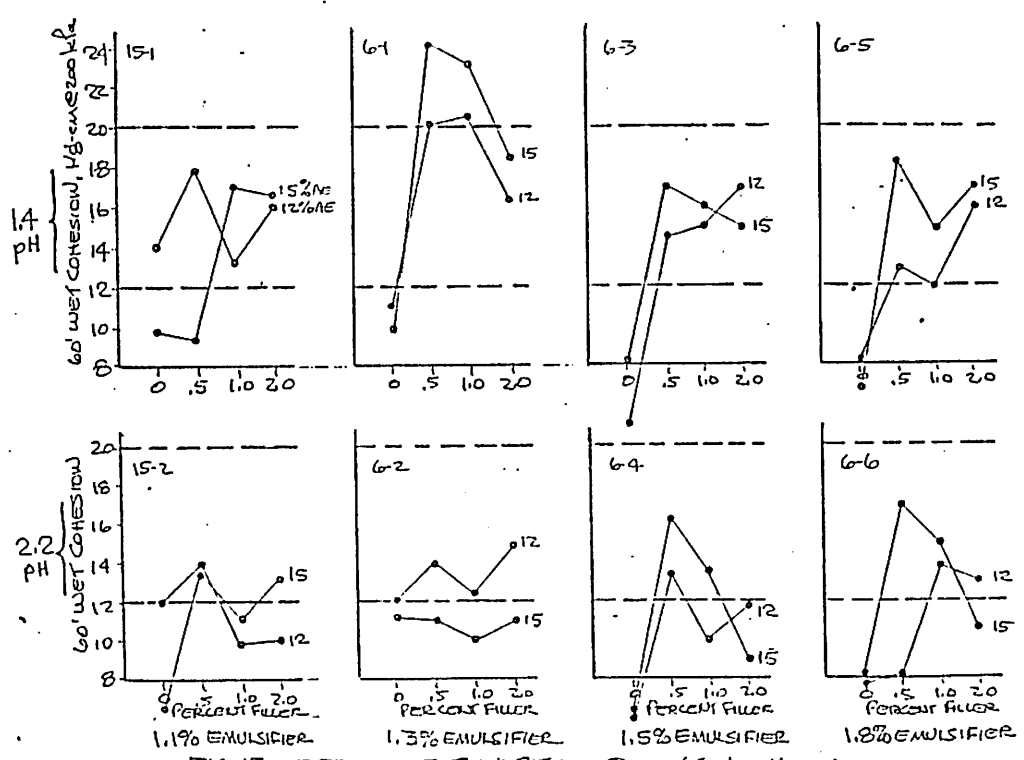

FIG. 17   EFFECT OF EMULSIFIER QUANTITY & pH ON
60-MINUTE WET COHESION (91200 SERIES) AMAC

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Only one emulsion, 6-1, can be classified as "QT" at optimum cement content. 6-1 also has a "broad peak" cement content ranging from about .4% to 1.5% cement when using 15% AE. At 12%, the cement content range is narrowed; from .5 to 1.0, i.e., slightly less cement is required for less emulsion.

It is interesting that nearly all peak 60' wet cohesion occur at .5% cement. Note: the overall 60' wet cohesions are highest, by far at the low pH. Note also the huge difference in 6-1 and 6-2 (high, low pH). Low pH is the clear preference for set time and traffic time.

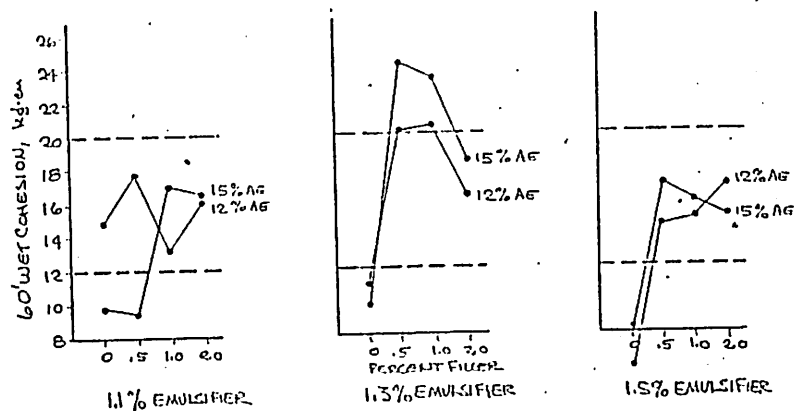Figure 18 shows the OPTIMUM peak emulsifier content at 1.3% and 1.4pH.

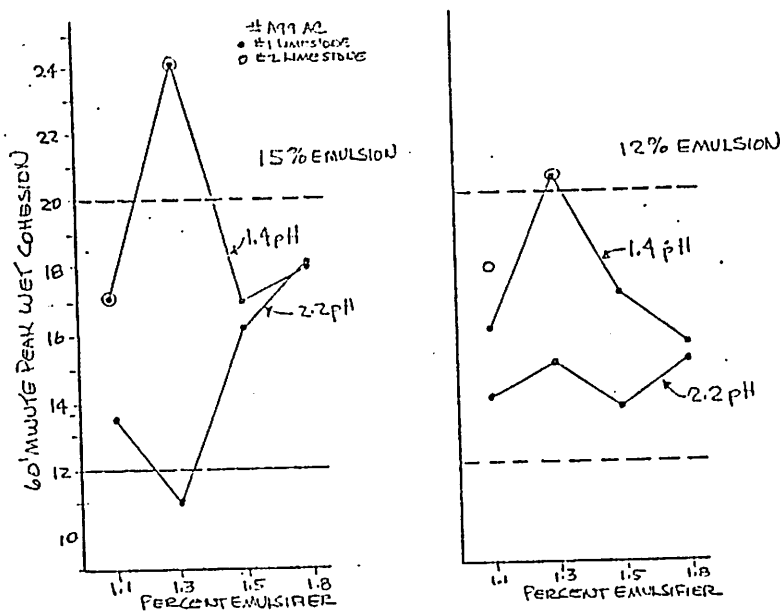FIG. 18 OPTIMUM EMULSIFIER AND CEMENT CONTENTS DETERMINED BY 60' WET COHESION (9120G SERIES, 1.4pH)

FIG. 19 60-MINUTE WET COHESION @ OPTIMUM CEMENT FOR EACH SET. 9120G SERIES, 499 AC 4/LS.#1

Figure 19 summarizes the peak 60' wet cohesion for all emulsifier contents, emulsion contents, and pH levels. The OPTIMUM becomes quite clear for this system.

<u>Caution:</u> Any change in any one of the ingredients, crude source, aggregate type or gradation, emulsion, content, pH, will likely change the above results; perhaps radically. **"EACH SYSTEM IS IT'S OWN THING!"**

<u>8. OPTIMUM STABILITY</u> curves can be also drawn. 1.3% emulsifer at 1.4 pH coincidentally not only performs best regarding set and traffic time but also exhibits the best storage stability...by far as shown in figure 20.
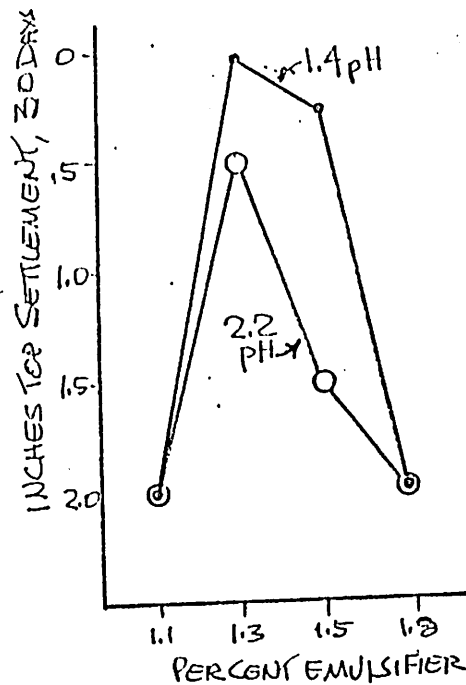

FIG. EFFECT OF pH & EMULSIFIER
20   CONCENTRATION ON TOP
       SETTLEMENT (1206 Series)
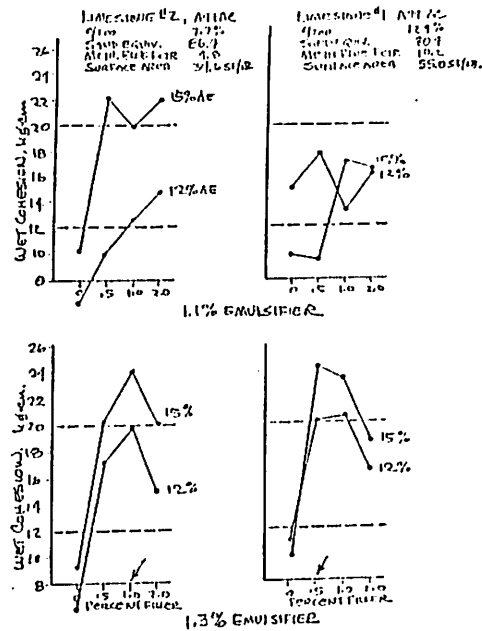
9. EFFECT OF GRADATION - FINES CONTENT

FIG.21 EFFECT OF AGGREGATE FINES QUANTITY & QUALITY AND EMULSIFIER CONCENTRATION ON GO-NO/GO QUALITY (QUICK SET) pH SWINGS)

Figure 21. A similar aggregate of the same chemical type (Dolomite) was mixed and tested for comparison with our first reference aggregate. The second aggregate had lower fines (0#200), higher sand equivalent and half the Methylene Blue factor. At 1.1% emulsifier the 8% 0/#200 (low fines) aggregate did quite well while at 15% AE but poorly at 12% AE. The 12% 0/200 (high fines) aggregate did poorly at either 15 or 12% AE.

At 1.3% emulsifier, both lo and hi fines aggregates did well at both 15 and 12% AE. As is noted, however, that 1% cement was required for the low fines aggregate while only .5% cement was required for high fines aggregate.

We interpret this to mean, in this case at least, that more fines, lower sand equivalent, higher Blue Factors, and greater surface areas requires more emulsifier than the an aggregate with lower fines etc. Also, the fines ACT to replace or substitute for cement.

What we see here is a specific OPTIMUM emulsifier content and OPTIMUM pH required to satisfy the specific aggregate chemistry. In this case, .5% Portland cement is equal to about 5.2% 0/#200 fines; i.e., Portland cement has 10X more chemical reactivity than does the 0/#200 aggregate!

It may be possible to discover the precise optimum emulsifier content and pH level for a given aggregate by this method by making and testing with more complete increments.

10. NOTES ON EMULSION pH SHIFT

We have seen where optimum mix performance is related (among other factors) not only to a specific emulsifier concentration but also to the emulsifier solution pH with a given aggregate.

We note however that the emulsifier solution pH is usually not the same as the finished emulsion pH. There is what we call a pH shift. In some cases there is an immediate ph shift to a constant value. In other cases the emulsion pH after the initial shift keeps rising. With one system we note that an emulsion that was initially a QS-QT changed in a few days to QS-ST and still later changed again to a SS-ST system as shown in figure 22. This change in emulsion properties was due to pH shift.
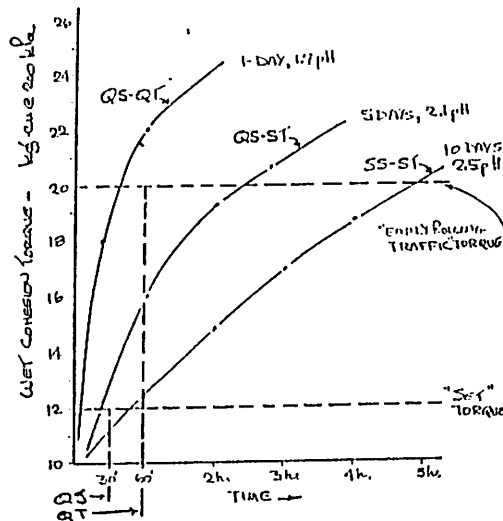

FIG.22 EFFECT OF LONG TERM pH SHIFT ON
SET & CURE CHARACTERISTICS

What is happening here? It seems that we are measuring the pH or hydrogen ion (HCl?) relative concentration in the continuous phase (soap phase) of the emulsion. Are we measuring a dilution of the soap phase? Does the emulsifier break apart and react to remove acid from solution? Does the asphalt contain caustic materials or clays which would neutralize the acid and consequently release unneutralized emulsifier which may then act as a retarder? Does the asphalt contain Nitrogen compounds or other groups that might react with the acid or emulsifer. Does the emulsifier get completely swallowed or dissolved by the asphalt carrying along the associated acid?

Whatever is going on, the emulsion pH does rise and this pH shift affects the mix performance.

An experiment was tried to see what relation there might possibly be to the titration and dilution curves of the emulsifier system.

Six emulsions were prepared using a West Coast commodity grade asphalt and Polymul #320 emulsifier at a constant 1.5% concentration and 3.2, 2.7, 2.2, 2.0, 1.8 and 1.6 pH.

The titration curve used 10 grams emulsifier in 300 grams of distilled water against 20° Be HCl is shown in figure 23. From this curve it is possible to calculate the amount of acid consumed by the asphalt in the emulsion from the shift in pH.
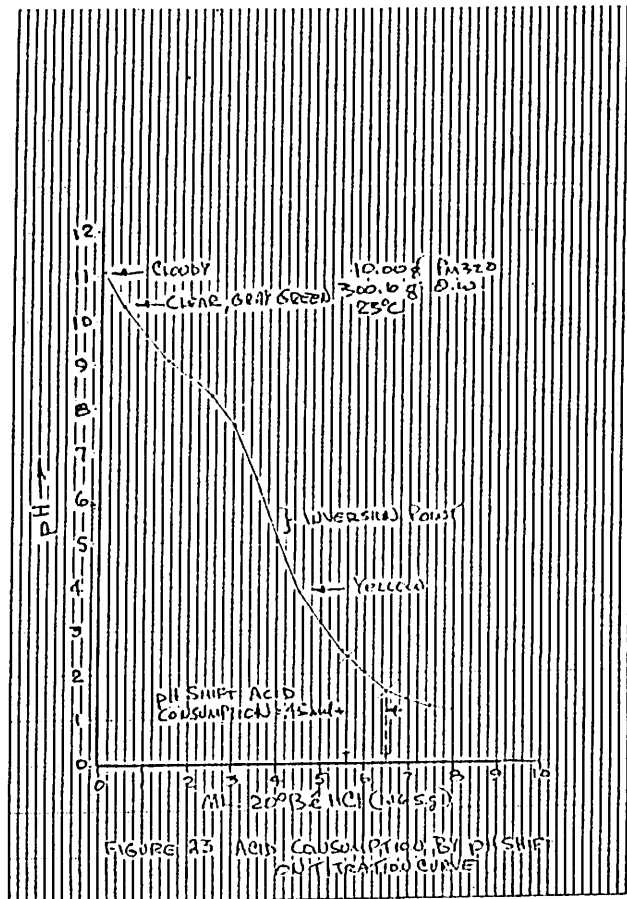
After calculation, plots were made of the pH shift related to the acid required for neutralization. Something looked interesting so a further plot was made relating the acid consumption by the asphalt and the amount of acid used for neutralization as ml HCl/gram of emulsifier. An interesting peak appears:

11. EFFECT OF CHEMICAL FILLERS & AGGREGATE ON MIX pH

As aggregate, water, cement, accelerators or retarders and emulsion are combined, the pH of the resulting "ionic soup" undergoes radical changes. As previously shown, the amount of cement controlled the development of cohesive strength with peak strength at an optimum percent cement.

About a year ago we started to look at these effects of aggregate fines and cement on various systems. Figure 26 shows results of our initial attempts using the 0/#325 fraction of two aggregate types; Sandusky Dolomite and a Basaltic Trap Rock. The Dolomite fines shifted pH to 7.5 but no more. The Basalt fines had virtually no effect. Cement was required to reach 11 pH; in each case about the same amount.
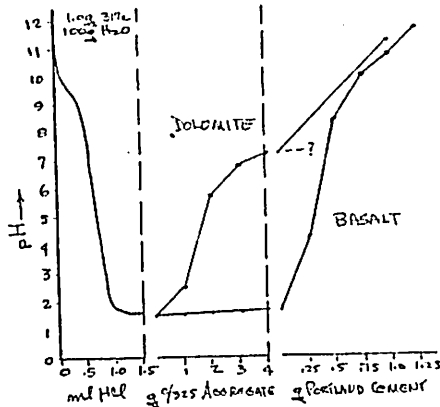

FIGURE 26 EFFECT OF AGGREGATE & PORTLAND CEMENT ON pH OF EMULSIFIER SOLUTION

We then looked at the dilution effect of mix water content on the pH of emulsion and diluted emulsions, figure 27. The emulsifier contents of 1.1 and 1.8 prepared at 1.4 pH showed no difference in pH shift due to dilution; there appeared to be a significant diversion in the higher 2.2 pH emulsions as they were diluted with mix water additions.
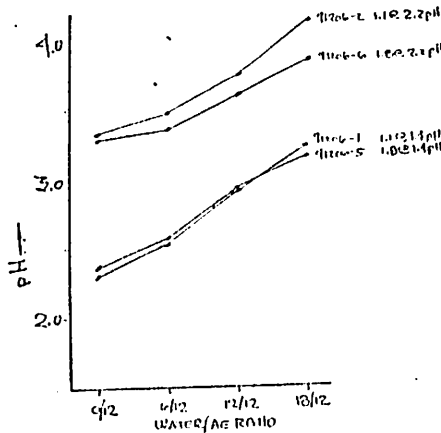

FIG.27 DILUTION EFFECT ON pH OF MIX WATER @ 170 AC

Finally, pH's of the wet mixes themselves are interesting.
Figure 28 shows a mix made with 0/#4 dolomite and 12% emulsion.
The emulsifier solution was 2.2 pH which shifted to 2.75 in the
emulsion. The addition of aggregate and mix water increased the
system pH to 5.9. With .5% cement the system pH was 11.4 and
apparently completely reacted. Further pH increases were due
only to cement.

We note that this .5% cement quantity with this Dolomite is seen
as the OPTIMUM peak throughout this study irrespective of the %
emulsifier or the pH of the emulsion. Additional cement has an
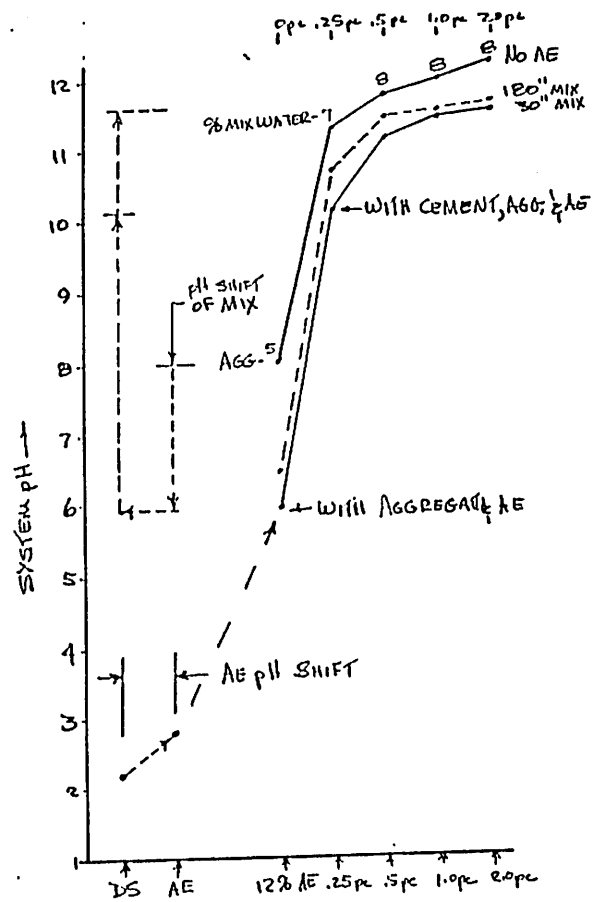adverse effect on Wet Cohesion as previously shown.

FIG. 28   SLURRY SYSTEM pH SHIFT-LATHAM
          O/#4 DOLOMITE AND, OO127-2 AE

A change of emulsifier chemical type, base asphalt, various
additives or aggregate chemistry will undoubtedly change the
optimum location on these curves...perhaps radically. Again, our
caution "EACH SYSTEM IS ITS OWN THING."

15.

12. EFFECT OF PORTLAND CEMENT ON SAND EQUIVALENT

While preparing our 1987 Geneva study on Effects of Fillers, we tried adding cement to one 5% 0/#200 sand Equivalent test of the Sandusky Aggregate. The sand equivalent rose from 93 to 100!

As an experiment here, we did only one set of sand equivalents with the Latham aggregate using incremental additions of cement. Plots of the results follow in Figure 29:
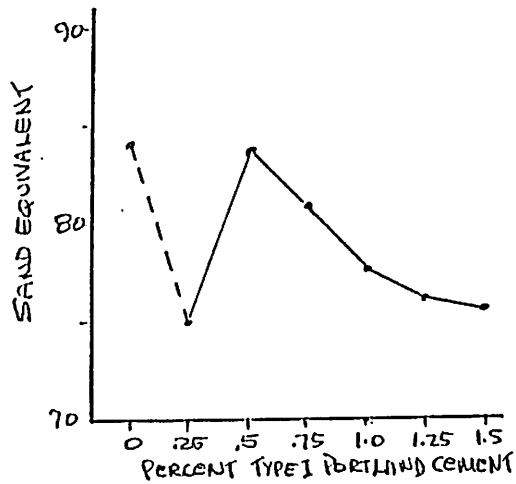

FIG. 29   EFFECT OF CEMENT ON
SAND EQUIVALENT
(LATHAM 0/#4)

We note a coincidence that the SE-cement curve peaks at .5% cement; the same optimum cement content found in the previous examples as well as in 2 other studies with the same aggregate not reported here:

No conclusions are drawn.

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