LABORATORY EVALUATION OF TRINIDAD LAKE ASPHALT

Final Report

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ABSTRACT

The Department has examined several asphalt cement additives over the last 6-8 years in an attempt to produce an increased strength dense graded asphaltic concrete or an acceptable mix using marginal sand aggregates. Trinidad Lake Asphalt, a naturally occurring asphalt, is another material purported to enhance mix properties. Trinidad Lake Asphalt in both an epure and a powder form was examined in the laboratory.

Laboratory testing included: binder properties testing of combinations of Trinidad with three asphalt cements at three levels of addition; binder durability testing using the Thin Film Oven; Marshall optimization of mix design for a low stability dense graded mix, a high stability dense graded mix and sand mix each at three Trinidad addition levels; water susceptibility testing; and, fundamental properties testing. Also, an economic analysis was performed.

In general, Marshall stabilities were found to increase with increasing Trinidad Lake Asphalt content for all mix designs. Modulus values and tensile stress at failure were increased with the use of the Trinidad material while the tensile strain at failure was decreased. Due to the mineral matter in the naturally occurring asphalt, viscosities were higher and penetration and ductilities were lower than values normally associated with conventional binders. Viscosity indices after thin film oven treatment, however, demonstrated no unexpected hardening. An economic analysis on either a first cost or life cycle basis showed that a Trinidad mix would have to perform an additional two years beyond a conventional mix in order to achieve economic parity.

METRIC CONVERSION FACTORS*

To Convert from	To	Multiply by
	Length	
foot	meter (m)	0.3048
inch	millimeter (mm)	25.4
yard	meter (m)	0.9144
mile (statute)	kilometer (km)	1.609
	Area	
square foot	square meter (m^2)	0.0929
square inch	square centimeter (cm^2)	6.451
square yard	square meter (m^2)	0.8361
	Volume (Capacity)	
cubic foot	cubic meter (m^3)	0.02832
gallon (U.S. liquid)**	cubic meter (m^3)	0.003785
gallon (Can. liquid)**	cubic meter (m^3)	0.004546
ounce (U.S. liquid)	cubic centimeter (cm^3)	29.57
	Mass	
ounce-mass (avdp)	gram (g)	28.35
pound-mass (avdp)	kilogram (kg)	0.4536
ton (metric)	kilogram (kg)	1000
ton (short, 2000 lbs)	kilogram (kg)	907.2
	Mass per Volume	
pound-mass/cubic foot	kilogram/cubic meter (kg/m^3)	16.02
pound-mass/cubic yard	kilogram/cubic meter (kg/m^3)	0.5933
pound-mass/gallon (U.S.)**	kilogram/cubic meter (kg/m^3)	119.8
pound-mass/gallon (Can.)**	kilogram/cubic meter (kg/m^3)	99.78
	Temperature	
deg Celsius (C)	kelvin (K)	$t_K=(t_C+273.15)$
deg Fahrenheit (F)	kelvin (K)	$t_K=(t_F+459.67)/1.8$
deg Fahrenheit (F)	deg Celsius (C)	$t_C=(t_F-32)/1.8$

*The reference source for information on SI units and more exact conversion factors is "Metric Practice Guide" ASTM E 380.

**One U.S. gallon equals 0.8327 Canadian gallon.

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IMPLEMENTATION STATEMENT

The recommendations of this report call for the construction of an experimental field trial utilizing Trinidad Lake Asphalt and/or several other asphalt cement additives which have been examined over the past several years. The focus of such a trial would be to assess the anticipated increase in durability associated with these additives as manifested by additional pavement life. Information gathered in this study would form the basis for both project and mix design.

INTRODUCTION

During the 1970s, Louisiana research was directed toward the problem of decreasing availability of quality aggregate materials. This research culminated in laboratory and field evaluations of such processes as sulphur extended asphalt (1)* and Chemkrete modified asphaltic mixes (2). Of particular interest was the possibility of producing either an increased strength dense graded asphaltic concrete or an acceptable mix using marginal sand aggregates. Recently a rather old product which has been little marketed in this country has made a reappearance. This product--Trinidad Lake Asphalt--has been promoted as another alternative.

Trinidad Lake Asphalt, a naturally occurring asphalt, was first used in this country in the 1870s. Similar to other natural asphalts which have been utilized by man since 3200 B.C., Trinidad Lake Asphalt is a mixture of asphalt and/or oil and mineral matter which occurred as a result of complex geological movements. This oil being kept in constant agitation due to gas flows ascended to the surface through major faulted areas. Today this material is refined (water and gas driven off and vegetable matter screened) but retains much of the mineral matter in a colloidal system. It is this asphalt and mineral matter system which provides the purported beneficial properties of Trinidad Lake Asphalt. The product is marketed in two forms: Trinidad "epure" as refined, and Trinidad powder, a 50/50 blend by weight, with a limestone dust for ease of handling.

Trinidad Lake Asphalt is currently used in over 50 countries throughout the world. Recent research (3, 4) in the United States with dense graded asphaltic concrete demonstrated increases in

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*Underlined numbers in parentheses refer to List of References.

Marshall stability, elastic modulii and fatigue life. Similar findings were developed with sand/asphalt mixes (5). With this background it was thought beneficial to evaluate Trinidad Lake Asphalt with Louisiana materials and mix designs.

SCOPE

The aim of this evaluation was to determine in the laboratory the properties of Trinidad Lake Asphalt with respect to binder characterization and its compatibility in two Louisiana mix types and a sand/asphalt mix. This study was conducted in four phases:

Phase I - Binder properties testing;

Phase II - Mix optimization, by the Marshall method, for high stability, low stability and sand/asphalt mixes;

Phase III - Water susceptibility testing; and,

Phase IV - Fundamental properties testing.

METHODOLOGY

Phase I - Binder Properties

The first phase of this study consisted of binder properties testing including penetration (77°F), viscosity (140°F) and ductility (77°F) for each of three different crude based AC-30 asphalt cements (Exxon, Lion and Texaco) and blends of these asphalts with Trinidad Lake epure (at 15, 30 and 45 percent by weight). Tests were conducted on both the original samples and after subjection to the Thin Film Oven test. Results are presented in Table 1.*

Phase II - Mix Optimization

The Marshall method of mix design was used to optimize the binder content for Louisiana Type 1 (1200-pound stability), Type 3 (1700-pound stability) and a sand/asphalt mix. Lion AC-30 was the asphalt cement utilized for each of these mixes. Additionally, the Type 1 mix was tested with the Exxon and Texaco asphalt cements at the optimum asphalt content. Tables 2 through 5 present the mix gradations and Marshall properties resulting from the optimization procedure for these control mixes.

Trinidad Lake Asphalt in both the epure and powder forms was blended with the Lion AC-30 for binder optimization of each mix type. Within each mix type, the Trinidad Lake Asphalt was blended at 15, 30 and 45 percent by weight of the asphalt cement at each binder content. In the epure form, Trinidad Lake Asphalt is substituted at the applicable percentage. Thus, a 5.0 percent binder content assuring a 30 percent blend would contain 4.5 percent asphalt cement and 1.5 percent Trinidad Lake Asphalt. Allowances were made for the limestone dust when the powder form was used (the limestone was treated as aggregate for mix design purposes). The Marshall properties found in this optimization process are provided in Tables 6 through 8.

The Type 1 mix was also examined using blends of Trinidad Lake Asphalt epure and powder and both Exxon and Texaco AC-30s at the

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*All tables may be found in the Appendix (page 27).

optimum binder content, 5.7, for the control mix. Marshall properties for these mixes are presented in Tables 9 and 10.

All Marshall briquettes were fabricated according to DOTD TR 303-79, Method B using a 75 blow design. The properties presented in Tables 1 through 10 represent average values of three specimens.

Phase III - Water Susceptibility Testing

Susceptibility to water was examined using the index of retained Marshall stability. Type 1 mix was prepared using an optimum asphalt content of 5.7 percent. A factorial utilizing the three asphalt cements, Lion, Exxon and Texaco, and 0 percent Trinidad Lake Asphalt, 30 percent epure and 15 percent powder was designed. The Type 3 and sand/asphalt mixes were examined only with Lion AC-30 at Trinidad Lake Asphalt addition rates of 0 percent, 30 percent epure and 30 percent powder. Each mix design was examined for absorption, swell and the percent retained Marshall stability.

Loose mix was examined for stripping susceptibility in a ten-minute boil test. In this test, loose mix is placed in a jar of boiling water and boiling is continued for ten minutes. After boiling, the material is removed and dried on paper towels and a visual examination is made. A matrix for the Type 1 mix included 0 percent Trinidad Lake Asphalt, 30 percent epure and 15 percent powder for each of the three asphalt cements utilized in this study.

Phase IV - Fundamental Properties

In this phase, the Indirect Tensile Test was utilized to determine fundamental properties of Trinidad mixes such as modulus of elasticity, poisson's ratio, tensile stress at failure and tensile strain. Briquettes were constructed for all three mix types using Lion AC-30 at the optimum asphalt content. Trinidad Lake Asphalt in both the epure and powder forms was examined.

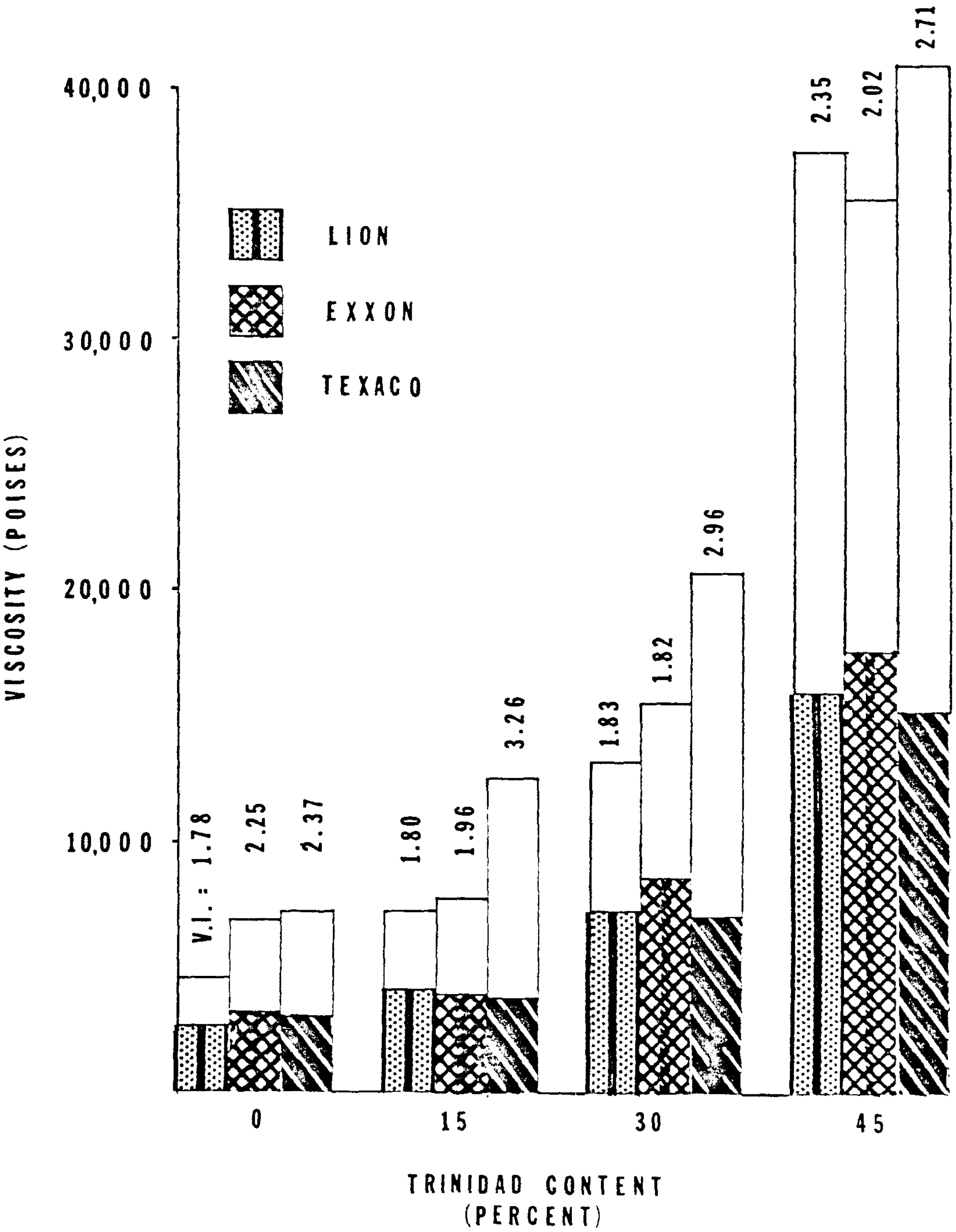
DISCUSSION OF RESULTS

Phase I - Binder Properties

As reported earlier, Trinidad Lake Asphalt epure is actually a colloidal system comprised of approximately 55 percent bitumen and 45 percent mineral matter. For this reason, the standard descriptive asphalt cement tests were anticipated to provide atypical results. These expectations were realized as indicated in Table 1 (page 29).

Figure 1 presents the viscosity data in a graphic format. The shaded portions of each bar represent the viscosity prior to the Thin Film Oven test, and the clear portion of the bar shows the viscosity after exposure to the Thin Film Oven (TFO). Each of the three asphalt cements are shown with the addition of 0, 15, 30 and 45 percent by weight of Trinidad Lake Asphalt. It is readily apparent that the viscosity of both the before and after TFO samples increases with increasing Trinidad Lake Asphalt content. The increase in viscosity for each asphalt cement (Lion, Exxon, Texaco) with increasing epure content is a function of the amount of mineral matter in the narrow viscometer tubes. Generally, the viscosity indices (ratio of after TFO to before TFO viscosities) of those samples with the epure are similar to the base asphalts for Lion and Exxon while the Texaco plus epure is higher than the base Texaco asphalt. All of the viscosity indices are well under Louisiana's 4.0 maximum allowable viscosity index.

The penetration and ductility testing also demonstrated the anticipated results of decreasing values with increasing epure content. Penetration levels for the bitumen in Trinidad Lake Asphalt have been reported as 1-2. Thus, when blended with the base asphalts at various percentages and along with the additional "hardening" effect of the mineral matter, the test results can be reconciled. The susceptibility to oxidation of the asphalt plus epure blends



Viscosity Indices

FIGURE 1

as described by penetration loss is consistent with the viscosity results in that both the Lion and Exxon based blends show hardening at about the same rate as the base asphalts while the Texaco blend hardens at an increased rate. The usefulness of the ductility test is difficult to ascertain due to the presence of the mineral matter in the binder.

Due to the additional filler material in the 50/50 Trinidad Lake Asphalt blend, binder properties testing was not considered.

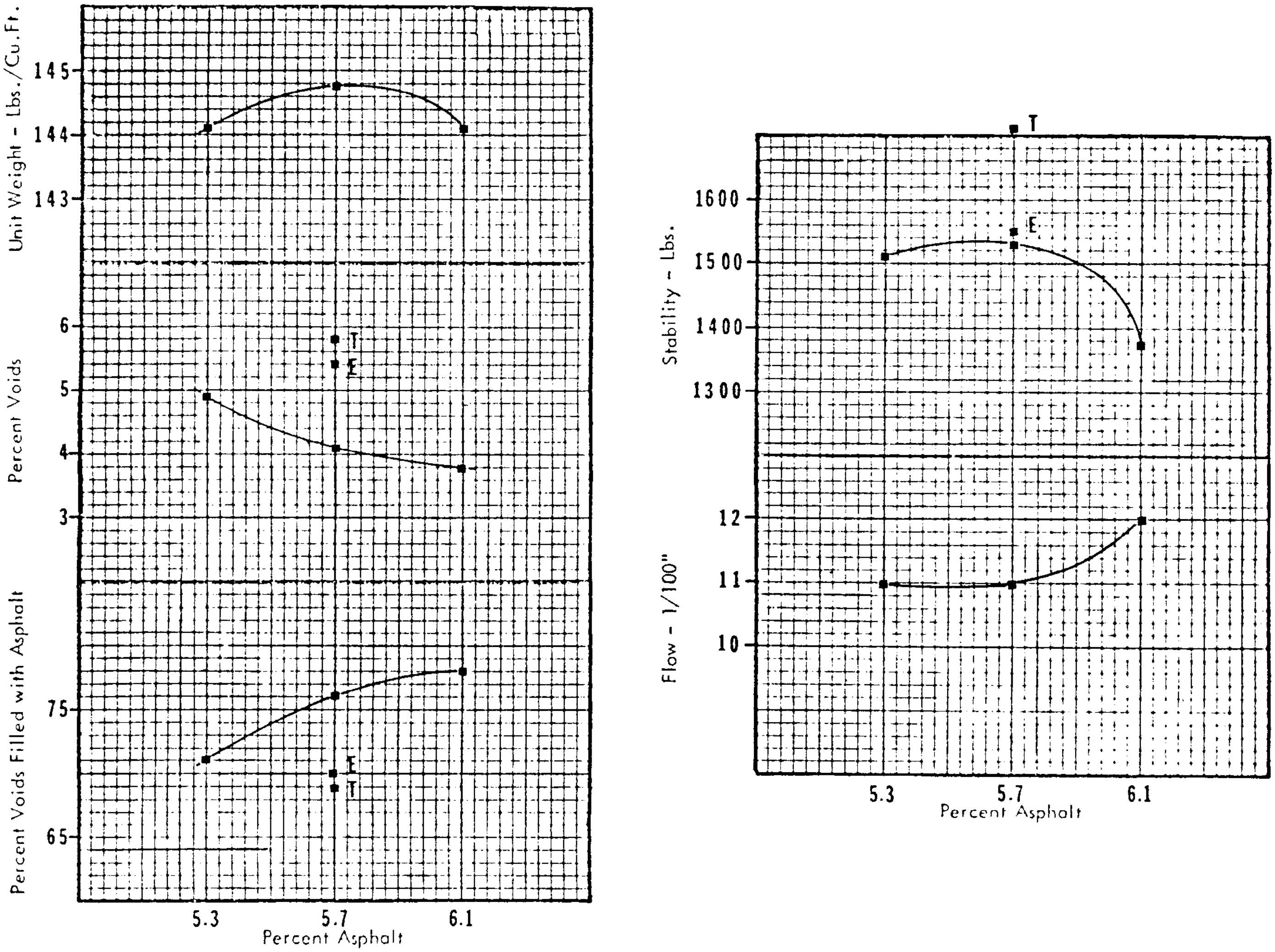
Phase II - Mix Optimization

Type 1 Mix

Figure 2 graphically presents the Marshall property data for the Type 1 mix using Lion AC-30 (Table 2, page 30). The binder content is optimized at 5.7 percent. Marshall properties for mixes utilizing Exxon (E) and Texaco (T) asphalt cements at 5.7 percent binder content were also determined and have been presented in Figure 2.

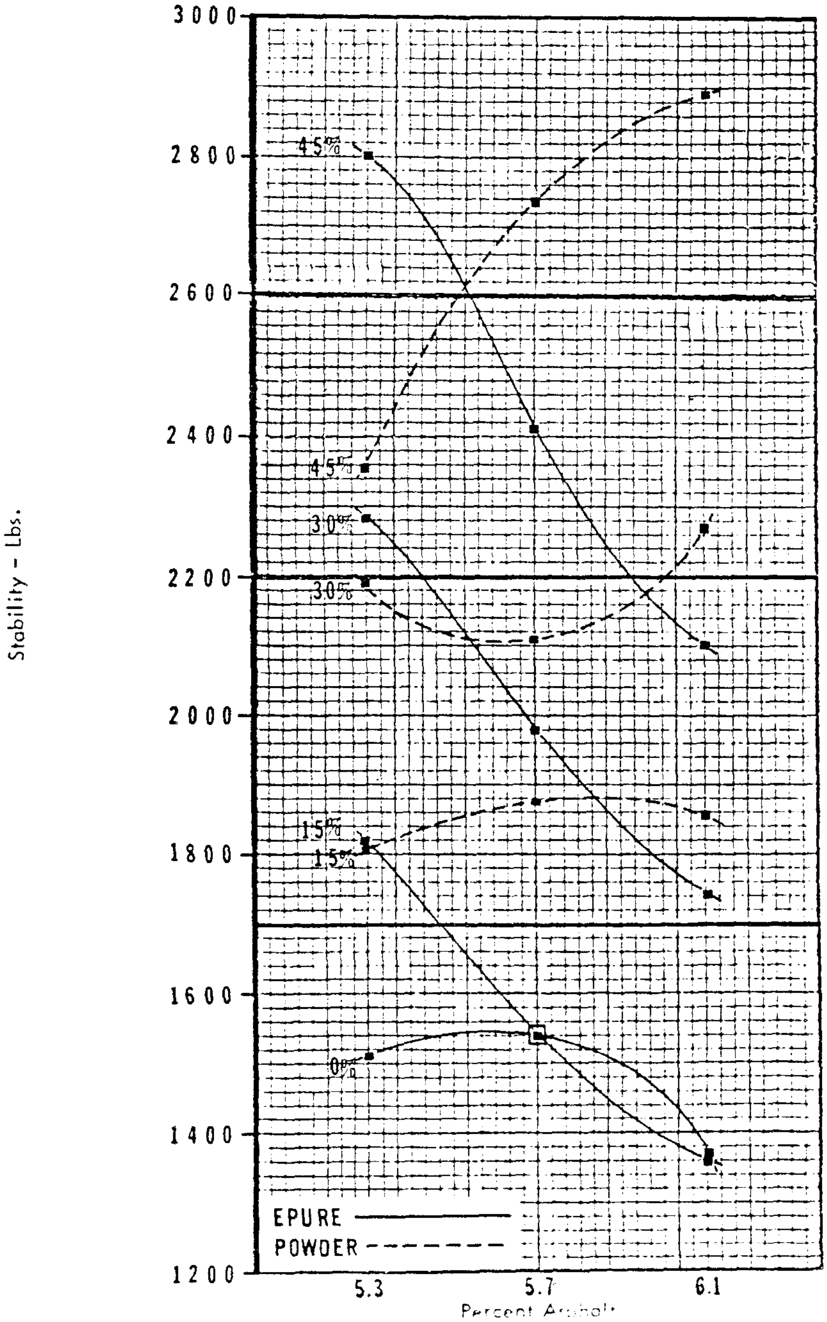
Marshall property data for the Type 1 mix with Lion AC-30 and Trinidad Lake Asphalt are presented in Table 6 (page 34). Air voids and voids filled with asphalt (VFA) were very similar to the control mix for the epure regardless of epure content, while the powder had higher air voids and thus lower VFAs. As the total amount of Trinidad Lake Asphalt was the same in each design, it is believed that the additional fines from the limestone filler are the cause. It would appear that additional asphalt cement might be required.

Figure 3 presents the Marshall stabilities for control, epure and powder mixes. Generally, it can be observed that Trinidad Lake Asphalt at any level of addition provides an increase in stability. An increase in either epure or powder increases stability levels with the powder providing a greater increase. At the control mix optimum binder content the epure has increased stability 0, 29 and



Type 1 Mix Optimization

FIGURE 2



Marshall Stabilities for Type 1 Epure and Powder Mix

FIGURE 3

57 percent for the 15, 30 and 45 percent addition rates, respectively, while the powder demonstrated increases of 22, 37 and 78 percent for these same levels of Trinidad Lake Asphalt addition.

The stability data also indicates that higher stabilities were attained at 5.3 percent binder content for the epure mix. This is consistent with field data for this particular mix design. Also, it was noted that stabilities for the powder mixes are generally consistent within each addition level regardless of binder content, indicating the efficiency of aggregate interlock with this mix design. It appears that the limestone filler is responsible for the higher stabilities attained.

Type 1 mix utilizing 0, 15, 30 and 45 percent Trinidad Lake Asphalt, epure and powder, was also investigated with Exxon and Texaco asphalt cement at a binder content of 5.7 percent. Marshall properties are presented in Tables 9 and 10 (page 37). Generally, these mixes proved less dense as air voids were higher and VFAs lower for both control and Trinidad Lake Asphalt, either epure or powder. Curiously, however, the powder mixes achieved lower void contents than the epure. Air void contents were consistent regardless of Trinidad Lake Asphalt addition rate.

With respect to stability, the trend was similar to that found previously; increased levels of epure or powder produced higher stabilities for both the Exxon and Texaco mixes. The percentage increases in stability were similar in trend to those established by the Lion mix with the powder providing larger increases:

	Exxon		Texaco	
Addition Rate	Epure	Powder	Epure	Powder
15	18	24	7	14
30	28	30	25	27
45	55	84	35	58

Type 3 Mix

The Type 3 control mix Marshall design data is provided in Figure 4 (from Table 3, page 31). While the optimum binder content would appear to be 5.9 based on these graphs, 5.6 was chosen so as to coincide with the maximum stability and field data (job mix formula for this mix design).

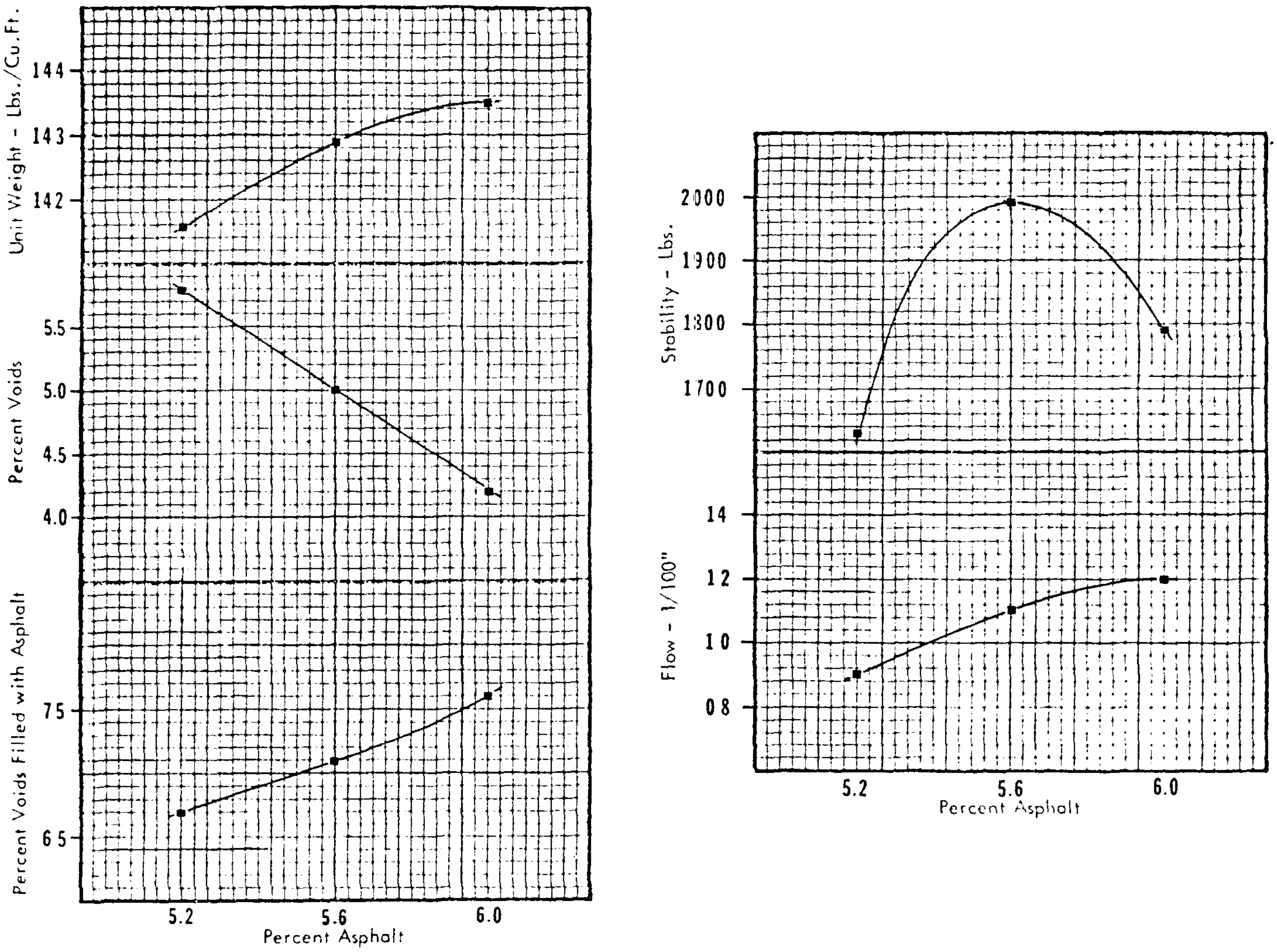
Air void levels and VFAs were consistent between the epure and powder mixes (Table 7, page 35). The air voids were greater than the control mix while VFAs were lower. The 15 percent screenings utilized in the Type 3 mix probably created a rather harsh mix which did not leave room for these additional filler materials of the Trinidad Lake Asphalt.

Stabilities, as demonstrated in Figure 5, followed a pattern similar to the previous mix type in that stability increased with increasing Trinidad Lake Asphalt content. However, there was little difference between the epure and powder. Again, this was probably due to the aggregate mixture. It is apparent that the benefit of Trinidad Lake Asphalt in the Type 3 mix is not as obvious due to the harshness of the mix and lack of compaction. This is readily seen when observing the percentage increase in stability at the 5.6 percent binder content:

Addition Rate	Epure	Powder
15	-13	- 7
30	9	15
45	25	22

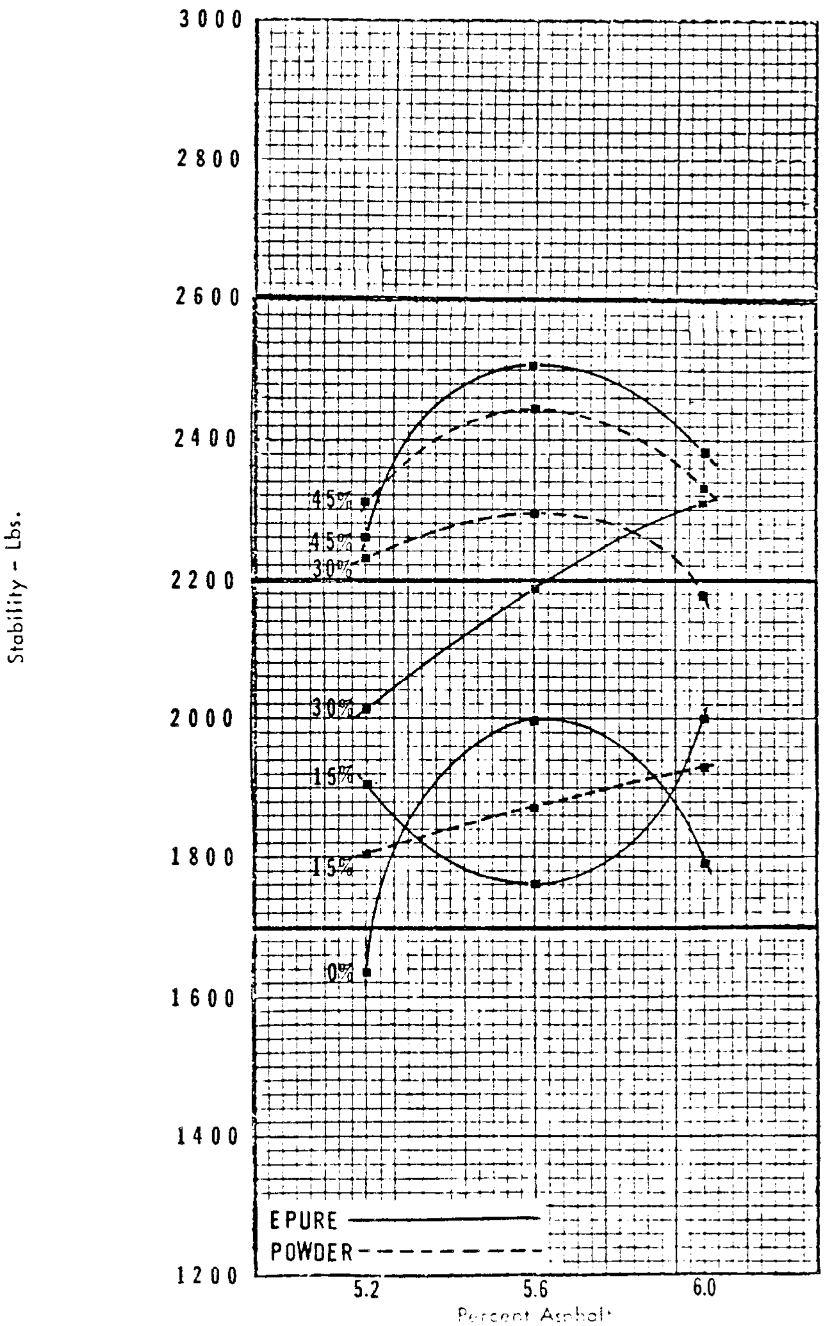
Sand/Asphalt Mix

Louisiana specifications do not currently contain sand/asphalt mixtures as its locally available sands are rounded and generally produce stabilities in the range of 200-700 pounds. Additionally, the increase in binder content required by these mixes in the range of 8 to 10 percent makes them prohibitive from an economic point of



Type 3 Mix Optimization

FIGURE 4



Marshall Stabilities for Type 3 Epure and Powder Mix

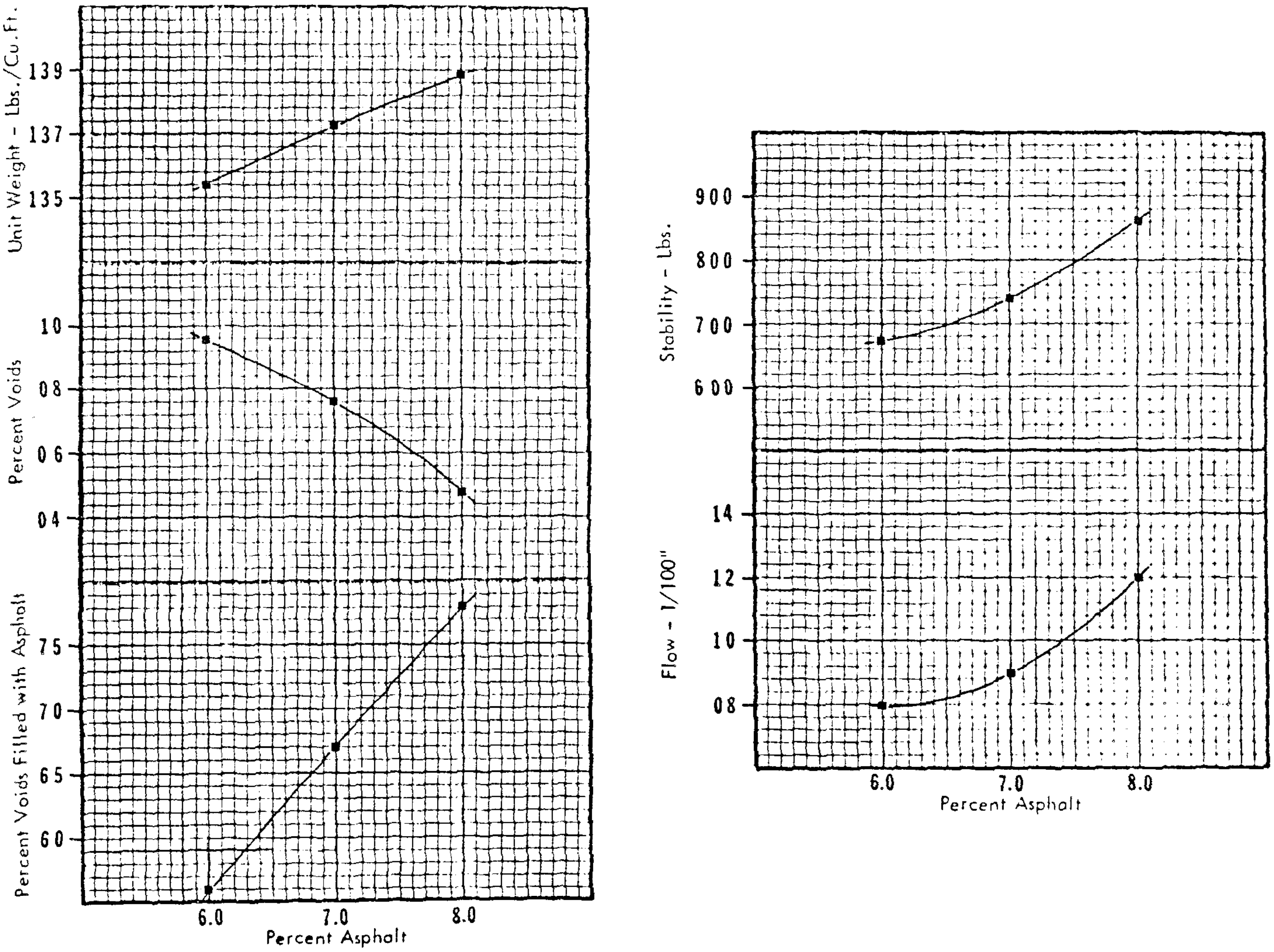
FIGURE 5

view. The introduction of extenders and additives such as sulphur and Chemkrete, though, provided the opportunity to increase stability and reduce binder content, thus providing an economically feasible sand/asphalt mix for those areas of the state where quality aggregate had to be hauled long distances. It was believed that Trinidad Lake Asphalt might provide similar benefits.

An attempt to optimize binder content for a sand/asphalt mix was made using 6, 7 and 8 percent asphalt cement. As can be observed in Figure 6 (data from Table 4, page 32), these binder contents neither maximized stability nor brought air voids and VFAs into acceptable ranges (less than 3-5 and 70-80, respectively) unless the binder content was increased to 8 percent or greater. A 7 percent binder content, though, would provide void and VFA levels similar to those obtained with sulphur extended asphalt and Chemkrete mixes and would be more economical. It was therefore decided to use this binder content for the Trinidad Lake Asphalt optimization.

Table 8 (page 36) presents the optimization data for the epure and powder mixes. The Trinidad Lake mixes produced air void and VFA levels consistent with the control mix for both the epure and powder at all but the 45 percent addition level. Also at the 30 and 45 percent rate, they provided stabilities above Louisiana's minimum 1200-pound limit (for Type 1 mix). Following the trend of the other mix types the following percentage increases at 7 percent binder content in stabilities are reported:

Addition Rate	Epure	Powder
15	30	54
30	64	84
45	103	67



Sand/Asphalt Mix Optimization

FIGURE 6

Phase III - Water Susceptibility Testing

The Marshall immersion properties are reported in Tables 11, 12 and 13 (pages 38, 39) for the Type 1, Type 3 and sand/asphalt mixes, respectively. In most instances for the Type 1 and Type 3 mixes, the percent retained strength was improved with the addition of Trinidad Lake Asphalt. The percent swell was within the maximum allowable limit for each of these mix types. All of the sand/asphalt mix, however, failed both the percent retained strength and percent swell. This is no doubt reflected by the higher air void content of the sand mix. It should be noted, though, that the air void content of the control, epure and powder briquettes was the same, yet those specimens with Trinidad Lake Asphalt did not perform as well as the control.

Loose mix samples of Type 1 mix including Lion, Exxon and Texaco asphalt cements, 30% epure and 15% powder were subjected to the ten-minute boil test. The results are reported below on a scale from A+ to F with a score of C being acceptable. The Trinidad Lake Asphalt demonstrated marginally improved results over the control samples with the exception of the Exxon mixes where the control was slightly better.

	Asphalt		
Percent Trinidad Lake Asphalt	Lion	Exxon	Texaco
0	C+	B+	C-
30% epure	B	B	C+
15% powder	B	B	C+

Phase IV - Fundamental Properties

Fundamental properties for each mix type are presented in Table 14 (page 40). The data from this table demonstrates that both the epure and powder form of the Trinidad Lake Asphalt when added to any mix type will produce a stiffer mix. This confirms the trend observed in Marshall optimization procedure. Generally, the modulus value increases approximately 50 percent at the 30% addition rate, lateral strain is reduced thereby reducing poisson's ratio, tensile stress at failure is increased and tensile strain decreased.

ECONOMIC ANALYSIS

The results of this laboratory study indicate that Trinidad Lake Asphalt at a 30 percent additive rate can enhance dense graded mix strength properties by approximately 30 percent and also increase sand/asphalt mix stabilities above the 1200-pound Type 1 mix requirement. These findings are similar to those of other additives that Louisiana has tested such as Chemkrete, sulphur, polymerized asphalt (Styrelf 13), latex and carbon black. Each of these products proclaims mix enhancements such as increased strength, increased fatigue resistance, increased resistance to deformation, improved low temperature susceptibility properties, etc. The utility of such benefits must necessarily be balanced against product costs.

Materials costs for gravel, stone, coarse sand, fine sand and asphalt cement were solicited from contractors in representative areas of the state. Also, a representative of Trinidad Lake Asphalt estimated the cost of epure at approximately $500 per ton. These costs were used with typical Type 1 and sand/asphalt mix designs to develop the following estimated materials costs per ton of hot mix (estimates for several of the other additives using typical mix designs have been included for reference):

Mix Type	Baton Rouge $/ton	Lake Charles $/ton	New Orleans $/ton
Type 1 (gravel)	15.47	17.63	16.64
Type 1 (stone)	18.02	16.57	19.21
Type 1 (30% epure)	20.63	22.78	21.72
Type 1 (Styrelf 13)*	20.97	23.09	21.87
Type 1 (latex)*	20.21	22.37	21.38
Sand/ashpalt	15.92	16.30	17.08
Sand/asphalt (30% epure)	22.86	23.23	23.92
Sand/asphalt (Chemkrete)*	20.49	21.13	21.89
Sand/asphalt (sulphur)*	18.48	19.06	19.29

*Based on the following costs:

Styrelf 13	$ 275/ton
Chemkrete	$1200/ton
Latex	$8.00/gallon
Sulphur	$ 150/ton

It is observed that the use of Trinidad Lake Asphalt in a Type 1 mix will increase materials costs about $5.00 per ton while the increase for a sand mix would be approximately $7.00 per ton. The use of stone instead of gravel would either increase or decrease mix costs depending on location, but would be less than the use of the epure. Another observation is that, generally, sand/asphalt mix costs, due to the increased binder content, are slightly greater than conventional Type 1 mix. This in combination with the $7.00 per ton increase with Trinidad Lake Asphalt would seem to greatly restrict the utility of sand mix.

While it can be argued that the substitution of stone could provide mix with strengths equivalent to epure mixes at approximately one-half the cost, the additive ability to increase durability would not be recognized. To examine this aspect from an economic viewpoint, an annual cost comparison was examined to provide estimated life spans for equal annual costs. For this comparison the $5.00 per ton additional cost of Trinidad Lake Asphalt was added to a typical hot mix price of $30.00 per ton. A capital rate of return of 8.0 percent was assumed with no maintenance costs providing the following results:

Mix Type	First Cost ($/Ton)	Life for Equal Annual Cost (Years)			
Type 1 (gravel)	30	4.0	6.0	8.0	10.0
Type 1 (gravel-30% epure)	35	4.8	7.4	10.0	12.8

Thus, durability associated with a Trinidad Lake Asphalt would have to provide more than an additional two years of life for a conventional mix lasting eight years according to the results of a first cost analysis.

An economic analysis of life cycle costs was also undertaken. For this evaluation, first costs were converted to price per square yard figures for 1.5 inches of mix. Costs for maintenance and additional overlays for a 20-year design life were assumed on the basis that the initial use of Trinidad Lake Asphalt would increase the time to first overlay by two years. Thereafter, conventional mix would be placed. Again an 8.0 percent rate of return was used providing the following results:

	Type 1 (Gravel)		Type 1 (Gravel-30% Epure)	
Year	Cost ($/yd²)	Present Worth ($/yd²)	Cost ($/yd²)	Present Worth ($/yd²)
0	2.48	2.48	2.89	2.89
1				
2				
3				
4	0.10	0.074		
5	0.10	0.068		
6	0.15	0.095	0.10	0.063
7	2.48	1.447	0.15	0.086
8			0.25	0.135
9			2.48	1.241
10	0.10	0.046		
11	0.15	0.064		
12	2.48	0.985	0.10	0.040
13			0.15	0.055
14			2.48	0.844
15	0.10	0.032		
16	0.15	0.045		
17	2.48	0.670	0.10	0.027
18			0.15	0.038
19			2.48	0.575
20	0.10	0.021		
Total Present Worth		5.99		6.03
Capital Recovery Factor		0.10185		0.10185
Uniform Annual Cost		0.61		0.61

On the basis of the assumptions made in this life cycle analysis the results are similar to those of using first costs only: i.e., an additional two years of life from a Trinidad Lake Asphalt pavement would produce a system of equivalent cost.

CONCLUSIONS

The following conclusions are drawn from the data generated in this study and, as such, are confined to the materials sources examined:

1. An addition rate of 30 percent Trinidad Lake Asphalt provided a minimum increase in Marshall stability of 25 percent for a type 1 mix design (1200-pound minimum). A 45 percent additive rate was required for a type 3 mix design (1700-pound minimum) to attain an equal percentage increase in stability.

2. The use of Trinidad Lake Asphalt at a 30 percent level in a sand mix can produce stabilities equal to those required by type 1 specifications.

3. Similar to the results obtained in the Marshall testing, fundamental properties testing for all mix types demonstrated increasing modulus, increasing tensile stress and decreasing tensile strain for increasing rates of Trinidad Lake Asphalt.

4. An economic analysis on both a first cost and life cylce basis indicates that the use of Trinidad Lake Asphalt would have to increase pavement life by greater than two years to achieve feasibility.

5. Binder properties testing showed increasing viscosities, and decreasing penetrations with increasing Trinidad Lake Asphalt content. These results are attributed to the mineral content of the natural asphalt. The value of ductility testing is questionable due to the mineral matter.

6. Viscosity indices for binders with Trinidad Lake Asphalt added were similar to the conventional asphalt cements.

RECOMMENDATIONS

The results of this laboratory study indicate that Trinidad Lake Asphalt performs similar to other asphalt additives currently marketed in that they can enhance mix properties. Products which increase mix strength such as Chemkrete and sulphur have been examined by Louisiana in the laboratory and are currently undergoing field evaluations. Other products such as Styrelf 13, latex and carbon black have shown increased mix durability by increasing resistance to fatigue and permanent deformation in the laboratory. The additional materials costs associated with these materials (approximately $4.00-6.00/ton of hot mix), however, may be economically prohibitive. Utilization of these additive materials would be limited to: (1) improve properties of sand mix for those areas where quality aggregate is scarce; (2) increase mix stability for heavily stressed areas; (3) reduce thick section design; and, (4) enhance mix properties and durability in thin lift overlays.

Perhaps the most promising utilization of asphalt cement additives would be in thin lift design. Their use in sand mixes has been shown to be expensive due to the increased binder content associated with sand mix. Increasing mix stability for high stress areas or reducing thick section design would probably be better addressed by the use of stone rather than additives. However, the increased durability associated with several of these additives should favor their use in thin lift design. As demonstrated in the economic analysis, the approximate 15 percent additional initial cost for a 1½-inch overlay could be amortized with an additional two years of life. It appears that such a benefit could be realized with several of these additives, and, therefore, a field trial utilizing one or more of these additives is recommended.

LIST OF REFERENCES

1. Carey, D. E., and Paul, H. R., Sulphur Extended Asphalt, Louisiana DOTD, Research Report No. 144, May 1980.
2. Carey, D. E., and Paul, H. R., Laboratory Evaluation of Modified Asphalt, Louisiana DOTD, Research Report No. 142, January 1981.
3. Witczak, M. W., The Influence of Trinidad Epure Upon the Elastic Moduli Behavior of Asphaltic Mixtures, Consulting Report, January 1978.
4. Witczak, M. W., Fatigue Behavior of a Trinidad Epure Mix, Consulting Report, July 1980.
5. Witczak, M. W., Influence of Trinidad Epure Upon Georgia DOT Sand Asphalt Mixtures, Consulting Report, December 1981.

APPENDIX

LIST OF TABLES

TABLE 1

BINDER PROPERTIES

Asphalt Source	% Epure	Penetration @ 77°F		Viscosity @ 140°F, poises		Ductility @ 77°F	
		Before T.F.O.	After T.F.O.	Before T.F.O.	After T.F.O.	Before T.F.O.	After T.F.O.
Lion	0	50	39	2,603	4,646	150+	150+
	15	38	29	4,021	7,222	88	79
	30	31	22	7,127	13,076	46	38
	45	20	16	15,942	37,472	27	19
Exxon	0	60	44	3,074	6,913	150+	150+
	15	45	39	3,951	7,750	55	34
	30	31	24	8,554	15,541	42	22
	45	23	19	17,590	35,449	22	16
Texaco	0	60	43	3,003	7,110	150+	150+
	15	52	32	3,863	12,584	89	27
	30	42	22	7,004	20,700	50	11
	45	30	12	15,078	40,955	23	6

TABLE 2

TYPE 1 CONTROL MIX PROPERTIES
LION AC-30

	Percent Passing			
U.S. Sieve Size	Crushed Gravel	Coarse Sand	Fine Sand	Design (63-20-17)
3/4 inch	100	100	100	100
1/2 inch	78	100	100	86
3/8 inch	61	97	100	74
No. 4	33	93	100	57
No. 10	16	84	99	44
No. 40	5	51	79	26
No. 80	3	8	39	11
No. 200	2	2	25	5

% Binder Content	% Air Voids	% V.F.A.	Stability	Flow
5.3	4.9	71	1510	11
5.7	4.1	76	1535	11
6.1	3.8	78	1370	12

TABLE 3

TYPE 3 CONTROL MIX PROPERTIES
LION AC-30

U.S. Sieve Size	Percent Passing Crushed Gravel	Screenings	Coarse Sand	Fine Sand	Design (60-15-15-10)
3/4 inch	99	100	100	100	99
1/2 inch	91	100	100	100	95
3/8 inch	82	100	99	100	89
No. 4	39	100	95	100	62
No. 10	17	75	85	99	44
No. 40	6	20	37	98	23
No. 80	3	10	2	96	14
No. 200	2	6	0	40	6

% Binder Content	% Air Voids	% V.F.A.	Stability	Flow
5.2	5.8	67	1636	9
5.6	5.0	71	1999	11
6.0	4.2	76	1790	12

TABLE 4

SAND/ASPHALT CONTROL MIX PROPERTIES
LION AC-30

U.S. Sieve Size	Percent Passing: Coarse Sand	Percent Passing: Fine Sand	Percent Passing: Design (70-30)
1/2 inch	100	100	100
3/8 inch	97	100	98
No. 4	93	100	95
No. 10	84	99	89
No. 40	51	98	65
No. 80	8	96	84
No. 200	2	40	13

% Binder Content	% Air Voids	% V.F.A.	Stability	Flow
6	9.7	56	674	8
7	7.6	67	740	9
8	4.8	78	861	12

TABLE 5

TYPE 1 CONTROL MIX PROPERTIES
EXXON AND TEXACO AC-30
5.7% BINDER CONTENT

Asphalt	% Air Voids	% V.F.A.	Stability	Flow
Exxon	5.4	70	1543	9
Texaco	5.8	69	1711	9

TABLE 6

TYPE 1 TRINIDAD MIX OPTIMIZATION
LION AC-30

EPURE

% Epure Content	% Binder Content	% Air Voids	% V.F.A.	Stability	Flow
15	5.3	4.4	73	1820	9
15	5.7	4.1	76	1537	12
15	6.1	3.3	81	1363	13
30	5.3	4.5	73	2282	10
30	5.7	4.1	76	1980	12
30	6.1	2.9	83	1740	13
45	5.3	5.0	71	2800	9
45	5.7	4.1	76	2407	12
45	6.1	3.3	81	2100	11

POWDER

% Powder Content	% Binder Content	% Air Voids	% V.F.A.	Stability	Flow
15	5.3	6.2	65	1813	10
15	5.7	5.8	68	1877	9
15	6.1	4.2	76	1855	11
30	5.3	5.8	67	2196	10
30	5.7	5.0	72	2110	11
30	6.1	4.2	76	2267	11
45	5.3	7.0	62	2356	10
45	5.7	6.6	65	2737	10
45	6.1	4.6	75	2892	12

TABLE 7

TYPE 3 TRINIDAD MIX OPTIMIZATION
LION AC-30

EPURE

% Epure Content	% Binder Content	% Air Voids	% V.F.A.	Stability	Flow
15	5.2	7.0	62	1905	9
15	5.6	5.8	68	1763	9
15	6.0	4.6	74	2000	10
30	5.2	7.4	61	2013	10
30	5.6	5.4	70	2188	10
30	6.0	4.6	74	2307	11
45	5.2	8.6	57	2261	11
45	5.6	6.6	65	2506	11
45	6.0	5.4	71	2382	13

POWDER

% Powder Content	% Binder Content	% Air Voids	% V.F.A.	Stability	Flow
15	5.2	7.0	62	1803	11
15	5.6	5.4	70	1872	11
15	6.0	4.6	74	1930	11
30	5.2	7.8	59	2231	10
30	5.6	6.2	67	2293	11
30	6.0	5.0	73	2178	11
45	5.2	8.2	58	2310	12
45	5.6	6.6	65	2446	13
45	6.0	5.4	71	2333	13

TABLE 8

SAND/ASPHALT TRINIDAD MIX OPTIMIZATION
LION AC-30

EPURE

% Epure Content	% Binder Content	% Air Voids	% V.F.A.	Stability	Flow
15	6.0	9.2	58	893	9
15	7.0	7.6	66	960	10
15	8.0	4.7	79	1145	12
30	6.0	9.6	57	1188	10
30	7.0	7.6	66	1213	11
30	8.0	4.3	80	1370	11
45	6.0	10.4	55	1274	9
45	7.0	8.0	65	1503	10
45	8.0	6.0	74	1525	11

POWDER

% Powder Content	% Binder Content	% Air Voids	% V.F.A.	Stability	Flow
15	6.0	9.2	58	910	8
15	7.0	6.7	69	1140	8
15	8.0	3.8	82	1231	9
30	6.0	9.6	57	1101	9
30	7.0	7.6	66	1359	8
30	8.0	4.7	79	1507	10
45	6.0	12.9	49	1041	9
45	7.0	10.9	57	1233	9
45	8.0	8.1	67	1410	10

TABLE 9

TYPE 1 TRINIDAD MIX OPTIMIZATION
EXXON AC-30
5.7% BINDER CONTENT

% Trinidad Content	% Air Voids		% V.F.A.		Stability		Flow	
	Epure	Powder	Epure	Powder	Epure	Powder	Epure	Powder
15	5.8	5.4	69	70	1821	1915	10	11
30	6.2	5.0	67	72	1978	2013	8	10
45	6.2	5.4	67	70	2391	2843	7	10

TABLE 10

TYPE 1 TRINIDAD MIX OPTIMIZATION
TEXACO AC-30
5.7% BINDER CONTENT

% Trinidad Content	% Air Voids		% V.F.A.		Stability		Flow	
	Epure	Powder	Epure	Powder	Epure	Powder	Epure	Powder
15	5.8	5.0	69	72	1824	1948	10	8
30	5.4	5.0	70	72	2139	2167	9	10
45	5.8	5.8	69	69	2311	2696	11	11

TABLE 11

MARSHALL IMMERSION PROPERTIES - TYPE 1 MIX

LION AC-30

Properties (Percent)	Control	30% Epure	15% Powder
Swell	0.2	0.8	0.4
Retained Strength	92.7	71.6	104.0

EXXON AC-30

Properties (Percent)	Control	30% Epure	15% Powder
Swell	0.0	0.3	0.3
Retained Strength	89.9	101.4	99.2

TEXACO AC-30

Properties (Percent)	Control	30% Epure	15% Powder
Swell	0.2	0.4	0.4
Retained Strength	70.3	100.6	92.8

TABLE 12

MARSHALL IMMERSION PROPERTIES - TYPE 3 MIX

Properties (Percent)	Control	30% Epure	30% Powder
Swell	0.2	0.8	0.9
Retained Strength	81.9	91.2	81.7

TABLE 13

MARSHALL IMMERSION PROPERTIES - SAND/ASPHALT MIX

Properties (Percent)	Control	30% Epure	30% Powder
Swell	1.2	1.5	2.9
Retained Strength	61.4	53.5	49.2

TABLE 14

FUNDAMENTAL PROPERTIES

Mix Type	% Additive	Modulus of Elasticity	Poisson's Ratio	Tensile Stress (PSI)	Tensile Strain (In/In)
Type 1	0	42,458	0.4028	106	0.0082
	15% Powder	65,001	0.3168	133	0.0056
	30% Epure	85,112	0.2582	164	0.0047
Type 3	0	59,265	0.3704	128	0.0067
	30% Powder	95,150	0.2683	187	0.0047
	30% Epure	77,579	0.2593	192	0.0058
Sand/ Asphalt	0	27,662	0.4651	83	0.0115
	30% Powder	42,739	0.3321	110	0.0072
	30% Epure	45,317	0.3124	134	0.0080