SULPHUR EXTENDED ASPHALT

RESEARCH REPORT

BY

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Research Report No. FHWA/LA-80/144

Research Project No. 79-1DEM
Louisiana HPR 0010(003)

Conducted by
LOUISIANA DEPARTMENT OF TRANSPORTATION
AND DEVELOPMENT
Research and Development Section
In Cooperation with
U. S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

MAY 1980

METRIC CONVERSION FACTORS*

To convert from	To	Multiply by
	Length	
foot	meter (m)	0.3048
inch	millimeter (mm)	25.4E
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 lbm)	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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Extensive research has been directed toward the addition of sulphur to asphaltic concrete mixes to function as either a quality aggregate or as an asphalt cement extender. By utilizing a high sulphur/asphalt ratio sulphur extended asphalt mix, it was believed that marginal aggregate could be substituted for quality aggregate. This report discusses the design, construction and evaluation of two such projects. One project, using an in-line blender to produce the binder, consisted of five inches of SEA sand base and two inches of SEA wearing course. The direct substitution method was used for a second project in which five inches of SEA sand base were laid. Each project was evaluated with respect to construction techniques, mix quality and performance. Results are presented for both projects which indicate that while the anticipated high mix strengths were attained at the plant, these strengths did not materialize in the field.

IMPLEMENTATION STATEMENT

The recommendations of this report call for another field trial to determine if the expected strengths can be attained in the field. This trial should be accomplished prior to implementation.

INTRODUCTION

Background

Extensive research has been conducted during the 1970's involving the utilization of sulphur in highway construction. The limited availability of asphalt and its correspondingly higher cost due to the energy crisis in 1973 was of prime importance in encouraging the highway industry in these endeavors. An additional stimulus was the passing of the Clean Air Acts through which industrial waste surplus sulphur was anticipated. The majority of this research was directed toward the addition of sulphur to asphaltic concrete mixes to function either as (1) a quality aggregate substitute, or (2) an asphalt cement extender.

In response to the depletion of quality aggregates in southern portions of the state, Louisiana initiated a research study (1)* in 1974 to evaluate sand-asphalt-sulphur mixes (S-A-S) in the laboratory. The successful results indicated that sulphur, used as a structuring agent, could be substituted for quality aggregates. A field demonstration project was constructed in January 1977 (2) in which 1000 tons of S-A-S mix were laid as a base course according to the technology developed by Shell Canada, Limited. At this time performance data indicates that this mix possesses properties equal to or superior to conventional hot mix.

While the S-A-S mix provides a solution to the state's aggregate problems, it does little to quiet the concern regarding asphalt cement supplies. Refined petroleum priorities are ever changing and create uncertainties involving asphalt cement production. With this in mind, the Department considered the recent advances in sulphur extended asphalt (SEA) state of the art.

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*Underlined numbers in parentheses refer to Bibliography.

In the SEA technologies, molten sulphur is blended with asphalt cement at elevated temperatures. Conditional on the type of asphalt used, approximately 20 to 25 percent sulphur by weight can be dissolved. This dissolved sulphur either reacts chemically with the asphalt or goes into solution. Quantities of sulphur above this amount are dispersed in the asphalt and, upon cooling, form a continuous crystalline structure which behaves as mineral aggregate. The most effective SEA mixes are composed of 25 to 50 percent sulphur by weight (15 to 35 percent by volume).

Several field trials in North America and Europe had shown SEA mixes to be a viable alternative to conventional asphaltic concrete: the major difference in these projects was the method of processing the sulphur asphalt binder--mill, in-line blender or direct substitution. It was reasoned that a field trial should be conducted incorporating SEA technology and the use of non-quality aggregates. A demonstration project was constructed in November 1978 using the Gulf Oil Canada, Limited, process (in-line blender).

Construction procedures and preliminary findings are discussed in this report. Although not originally considered, the apparent success of the Gulf section provided impetus to evaluate pugmill-blended SEA mixes. A second SEA project using the U.S. Bureau of Mines direct substitution method is included. In this method the sulphur and asphalt cement are blended together in the pugmill.

Participants

This demonstration project was made possible by the close cooperation of the following organizational groups:

- Federal Highway Administration
- The Sulphur Institute, Washington, D.C.
- Gulf Oil Canada, Limited, Ontario, Canada
- W. E. Blain and Sons, Mt. Olive, Mississippi (Contractor)
- Freeport Sulphur Company, New Orleans, Louisiana
- Louisiana Department of Transportation and Development

SCOPE

The aim of this demonstration project was to familiarize the Department with the design and construction of SEA sand base and wearing course mixes utilizing an in-line blender process. Roadway properties on a one-mile trial section were to be evaluated. The overall objective was to determine the feasibility of SEA mixes--SEA sand base in particular--for use in Louisiana. An economic evaluation of SEA mixes is not considered to be in the scope of this study.

Although not in the original scope of this project, a second 0.5-mile experimental SEA sand base section was constructed to evaluate the direct substitution method.

METHODOLOGY

Location and Section Design

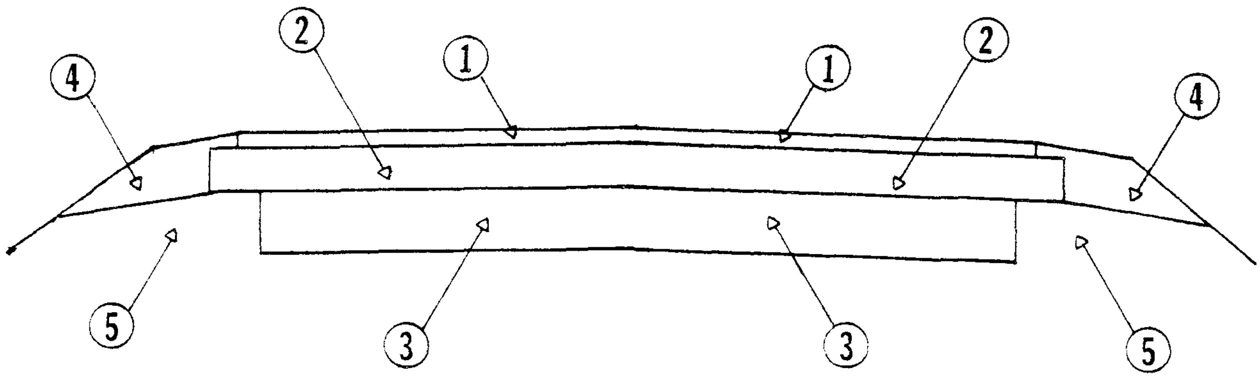
The trial section was contracted as part of a 7.546-mile project on La. 22, from La. 70 to Darrow, which called for reconstruction of the existing sand-gravel base and surface treatment with 8.5 inches of in-place stabilization, 2 inches of binder course and 1.5 inches of wearing course. The Gulf experimental section was located between stations 101+00 and 154+00.

By assuming the SEA sand base course would have a structural coefficient similar to black base, a design was proposed which provided 5 inches of SEA sand base and 2 inches of SEA dense-graded wearing course. A typical section is provided in Figure 1. The existing section (20 feet in width) was to be widened to 23 feet. The outside 1.5 feet of new mix would thus be placed on the existing shoulder material. The SEA base would extend for the entire one-mile trial with the SEA wearing surface covering one half of the base and a conventional wearing course on the other half. A plan view is shown in Figure 2.

The pugmill-blended trial was plan-changed into the contract and was located at the end of the project between stations 365+61 and 392+04 (approximately 0.5 miles). This trial section consisted of 5 inches of SEA sand base and 2 inches of conventional wearing course.

Materials and Mix Design

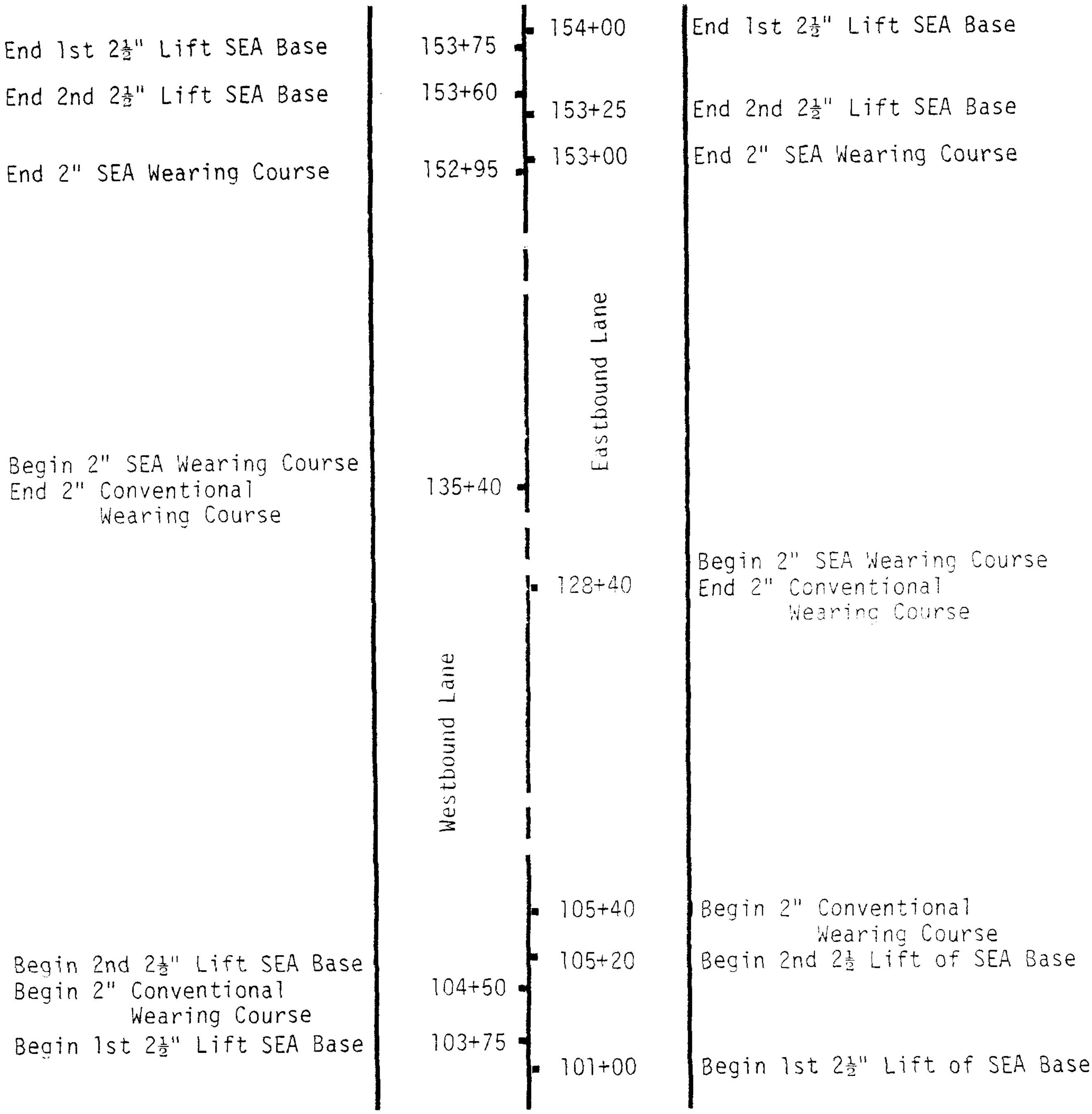
Gravel, coarse sand and fine sand were sampled from the contractor's yard prior to construction. These materials were forwarded to Gulf Canada along with samples of asphalt cement (AC-40) to determine mix designs. An optimum mix design for the sand base was found to be 65 percent coarse sand and 35 percent fine sand with a total



① 2-INCH SEA WEARING COURSE
② 5-INCH SEA SAND BASE COURSE
③ EXISTING SURFACE & BASE
④ AGGREGATE SURFACE COURSE
⑤ EXISTING SHOULDER

Typical SEA Section

FIGURE 1



In-Line Blender Section - Plan View

FIGURE 2

binder content of 9 percent. The SEA wearing course was optimized at 65 percent gravel, 21 percent coarse sand, 14 percent fine sand and a binder content of 5.8 percent. A sulphur to asphalt ratio of 40:60 by weight was maintained for both mixes. Component and design gradations are presented in Table 1.* Mix properties are given in Table 2.

The source of sand for the field trial was Louisiana Sand and Gravel. The asphalt cement was an Exxon AC-30 viscosity grade with the following properties:

Penetration (77°F)	63
Viscosity (275°F)	263 Saybolt Furol Seconds

The sulphur was supplied by Freeport Sulphur Company.

Equipment and Plant Modifications

The focal point of the Gulf process is the sulphur asphalt module (SAM) which is a portable pumping and mixing station. Separate pumps deliver measured volumes of asphalt and sulphur to a mixer where part of the sulphur is dissolved in the asphalt and the remainder is dispersed in the asphalt as an emulsion. The SAM unit is capable of linkage to either storage tanks or transports. A computerized control panel assures a proper blend by dialing in the desired sulphur-asphalt ratio. Digital output displays allow for easy verification of binder content.

A SEA binder handling system with the capacity for in-line blending or direct substitution is presented in Figure 3. It was the contractor's responsibility to provide heated and insulated piping which included suction lines, three-way hydraulic valve and purge line. The plant's normal hot oil supply was used to heat the SEA piping. Due to the low tonnage of the project, the contractor elected to pay demurrage charges and work from the sulphur transports rather than use his asphalt storage tank.

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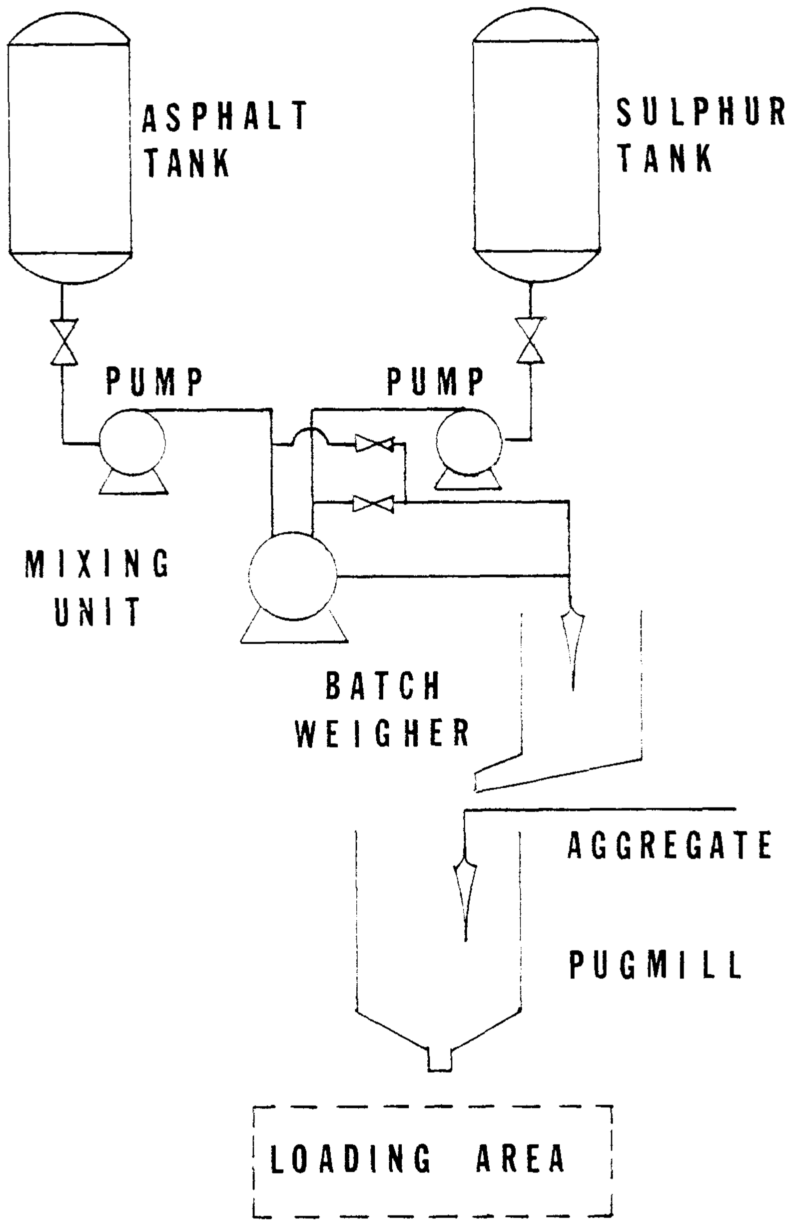
*All tables may be found in the Appendix, page 33.



SEA Plant Schematic

FIGURE 3

No further modifications were required either at the plant or at the roadway with regard to transporting the SEA mixes or laydown equipment.

CONSTRUCTION

General Plant Process

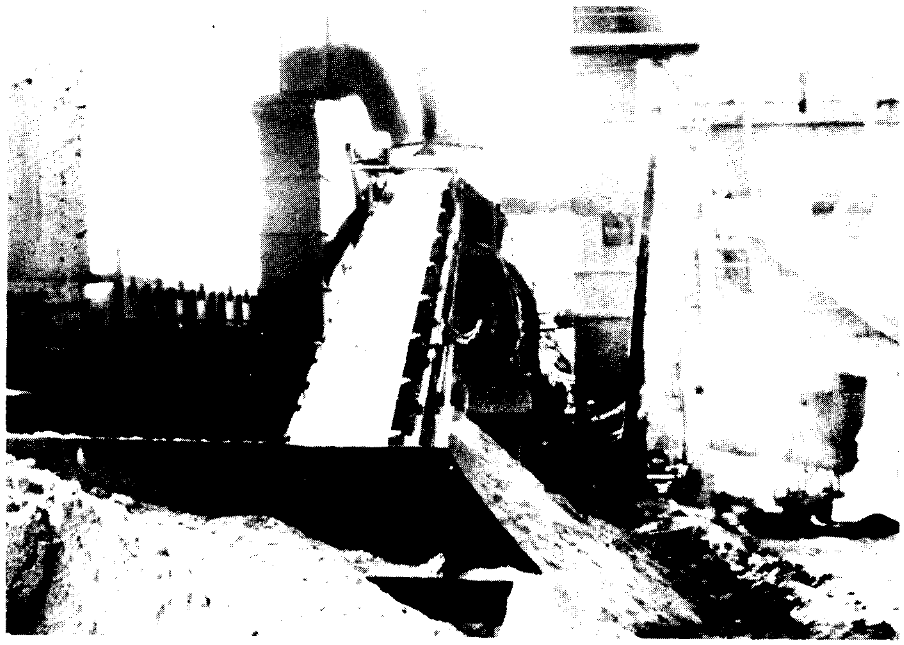
As is consistent with normal batch plant operations, the aggregate was heated and dried, conveyed to hot bins, and introduced into the pugmill by design weight. The SAM unit, under the operation of several Gulf representatives, blended the sulphur and asphalt according to the pre-set ratio and delivered this SEA binder to the asphalt weigh bucket. A dry mix cycle of 8 seconds was followed by a wet mix cycle of 30 seconds. Batching weights were 6,000 pounds. The mix was conveyed to a 100-ton surge silo before being placed in the haul trucks (Figure 4).

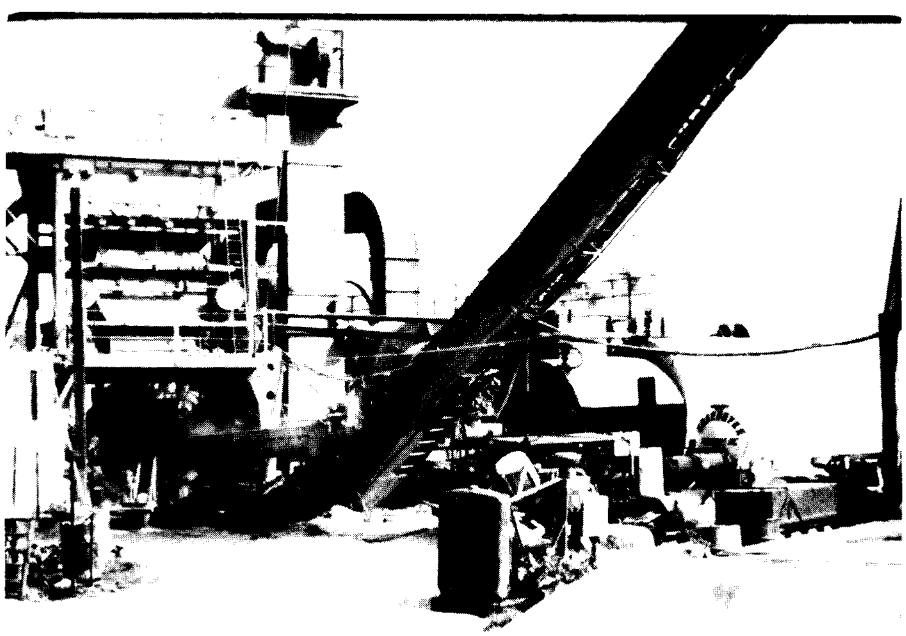
The pugmill-blended SEA sand base was produced in a similar manner with the exception of the addition of both sulphur and asphalt to the weigh bucket. In this process the asphalt cement was added first and then the sulphur.

Following the last batch of SEA mix on any given day, a mixture of normal sand asphalt was made. This cleansing batch served to flush out any remaining sulphur from the weigh bucket, spray bars and the pugmill.

Production

Gulf-processed SEA mix construction began on November 20, 1978. The base course consisting of 3,550.99 tons of SEA sand base was completed on December 1, 1978. Also laid on December 1, 1978, was 616.81 tons of SEA wearing course. Production was limited daily by the amount of sulphur available, as the contractor elected to use only one transport per day. Daily tonnage reports for the SAM-processed SEA mixes are presented in Table 3.





Plant Processing

FIGURE 4

No major problems associated with the Gulf process were encountered at the plant. An external delivery valve on the transport, frozen by sulphur which had solidified, sometimes caused a delay in the early morning. When this occurred, the valve would have to be heated to melt the crystallized sulphur. Similarly, the sulphur meter on the SAM unit froze during operations resulting in approximately one hour of down time. Other than these minor incidents, the overall process-related operation was excellent.

A more extensive problem was associated with the production of a sand mix. As Louisiana's specifications do not allow sand mixes, contractors are unfamiliar with such mixes. Several difficulties arose during this project with regard to temperature and gradation control which directly affected production rates.

The special provisions written for this project limited the final mix temperature to a range of 240°F to 300°F. Based on prior experience, the upper limit was established to prevent toxic gas emissions (H_2S and SO_2) which are known to occur at higher temperatures. The minimum was chosen to allow for successful placement of the mixture (prior to the phase change of the sulphur). A mix temperature of 280°F was set as a goal. Prior to construction, however, heavy rains had saturated the sand stockpiles. Residual time in the dryer was increased in an effort to reduce the moisture content of the finished mix, which decreased production rates. Initial batch time was 80 seconds (135 tons per hour) as opposed to 50 seconds (215 tons per hour) for conventional dense-graded mixes. Also, temperatures fluctuated greatly (210°F to 330°F) depending on the degree of saturation of the sand aggregate. In order to establish a more normal production rate and to stabilize temperatures, the mix composition was changed several times during the first few days. A steady production rate of 60 seconds per batch (180 tons per hour) was achieved for the remainder of the project.

Compositional modifications were also made in reaction to the presence of clay balls in the mix. While the source material conformed to the special provisions limiting plasticity index and liquid limit to maximums of 6 and 25, respectively, clay balls were evident in hot bin 2 and in material discarded from the scalping screen. Due to both the maximum mix temperature, specified to prevent toxic gas emissions, and the absence of +4 material in the aggregate, these clay balls were not degraded in the dryer. Their presence affected both gradation and strength properties of the SEA sand base. This problem was not encountered with the SEA wearing course.

Construction of the pugmill-blended SEA sand base began January 23, 1979, and was completed on February 8, 1979. A total of 1,897.63 tons were laid as indicated in Table 4. The problem of temperature fluctuation was sustained throughout this trial as almost 20 inches of rain in the month of January maintained the stockpiles in a saturated state. The production rate remained 60 seconds per batch.

Roadway Procedures

Both the SEA sand base and SEA wearing course mixes were processed similarly to conventional dense-graded mixes; the SEA material was unloaded from the truck bodies into the hopper of the paver and placed without incident. Screeded SEA sand base and wearing courses are shown in Figures 5, 6 and 7. Compaction procedures, however, had to be modified owing to tenderness of the sand mixes.

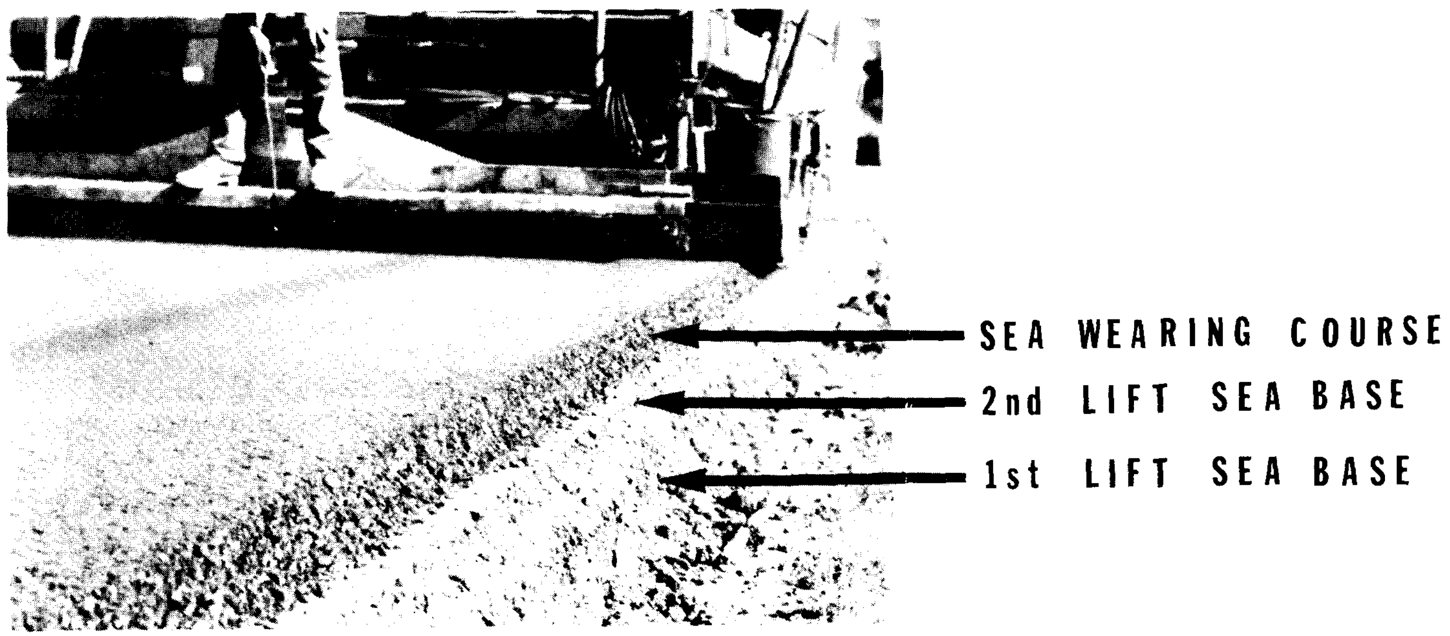
The temperature of the mat behind the paver reflected the variation in plant temperatures. While the mean temperature was 265°F, the standard deviation was 26°F for a population of 59 (range: 215°F, to 315°F). Initial attempts of breakdown with a steel-wheeled roller found the material picking up on the wheels. Hairline checking was observed after rolling. The roller operator was directed to remain

SEA Sand Base

FIGURE 5

SEA Wearing Course

FIGURE 6

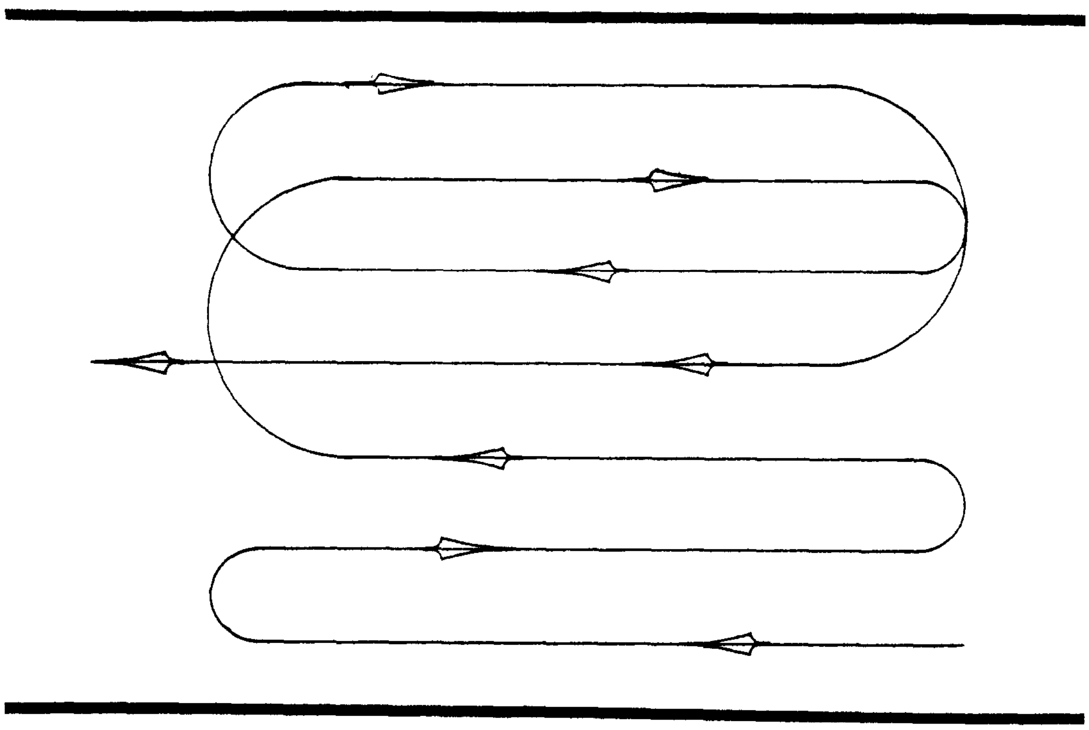


SEA Pavement System

FIGURE 7

several hundred feet behind the paver. It was found that pick-up was eliminated when the mat was 230°F or less. Additionally, the checking seemed to be reduced. Some concern was expressed, however, regarding the possible destruction of the crystalline sulphur structure which begins to form at 240°F. A representative from Gulf, who remained at the roadway for the duration of the project, indicated that breakdown rolling at 220°F - 230°F would not be detrimental to the pavement's structural integrity. The breakdown rolling occurred approximately 200 to 400 feet behind the paver. Final rolling took place about 700 feet behind the paver with a temperature range of 160°F to 190°F.

A Troxler nuclear density gauge was used the second day to determine a rolling pattern for optimum compaction. Compaction was optimized with two passes on the outside and inside of the lane and three passes on the middle as shown in Figure 8.



Optimized Rolling Pattern

FIGURE 8

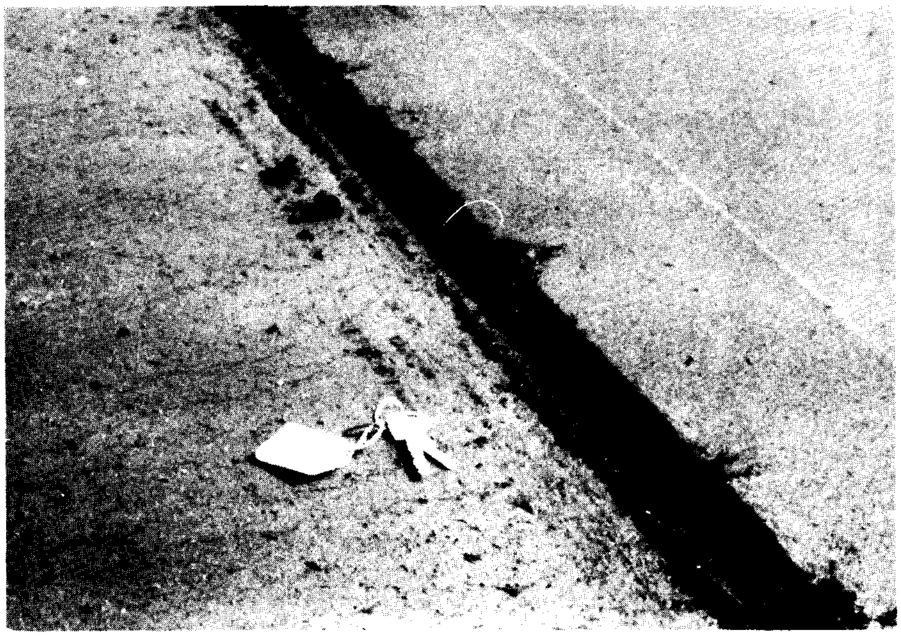
Design plans specified 5 inches of SEA sand base to be laid in two 2.5-inch lifts. The mix had to be placed approximately 3 to 3.5 inches to account for fluffing of the material (Figure 9). After compaction, an average thickness of 2.6 inches was found. An emulsion (SS-1H) was used to tack between lifts.

The mix tended to shove under the influence of the rollers indicating a lack of sideward stability. This posed a problem near the outside edge where the shoulder had been bladed to widen the roadway. As a result, no breakdown rolling was attempted on the edge with the only compaction coming from two passes of the final roller.

Steam was observed rising from the roadway as was the presence of moisture bubbles after breakdown rolling (Figure 10). The plant's effort to reduce the moisture by increasing temperature (above 280°F) was thus not completely effective. The elevated temperatures did produce noticeable fumes and eye irritation when mat temperatures exceeded 285°F. All members of the laydown crew used masks to cover their mouths and noses, and the machinery operators also wore eye goggles.

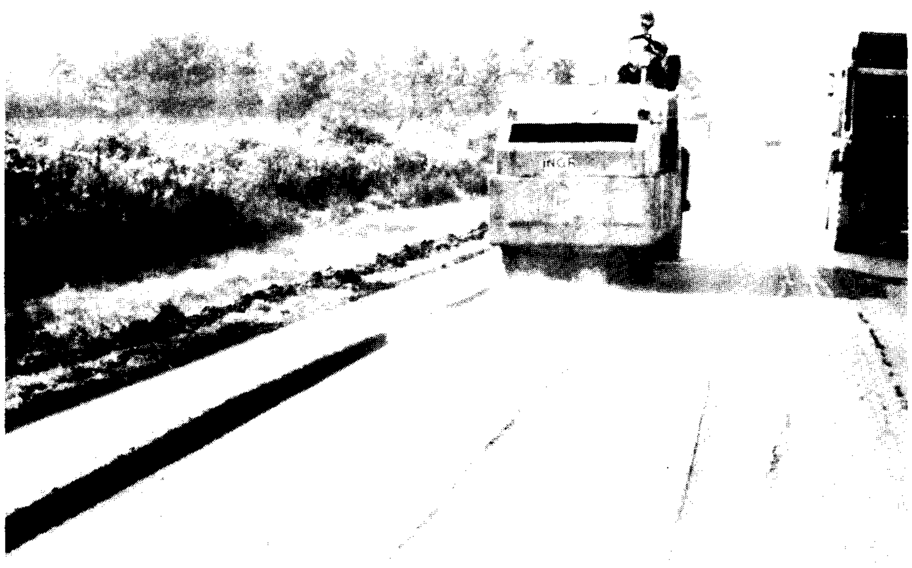
The section of the roadway between stations 100+00 and 112+00 was scarified and re-shaped prior to construction. This work was deemed necessary because of extensive base failures in this area. SEA sand base laid on this section seemed extra tender when compacted. Severe deformation was observed the following day. The section was subsequently replaced and removed from consideration in the SEA trial.

The pugmill-blended section followed the same roadway procedures that are cited for the Gulf mixes. There were no roadway-related differences observed between mixes from the two processes.



Placement of 2nd SEA Sand Base Lift

FIGURE 9



Rolling SEA Sand Base

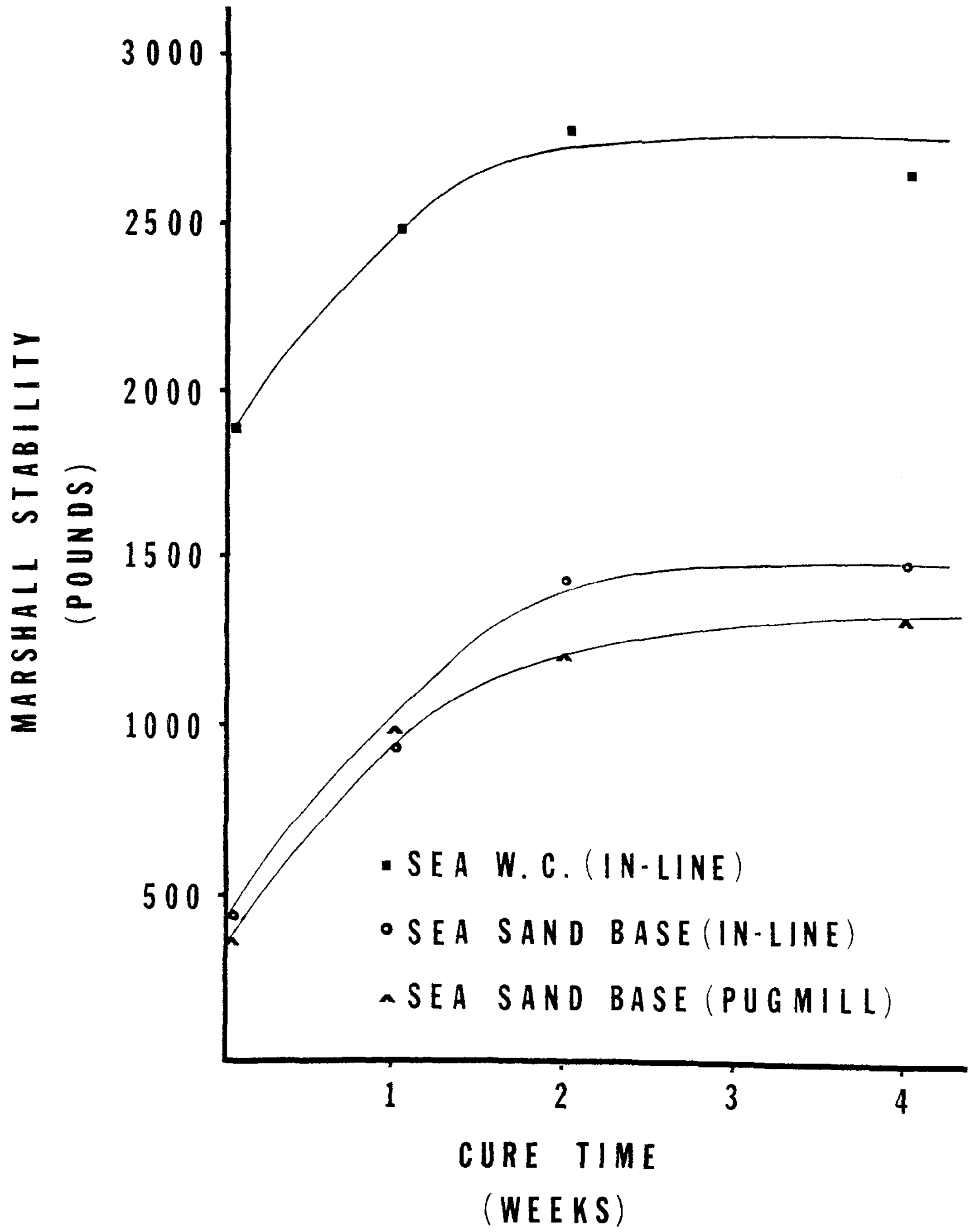
FIGURE 10

Quality Control

Marshall briquette properties, mix gradation, binder content and roadway densities were used for quality control and related testing. The frequency of testing was modified for this field trial because of the unfamiliarity with SEA mixes and their properties.

For control purposes, Marshall briquettes were made to evaluate physical properties such as stability, flow, bulk specific gravity and percent air voids. The stabilities of the initial specimens seemed low with regard to values anticipated from Gulf's laboratory design work. Gulf representatives indicated that their laboratory briquettes were usually cured for a period of one month to allow the sulphur structure to develop. Consequently, plant briquettes were set aside to cure for periods of 1, 2 and 4 weeks. Tables 5, 6 and 7 present the data for the Gulf-processed SEA sand base and SEA wearing course, and the pugmill-blended SEA sand base, respectively. The compositional changes which occurred in the SAM-blended mixes have been included in these tables.

The Marshall briquettes have been tabulated, for convenience, according to their age at the time of testing. In this manner, the increase in strength with time can be observed. A graphical representation is provided in Figure 11. The SEA mixes show a characteristic steep increase in strength, achieving a near asymptotic value with a 14-day cure. Little difference can be observed in strengths between mixes from the two processes. Initial breaks of the SEA wearing course specimens obtained values similar to Louisiana's Type 3 (high volume) asphaltic concrete. Fully cured strengths are approached at 7 days. (Note: Specimen No. 13, December 1, was eliminated from consideration due to its abnormal flow.)



Strength-Cure Time Relationships for SEA Mixes

FIGURE 11

Overall property values for the SEA mixes are as follows:

	SEA Base (Gulf)		SEA Base (Pugmill)		SEA W.C. (Gulf)	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Specific Gravity	2.220	.028	2.223	.014	2.345	.016
Percent Air Voids	7.5	0.6	7.4	1.2	5.1	0.6
Marshall Flow	9.4	1.6	7.5	2.2	6.5	1.3

While the overall flow values for the two processes are within standard deviations of each other, a trend of decreasing flow with increasing cure time was observed for the pugmill-blended mix. The SAM-blended mix remained fairly constant regardless of cure time. According to the literature, sulphur dispersion by means of a colloidal mill or turbine creates a finer sulphur particle than that generated by the shearing action in a pugmill. Resistance to flow in the pugmill-blended mix may, thus, be attributed to larger sulphur crystals.

In an effort to overcome what was thought to be the clay ball-related problems of low specific gravities and high air void percentages, four special batches using the Gulf process were formulated. Each was designed to increase fines (eliminate clay balls) or increase binder (reduce voids). Marshall stabilities were increased slightly, but specific gravities and percent air voids were unchanged. These batches are included in Table 5 and were composed as follows:

% Total Binder	S/A Ratio	CS/FS Ratio
9.4	50/50	68/32
11.0	50/50	68/32
9.0	40/60	Bin 1 only
9.0	40/60	68/32, 9% Mineral Filler

The procedure for constructing plant briquettes was modified during the pugmill blending process. Preliminary testing of the compacted roadway did not show the expected SEA strength. Breakdown rolling at 230°F and final rolling at 160°F - 190°F had been questioned as possibly being destructive to the sulphur structure. An attempt to duplicate this roadway compactive effort at the plant was made by molding the briquettes with 60 blows per side at 230°F, followed by 15 blows per side at 190°F. These briquettes are included in Table 7. Mean Marshall stabilities and specific gravities of these briquettes, as shown in Table 8, indicate little effect by this procedural modification.

Attempts to obtain mix gradations proved futile because of the clay ball situation. Washing the aggregate would break down the balls into their constituent sizes but would not be representative of the actual mix gradation. A typical unwashed sieve analysis was as follows:

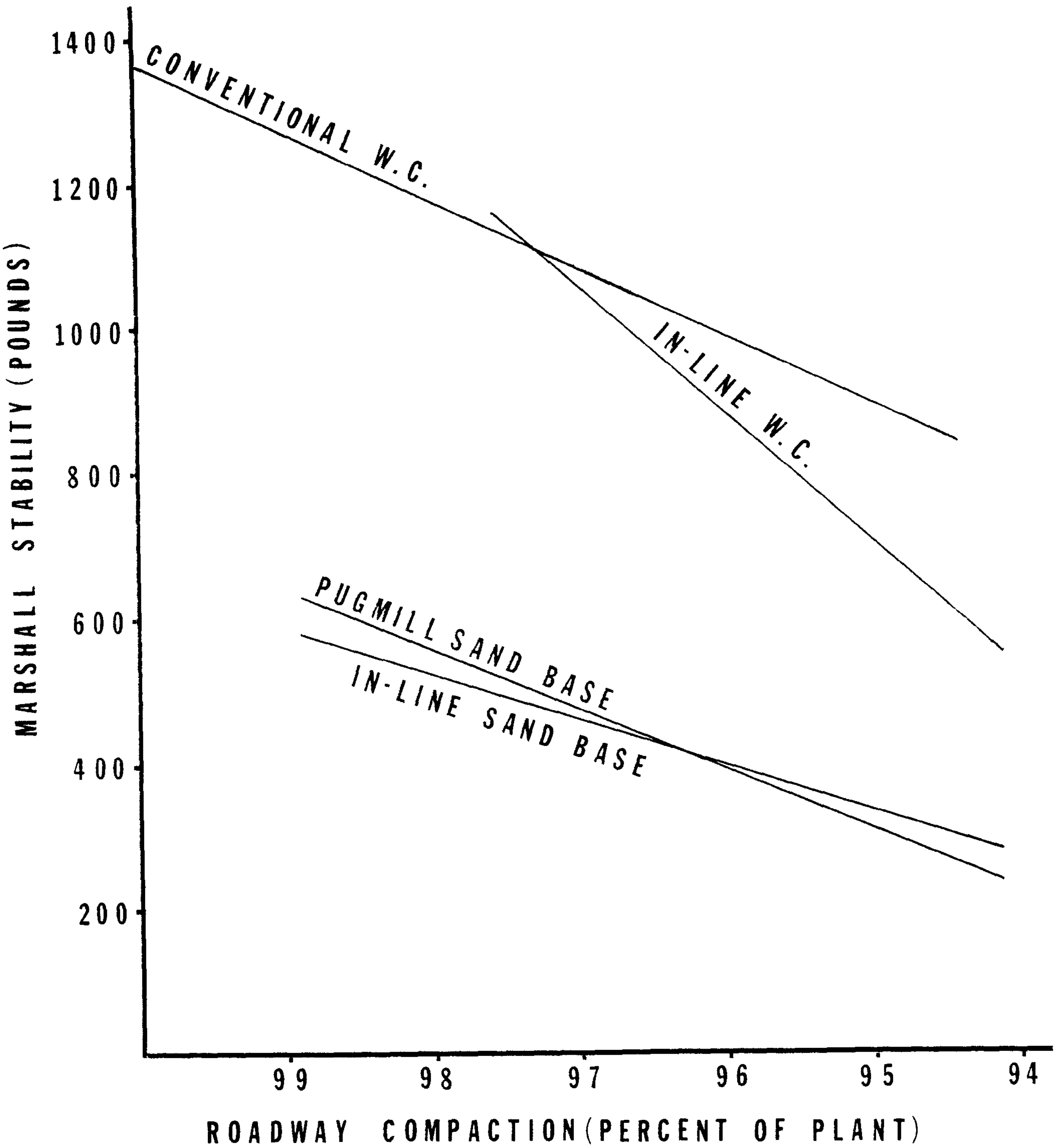
U.S. Sieve	Percent Passing
3/8	100
4	98
10	88
40	60
80	23
200	5

Total binder content was determined by the Gulf representatives using a Troxler nuclear gage procedure. This total binder content was checked by the contractor's laboratory personnel in the following manner: First, the asphalt and possibly some sulphur was extracted from a representative sample. Then, the aggregate was placed in a crucible from which the remaining sulphur was driven off with a butane burner. The total weight loss from the extraction and the incineration was taken as the total binder content. This method produced results within 0.1 percent of the values obtained with Gulf's Troxler procedure.

Daily roadway cores for the Gulf processing were taken and are listed in Tables 9 and 10. The overall roadway specific gravity was 2.096 for the base course and 2.233 for the wearing course, which relates to an overall percent compaction of plant briquette gravity of 94.4 and 95.2, respectively. Marshall stability testing was also accomplished with these cores to determine relative strength increases with time. The original roadway cores were tested at periods of 7, 14 and 28 days. The increase of strength with time associated with the plant briquettes was not apparent with the roadway specimens. It was assumed that the mechanical coring action was perhaps detrimental to the structural integrity of these samples, and additional cores were taken from the roadway after 28 days. These cores were cut into lifts with a saw and tested. The overall stabilities increased slightly for both the base and wearing courses.

The roadway cores from the pugmill-blended section are shown in Table 11. An overall specific gravity of 2.078 was found, which corresponds to 93.5 percent of the plant briquette gravity. Stabilities were not run due to the results of the SAM-blended cores.

Roadway cores were taken again in August 1979 and February 1980 from both sections. Specific gravities and air voids were determined and the cores were tested for stability by the Marshall method. The mean properties obtained from these cores are presented in Tables 12 and 13 along with the mean 28-day cured plant briquette data. A decrease in air voids and some increase in strength due to traffic densification is reflected in the tables. It is apparent, however, that the sulphur structure that was able to set up in the undisturbed plant samples has not developed in the field as the strengths are far from the anticipated plant values of 1400 and 2650 for the base and wearing courses, respectively. This is best demonstrated in Figure 12 where field strengths are seen as a function of roadway compaction.



Field Strength as a Function of Roadway Compaction Due to Traffic

FIGURE 12

Initially, the low field strength associated with the SEA base course was attributed to the compactive effort. It is theorized that the high air voids resulted in such a "loose" mix that the potential sulphur structure was unable to develop; the newly formed sulphur structure was not bonded closely enough to withstand immediate traffic. This does not appear to apply, though, to the SEA.wearing course which had an acceptable void content (for normal hot mix) at construction, and yet, still failed to reach the expected strength. A question is then raised concerning the strength development of SEA mixes: Is there a void content at construction above which the anticipated strength development will not occur?

POST-CONSTRUCTION EVALUATION

The Dynamic Deflection Determination System (Dynaflect) was used to evaluate the strengths of both the existing surface and the newly constructed SEA pavement systems.

Deflection tests were originally conducted on the old surface at 14 locations for the Gulf section and 16 locations for the pugmill section. At these same locations, deflection tests were conducted on the wearing surfaces of the SEA systems in August 1979.

A combination of two-layered elastic theory and the Louisiana AASHO Flexible Pavement Design Guides is used to evaluate the structural effect of the SEA sand base. All deflections are adjusted to equivalent deflections at 60°F. Structural numbers are determined by using the average maximum deflections and the layered theory. The difference in structural number, or SN Gain, between the entire pavement system and the old surface yields the strength solely reflective of the new system. The AASHO Design Guide provides a means of translating this strength into a structural coefficient, which is the index of strength used in flexible pavement design. Following this method, structural coefficients for the SEA sand base have been determined as presented in Table 14, Structural Analysis.

Louisiana's AASHO Design Guide structural coefficient for wearing course (1200-pound stability) is 0.33. Applying this number to the equation shown in Table 14 and using the thicknesses presented (determined from cores taken at the deflection sites), the structural coefficients for the Gulf and pugmill SEA sand base sections are found to be 0.21 and 0.28-0.29, respectively. If the 0.21 coefficient is assumed for the SEA sand base under the SEA wearing course section, a coefficient of 0.37 is found for the SEA wearing course.

The deflection analysis indicates that the SEA wearing course is slightly better able to distribute induced loads than conventional asphaltic concrete. Pugmill-blended SEA sand base appears to be somewhat stronger than the Gulf-processed base. However, even the Pugmill section is apparently not as strong as conventional asphaltic concrete base courses, which have a coefficient of 0.33.

Skid resistance measurements were taken in November 1979 on the Gulf section. The conventional wearing course had a mean of 39.7 and a standard deviation of 2.3, while the SEA wearing course had a mean of 35.6 and a standard deviation of 3.9.

CONCLUSIONS

1. A conventional asphaltic concrete batch plant was easily modified to produce sulphur extended asphalt mixes using both the Gulf Oil Canada, Limited, in-line blender process and the U.S. Bureau of Mines direct substitution method. The modification allowed the plant to produce either conventional asphaltic concrete or SEA mixes.

2. Difficulties were encountered in the production of the SEA sand mixes due to the presence of saturated aggregate stockpiles. Clay balls were present in the mix, which, due to the combination of a limiting dryer temperature to reduce the possibility of toxic emissions, and the absence of +4 material in the aggregate, could not be degraded in the dryer. Residual time in the dryer was increased with the resulting decrease in production rate. No problems were associated with the processing of the SEA binder with either the in-line blender or direct substitution methods.

3. Compaction procedures had to be modified for the SEA sand base course, owing to the inherent tenderness of sand mixes.

4. The SEA sand base produced by both the in-line blender process and the direct substitution method possessed Marshall plant briquette properties (when fully cured) similar to Louisiana's Type 5A black base course (1200-pound minimum). Differences in Marshall properties of the two processes were not discernible. The Marshall properties of the SEA wearing course mix were equivalent to or superior to Louisiana's Type 3 wearing course (1700-pound minimum).

5. Marshall stabilities approached asymptotic values after 14 days cure time for the SEA sand base and 7 days for the SEA wearing course.

6. The mix strength at the plant in terms of stability was not observed in the field. This lack of strength is felt to be a function of void content. Data indicates that acceptable void contents for conventional mixes (both dense graded and sand) may not be justified for SEA mixes in that a lower void content appears necessary for the sulphur structure to form. It must be noted, however, that agencies who wish to use SEA mixes strictly as a means of asphalt conservation would not be affected by this premise as the strength of the SEA field specimens were equivalent to conventional mixes.

7. Initial deflection data indicates that the pugmill-blended SEA sand base is better able to distribute induced loads than the Gulf-processed SEA sand base. Neither SEA sand base mix attained a structural coefficient equivalent to Louisiana's Type 5A black base (1200-pound minimum). However, the presence of clay balls was observed in the mix, which would have a detrimental effect on the structural integrity of the pavement system.

8. Irritating fumes were noted when the mix temperature at the roadway exceeded 285°F, as evidenced by the protective mouth and nose masks and eye goggles worn by the laydown crew.

RECOMMENDATIONS

1. Field evaluation of the SEA sections should continue to further evaluate their performance characteristics with respect to time.

2. The presence of clay balls must be eliminated in sand mixes. This may be accomplished by reducing the plasticity index specification.

3. Another field trial is recommended at this time to further refine mix design for specification writing. A major portion of this field trial should be devoted to compaction procedures. The intent would be to determine if the mat could be compacted to a void content which would allow the sulphur structure to develop.

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2. D. E. Carey, "Sand-Asphalt-Sulphur Hot Mix," Demonstration Project Research Report, Louisiana Department of Transportation and Development, Baton Rouge, June 1977.

3. W. J. Rennie, "Sulphur Asphalts," Sulphur Development Institute of Canada, Calgary, 1979.

APPENDIX

TABLE 1: SEA BASE AND WEARING COURSE GRADATIONS*

U.S. Sieve Size	Gravel	Coarse Sand	Fine Sand	SEA Base 65/35	SEA W.C. 65/21/14
3/4 inch	100.0	100.0	100.0	100.0	100.0
1/2 inch	90.0	100.0	100.0	100.0	93.5
3/8 inch	70.0	100.0	100.0	100.0	80.5
No. 4	37.0	98.0	100.0	98.7	58.6
No. 10	17.0	86.0	100.0	90.9	43.1
No. 40	6.0	42.0	99.0	61.9	26.6
No. 80	4.0	2.0	96.0	34.9	16.5
No. 200	2.0	0.5	54.0	19.2	9.0

*Percent Passing

TABLE 2: MARSHALL DESIGN PROPERTIES*

Properties	SEA Sand Base	SEA W.C.
% Total Binder	9.00	5.80
S/A Ratio	40/60	40/60
% Sulphur	3.60	2.30
% AC	5.4	3.5
Bulk Specific Gravity	2.305	2.317
Max. Specific Gravity	2.406	2.435
% Air Voids	4.20	4.90
% VMA	20.50	18.00
Marshall Flow	9.1	8.0
Marshall Stability (lbs.)	1933.	2334.

*75 Blows/Face

TABLE 3: DAILY TONNAGE (IN-LINE BLENDER)

Date	Total (Tons)	Roadway (Tons)	Wasted (Tons)	Asphalt Cement (Imp. Gal.)	Asphalt Cement (Tons)	Sulphur (Tons)	Sand (Tons)	Gravel (Tons)
11/20	475.890	444.790	31.100	8733	41.045	16.012	418.833	
11/21	813.620	813.620	0	10960	51.512	29.290	732.818	
11/22	584.590	540.480	44.110	7085	33.290	19.457	531.843	
11/28	693.760	693.760	0	8511	40.002	24.975	628.783	
11/29	154.250	154.250	0	2617	12.300	5.553	136.397	
11/30	713.880	662.410	51.470	7723	36.298	23.847	653.735	
12/1	293.350	241.680	51.670	3370	15.835	8.700	268.815	
12/1	616.810	616.810	0	4141	19.463	14.310	233.215	349.822
	4,346.15	4,167.800	178.35	51,140	249.745	142.144	3,604.439	349.822

TABLE 4: DAILY TONNAGE (PUGMILL)

Date	Total	Roadway	Wasted	Asphalt Cement	Sulphur	Sand
1/23	72.100	72.100	0	3.893	2.596	65.611
1/26	124.040	124.040	0	6.698	4.466	112.876
2/1	571.870	547.050	24.820	30.881	20.587	520.402
2/2	697.260	697.260	0	37.652	25.101	634.507
2/7	255.010	255.010	0	13.771	9.180	232.059
2/8	202.170	202.170	0	10.917	7.278	183.975
	1922.450	1897.630	24.820	103.812	69.208	1749.430

TABLE 5: PLANT BRIQUETTE COMPOSITION AND PROPERTIES - BASE COURSE (IN-LINE BLENDER)

Age at Testing (Days)	Date Sampled	Sample No.	% Total Binder	S/A Ratio	CS/FS Ratio	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In.x 10^{-2})
*	11/20	1	9.0	40/60	65/35	2.23	7.1	618	10
*	11/20	4	9.0	40/60	65/35	2.22	7.5	423	14
*	11/20	6	9.0	40/60	65/35	2.20	8.3	389	12
*	11/20	8	9.0	40/60	50/50	2.15	10.4	489	10
*	11/21	1	9.0	40/60	70/30	2.23	7.1	256	8
*	11/21	3	9.0	40/60	70/30	2.20	8.3	287	10
*	11/21	5	9.0	40/60	75/25	2.23	7.1	189	10
*	11/21	9	9.0	40/60	75/25	2.25	6.2	547	8
*	11/22	1	9.0	40/60	68/32	2.28	5.0	476	9
*	11/22	4	9.4	50/50	68/32	2.20	8.7	243	10
*	11/22	6	11.0	50/50	68/32	2.24	5.9	457	8
*	11/22	8	9.0	40/60	Bin 1	2.24	6.7	463	9
*	11/22	9	9.0	40/60	68/32 9% M.F.	2.23	7.1	481	8
*	11/28	1	9.0	40/60	68/32	2.20	8.3	308	8
*	11/28	4	9.0	40/60	68/32	2.21	7.9	317	8

TABLE 5: PLANT BRIQUETTE COMPOSITION AND PROPERTIES - BASE COURSE (IN-LINE BLENDER) (CONTINUED)

Age at Testing (Days)	Date Sampled	Sample No.	% Total Binder	S/A Ratio	CS/FS Ratio	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In.x 10^{-2})
*	11/30	1	9.0	40/60	68/32	2.24	6.7	360	10
*	11/30	4	9.0	40/60	68/32	2.23	7.1	297	10
*	11/30	7	9.0	40/60	68/32	2.23	7.1	441	8
*	12/1	1	9.0	40/60	68/32	2.22	7.5	389	8
1	11/20	2	9.0	40/60	65/35	2.21	7.9	723	10
2	11/20	5	9.0	40/60	65/35	2.20	8.3	525	10
1	11/20	9	9.0	40/60	50/50	2.13	11.2	608	12
1	11/21	2	9.0	40/60	70/30	2.22	7.5	347	9
1	11/21	4	9.0	40/60	70/30	2.19	8.7	347	10
1	11/28	2	9.0	40/60	68/32	2.19	8.7	322	9
2	11/28	5	9.0	40/60	68/32	2.21	7.9	389	10
7	11/21	7	9.0	40/60	75/25	2.21	7.9	611	10
6	11/22	3	9.4	50/50	68/32	2.20	8.7	838	12
6	11/22	5	11.0	50/50	68/32	2.23	6.3	1112	12
6	11/22	7	9.0	40/60	Bin 1	2.23	7.1	1091	8
6	11/22	10	9.0	40/60	68/32 9% M.F.	2.22	7.5	977	12

TABLE 5: PLANT BRIQUETTE COMPOSITION AND PROPERTIES - BASE COURSE (IN-LINE BLENDER) (CONTINUED)

Age at Testing (Days)	Date Sampled	Sample No.	% Total Binder	S/A Ratio	CS/FS Ratio	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In.x 10^{-2})
7	11/28	6	9.0	40/60	68/32	2.19	8.7	546	10
7	11/30	8	9.0	40/60	68/32	2.20	8.3	967	8
7	12/1	4	9.0	40/60	68/32	2.25	6.2	1408	7
14	11/30	5	9.0	40/60	68/32	2.25	6.2	1435	8
14	11/30	9	9.0	40/60	68/32	2.23	7.1	1716	9
14	12/1	2	9.0	40/60	68/32	2.19	8.7	1186	7
**28+	11/20	3	9.0	40/60	65/35	2.17	9.6	851	9
**28+	11/20	7	9.0	40/60	65/35	2.21	7.9	1903	9
**28+	11/21	6	9.0	40/60	75/25	2.22	7.5	1567	9
**28+	11/21	8	9.0	40/60	75/25	2.25	6.2	1206	9
**28+	11/22	2	9.0	40/60	68/32	2.27	5.4	1594	10
**28+	11/28	3	9.0	40/60	68/32	2.22	7.5	1329	9
28	11/30	2	9.0	40/60	68/32	2.24	6.7	1650	7
**28+	11/30	3	9.0	40/60	68/32	2.24	6.7	1484	10
**28+	11/30	6	9.0	40/60	68/32	2.26	5.8	1565	12

TABLE 5: PLANT BRIQUETTE COMPOSITION AND PROPERTIES - BASE COURSE (IN-LINE BLENDER) (CONTINUED)

Age at Testing (Days)	Date Sampled	Sample No.	% Total Binder	S/A Ratio	CS/FS Ratio	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In.x 10^{-2})
28	11/30	10	9.0	40/60	68/32	2.22	7.5	1685	7
**28+	12/1	3	9.0	40/60	68/32	2.25	6.2	1573	10
28	12/1	5	9.0	40/60	68/32	2.24	6.7	1560	7

NOTE 1: Briquettes marked with an asterisk (*) were tested at the plant the same day as fabricated.

NOTE 2: Briquettes marked with a double asterisk (**) were tested by Gulf Oil Canada, Limited.

NOTE 3: % Air Voids were based on a theoretical gravity of 2.40 determined from apparent specific gravities of the component materials.

TABLE 6: PLANT BRIQUETTE COMPOSITION AND PROPERTIES - WEARING COURSE (IN-LINE BLENDER)

Age at Testing (Days)	Date Sampled	Sample No.	% Total Binder	S/A Ratio	GR/CS/FS Ratio	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In.x 10^{-2})
*	12/1	1	5.8	40/60	65/21/14	2.37	4.0	2119	8
*	12/1	4	5.8	40/60	65/21/14	2.35	4.9	1681	7
*	12/1	7	5.8	40/60	65/21/14	2.35	4.9	1672	9
*	12/1	10	5.8	40/60	65/21/14	2.35	4.9	2070	7
7	12/1	2	5.8	40/60	65/21/14	2.36	4.5	2678	7
7	12/1	6	5.8	40/60	65/21/14			2356	6
7	12/1	12	5.8	40/60	65/21/14	2.33	5.7	2450	6
14	12/1	3	5.8	40/60	65/21/14	2.36	4.5	2792	5
14	12/1	8	5.8	40/60	65/21/14	2.34	5.3	2558	5
14	12/1	11	5.8	40/60	65/21/14	2.34	5.3	2967	5
28	12/1	5	5.8	40/60	65/21/14	2.35	4.9	2948	5
28	12/1	9	5.8	40/60	65/21/14	2.32	6.1	2438	7
**28+	12/1	13	5.8	40/60	65/21/14	2.35	4.9	1861	13
**28+	12/1	14	5.8	40/60	65/21/14	2.32	6.1	2564	7

NOTE 1: Briquettes marked with an asterisk (*) were tested at the plant the same day as fabricated.

NOTE 2: Briquettes marked with a double asterisk (**) were tested by Gulf Oil Canada, Limited.

NOTE 3: % Air Voids were based on a theoretical gravity of 2.47 determined from apparent specific gravities of the component materials.

TABLE 7: PLANT BRIQUETTE PROPERTIES - BASE COURSE (PUGMILL)

Age at Testing (Days)	Date Sampled	Sample No.	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In. x 10^{-2})	Blows
*	1/26/79	1	2.22	7.5	319	14	75
*	1/26/79	4	2.24	6.7	293	12	75
*	2/1/79	1	2.23	7.1	406	8	75
*	2/1/79	4	2.22	7.5	328	6	60/15
*	2/2/79	1	2.23	7.1	312	8	60/15
*	2/2/79	4	2.20	8.3	240	6	75
*	2/7/79	1	2.24	6.7	511	10	60/15
*	2/8/79	1	2.21	7.9	245	8	75
7	2/1/79	2	2.23	7.1	998	7	75
7	2/2/79	2	2.24	6.7	1014	8	60/15
7	2/2/79	5	2.21	7.9	733	8	75
7	2/7/79	2	2.24	6.7	1232	8	60/15
7	2/8/79	2	2.22	7.5	998	8	75
14	1/26/79	2	2.23	7.1	1170	8	75
14	1/26/79	5	2.23	7.1	1016	8	75
14	2/1/79	6	2.23	7.1	1186	7	60/15

TABLE 7: PLANT BRIQUETTE PROPERTIES - BASE COURSE (PUGMILL) (CONTINUED)

Age at Testing (Days)	Date Sampled	Sample No.	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In. x 10^{-2})	Blows
14	2/2/79	6	2.19	8.7	984	7	75
14	2/7/79	3	2.24	6.7	1671	5	60/15
14	2/8/79	3	2.20	8.3	1248	7	75
28	1/26/79	3	2.21	7.9	1279	4	75
28	1/26/79	6	2.21	7.9	1170	6	75
28	2/1/79	3	2.23	7.1	1543	5	75
28	2/1/79	5	2.22	7.5	1289	5	60/15
28	2/2/79	3	2.23	7.1	1357	7	60/15

NOTE 1: Briquettes marked with an asterisk (*) were tested at the plant the same day as fabricated.

NOTE 2: % Air Voids were based on a theoretical gravity of 2.40 determined from apparent specific gravities of component materials.

TABLE 8: MEAN PLANT BRIQUETTE PROPERTIES (PUGMILL)

Age at Time of Test	75 Blow			60/15 Blow		
	$\bar{x}$	σ	n	$\bar{x}$	σ	n
Plant	301	68	5	384	111	3
7 Days	910	153	3	1123	154	2
14 Days	1105	125	4	1428	343	2
28 Days	1331	192	3	1323	48	2
Specific Gravity	2.217	.014	15	2.232	.008	9

TABLE 9: ROADWAY CORE PROPERTIES - BASE COURSE (IN-LINE BLENDER)

Age at Testing (Days)	Date Laid	Lift	Location	Thickness (Inches)	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In.x 10^{-2})
7	11/28	2nd	144+15/4' Rt. ℄	2-15/16	2.08	13.3	188	15
7	11/28	2nd	123+55/5' Rt. ℄	2-3/4	2.07	13.7	190	17
7	11/30	2nd	148+50/2' Lt. ℄	2-3/4	2.11	12.1	272	15
7	11/30	2nd	118+30/9' Lt. ℄	2-5/8	2.08	13.3	204	14
14	11/20	1st	150+40/3' Lt. ℄	2-5/8	2.01	16.2	28	15
14	11/20	1st	135+00/4' Lt. ℄	2-15/16	2.08	13.3	234	14
14	11/20	1st	124+60/7' Lt. ℄	2-3/4	2.01	16.2	164	14
14	11/21	1st	151+20/3' Rt. ℄	2-5/16	2.14	10.8	125	14
14	11/21	1st	138+45/8' Rt. ℄	2-7/16	2.12	11.7	177	15
14	11/21	1st	115+00/9' Rt. ℄	2-7/16	2.14	10.8	323	16
14	11/22	1st	104+20/6' Rt. ℄	2-5/8	2.17	9.6	222	14
14	11/22	1st	110+75/5' Lt. ℄	2-3/8	2.10	12.5	158	16
14	11/28	2nd	150+05/2' Rt. ℄	2-9/16	2.05	14.6	163	13
14	11/28	2nd	116+25/8' Rt. ℄	2-1/2	2.08	13.3	190	13
14	11/30	2nd	137+30/5' Lt. ℄	2-3/8	2.10	12.5	223	17

TABLE 9: ROADWAY CORE PROPERTIES - BASE COURSE (IN-LINE BLENDER) (CONTINUED)

Age at Testing (Days)	Date Laid	Lift	Location	Thickness (Inches)	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In.x 10^{-2})
14	11/30	2nd	109+55/6' Rt. ℄	2-1/2	2.12	11.7	229	12
28	11/20	1st	142+30/2' Lt. ℄	2-1/4	2.03	15.4	75	15
28	11/20	1st	129+19/5' Lt. ℄	2-1/2	2.09	12.9	220	11
28	11/21	1st	142+60/6' Rt. ℄	2-1/2	2.10	12.5	140	13
28	11/21	1st	126+50/7' Rt. ℄	2-5/16	2.14	10.8	182	15
28	11/22	1st	108+40/4' Rt. ℄	2-1/2	2.13	11.2	140	18
28	11/22	1st	115+25/7' Lt. ℄	2-3/4	2.11	12.1	121	14
28	11/22	1st	106+95/8' Lt. ℄	2-7/16	2.20	8.3	359	13
28	11/28	2nd	136+75/6' Rt. ℄	2-9/16	2.05	14.6	135	11
28	11/30	2nd	129+80/7' Lt. ℄	2-3/8	2.10	12.5	152	15
*28		1st	151+00	2-5/8			435	9
*28		2nd	151+00	2-5/8			491	8
*28		1st	148+00	2-7/8			78	7
*28		2nd	148+00	3-1/16			433	10
*28		1st	145+00	2-7/8			153	10

TABLE 9: ROADWAY CORE PROPERTIES - BASE COURSE (IN-LINE BLENDER) (CONTINUED)

Age at Testing (Days)	Date Laid	Lift	Location	Thickness (Inches)	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In.x 10^{-2})
*28		2nd	145+00	2-13/16			619	8
*28		1st	139+00	2-1/2			110	9
*28		2nd	139+00	2-9/16			404	8
*28		1st	136+00	2-3/4			190	9
*28		2nd	136+00	2-3/4			457	8
*28		1st	133+00	2-11/16			460	7
*28		2nd	133+00	3-0			496	7

NOTE 1: % Air Voids were based on a theoretical gravity of 2.40 determined from apparent specific gravities of the component materials.

NOTE 2: All cores marked with an asterisk (*) were sampled from the roadway 28 days after construction.

TABLE 10: ROADWAY CORE PROPERTIES - WEARING COURSE (IN-LINE BLENDER)

Age at Testing (Days)	Date Laid	Location	Thickness (Inches)	Bulk Specific Gravity	% Air Voids	Stability (Lbs.)	Flow (In.x 10^{-2})
7	12/1	137+20/7' Lt. ℄	2-1/4	2.24	9.4	190	12
14	12/1	143+70/6' Rt. ℄	2-1/4	2.20	10.9	280	14
28	12/1	149+80/5' Lt. ℄	2-1/4	2.26	8.5	348	15
*28		151+00	2-5/16			392	10
*28		148+00	2-3/16			312	6
*28		145+00	2-1/4			595	9
*28		139+00	2-1/4			631	9
*28		136+00	2-1/4			429	12
*28		133+00	2-1/8			329	7

NOTE 1: % Air Voids were based on a theoretical gravity of 2.47 determined from apparent specific gravities of the component materials.

NOTE 2: All cores marked with an asterisk (*) were sampled from the roadway 28 days after construction.

TABLE 11: ROADWAY CORE PROPERTIES - BASE COURSE (PUGMILL)

Date Laid	Lift	Location	Thickness (Inches)	Bulk Specific Gravity	% Air Voids
1/26	1st	367+42/4' Lt. ℄	3	2.11	12.1
1/26	1st	369+12/5' Lt. ℄	3	2.07	13.7
1/26	1st	371+27/7' Lt. ℄	3	2.10	12.5
1/26	1st	372+15/2' Lt. ℄	3	2.13	11.2
1/26	1st	374+52/3' Lt. ℄	3	2.17	9.6
2/1	1st	376+46/6' Lt. ℄	3 1/4	2.10	12.5
2/1	1st	380+12/3' Lt. ℄	2 3/4	2.08	13.3
2/1	1st	389+53/5' Lt. ℄	3	2.08	13.3
2/1	1st	368+24/2' Rt. ℄	3	2.11	12.1
2/1	1st	373+35/7' Rt. ℄	2 3/4	2.11	12.1
2/2	1st	380+12/4' Rt. ℄	3 1/4	2.07	13.7
2/2	1st	390+34/6' Rt. ℄	2 3/4	2.10	12.5
2/2	2nd	366+28/7' Lt. ℄	3	2.05	14.6
2/2	2nd	370+45/3' Lt. ℄	2 3/4	2.02	15.8
2/2	2nd	385+57/8' Lt. ℄	2 1/2	2.10	12.5
2/7	2nd	366+35/4' Rt. ℄	2	2.00	16.7
2/7	2nd	370+12/7' Rt. ℄	2 3/4	2.11	12.1
2/7	2nd	374+56/9' Rt. ℄	3 3/4	2.01	16.2
2/7	2nd	376+11/5' Rt. ℄	2	2.06	14.2
2/7	2nd	378+05/3' Rt. ℄	2 3/4	2.09	12.9
2/8	2nd	380+24/4' Rt. ℄	3 3/8	2.05	14.6
2/8	2nd	382+17/8' Rt. ℄	3 1/8	2.07	13.7
2/8	2nd	385+36/9' Rt. ℄	2 1/2	2.04	15.0
2/8	2nd	388+48/6' Rt. ℄	2 1/8	2.09	12.9
2/8	2nd	399+56/5' Rt. ℄	2 5/8	2.04	15.0

TABLE 12: MEAN ROADWAY CORE PROPERTIES (IN-LINE BLENDER)

Course	January 1979		August 1979		February 1980		Plant Briquettes	
	Stab. (Lbs)	Specific Gravity	Stab. (Lbs)	Specific Gravity	Stab. (Lbs)	Specific Gravity	Stab. (Lbs)	Specific Gravity
1st Lift	238	2.1047 (12.3)	323	2.112 (12.0)	286	2.103 (12.4)	1424	2.216 (7.7)
2nd Lift	483	2.084 (13.2)	365	2.121 (11.6)	591	2.167 (9.8)	1549	2.224 (7.4)
SEA W.C.	448	2.233 (9.6)	928	2.262 (8.4)	1121	2.273 (8.0)	2650	2.345 (5.1)
Conventional W.C.	-	-	1150	2.323 (4.0)	-	-	1330	2.33 (3.7)

Air void contents in parentheses are based on theoretical densities of:

SEA Base = 2.40

SEA W.C. = 2.47

Conventional W.C. = 2.42

TABLE 13: MEAN ROADWAY CORE PROPERTIES (PUGMILL)

Course	February 1979		August 1979		February 1980		Plant Briquettes	
	Stab. (Lbs)	Specific Gravity	Stab. (Lbs)	Specific Gravity	Stab. (Lbs)	Specific Gravity	Stab. (Lbs)	Specific Gravity
1st Lift	-	2.103 (12.4)	464	2.153 (10.3)	473	2.153 (10.3)	1328	2.221 (7.5)
2nd Lift	-	2.056 (14.3)	392	2.130 (11.2)	428	2.143 (10.7)	-	2.222 (7.4)
Conventional W.C.	-	2.230 (7.9)	1367	2.303 (4.8)	1299	2.278 (5.9)	1360	2.325 (4.0)

Air void contents in parentheses are based on theoretical densities of:

SEA Base = 2.40

SEA W.C. = 2.47

Conventional W.C. = 2.42

TABLE 14: STRUCTURAL ANALYSIS

Section	Before Overlay Ave. SN	August 1979 Ave. SN	SEA Base Structural Coefficient*	SEA W.C. Structural Coefficient*
Gulf (Sta. 151-130)	1.6	3.60		0.37
Gulf (Sta. 127-118)	1.2	3.4	0.21	
Pugmill (Eastbound)	0.5	2.65	0.28	
Pugmill (Westbound)	0.8	2.8	0.29	

*SN Gain = $(T_{base})\ (C_{base}) + (T_{surface})\ (C_{surface})$

where the following average thicknesses were used:

SAM (Sta. 151-130)	SAM (Sta. 127-118)	Pugmill (Eastbound)	Pugmill (Westbound)
SEA Base - 5.69"	SEA Base - 7.00"	SEA Base - 6.02"	SEA Base - 4.96"
SEA W.C. - 2.20"	Regular W.C. - 2.12"	Regular W.C. - 1.42"	Regular W.C. - 1.69"

and a structural coefficient of 0.33 was assumed for the Regular Type I W.C.