DURABILITY CHARACTERISTIC OF FOAMED ASPHALT MIXTURES

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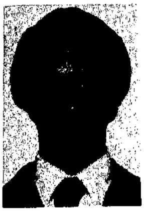
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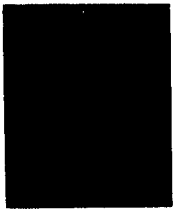
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Durability Characteristics of Foamed Asphalt Mixtures

HIGHLIGHT SUMMARY

A laboratory investigation was performed to establish the durability characteristics of foamed asphalt mixtures. Durability was characterized by a water sensitivity test and cyclic freezing and thawing. The various foamed asphalt mixtures were tested for durability after the mixtures had been compacted and cored into 10.16 cm. [4.00 in.] diameter by approximately 6.35 cm. [2.50 in.] high specimens, and cured.

The effects of different variables on durability were evaluated in this laboratory study. These variables were: foamed asphalt content (2 levels for water sensitivity section, 1 level for freeze-thaw section), aggregate (3 types, used in both sections), additives (3 types, plus a set without additives), and additive content (2 levels for each additive in the water sensitivity section, 1 level for each additive in the freeze-thaw section). One asphalt type, one mixing and testing temperature, one set of curing conditions, and one moisture content per aggregate were used.

Durability characteristics of the mix in the water sensitivity section were monitored by resilient modulus and modified Marshall stability tests. Durability in the freezing and thawing section was monitored by pulse-velocity, resilient modulus and modified Marshall stability tests.

Durability, strength, and longevity of the foamed asphalt mixtures were substantially improved when lime was used as an additive. By adding lime, the improvement was such that a material generally less suitable for bituminous mix such as outwash sand or pit run gravel may rival a material more suitable for bituminous pavement mix such as crushed limestone.

Pulse-velocity is a non-destructive test that appears to be related to the modified Marshall stability values obtained in this study. There were similar rates of decline per cycle for pulse-velocity and modified Marshall stability. There seemed to be a good reproducibility of pulse-velocity values among like specimens.

INTRODUCTION

There is no question that an integral part of today's transportation system is the highway. Man is constantly striving to improve these highways in order to make that part of the transportation system more cost effective. Traditional methods of improving highways and roads are undergoing changes to better meet constraints such as: (a) limited amount of natural resources, (b) the level of acceptable pollution which is unavoidably created by the use of certain resources, and (c) man's limited budget which must deal with the ever-increasing financial cost of certain resources.

One of these traditional methods for improving highways is the stabilization of aggregates with bituminous materials which are largely a by-product of petroleum refining. Petroleum is a limited resource, a fact which has become more apparent in recent years. Certain methods of paving with bituminous materials cause higher levels of hydrocarbons to be released into the environment than other methods (i.e., using cutbacks or hot asphalt cement vs. emulsified asphalts).

The increasing scarcity of petroleum and tighter environmental controls cause the cost of bituminous materials to continually increase. Other expenses include the heating of aggregates and bitumen for hot mix applications, the transportation of water for emulsified asphalt uses, and the amount of time (which is money) needed for aeration of emulsified and cutback applications.

More attention has been given lately to a binder material known as foamed asphalt. Foamed asphalt falls within the limits of the aforementioned constraints better than other forms of bituminous material for a number of reasons.

First, a lesser amount of asphalt is generally needed for foaming than in other kinds of asphalt applications. The foamed asphalt is sprayed onto cold and wet aggregates which, in turn, are coated better than if the asphalt was not foamed. To obtain the same degree of coating with hot liquid asphalt cement, either the aggregate would need to be hot and dry, or else more asphalt would be necessary.

Second, there is not the same level of hydrocarbon pollutant release when paving with a foamed asphalt mix as there is when paving with cutback or emulsified asphalt mixes, notably during the aeration period for the cutback. In fact, there is generally no need for aeration of the mix with foamed asphalt. The asphalt is foamed by virtue of an injection of approximately 2 percent (by weight of asphalt) cold water into hot asphalt at approximately 160°C (325°F). The foamed asphalt mix is stable upon compaction and does not need to cure or "break".

Third, the foamed asphalt process is less expensive once a foamed asphalt generator has been made available. The aggregate is used in a cold, wet condition and thus requires no heating or drying energy. As indicated before, there is no aeration period, so weather plays a minor role during field compaction. Foamed asphalt mixtures have been stockpiled for up to a year before placement and compaction [1]*.

However, the durability of foamed asphalt mixtures has been questioned as more knowledge is being gained in recent research work. The concern is due to foamed asphalt mixtures having lower bitumen contents and higher voids contents than standard asphalt mixes [1]. This study addresses the durability question. Two types of durability were investigated: (i) the effect of soaking in water, and (ii) the effect of cycles of soaking in water, freezing, and thawing, on the stability and strength of foamed asphalt specimens. Control samples, i.e., specimens which have not been subjected to soaking or freezing and thawing, were also made and monitored for stability and strength.

A common problem limiting the durability of asphalt concrete is that of the asphalt being stripped from the aggregate due to the action of water. Certain chemicals have been found to increase the adhesion of asphalt to aggregates [2]. Three additives were utilized in this study to determine if they have any effect in the durability of foamed asphalt specimens. Also, a series of specimens without any additives were used as a control set. The additives used were calcium hydroxide (lime), Silane and Indulin. Lime has been used successfully as an additive to asphalt concrete in the past [2]. In this study the lime was added in a slurry form to the finer aggregate particles.

Silane, the name of a family of organic chemicals, has been recommended as a possible anti-stripping agent [3]. It can be either added directly to the asphalt or used as an aggregate pretreatment. In this study the Silane was added to the water used to bring the aggregate to the specified mixing moisture content. Indulin, typical of several liquids which are marketed as anti-stripping agents, was added directly to the asphalt in the heating tank before it was foamed.

Several tests were performed to monitor the effect of water and cyclic freeze-thaw on the strength and stability of the foamed asphalt mix samples. These test include: resilient modulus, a modified Marshall stability method, and pulse-velocity measurements. The results of the "non-destructive" tests as determined from the resilient modulus and pulse-velocity test, were compared to the results of the modified, more common (but destructive) Marshall stability test. The purpose of this comparison was to establish the likelihood of a correlation between the modified Marshall method and a non-destructive test. Such a correlation might then be used as gage of relative deterioration of a foamed asphalt specimen subjected to cycles of water soaking, freezing and thawing.

As a result of this study, it was hoped that the durability of foamed asphalt mixtures would be better understood so that this type of pavement mix can be seriously considered for field use.

MATERIALS AND EQUIPMENT

Aggregate Material.-

Three different types of aggregate material were used in this research study. They were outwash sand, pit-run gravel and crushed limestone. Three aggregates were used because there was some suspicion that the characteristics of foamed asphalt will allow successful use of a broader spectrum of aggregate and soil materials as stabilized bases and subbases [1,5]. Also, any universal effect from the additives included in this study could be verified by more than one occurrence by comparing the results of the three aggregates.

These aggregates were used in previous foamed asphalt studies [4, 5, 6]. Their gradations and other physical properties are presented in Table 1 and Table 2 of this report.

Bituminous Material.-

An AC-20 asphalt cement together with the respective amounts used with each different aggregate, were selected based in findings and results of previous studies [4, 5, 6] conducted at Purdue University, Colorado [1], and data obtained by CONOCO Oil Co. [9], the developer of the laboratory foamed asphalt generator used in this study. The properties and foam characteristics of this binder material are listed in Table 3.

Additives.-

Three different types of additives were used in this laboratory investigation. They were Lime, Silane and Indulin. Additives were included in this work because of the history of poor performance by foamed asphalt mixtures with respect to moisture deterioration [5, 7, 8]. Previously the durability problem was handled in the field by assuring that the foamed asphalt was drained and sealed [6, 7]. However, if an effective and economical additive could be found which will improve foamed asphalt mixtures' resistance to deterioration, then foamed asphalt would be a more viable alternative to other forms of bitumen stabilization. A detailed listing of the additives characteristics and properties is presented in Table 4, Table 5 and Table 6 of this report.

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* Note: Numbers in brackets refer to list of REFERENCES in this report.

Table 1.- Gradation of Mineral Aggregates (% Passing).

Sieve Size	Pit-Run Gravel	Outwash Sand	Crushed Limestone
1 in	100.0	100.0	100.0
3/4 in	90.0	100.0	96.7
1/2 in	84.0	99.7	79.0
3/8 in	76.0	99.5	66.0
No. 4	65.0	97.6	43.5
No. 8	50.0	94.3	34.0
No. 16	35.0	90.7	25.0
No. 30	20.0	78.4	17.1
No. 50	8.0	38.3	14.0
No. 100	5.0	9.5	11.5
No. 200	3.0	2.4	9.0

Table 2.- Properties of Mineral Aggregates.

Properties	Bulk Sp. Gr.(SSD)	Apparent Sp. Gr.	Absorption (%)	Mineral Filler
Std. Test (ASTM)	C - 127	C - 127	C - 127	D - 424
Pit-Run Gravel	2.644	2.710	1.56	Non-plastic
Outwash Sand	2.607	2.707	1.20	Non-plastic
Crushed Limestone	2.696	2.741	1.28	Non-plastic

Table 3.- Properties of Asphalt Cement AC-20.

Penetration (0.1 mm), 100 gr., 5 sec., 25°C	42
Softening Point, Ring and Ball	48°C (118°F)
Ductility, 25°C (77°F), 5 cm/min.	150 cm
Kinematic Viscosity, 150°C (300°F)	229 cSt
Kinematic Viscosity, 160°C (325°F)	126 cSt
Kinematic Viscosity, 180°C (350°F)	72 cSt
Foam Characteristics:	
Expansion Ratio	13
Half Life	14 sec

Table 4.- Silane Properties (after Reference No. 13).

Appearance	clear liquid (CTM 0176) *
Color	light straw to yellow (CTM 0176)
Viscosity	6 cSt (CTM 0004)
Specific Gravity (25°C)	1.02 gr/ml (CTM 0001A)
Flash Point, Cleveland Open Cup	127°C (260°F) (CTM 0006)

* CTM stands for Corporate Test Method, and they generally correspond to ASTM standard test methods. CTMs are available from Dow Corning upon request.

Table 5.- Calcium Hydroxide Lot Analysis.

Ca (OH)	F. W. =	74.09
Chloride (Cl)		0.01%
Iron (Fe)		0.05%
Sulfur Compounds		0.06%
Heavy Metals (as Pb)		0.002%
Magnesium and Alkali Salts		0.62%
Insoluble in Dilute HCl		0.006%

Table 6.- Indulin Properties (after Reference No. 14).

Active ingredients	100%
Form	viscous liquid
Color	dark brown
Specific Gravity, 25°C/50°C	0.970/0.963
Pour Point	13°C (55°F)
Viscosity, SSF 50°C (122°F)	80
Viscosity, CPS 25°C (77°F)	2450
Viscosity, CPS 50°C (122°F)	150
Flash Point, Cleveland Open Cup	160°C (320°F)
Fire Point, Cleveland Open Cup	168°C (335°F)
Weight/gallon 25°C (77°F)	8.10 lbs.

Equipment.-

The following is a list of the laboratory equipment used in this study:

Foamed Asphalt Generator	[5, 9]
California Kneeding Compactor	[10]
Compression Machine, Mechanical Mixer, Ovens and Scales	[5]
Vacuum Saturation Apparatus	[6]
Freeze-Thaw Apparatus	[6]
Pulse-Velocity Apparatus	[11]
Diametral Resilient Modulus Device	[5]
Marshall Testing Apparatus	[10]

Detailed information on the various pieces of equipment used to prepare and test the foamed asphalt samples, can be found in the respective references listed in brackets next to each item.

EXPERIMENTAL PROCEDURE

The main purpose of this study was to determine the durability characteristics of foamed asphalt mix specimens. These characteristics were investigated by conducting a water sensitivity test and a freeze-thaw test. Untested specimens were used as a control set.

Water Sensitivity Test.-

Foamed asphalt mix specimens have been subjected to water sensitivity tests before, but the procedure used was often very severe [5]. There is little point in using a test if it is so harsh that after only one cycle there is no specimen left to monitor. Consequently, a less harsh test recommended by Ruckel, Acott, and Bowering [8] was used. The procedure is quite similar to the one found in the Asphalt Emulsion Manual (MS-19) of the Asphalt Institute [10].

Freeze-Thaw Procedure.-

Pulse-velocity and resilient modulus results were obtained from test specimens before performing each vacuum saturation and freezing-thawing cycle. After the last freeze-thaw cycle was completed, the specimens were tested in the Marshall stability apparatus.

Control Testing.-

Six specimens were foamed of each combination of the variables involved in this study to be used in each of the durability tests (water saturation, and water saturation plus freeze-thaw tests). Three of these six samples were used as control specimens in both durability sections. In other words, immediately after curing these specimens were subjected to the full battery of testing, and thus were destroyed (by the modified Marshall stability test) before any vacuum saturation, freezing, or thawing could occur. The results of a given set of three samples were averaged together to yield the "original" values of those mixtures.

Testing Routine.-

Several tests were used to quantify the

The pulse-velocity procedure used in this laboratory study was performed following ASTM D-2845 standard test procedure. The recorded values were in microseconds. A pulse-velocity value was calculated by dividing the height of the specimen by the recorded microsecond value. The velocity units are centimeters per second (cm/sec).

The resilient modulus test was used in both the water sensitivity and freezing and thawing studies. The samples used as controls and for the durability studies were measured as specified for the pulse-velocity test, early in this section. The water sensitivity test specimens were subjected to one cycle of vacuum saturation, and then tested for resilient modulus and modified Marshall stability. The freeze-thaw samples were tested (when thawed) for resilient modulus every few cycles until they, too, were destroyed by Marshall testing.

The diametral resilient modulus test procedure used in this study was similar to the procedure developed by Schmidt with some modifications [5, 6]. A pulsating load of 110 kg. (50 lbs.) was applied across the vertical diameter of the specimen with a dwell time of 0.1 seconds, every 3 seconds. Vertical deformations were recorded from LVDT's, on a strip chart recorder from which the instantaneous resilient modulus of the sample was obtained. The test was performed at room temperature of approximately 22°C (72°F).

The modified Marshall stability test was used in both the water sensitivity and freeze-thaw studies. The foamed asphalt mix specimens were prepared, cured and measured for height and weight prior to modified Marshall stability testing. The term "modified" is used to indicate a test temperature of approximately 22 ° C (72°F) which is different than the standard test temperature. The rest of the Marshall test was performed according to ASTM D-1559 standard test procedures.

In the freeze-thaw section of the durability study, the two non-destructive tests (pulse-velocity and resilient modulus) were conducted several times on each specimen over a period of weeks so that the results can be compared per specimen. Since the Marshall test is destructive, it could only be performed one time per specimen. In order to have modified Marshall stability values at different intervals over the "life" of a specimen, several samples of each composition of variables were made. Three were destroyed by Marshall stability before any soaking, freezing or thawing; two were destroyed at what was felt to be a half way point, and the last one was destroyed at the point of almost disintegration. Thus, the resilient modulus and pulse-velocity values are charts of a single specimen's response. The Marshall stability values are charts of six specimens' responses: the first point has three values averaged together; the second, two values, and the final point has but one value.

DISCUSSION OF TEST RESULTS

Water Sensitivity Test.-

Trends in the data were apparent in the water sensitivity section when considering the modified Marshall stability results for pit-run gravel and outwash sand foamed asphalt specimens. It was more difficult to determine trends for the crushed stone samples. Crushed limestone is an inherently strong material and additive effects in this type of foamed asphalt mixtures was minimal.

Specimens without any additives generally had among the highest stabilities before being subjected to water sensitivity test. After water saturation, however, specimens without additives had among the lowest stabilities.

Specimens with additives retained significantly higher percentages of modified Marshall stability after undergoing the water sensitivity test. The Silane and Indulin additives appeared to have had a weakening effect on the control samples (those samples not soaked in water). After the water sensitivity test, however, the Silane and Indulin additives cause these specimens to retain higher modified Marshall stabilities than the specimens without additives. Specimens with lime added, benefited both before and after the water sensitivity test. Samples with lime were as strong or stronger than samples without additives before the water sensitivity test. A graph of the modified Marshall stability values for pit-run gravel samples with 4.00 % foamed asphalt content both before and after the water sensitivity test is shown in Figure 1. This graph is representative of the trends observed with the rest of the specimens.

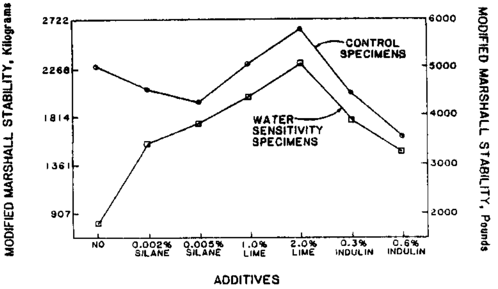

FIGURE 1. MODIFIED MARSHALL STABILITY FOR PIT-RUN GRAVEL MIXTURES WITH 4% FOAMED ASPHALT CONTENT

Lime has performed favorably as an additive to asphalt cement mixes in the past [12]. This good performance is more likely for the following two reasons: (a) lime is a hydrophilic material and so would tend to attract the water to itself. Thus, the water would be unable to cause stripping of the asphalt from the aggregate. Instead, the water would be "fixed" by the lime; and (b) when used in small quantities such as the amounts used in this study, lime, being a fine-grained material, serves to stiffen the asphalt matrix so that the stability increases without the specimen becoming brittle.

Silane and Indulin, both increase a foamed asphalt mix specimen's resistance to water by improving the bond between the asphalt and the aggregate. Both are liquid additives and so do not contribute any fine-grained material to the mix as does lime. Thus the benefit of using Silane or Indulin, as opposed to no additive, is that they make it more difficult for water to get in between the asphalt and the aggregate.

There were two levels for each of the additives in the water sensitivity section. The modified Marshall stabilities for one type of additive were generally fairly close in value at the two levels for that type of additive. For the samples made with Silane, the higher level (0.005% vs. 0.002%) usually had a slighter higher stability than the lower level. For the lime specimens, the higher level (2.0% vs. 1.0%) usually had a slightly higher stability than the lower level. For the Indulin samples, the lower level (0.3% vs. 0.6%) usually had a slightly higher stability than the higher level of this additive. A more complete battery of tests have to be conducted to determine the optimum level of each additive to be used with the different aggregates.

The crushed limestone-foamed asphalt mix specimens almost without exception had higher modified Marshall stabilities than the pit-run gravel and outwash sand specimens. The modified stabilities for the latter mixtures were fairly close in range. The pit-run gravel stabilities were somewhat higher than the outwash sand stabilities, though. Crushed stone is a strong aggregate material and thus it was expected to yield the higher stabilities among all the aggregates used in this study.

With each aggregate two levels of foamed asphalt content were used: an "optimum" level and an "optimum" plus 1% level based upon mix design procedures developed early for the case of specimens with the same gradations used here and no additives [5, 6]. There was not much difference in the modified Marshall stability between the two foamed asphalt contents within the water sensitivity section or the control section. The better amount of binder content would be then the lower level for each aggregate simply because of economic reasons.

The resilient modulus test did not indicate any clear trend in the water sensitivity section of this study.

Freezing and Thawing Test.-

Modified Marshall stability and pulse-velocity values showed some trends in the freeze-thaw section. In fact these trends were comparable with each other. Crushed stone specimens were again strong so that the effect of the additives was minimal. Trends and effects were much more visible with the pit-run gravel and outwash sand mixtures.

Specimens without additives usually had the lowest stability and pulse-velocity values, and disintegrated the fastest. Specimens with additives had increased longevity. Lime was by far the best of the three additives in this part of the study. For pit-run gravel and outwash sand samples the lime, Silane and Indulin treated specimens had markedly improved modified Marshall stabilities over the non-additive specimens. Graphs of modified Marshall stabilities versus number of freeze-thaw cycles for all three aggregates are presented in Figure 2, Figure 3 and Figure 4 of this paper (pit-run gravel, outwash sand, and crushed stone, respectively).

The pulse-velocity values for the lime-treated specimens were also consistently high. Pit-run gravel and outwash sand specimens with lime had by far the highest number of freezing and thawing cycles to disintegration. In fact, the pit-run gravel and outwash sand specimens treated with lime were destroyed by the Marshall stability test prematurely in the interest of time. They could have easily existed far beyond the 60 cycles indicated in Figure 5 where number of freeze-thaw cycles are plotted against type of additive.

The success of lime as an additive for foamed asphalt mixes can be attributed to the characteristics of lime mentioned before (hydrophilic nature and stiffening effect). These beneficial characteristics were also observed in the freeze-thaw section of this laboratory study.

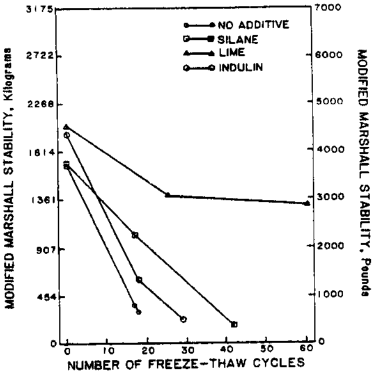

FIGURE 2. MODIFIED MARSHALL STABILITY VERSUS NUMBER OF FREEZE-THAW CYCLES FOR PIT-RUN GRAVEL MIXTURES

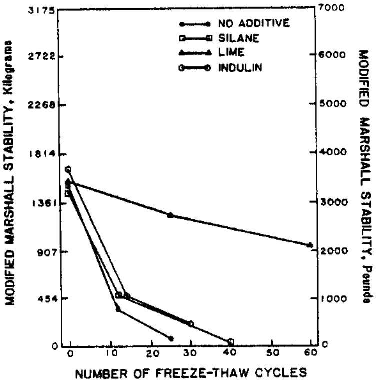

FIGURE 3. MODIFIED MARSHALL STABILITY VERSUS NUMBER OF FREEZE-THAW CYCLES FOR OUTWASH SAND MIXTURES

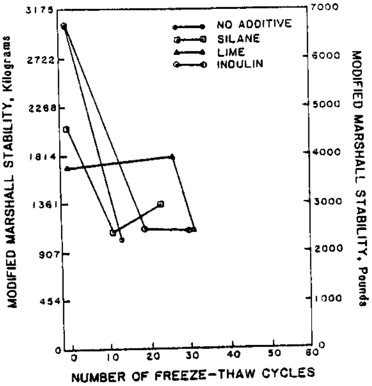

FIGURE 4. MODIFIED MARSHALL STABILITY VERSUS NUMBER OF FREEZE-THAW CYCLES FOR CRUSHED STONE MIXTURES

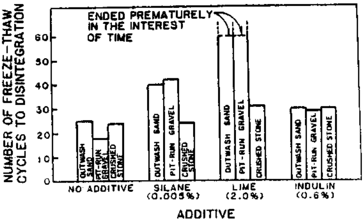

FIGURE 5. LONGEVITY GRAPH--NUMBER OF FREEZE-THAW CYCLES BEFORE DISINTEGRATION

TEST CORRELATIONS

The pulse-velocity results and modified Marshall stability values show correlation possibilities between the two methods. For practically all of the specimens analyzed in the freeze-thaw section, the pulse-velocity values closely paralleled the trends observed with the modified Marshall stability values Not only were similar rates of change apparent when comparing the two measurements, but relative values seemed to agree as well: a high modified Marshall stability value often correspond to a high pulse-velocity value. An example of pulse-velocity and modified Marshall stability values for a specimen can be seen in Figure 6. The specimen shown is composed of outwash sand aggregate with 0.6% Indulin and 4.25% foamed asphalt content.

Pulse-velocity values appear to have good reproducibility. Like specimens have similar pulse-velocity values when compared at a given number of freeze-thaw cycles. An example of pulse-velocity reproducibility for a given type of mix can be seen in Figure 7. The type of sample in this graph is a pit-run gravel with no additive and with 4.00% foamed asphalt content.

There was one small problem with the pulse-velocity test: a slight zigzagging of pulse-velocity values with time. If this could be eliminated, the decrease in pulse-velocity with each freeze-thaw cycle would be more obvious (and easier to correlate). This is, of course, assuming that the zigzagging of values is caused by something other than the different properties of the specimens themselves. Unfortunately, the resilient modulus results in both the water sensitivity and freeze-thaw sections of this study were, in general, discouraging in terms of revealing trends or the possibility for correlation with the modified Marshall stability test.

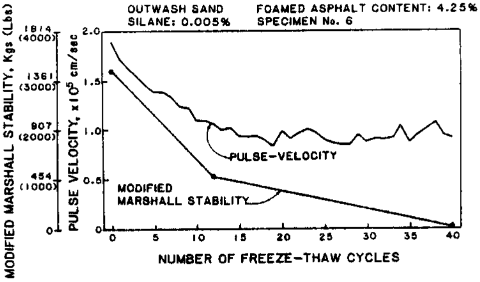

FIGURE 6. PULSE-VELOCITY – MODIFIED MARSHALL STABILITY COMPARISON

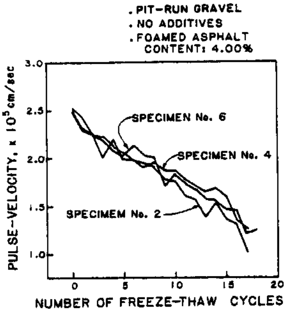

FIGURE 7. PULSE-VELOCITY REPRODUCIBILITY

CONCLUSIONS

This study investigated the durability of foamed asphalt specimens when subjected to a modified form of vacuum saturation for a water sensitivity test and cycles of freezing and thawing. The following conclusions were made from an examination of the results described in this report.

- Vacuum saturation weakened the foamed asphalt samples.

- The additives enabled outwash sand and pit-run gravel foamed asphalt samples to retain much more of their original stability after vacuum saturation than the untreated samples. Additives had little effect on the crushed stone samples in the water sensitivity test.

- Durability was generally better with higher levels of asphalt content in the water sensitivity test. Lime and Silane additives resulted in better durability than would have been obtained with the addition of more asphalt alone.

- Cyclic vacuum saturation, freezing and thawing weakened the foamed asphalt specimens.

- The additives enabled the foamed asphalt specimens to retain more of their original stability after repeated freezing and thawing, than the untreated specimens.

- Lime was the additive that produced the best performing mix. The improvement in the Marshall stability values, stability retention, and sample longevity is such that a material generally less suitable for bituminous mix such as outwash sand or pit-run gravel, gains so much from the addition of lime as to rival a better material such as crushed limestone. The outwash sand and pit-run gravel samples had somewhat lower stabilities than the lime-treated crushed stone samples, but they were able to withstand many more cycles of freezing and thawing before disintegrating.

- Silane and Indulin appear to yield favorable results in terms of stability retention; however, the results were not so marked when compared with the values obtained for the lime-treated specimens.

- Pulse-velocity is a non-destructive test that appears to be related with the modified Marshall stability test, according to the results obtained in this study. There are similar rates of decline per cycle for pulse-velocity and modified Marshall stability values. There also seems to be good reproducibility of pulse-velocity values among like specimens.

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