ABSTRACT

HUANG, YUANXIONG. Material Characterization and Performance Properties of Superpave Mixtures. (Under the direction of Dr. Akhtarhusein A. Tayebali)

The primary objectives of this research study was to characterize properties of two NCDOT Superpave mixes with regards to fatigue distress, and to develop phenomenological fatigue relationships for these mixes based on various levels of strain, asphalt content, air void content, and temperatures. Of particular importance was the sensitivity of the Superpave mixes to asphalt content and air void content that are usually expected in-situ.

Fatigue characterization of typical pavement sections using NCDOT fatigue models and using mechanistic analysis procedure suggests that the pavement fatigue life is sensitive to the mix variables and test temperatures considered in this study. A decrease in asphalt content by 0.5-percent (by wt. of mix) results in decrease of 18 to 25-percent fatigue life. An increase in 2% air void content will reduce pavement life by about 40% for 12.5-mm mixes, and by almost 60% for 19-mm mixes. An increase in temperature was found to result in decrease in fatigue life of pavement section under consideration, although, fatigue testing was conducted in controlled-strain mode-of-loading. A 5°C increase in temperature results in about 25-percent reduction in pavement life. Based on the overall result of the analysis, it appears that 19-mm mix is more sensitive to mix and test variables as compared to the 12.5-mm mix.

The study of frequency effect on fatigue life of typical pavement section suggests that prediction of fatigue life of pavement section is independent of load frequency used in fatigue test as long as tensile strain is computed based on the same load frequency.

MATERIAL CHARACTERIZATON AND PERFORMANCE PROPERTIES OF SUPERPAVE MIXTURES

By

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Dedication

I dedicate this dissertation to my father and to the memory of my mother.

BIOGRAPHY

Yuanxiong Huang was born in Huangmei county, Hubei province, China, in 1968. He received his Bachelor degree in civil engineering in Institute of Northwest Architecture and Engineering, Xian, China, in 1991. From August, 1991 to August, 1995, he worked in the Sixth Engineering Bureau of China Construction. He received his Master of Science degree in Geotechnical Engineering from Tongji University, Shanghai, China, in March, 1998. He worked as research engineer in Shanghai Seakon Research Institute of Geotechnical Engineering from April, 1998 to August, 2000. In September, 2000, he went to Stevens Institute of Technology, Hoboken, New Jersey, USA to study geo-environmental for one year. In July, 2001, he transferred to North Carolina State University, Raleigh, North Carolina, USA to study for his Ph.D. in Civil Engineering.

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List of Abbreviations and Symbols

AC	Asphalt Concrete/Asphalt Content
AFST	Axial Frequency Sweep Test
$\|E^*\|$	Dynamic axial stiffness
E''	Axial loss stiffness
FSCH	Frequency Sweep test at Constant Height
G_{mm}	Theoretical Maximum Specific Gravity (ASTM D2041)
$\|G^*\|$	Magnitude of complex shear modulus
G''	Shear loss stiffness
GLM	General linear model
JMF	Job Mix Formula
MTS	Material Test System
NCDOT	North Carolina Department of Transportation
N_{demand}	Pavement life in ESALs
N_f	Laboratory fatigue life
N_{supply}	Pavement fatigue life
PG	Performance Graded
S_0	Initial flexural stiffness
S_0''	Initial flexural loss stiffness
SGC	Superpave Gyratory Compactor
SST	Simple Shear Testing machine
SUPERPAVE™	SUperior PERforming PAVEments
UTM	Universal Testing Machine
ϕ	Phase angle

1. Introduction

1.1 Background

The update of the AASHTO Pavement Design Guide currently under development is geared to promote the use of a "Mechanistic/Empirical" design procedure. The mechanistic approach to design (for both new pavements and overlays) involves the prediction of performance-the manifestation and severity of distresses during the life of pavements.

A key component of performance testing is performance models. These are algorithms that predict pavement performance from the test results. The models account for both the new asphalt mixture being designed and the characteristics of the in-place pavement. The performance testing and performance prediction models represent an important new tool for engineers in designing and managing pavements. Superpave performance prediction is accomplished using four components as in Figure 1-1 [1]: material property model, environment effects model, pavement response model, and pavement distress model.

Performance test results from the SST and IDT are used as input to the material property model to determine non-linear elastic, viscoelastic, plastic, and fracture properties. The environmental effects model calculates pavement temperature as a function of depth and material thermal characteristics. The pavement response model uses output from the material property and environmental effects models to predict stresses and strains using a two-dimensional, axisymmetric finite element approach.

output from the pavement response and material property models is used by the distress models to estimate rutting and fatigue and low temperature cracking.

The mechanistic portion of this approach consists of Pavement Response Models (stress, strain and/or deflections). For a given pavement section and climatic conditions, the pavement distress model translates the stresses, strains and deflections induced by traffic loading to degree of distress (fatigue cracking, rutting, thermal cracking, etc.) manifestation using the laboratory evaluated materials property and performance testing. The mechanistically evaluated laboratory performance predictions are translated using empirical "transfer functions" (commonly known as shift factors) to account for the differences in loading, including vehicle types and axle configurations, rest periods between vehicle loads, traffic distribution, vehicle wander, differences in the mix compaction levels achieved and environmental factors such as seasonal temperature variations and temperature gradients that occur in the pavement.

In pavement distress model, there are three major components: rutting, thermal cracking and fatigue cracking. The fatigue resistance of asphalt mixes is generally defined as their ability to respond to repeated traffic loading under the prevailing environmental conditions without significant cracking or premature failure being induced. Damage in asphalt pavements due to repetitive stresses and strains caused by both traffic loading and environmental factors can manifest itself as fatigue cracking which is considered as a primary distress mechanism in asphalt pavements. The fatigue characteristics of asphalt mixes are therefore an important structural pavement design parameter. The tensile strain at the bottom of the asphalt layer is assumed, in the mechanistic design process, to be the parameter controlling fatigue cracking. One of the

main objectives of the mechanistic approach to the design of asphalt pavement is, therefore, to limit the maximum horizontal tensile strain and hence fatigue cracking in the asphalt layers. Mechanistic pavement design procedures ideally require an intensive laboratory material characterization at realistic loading (traffic speed, rest periods between traffic stresses, multi axle loading, etc.) and environmental (temperature, healing, aging, etc.) conditions. This is because the laboratory characterization of the fatigue performance of asphalt mixes suitable for local conditions, and the performance relationships derived from laboratory data, are fundamental to the development of field performance prediction models.

1.2 Effect of rest periods

Rest periods between loadings are introduced in some laboratory tests to simulate loading and non-loading periods of vehicular traffic. As a practical approximation, researchers have introduced, in the laboratory, rest periods ranging from 1 to 100 times the loading time.

Rest periods result in relaxation of stresses or recovery and chemical healing of micro-cracks already formed in the binder phase and, therefore, increase the fatigue life in laboratory tests, regardless of sample geometry or loading conditions (Kim, Little and Benson 1990; Kim, Whitmoyer, and Little 1994). However, mix type and test conditions (temperature, frequency, etc) have some influence on the level of improvement in the fatigue properties because of the mix stiffness and viscoelastic properties of the mix. The beneficial effect of rest periods on the fatigue life, expressed as a ratio of the number of cycles to failure with rest periods to the number of cycles to fatigue failure without rest

periods, is generally greater than one. Bonnaure, Huibers and Boonders (1982) reported that the effect of rest periods in controlled-stress loading resulted in a greater increase in fatigue life than under controlled strain loading. The fatigue tests were carried out by three-point bending of rectangular beams (230 mm by 30 mm by 20 mm) at 40 Hz and at 5, 20 and 25°C under sinusoidal loading. The beneficial effects of rest periods were significant at a load-to-rest period ratio of 10 and greater, up to 25, at higher temperatures and with a softer grade binder with other mix parameters remaining the same.

Initial stress/strain amplitude did not contribute to the beneficial effect of rest periods on fatigue life. However, Robertus (1993) reported that more healing appeared to occur at lower initial strains. Raintby and Sterling (1972) noted that at temperatures greater than 25°C there appeared to be a reduction in the beneficial effects due to rest periods. Furthermore, the beneficial effect of rest periods is also a function of the ratio of loading period to rest period. In general, fatigue life increases with the decrease of the ratio of loading period to rest period. However, the maximum benefit of rest period has been shown to level off beyond a loading-to-rest period ratio of 10 to 15 (Verstraeten, Veverka and Fancken 1982) or 25 (Bonnaure, Huibers and Boonders 1982). Van Dijk and Visser (1977) reported an improvement in fatigue life up to ten times, with the maximum benefit being achieved at a load to rest period of about 1:50. Molenaar (1984) has recommended a load to rest period ratio of 1:7.

1.3 Mode of loading

It is generally known that mode of loading has an influence on the laboratory fatigue result because the response of asphalt mixes could vary according to the input load or strain. There are two types of fatigue testing: control strain, control stress testing.

In the controlled strain test, the strain amplitude is maintained constant and the force required to maintain the initial strain level decreases gradually after crack initiation, as the flexural stiffness of the mix is effectively decreased. The failure, or termination point, is arbitrarily selected as a certain reduction in the initial stiffness from that at the commencement of the test, generally 50-percent, as there is no well-defined fracture of the specimen. The controlled strain mode of loading simulates conditions in thinner (<100 mm thick) asphalt pavements. The mix stiffness controls stress level which in turn controls the rate of crack propagation, and the measured fatigue life includes the number of cycles to crack propagation (Pell 1973). The performance of asphalt mixes with lower flexural stiffness (more flexible) is superior under controlled strain loading than under controlled stress testing at similar initial strain amplitudes. In controlled strain testing the fatigue life is longer because the crack propagation is included in the recorded "fatigue life". The initial dissipated energy per cycle is small, and the rate of energy dissipation is slow, until the very late stages of the test, when the crack propagation phase is dominant.

In the controlled stress mode of loading, the stress amplitude is maintained at the same level as the initial force. Because of repetitive application of this stress, the strain amplitude increases until it reaches twice the initial amplitude, when the flexural stiffness is reduced to half the initial flexural stiffness, which constitutes failure. According to

Button et al. (1987), this mode of loading does not account for both crack initiation and propagation, because the number of cycles to crack propagation is small compared to the number of cycles to failure. The end of test is defined by fracture of the sample. The initiation of cracks results in higher stresses at the crack tip (stress concentration effect), resulting in rapid crack propagation and failure of the specimen (Pell 1973). The rate of crack propagation in the laboratory is faster than that which would occur under prevailing in-situ field conditions. Controlled stress tests are more sensitive to mix variables than controlled strain tests (Rao Tangella et al. 1990).

Generally, in controlled stress tests, the mix stiffness will determine the strain level and hence the mix fatigue life, and asphalt mixes with higher initial flexural stiffness have a longer fatigue life (Pell 1973). Conventionally, this loading mode represents responses in thicker (>100 mm thick) pavements.

In the controlled stress mode, mixes with stiffer binders have been shown to have longer fatigue lives, and flatter slopes in the stress-fatigue relationship irrespective of whether the repeated flexure testing was conducted using two- or four-point bending (Baxin and Saunier 1967; Epps and Monismith 1969; Pell and Cooper 1975).

Controlled stress tests are more severe than controlled strain tests and the energy is absorbed more rapidly. The initial dissipated energy per cycle is high, and the rate of energy dissipation is faster, in the controlled stress mode of loading.

It is well known that there will be variability and scatter in the results of fatigue testing. However, when the stress in a controlled stress test is converted to strain, and strain is plotted against the number of cycles to failure, then the scatter is considerably

reduced (Monismith 1966b). This suggests that controlled strain tests reduce the scatter and variability associated with fatigue testing. Variability is also associated with sample (test specimen) dimensions, with the larger the sample size, the smaller is the scatter and variability in the fatigue test results.

A variety of loading patterns, such as sinusoidal, haversine, square and triangular-shaped waveforms with or without rest periods, has been used to simulate field traffic load pulses. The most commonly used are sinusoidal and haversine wave forms in the characterization of the mix and development of fatigue life prediction models.

A summary of some of the factors affecting controlled stress and controlled strain tests are listed in Table 1-1 (Rao Tangella et al. 1990).

1.4 Fatigue life prediction model

It is important to have a measure of the fatigue characteristics of specific mixes over a range of traffic and environmental conditions so that fatigue considerations can be incorporated into the process of designing asphalt-concrete pavement.

It has been generally accepted for many years that the fatigue behavior of asphalt-aggregate mixes can be characterized by a relationship of the form:

$$N_f = k_1 \cdot \varepsilon^{-k_2} \tag{1.1}$$

where,

N_f = fatigue life,

ε = initial maximum principal tensile strain, and

k_1, k_2 = experimentally determined coefficients.

Equation (1.1) is fundamental to any fatigue life prediction model, as the tensile strain in the asphalt layer determines the allowable number of traffic repetition depending on the stiffness of asphalt concrete. Nevertheless, coefficients k_1, k_2 are specific to asphalt mix type, volumetric composition and binder type. It is only applicable to a given asphalt mix.

Fatigue life prediction relationships should consider the effects of mix volumetric properties, temperature, loading time, ageing, healing, etc, on the fatigue life. Because asphalt concrete is a typical viscoelastic material under moderate temperature and loading frequencies, the incorporation of mix stiffness in the fatigue life prediction model would help to, at least, partly account for temperature and loading frequency effects. Then, the fatigue response of an asphalt mix to repetitive load applications in the laboratory tests may be more appropriate to take a more generalized form, as suggested by Monismith, Epps and Finn (1985) and others, is as follows:

$$N_f = k_1 \cdot \varepsilon_0^{-k_2} \cdot S_0^{-k_3} \tag{1.2}$$

where,

N_f = fatigue life,

ε_0 = initial maximum principal tensile strain,

S_0 = initial mix stiffness, and

k_1, k_2, k_3 = experimentally determined coefficients.

The laboratory model is then calibrated using a shift factor to correlate with different levels of cracking observed in the field to represent a field prediction of fatigue cracking. Based on AASHO Road Test data and observed cracking in the field,

laboratory-field shift factors of 13.4 and 18.45 for 10 percent and 45 percent cracking (in the wheel path areas) respectively were obtained by Finn et al. (1986).

Major institutions that provide fatigue-cracking curves include the Asphalt Institute (AI) (1981), Shell International Petroleum (Shell 1978; Shook et al. 1982), the university of California at Berkeley (Finn 1973; Finn et al. 1973, 1977; Craus et al, 1984), the Transportation and Road Research Lab (Powell et al. 1984), the U.S. Army (Department of Defense 1988), and the University of Nottingham (Brunton et al. 1987). Other simplified fatigue-cracking curves are also available in literature, such as the curves used in Illinois (Thompson 1987) and Minnesota (Timm et al. 1998), and the fatigue formula developed by Bergian and Pulles (1973) for cold climates. These fatigue-cracking curves are adopted by various highway agencies. Table 1-2 summarizes these fatigue-cracking models. In view of the fact that the number of load repetitions required to progress from the onset of cracking to limiting failure conditions is fewer for thin asphalt layers than for thicker layers, Craus et al. (1984) suggest that coefficient k_1 in AI model be reduced to 0.0636 for hot mixture asphalt layer less than 4 in thickness.

The fatigue life and flexural stiffness of asphalt pavement are also affected by binder volume and air void content of the mix. For an asphalt mix with a target asphalt content 5 percent (by weight) and 5 percent air void content, a 1 percent decrease in asphalt content, combined with a 1 percent increase in air void content, would lead to 39 percent decrease in fatigue life, while a 70 percent reduction in fatigue life could be expected for the same decrease in asphalt content but 3 percent higher air void content (Harvey et al. 1995).

The asphalt content can be converted into volume of asphalt. Volume of asphalt and air void content in the mix can be expressed as voids filled with binder. A couple of researchers showed that the fatigue life increases with the increasing voids filled with asphalt in the mix (Santucci 1977; Tayebali et al. 1993). The combined effect of asphalt content and air void content in the mix, in the form of percent void filled with asphalt, has also been considered as an important parameter in the fatigue life prediction models (Asphalt Institute (1981); SHRP (1994b); Harvey et al. (1995); Said (1997)).

Modified AI model (AI 1982), as described in equation (1.3), takes into account the effect of binder volume and air void content. Originally, the AI model only applies to a typical situation where the amount of asphalt cement in total mix is 5-percent. In case where the condition is not satisfied, the modified AI model can be used.

$$N_f = 0.07958 \cdot 10^{M} \cdot (\varepsilon_0)^{-3.291} \cdot |E^*|^{-0.854} \tag{1.3}$$

where,

$$M = 4.84 \cdot (\frac{V_b}{V_b + V_a} - 0.69),$$

V_a, V_b = the percentage volume of air voids and bitumen, respectively.

$|E^*|$ = dynamic modulus.

The American Strategic Highway Research Program (SHRP) carried out a detailed evaluation of performance-related laboratory tests for asphalt mixes. SHRP project A-003A focused on the fatigue performance of asphalt-aggregate mixes, including the selection of a test method for the characterization of the fatigue life asphalt mixes in the laboratory, the characterization of asphalt mixes according to an

experimental design and the development of fatigue performance prediction models (SHRP 1994a and b).

In the development and calibration of a surrogate fatigue life prediction model [2] which has considered the initial strain, initial loss stiffness and voids filled with asphalt as the independent variables affecting the fatigue life, it was observed that: (1).The effect of initial mix stiffness and phase angle on fatigue life can be expressed with equivalent accuracy by the mix initial loss stiffness. (2).The effect of mix voids on fatigue life can be expressed with equivalent accuracy by either the air void content or the percentage of voids filled with asphalt. (3).The effects of initial strain level, mix stiffness, and phase angle on fatigue life can be expressed with equivalent accuracy by the initial dissipated energy per cycle.

A general laboratory fatigue life prediction model was obtained (SHRP-A-404,[2]) in the following form:

$$N_{\sup ply} = 2.738 \cdot 10^5 \cdot \exp(0.077 \cdot VFB) \cdot \varepsilon_0^{-3.624} \cdot S_0^{''-2.72} \qquad (1.4)$$

where,

VFB = the voids filled with bitumen in percent as measured using the frequency-sweep specimens or as determined from the volumetric proportioning process,

$S_0^{''}$ = the initial flexural loss stiffness at 50th loading cycle in psi.

Other researchers (Chomton and Valayer 1972; van Dijk 1975; van Dijk and Visser 1977, Pronk and Hopman 1990; Tayebali et al. 1992) have used an energy

approach for describing fatigue behavior and have shown that the total or, cumulative, dissipated energy to failure is related to fatigue life as follows:

$$W_N = A\,(N_f)^z \tag{1.5}$$

where,

N_f	=	fatigue life,
W_N	=	cumulative dissipated energy to failure, and
A, z	=	experimentally determined coefficients.

In equations (1.1) and (1.2), fatigue life is related to initial test conditions, namely, the initial strain and initial mix stiffness. In equation (1.5), fatigue life is related to a terminal test condition, namely, the cumulative dissipated energy to failure. Neither approach directly recognizes how damage to the mix actually develops as loading proceeds from beginning to end. The cumulative dissipated energy to failure, W_N , is related to the energy dissipated during the ith load cycle, w_i , as follows:

$$W_N = \sum_{i=1}^{N_f} w_i \tag{1.6}$$

For a sinusoidal loading condition

$$w_i = \pi \cdot \varepsilon_i^2 \cdot S_i \cdot \sin(\phi_i) \tag{1.7}$$

where,

N_f	=	fatigue life,
w_i	=	dissipated energy at load cycle i,
$\boldsymbol{\varepsilon_i}$	=	strain amplitude at load cycle i,
S_i	=	mix stiffness at load cycle i,

ϕ_i = phase shift between stress and strain at load cycle i.

For controlled strain loading, the dissipate energy per cycle (w_i) decreases with an increasing number of load repetitions. For controlled–energy loading, the dissipated energy per cycle (w_i) remains constant during testing, and the cumulative dissipated energy is simply the product of the initial dissipated energy per cycle, w_o , and the number of cycles to failure, N_f. That is,

$$W_N = w_o \; N_f \tag{1.8}$$

or

$$W_N = \pi \cdot \varepsilon_0^2 \cdot S_0 \cdot \sin(\phi_0) \tag{1.9}$$

where,

N_f = fatigue life,
W_N = cumulative dissipated energy to failure,
w_o = initial dissipated energy per load cycle,
ε_0 = initial strain amplitude,
S_0 = initial mix stiffness
ϕ_0 = initial phase shift between stress and strain.

Combining equations (1.5) and (1.9), the following relationship is obtained under the assumption of constant dissipation of energy per cycle (controlled-energy loading):

$$N_f = \left\{ A \big/ (\pi \cdot \varepsilon_0{}^2 \cdot S_0 \cdot \sin(\phi_0) \right\}^{1/(1-z)} \tag{1.10}$$

For modes of loading other than controlled energy, a mode-of-loading-dependant energy ratio factor (Van Dijk 1975) is useful. The energy ratio factor, ψ, is defined as follows:

$$\psi = (N_f \cdot w_0)/W_N \tag{1.11}$$

Adding the energy ratio factor to Equation (1.11), yields

$$N_f = \left\{A \cdot \psi / (\pi \cdot \varepsilon_0{}^2 \cdot S_0 \cdot \sin(\phi_0)\right\}^{1/(1-z)} \tag{1.12}$$

In addition, generalizing for the purpose of regression analyses yields

$$N_f = a \cdot (\psi)^b \cdot (\varepsilon_0)^c \cdot (S_0)^d \cdot (\sin(\phi_0))^e \tag{1.13}$$

Or, replacing initial dissipated energy per cycle, w_o, for ε_0, S_0, and $\sin(\phi_0)$ yields

$$N_f = d \cdot (\psi)^f \cdot (w_0)^g \tag{1.14}$$

Equations (1.13) and (1.14) indicate that, for the controlled-strain mode-of-loading, the fatigue life is a function of the strain and the loss stiffness ($S_0 \cdot \sin(\phi_0)$), the viscous component of dynamic stiffness) of the mix, in effect, the energy that is dissipated during the initial load cycle

1.5 Fatigue test methods

Several test methodologies can be applied for measuring the fatigue behavior of asphalt-concrete. Brief description along with the advantages and disadvantages and limitations of selected test methodologies can be found in SHRP's "Summary Report on Fatigue Response of Asphalt mixes"[3].

On the basis of the findings of the summary report and the prior experience of the research team, the following test methods were identified as the most promising for possible use in measuring those mix properties which significantly affect pavement performance: (1). Flexural fatigue tests (third-point beam and trapezoidal cantilever test), (2). Tensile fatigue tests (diametral and uniaxial tension compression test), (3). Fractural mechanics approach (K, J, or C*-line integral), and (4). Tensile strength and stiffness (a surrogate for tensile fatigue effects).

In uniaxial tension-compression testing, persistent specimen failure at or near the end caps renders tests results questionable. Finite analysis of the test configuration confirmed that stress concentration would indeed occur at the end of specimen.

A number of researchers have used the diametral test for asphalt mix evaluation and pavement analysis. The test is simple to perform and is considered by some to be effective for characterizing materials in terms of fundamental properties. Although stress state within the specimen is complex, critical stress and strain are readily computed if linear elastic behavior is assumed. A biaxial state of stress exists along the vertical load axis. Along this axis, the horizontal tensile stress is reasonably constant while the vertical compressive stress varies more significantly.

In addition to the biaxial state of stress, fundamental differences between flexural beam and diametral fatigue tests includes the facts that 1) permanent deformation is usually prohibited in flexural tests but builds gradually under repetitive diametral loading, and 2) stress reversal is impractical in diametrical tests. One significant effect of these differences is that fatigue life is much smaller under diametral than under flexural testing.

Beam fatigue and trapezoidal fatigue share many common attributes. Both simulate the flexural stress pattern found in situ but apply uniaxial rather than triaxial stress. Both reverse the stresses (tension-compression), and neither permits the accumulation of permanent deformation with increasing numbers of load repetitions. Loading can be either in controlled stress and controlled strain modes to better simulate the range of conditions encountered in real pavements.

Response measures not only stiffness, phase angle, and cycles to failure but also dissipated energy. The use of such measures in appropriate design or performance models has often been successfully demonstrated over the years by numerous agencies. Although test measurements generally do not seem subject to the extraneous influences that might threaten their validity, the beam test avoids the possible edge effects of bonding trapezoidal specimens to their end plates.

Experience with flexural fatigue testing is extensive: the beam test has been popular in the United States: the trapezoidal test, in Europe. As experience has developed, improvements have made the tests not only easier and simpler to perform but more accurate as well. Significant new enhancements have emerged as a result of SHRP projects, particularly in the area of computer control and data acquisition. In addition, hardware has achieved notable improvements in test reliability as well. In each case, operations have also been simplified and eased.

One advantage of beam fatigue under third-point loading over trapezoidal fatigue is that a larger portion of the specimen is subjected to a uniform maximum stress level.

Thus, the likelihood is greater in beam testing that test results will reflect the weaknesses that naturally occur in asphalt-aggregate mixes.

1.6 Material property models

In terms of actual material characterization using laboratory tests, there are several material property models available. Bonnaure et al. (1977) developed both nomograph and equations for determining the stiffness modulus of HMA mixture. The three factors to be considered are the stiffness modulus of bitumen, percent volume of bitumen, and percent volume of aggregate. Witczak et al. (1979) developed a set of regression formula to determine the dynamic modulus of HMA. It considers more factors, such as the percentage of fines passing through No. 200 sieve and temperature. In 1999, Witczak et al. suggested a new version of the formula to predict the asphalt mix dynamic modulus.

With regard to phase angle of HMA, both University of Maryland and Bonnaure et al. provided empirical equations to determine phase angle. SHRP-A-404 report (Tayebali, et al, 1994) suggested a formula, which relates flexural stiffness to shear stiffness. It makes conversion from shear stiffness to flexural stiffness possible.

Although the concept of viscoelastic model and viscoelastic-plastic model is available, the parameters of those models have to be determined individually.

1.7 Research need

In lieu of actual material characterization using laboratory tests, there are several material property models as well as distress models available or under development by

many agencies such as AASHTO design guide and Superpave mix analysis models. However, these materials property models are rarely applicable directly to local situations as the HMA mix parameters continually vary based on the location of the project under consideration. For the distress models, the development of relationship(s) between pavement response and distress prediction as well as the determination of the empirical transfer functions need to be developed based on local experience for asphalt mixes which will be the responsibility of individual state highway agencies.

1.8 Objectives and scope of this study

Figure 1-2 provides the work plan of this project. The objectives of this study are to characterize HMA properties, and to develop phenomenological fatigue relationships for these mixes based on various levels of asphalt content, air voids content, and temperatures on Superpave mixes in use in North Carolina. The research includes laboratory investigation of 12.5-mm and 19-mm intermediate mixes at moderate temperatures of 15º C, 20º C and 25º C where predominant fatigue cracking is expected to be significant.

Specific work tasks that were considered are following:

1. Verify the job mix formula (JMF) provided by NCDOT for the 12.5-mm and 19-mm mixes.

2. For the design opt. AC content and an asphalt content 0.5-percent less than opt. AC, prepare rolling wheel compacted slabs to manufacture flexural beam specimens 15-in by 2.5-in by 2-in, and 6-in diameter cylindrical specimens for fatigue testing and shear stiffness characterization, respectively. Two 6-in prismatic specimens will also be sawed from the slab for axial stiffness

characterization. Slabs will be compacted to achieve 3-air voids level corresponding to 4-, 6- and 8-percent.

3. Conduct flexural fatigue testing on beam specimens at 15°C, 20°C and 25°C at 3 different strain levels to develop fatigue curves for the various mixtures.

4. For the core specimens, conduct shear frequency sweep test at the three temperatures and at frequencies ranging from 0.1 to 15Hz.

5. For the prismatic beam specimens, conduct axial frequency sweep test at the three temperatures and at frequencies ranging from 0.1 to 15 Hz.

6. Obtain a limited number of cores from the field for shear frequency sweep test.

7. Analyze the test results and develop fatigue distress models; and axial and shear stiffness models.

8. Develop a pavement and overlay design procedure based on typical pavement cross section encountered in North Carolina.

9. Study the effect of load frequency on pavement fatigue life.

Table 1-1 Factors affecting controlled stress and strain test (Rao Tangella et al.)

Factor	Controlled Stress Test	Controlled Strain Test
Failure of specimen	Well defined - specimen fractures at the end of test	No clear fracture at the end of test, stiffness reduction is the failure criterion
Number of specimens required	Small	Large
Flexural stiffness	Higher stiffness - increased fatigue life	Lower stiffness - increased fatigue life
Simulation of long term influence, e.g. ageing	Increased stiffness should lead to increased fatigue life	Increased stiffness should lead to reduced fatigue life
Effect of mixture variables	More sensitive	Less sensitive
Rate of crack propagation	Faster than under insitu pavement conditions	More representative of in situ pavement condition
Dissipated energy	Increases during the test	Decreases during the test
Rate of energy dissipation	Rapid and increasing	Slow and decreasing
Effect of rest periods	More beneficial	Relatively less beneficial
Pavement structure	Thick (>80 mm thick)	Thin (<80 mm thick)
Fatigue life	Low	High

Table 1-2 Predictive Models of Flexible Pavement Fatigue Cracking

Models	k_1	k_2	k_3	Sources
AI model	0.0796	3.291	0.854	Asphalt Institute (1981)
Shell model	0.0685	5.671	2.363	Shell Ltd. (Shell 1978; Shook et al. 1982)
Belgian Road Research Center	4.92×10^{-14}	4.76	0	Verstraeten et al. (1984)
UC-Berkeley	0.0636	3.291	0.854	Craus et al. (1984)
Modified AI model				
Transport and Road Research Laboratory	1.66×10^{-10}	4.32	0	Powell et al. (1984)
Illinois model	5×10^{-6}	3.0	0	Thompson (1987)
U.S. Army model	478.63	5.0	2.66	Department of Defense (1988)
Minnesota model	2.83×10^{-6}	3.21	0	Timm et al. (1998)
Indian model	0.1001	3.565	1.4747	Das and Pandey (1999)

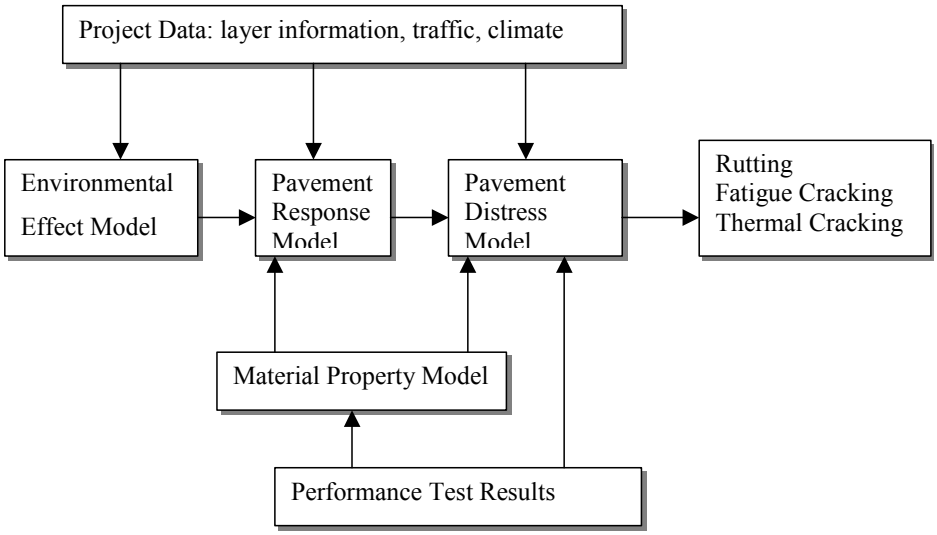


Figure 1-1 Schematic of Superpave performance predication [After 1]

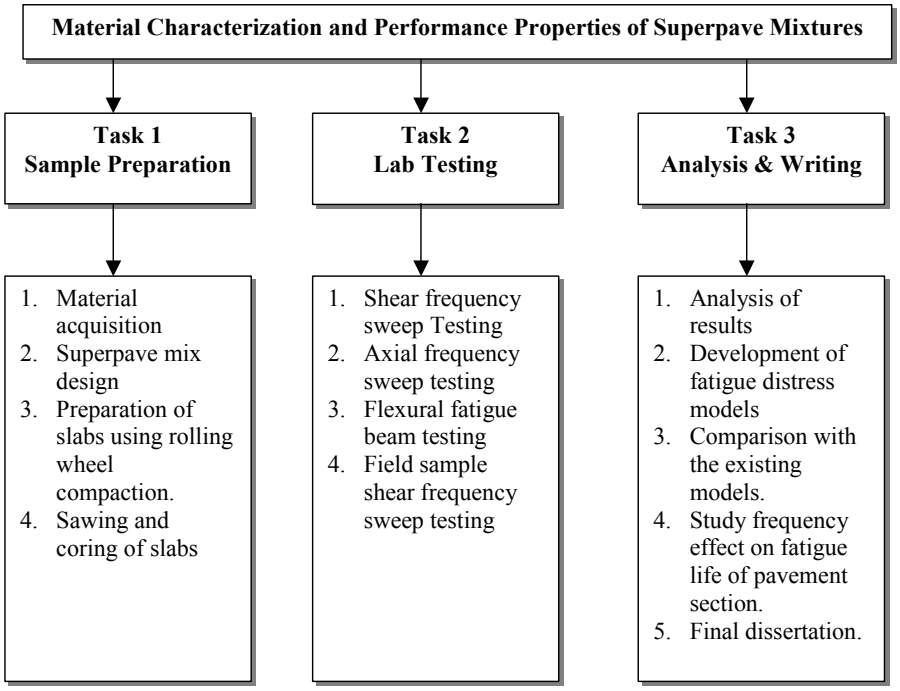


Figure 1-2 Summary of research approach

2. Mix Design Verification and Specimen Fabrication

2.1 JMF Verification

This section deals with the verification of the job mix formula (JMF) including the volumetric properties for the SP 12.5-mm and SP 19-mm mixes obtained from NCDOT. The NCDOT JMFs are attached in Appendix A.

2.1.1 Gradation requirement

Table 2-1 shows the source and proportion required for blending of the material for the 12.5-mm and 19-mm mixes. These materials are the same as ones used for the SPS-9A Project 370900, Highway US-1, Northbound, in Sanford, NC.

Several blending trials were conducted to achieve the required gradation. One problem that was encountered was that when using the first batch of screening material obtained did not give the required gradation, as shown in Figure 2-1. This was corrected by obtaining new screenings material. Table 2-2 and Table 2-3 show the final gradations used for 12.5-mm and 19-mm aggregates, which are also shown in Figure 2-2 and Figure 2-3.

2.1.2 Volumetric analysis

With the aggregate gradation shown previously, AC mixes were prepared using PG 64-22 Citgo Wilmington asphalt, and compacted using the Superpave Gyratory Compactor (SGC). Asphalt contents used were as per the JMF--5.2-percent by wt. of mix for 12.5-mm gradation and 4.7-percent by wt. of mix for 19-mm gradation.

Table 2-4 summarizes the volumetric properties from the JMF. For the mixes prepared in laboratory, the Rice Specific Gravity, and the volumetric properties are summarized in Table 2-5 through Table 2-7. Although there are some minor differences in volumetric properties obtained in lab vs. the JMF, in general, these mixes are fairly similar.

2.2 Specimen Fabrication

Three types of specimens were required for testing in this project--Flexural beam specimens (15-in, by 2-in by 2.5-in), cylindrical specimens (6-in×2-in) and prismatic specimens (6-in by 2-in by 2.5 in). These specimens were sawn or cored from rolling wheel compacted slabs of 24"×24" size. The air voids for the compacted slabs were targeted to 4, 6, 8-percent. However, it should be noted that actual air void content for individual specimens varied. Details for the air void contents of individual specimens will be given later when describing results for each test type.

Table 2-1 Source and proportion of material used

Supplier	Location/Source	Material	SP 12.5-mm Blend	Sp 19-mm Blend
			(%)	(%)
Martin Marietta	Lemon Springs Quarry	#67	15.0	50.0
Martin Marietta	Lemon Springs Quarry	#78	55.0	22.0
Martin Marietta	Lemon Springs Quarry	REG. SCRGS.	19.0	17.0
Lee Paving Company	Rambeaut Pit	N. SAND	10.0	10.0
		Bagfines	1.0	1.0

Table 2-2 Gradation analysis for SP 12.5-mm gradation

Sieve size (U.S. Designation)	Sieve size mm	Sample 1 % passing	Sample 2 % passing	Average % passing	Target % passing
3/4"	19	100	100	100	100
1/2"	12.5	95.355	95.16	95	94
3/8"	9.5	83.315	82.205	83	84
4	4.75	48.205	45.02	47	43
8	2.36	30.18	29.18	30	29
16	1.18	23.715	23.135	23	23
30	0.6	17.395	17.03	17	17
50	0.3	10.745	10.445	11	9
100	0.15	7.1	6.92	7	7
200	0.075	4.99	4.91	4.9	4.4

Table 2-3 Gradation analysis for SP 19-mm gradation

Sieve size (U.S. Designation)	Sieve size mm	Sample 1 % passing	Sample 2 % passing	Average % passing	Target % passing
1"	25	100	100	100	100
3/4"	19	98.088	98.788	98	99
1/2"	12.5	78.572	78.578	79	80
3/8"	9.5	59.466	58.408	59	62
4	4.75	36.796	37.644	37	35
8	2.36	27.318	28.014	28	27
16	1.18	22.186	22.516	22	22
30	0.6	16.412	16.482	16	16
50	0.3	9.934	9.972	10	9
100	0.15	6.552	6.606	7	6
200	0.075	4.584	4.656	4.6	4.2

Table 2-4 Superpave Hot Mix Asphalt Job Mix Formulas

Mix Type	Max. Sp. Gr.	Gyratory Sp. Gr.	Voids in	Voids in Min.	Voids Filled
	Gmm	G_{mb} @ N_d	total mix(%)	Aggregate (%)	w/ asph (%)
SP 12.5	2.464	2.356	4	14.8	73
SP 19.0	2.483	2.384	4	14	70

Table 2-5 Laboratory evaluated Rice specific gravity

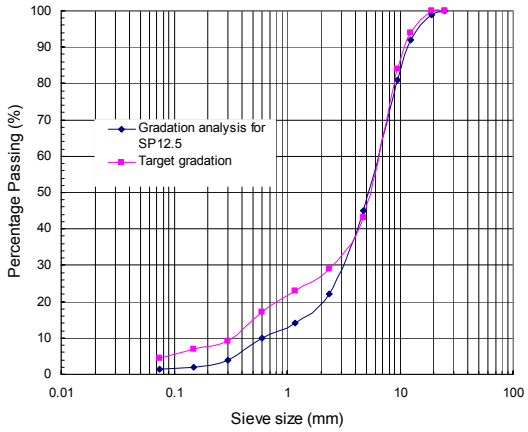
Gradation	AC	Average G_{mm}
19-mm	Optimum	2.487
	Optimum-0.5%	2.502
12.5-mm	Optimum	2.471
	Optimum-0.5%	2.489

Table 2-6 Volumetrics for mix types SP 12.5-mm and SP 19-mm

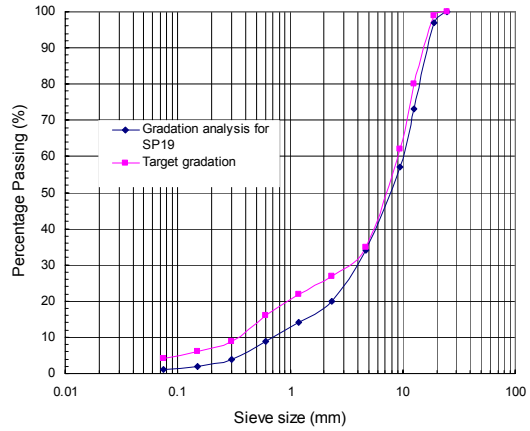
Asphalt	G_{mm}	# Of	Height	Mass	G_{mb}	Corr.	G_{mb}	%
Content %		Gyrations	mm	Wm (g)	Estimated	Factor	Corrected	G_{mm}
		N_{ini}	128.4		1.962		2.155	86.4%
		N_{des}	114.6	4452.1	2.198	1.098	2.415	96.8%
4.7	2.493	N_{max}	113.0		2.230		2.449	98.2%
		N_{ini}	125.9		2.117		2.125	86.0%
		N_{des}	112.4	4709.7	2.371	1.004	2.380	96.3%
5.2	2.471	N_{max}	110.8		2.405		2.415	97.7%

Table 2-7 Laboratory evaluated volumetrics for SP 12.5-mm and SP 19-mm

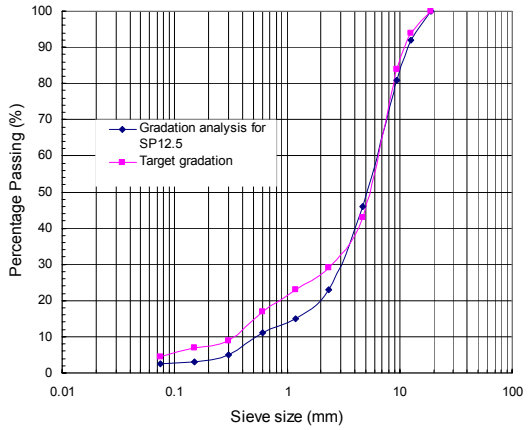
Asphalt	Agg.	Agg.	% G_{mm}	Voids	VMA	VFA
Content %	G_{sb}	G_{se}	@ N_{des}	%	%	%
4.7	2.639	2.681	96.8%	3.2%	12.8	75.3
5.2	2.631	2.687	96.3%	3.7%	14.2	74.3



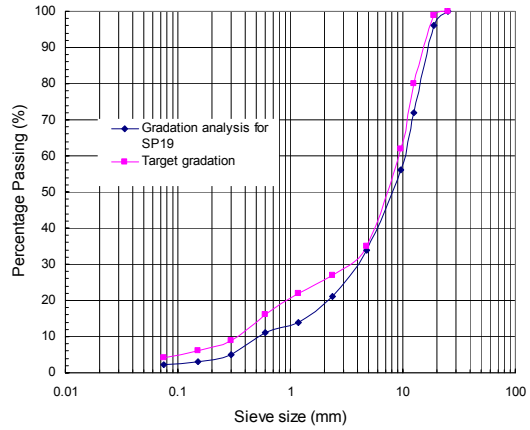
(a) SP12.5 without bagfines



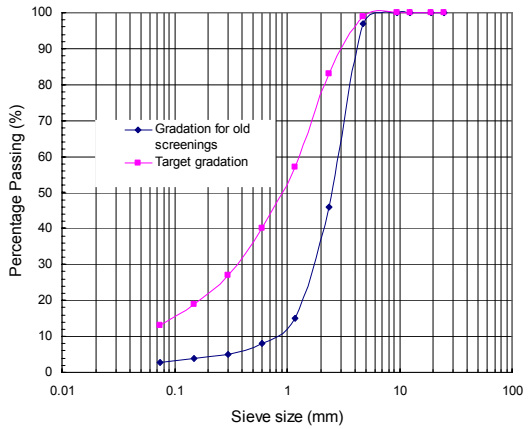
(b) SP19 without bagfines



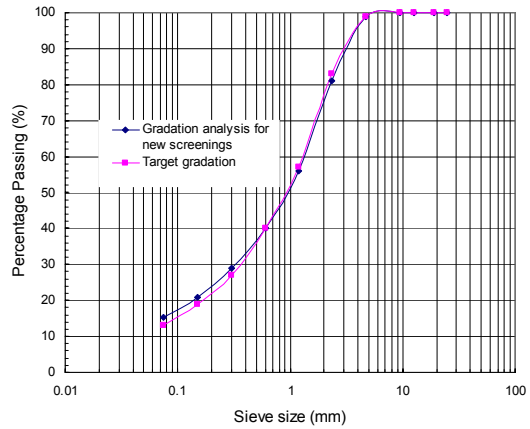
(c) SP12.5 with 1% bagfines



(d) SP19 with 1% bagfines



(e) Gradation using old screenings



(f) Gradation using new screenings

Figure 2-1 (a)-(f) Gradation analysis

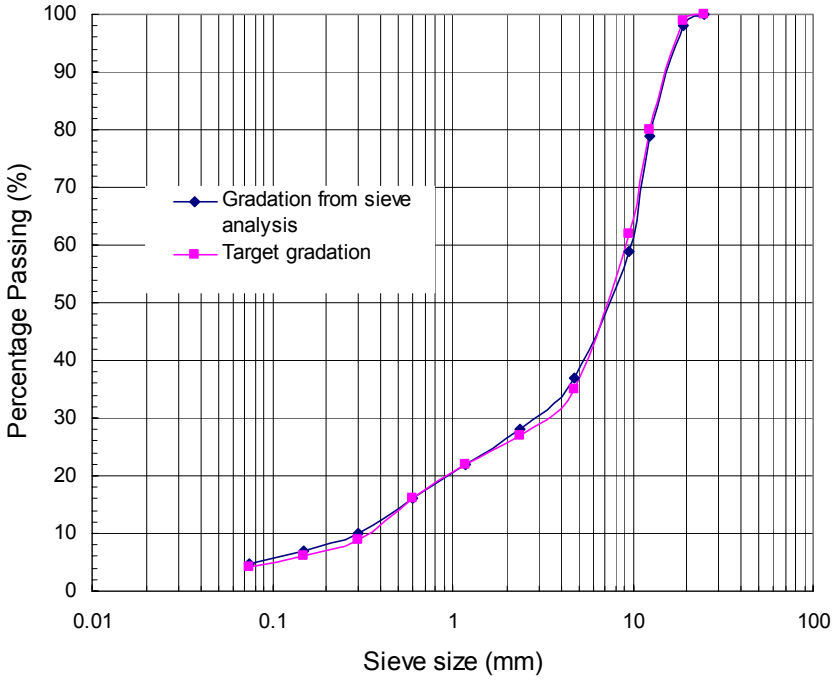


Figure 2-2 Final gradation for SP 12.5-mm gradation

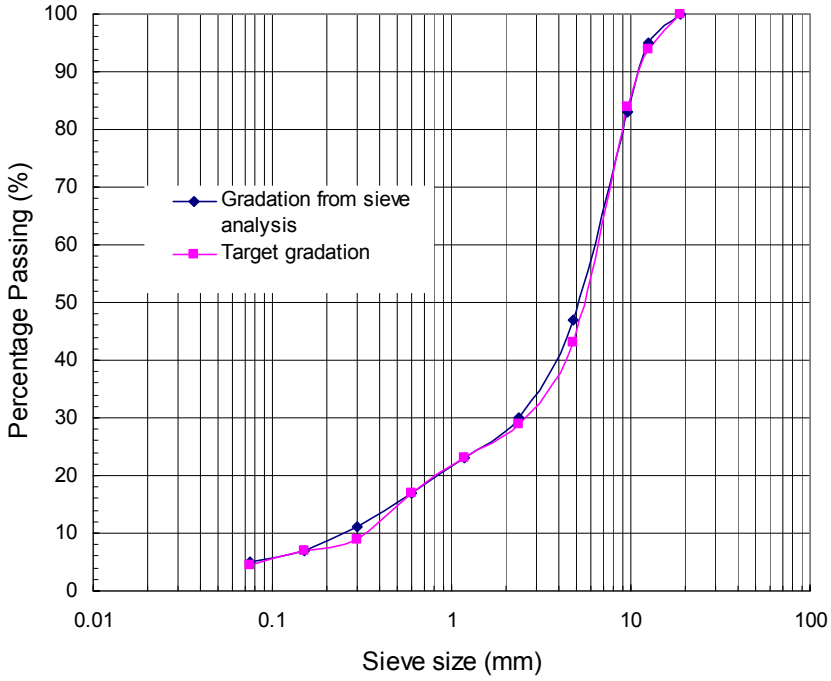


Figure 2-3 Final gradation for SP 19-mm gradation

3. Fatigue Testing

3.1 Objective

The primary purpose of this study was to evaluate the fatigue response of NCDOT Superpave 12.5-mm and 19-mm mixes. Variables that affect the fatigue response of asphalt mixes are asphalt type (temperature susceptibility) and grade, aggregate type (stripping potential) and gradation, asphalt content, air void content, temperature, and stress/strain level, aging, and moisture conditioning, etc. The significant variables considered in this study are asphalt content (AC), air void content (Va), temperature (Temp), and gradation (GR) as well as strain level. The other variables such as asphalt type and grade, aggregate type, aging as well as moisture conditioning, were not included in this study. The specific objectives of this experiment program were as follows:

1) Evaluating the effect of two levels of asphalt content (optimum and optimum minus 0.5-percent) on the fatigue response;

2) Assessing the effect of two gradations (SP 12.5-mm and SP 19-mm) on the fatigue response;

3) Investigating the effect of temperature on the fatigue response;

4) Estimating the effect of change in air void on the fatigue response, and

5) Based upon the effects of the above four factors and strain amplitude, developing a fatigue response model, initial flexural stiffness model and initial flexural loss stiffness model.

3.2 Mix and Test Variables

The mix and testing variables included in this testing program are summarized in Table 3-1 and are as follows:

- **Asphalt Cement:** PG64-22, Citgo Wilmington, NC.

- **Asphalt Content:** Two asphalt contents were used. One is optimum asphalt content, the other is optimum minus 0.5-percent by wt. of mix.

- **Aggregate Gradation:** Two types of aggregate gradation were used. The nominal aggregate size is 19-mmand 12.5-mm, respectively.

- **Air-Void Content:** Three levels of air void content were targeted to 4, 6 and 8-percent, with a tolerance of ±1-percent.

- **Strain Levels:** Three levels of strain, 200, 400, and 600 micro in/in, were selected as targets. During testing, the actual strain levels may be slightly different from the target strains.

- **Replicates:** Two replicate specimens were planned to use at each strain level. However, as will be shown later, replicates could not be tested at exactly the same strain level.

- **Test Frequency:** All the tests were performed in the controlled-strain mode-of-loading at a frequency of 10 Hz, sinusoidal loading with no rest periods.

- **Test temperature:** Three levels of temperature, 15°, 20° and 25° Celsius, were used.

The total number of compacted asphalt mixes used was 12, with total number of specimens that were planned to test being equal to 216 as shown in Table 3-1. However, some tests had to be repeated due to high variability in fatigue life for total number of tested specimens being 241.

As mentioned earlier, the fatigue tests conducted in this study was in controlled-strain mode-of-loading. The response variables measured was the stress (σ) and fatigue life. Based on the stress response, the stiffness was computed as the ratio of peak stress to peak strain, and the phase angle was computed as the phase lag between peak stress and peak strain. Initial stiffness was defined to correspond to 50th cycle; and fatigue life was defined to correspond to 50-percent reduction in initial stiffness.

Figure 3-1and Figure 3-2 shows typical evolution of stiffness as function of the number of loading cycles at 15 and 25°C.

3.3 Fatigue test results and discussion

3.3.1 Fatigue test results

The actual fatigue test results are given in Appendix B, which shows the strain level used, the initial stiffness, initial phase angle, initial loss stiffness, and the fatigue life for each specimen and test condition.

It should be noted that the mix type and test condition is coded in Appendix B for simplicity in presenting the data. Following is the code number system used in presenting the data:

Asphalt concrete (AC):	-1---optimum minus 0.5-percent, and +1---optimum
Aggregate gradation (GR):	-1---12.5-mm, and +1---19.0-mm
Temperature (Temp):	-1---15°C, 0---20°C, and +1---25°C
Repeat (RT):	-1---First repeat, and +1---Second repeat

The air void content and strain levels used are actual numbers, in percent and in/in, respectively.

3.3.2 Discussion of test results

For a large data set such as the one presented in this study, it is always difficult to describe the trend in data for each individual variable. Therefore, for simplicity in presentation the discussion below is subdivided based on grouping of data. It should be noted that the comparison presented herein may not be true reflection of the trends due to variations in air void content as well as the strain levels from specimen to specimen. Therefore, the following section presents just the general trend in data. More rigorous statistical analysis of the data is presented in chapter 4 of this report.

3.3.2.1 Effect of asphalt content

The effect of asphalt content on fatigue life is presented in Figure 3-3 to Figure 3-6. Figure 3-3 to Figure 3-5 pertains to 12.5-mm gradation. It can be seen from these figures that in general, there is distinct difference in fatigue life due to different asphalt content. Lower asphalt content results in lower fatigue life for the three temperatures as well as air void levels considered in this study. The same is also true for the 19-mm gradation mixes presented in Figure 3-6. It should be noted that there is some variability

in data, especially with regards to air voids. The design implication due to change in asphalt content will be enumerated in later chapter.

3.3.2.2 Effect of gradation on fatigue life

Figure 3-7 to Figure 3-12 show the effect of aggregate gradation on fatigue life of mixes. In general, there seems to be a difference in the performance with 19-mm gradation mixes showing lower fatigue life in comparison with 12.5-mm gradation mixes. However, it should be noted that the 19-mm mixes has optimum asphalt content of 4.7-percent compared to 12.5-mm mixes that has optimum asphalt content of 5.2-percent.

3.3.2.3 Effect of air void content

The effect of air void content is shown in Figure 3-13 and Figure 3-14 for 12.5-mm and 19-mm mixes, respectively. The results show very large variability in test results, especially for the 12.5-mm mixes. For 19-mm mixes, there is some indication of longer fatigue life for mixes with lower air voids, especially at low strain levels.

3.3.2.4 Effect of temperature on fatigue life

Figure 3-15 and Figure 3-16 shows the effect of temperature on fatigue life. Although, there is some variability, in general, the fatigue life is lower at lower temperature. This is expected as fatigue testing was conducted in strain-controlled-mode-of-loading.

Table 3-1 Features of the experimental study

Number of asphalts	1-PG64-22
Number of aggregate gradations	2-12.5-mm and 19-mm intermediate
Asphalt Contents	2-Superpave optimum 5.2-percent. and optimum minus 0.5-percent for SP12.5; Superpave optimum 4.7-percent and optimum minus 0.5-percent for Sp19
Air Void Levels	3- About 4, 6, and 8-percent
Temperatures	3- 15°C, 20°C, and 25°C
Test Frequency	10 Hz sinusoidal loading without rest period
Strain Levels	3-About 200, 400 and 600 micro in/in
Specimen Size	2 in height, 2.5 in width, 15 in length
Replicates	2- at each strain level
Total Number of Mixes	12- 2 gradations, 2 asphalt content, 3 air void
Total Number of Fatigue Tests	2 replicates x 12 mixes x 3 x 3 = 216

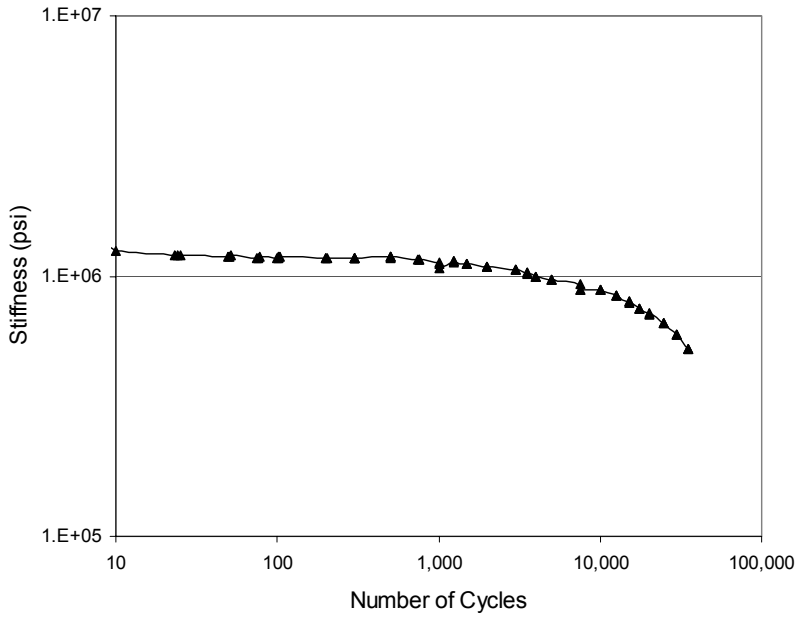


Figure 3-1 Stiffness vs. number of cycles for beam 1 in slab 2 at 15°C

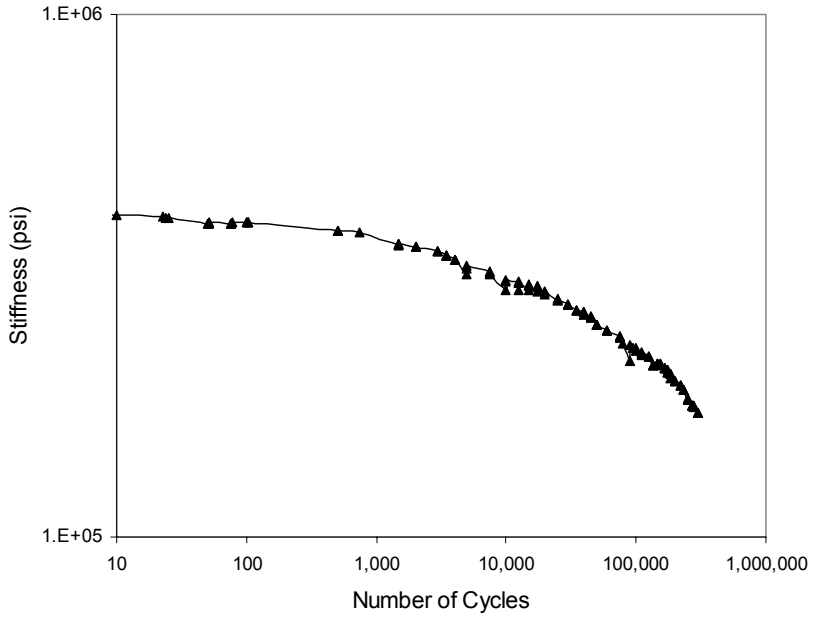
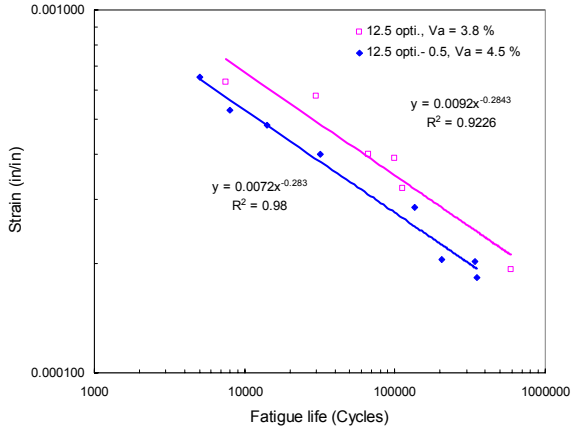
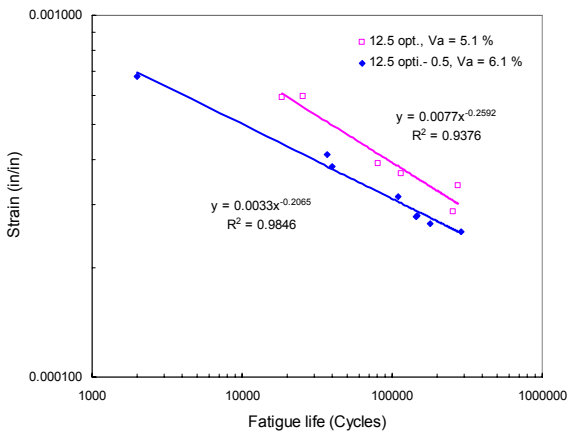


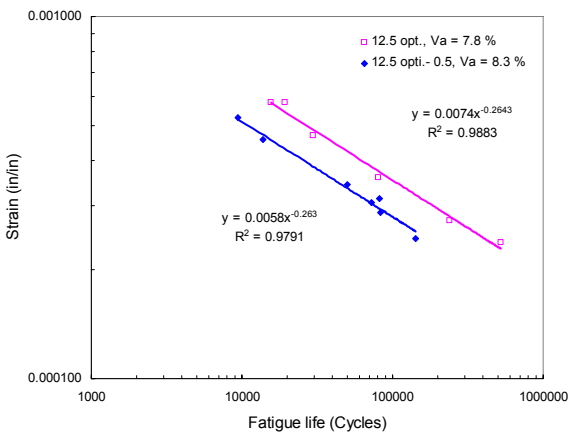
Figure 3-2 Stiffness vs. number of cycles for beam 7 in slab 26at 25°C



(a) T=15°C, Air void is about 4%

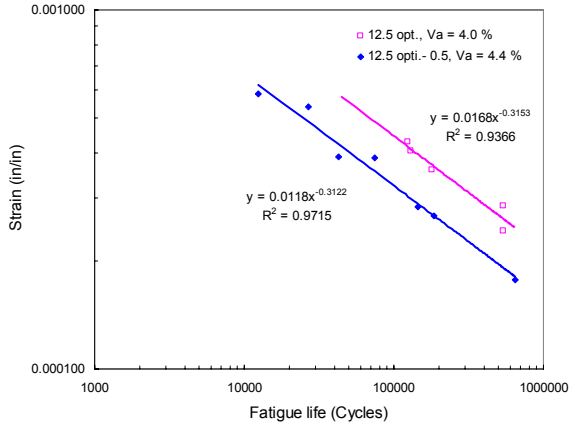


(b) T=15°C, Air void is about 5.5%

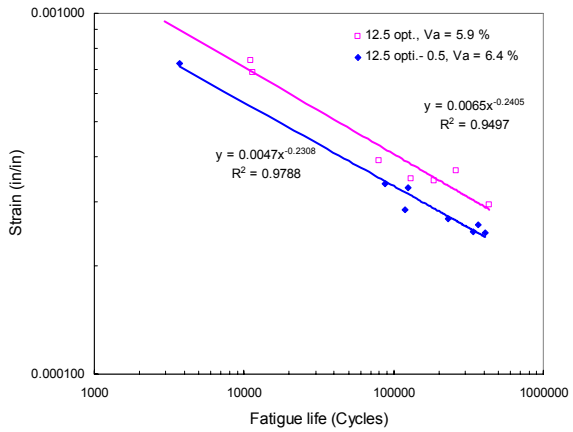


(c) T=15°C, Air void is about 8%

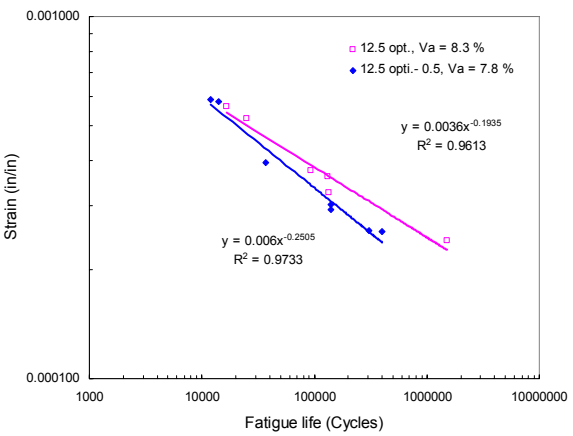
Figure 3-3 (a)-(c) Effect of asphalt content on fatigue life for 12.5-mm mixes, T=15°C



(a) T=20°C, Air void is about 4%

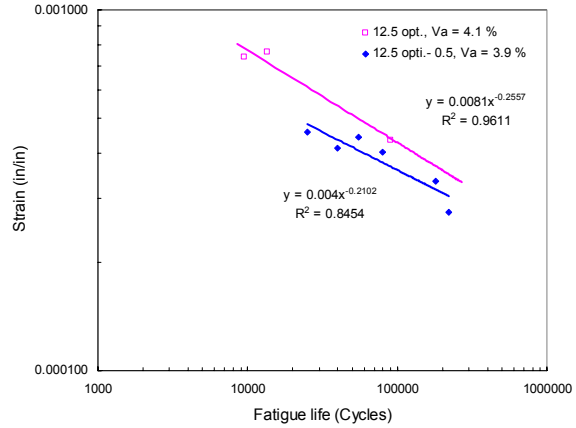


(b) T=20°C, Air void is about 6%

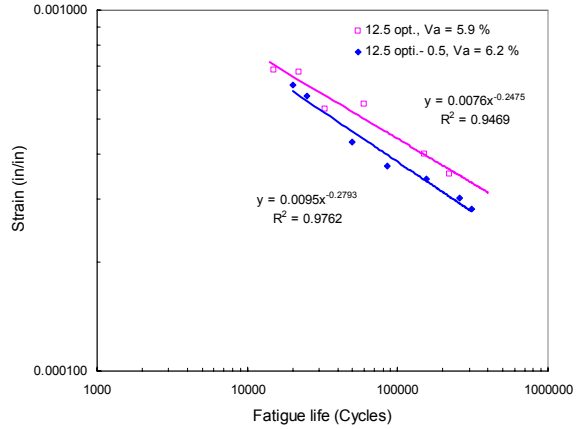


(c) T=20°C, Air void is about 8%

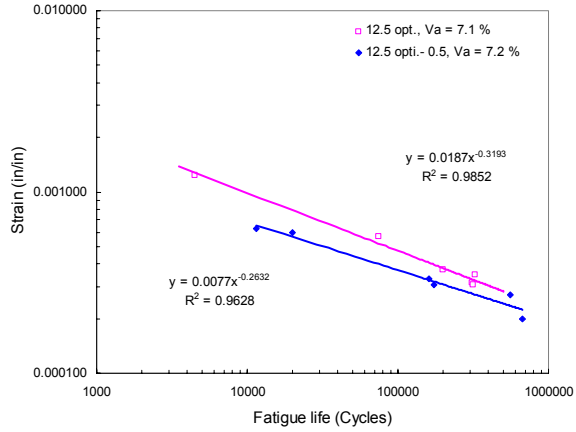
Figure 3-4 (a)-(c) Effect of asphalt content on fatigue life for 12.5-mm mixes, T=20°C



(a) T=25°C, Air void is about 4%

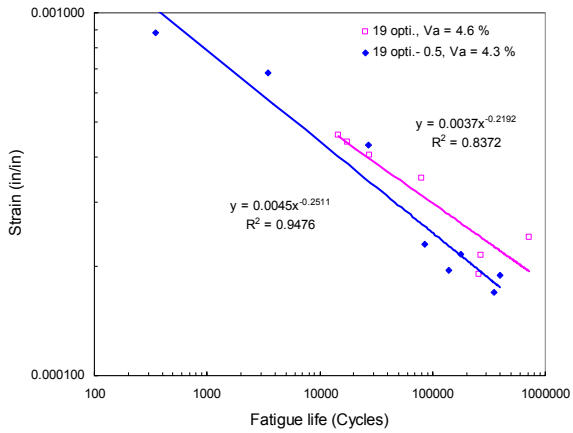


(b) T=25°C, Air void is about 6%

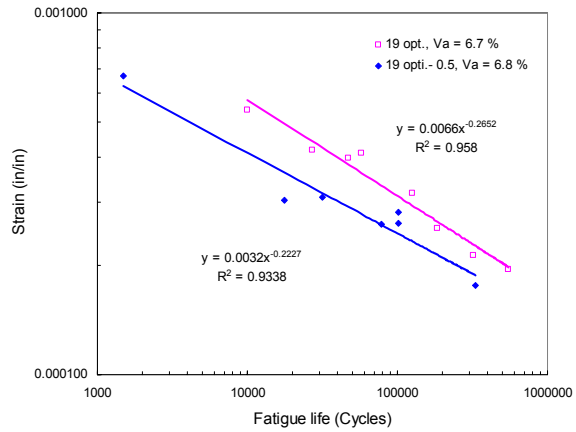


(c) T=25°C, Air void is about 7%

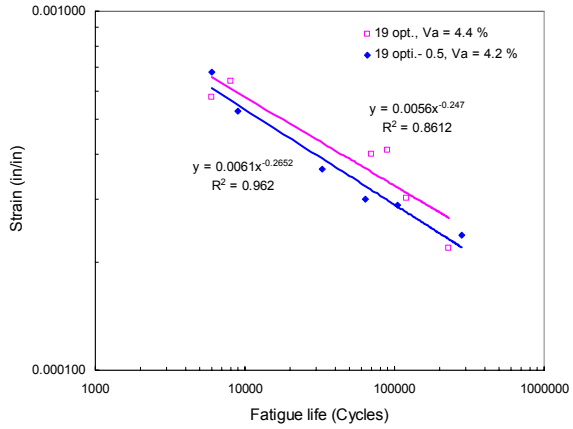
Figure 3-5 (a)-(c) Effect of asphalt content on fatigue life for 12.5-mm mixes, T=25°C



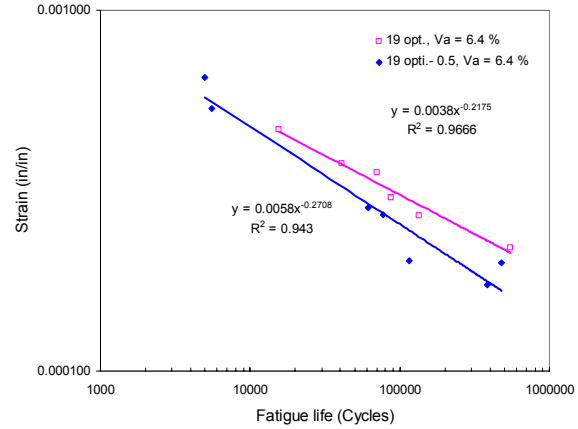
(a) T=15°C, Air void is about 4.5%



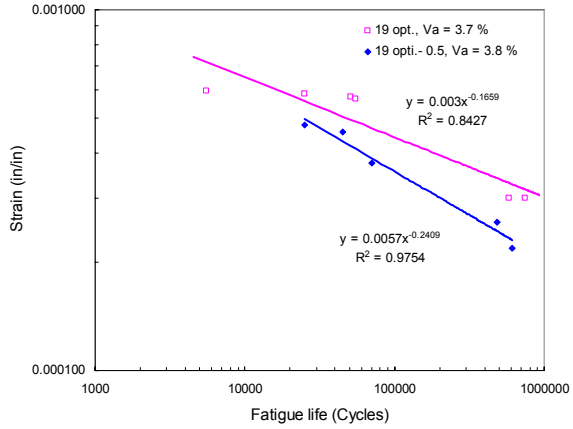
(b) T=15°C, Air void is about 7%



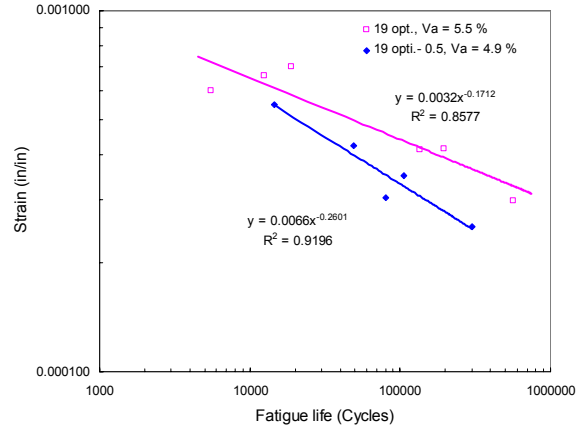
(c) T=20°C, Air void is about 4%



(d) T=20°C, Air void is about 6.4%

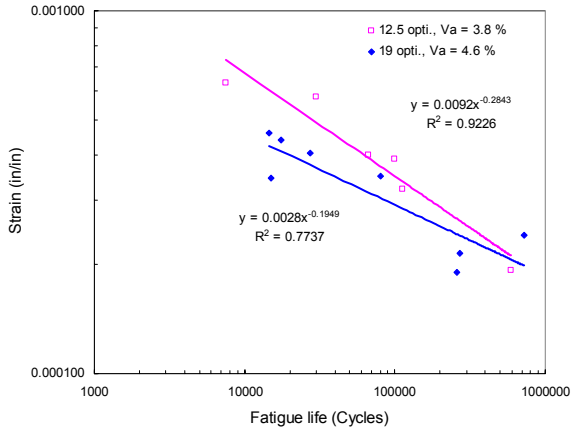


(e) T=25°C, Air void is about 4%

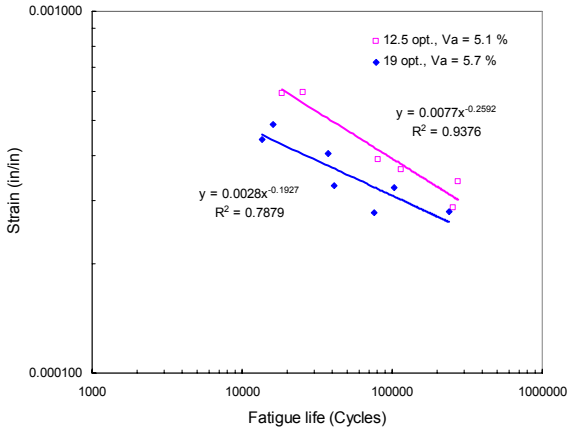


(f) T=25°C, Air void is about 5%

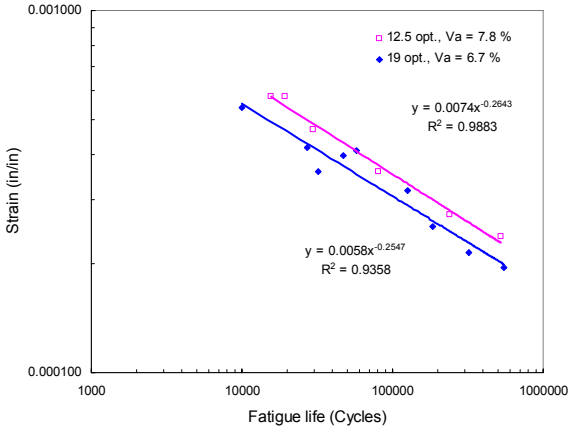
Figure 3-6 (a)-(f) Effect of asphalt content on fatigue life for 19-mm mixes



(a).T=15°C, Va≈4.2%, Optimum AC

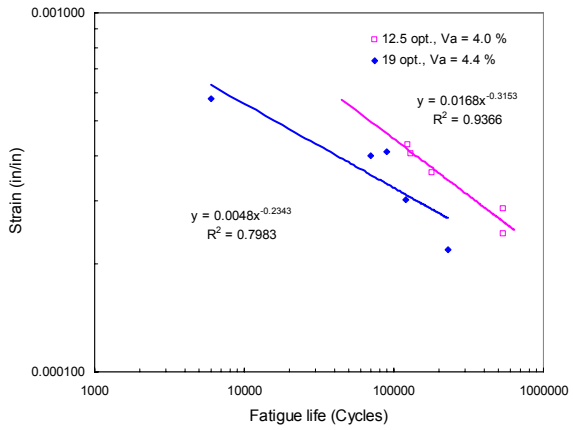


(b).T=15°C, Va≈5.4%, Optimum AC

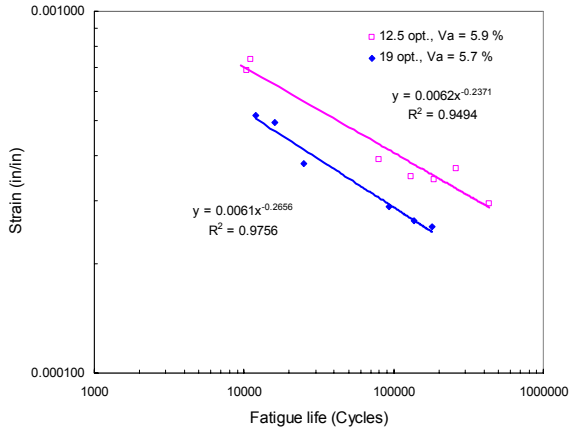


(c).T=15°C, Va≈7.2%, Optimum AC

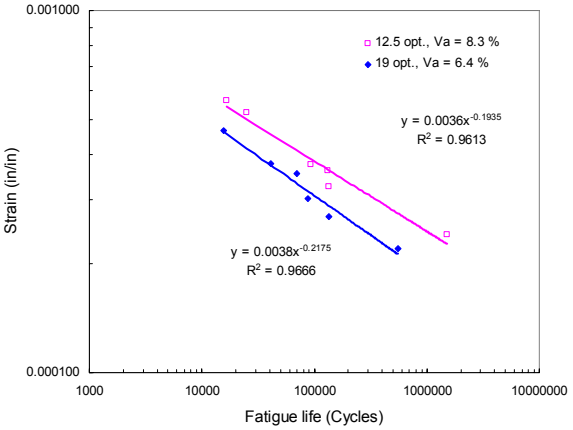
Figure 3-7 (a)-(c) Effect of gradation on fatigue life for optimum asphalt content, T=15°C



(a).T=20°C, Va≈4.2%, Optimum AC

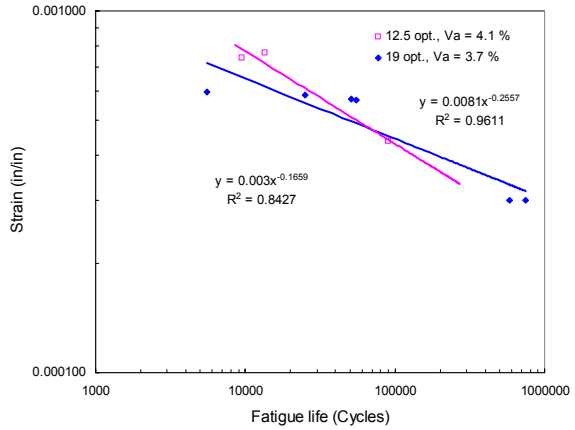


(b).T=20°C, Va≈5.8%, Optimum AC

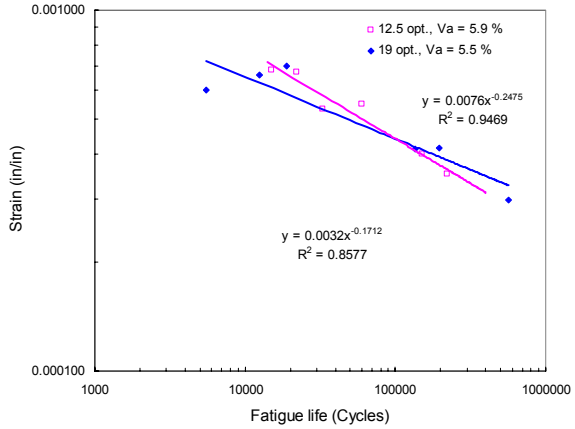


(c).T=20°C, Va≈7.4%, Optimum AC

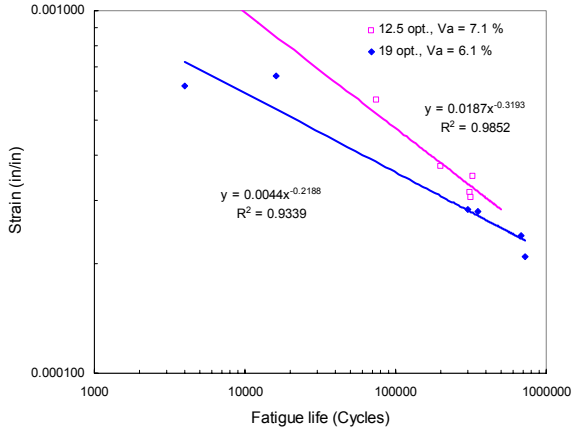
Figure 3-8 (a)-(c) Effect of gradation on fatigue life for optimum asphalt content, T=20°C



(a).T=25°C, Va≈3.9%, Optimum AC

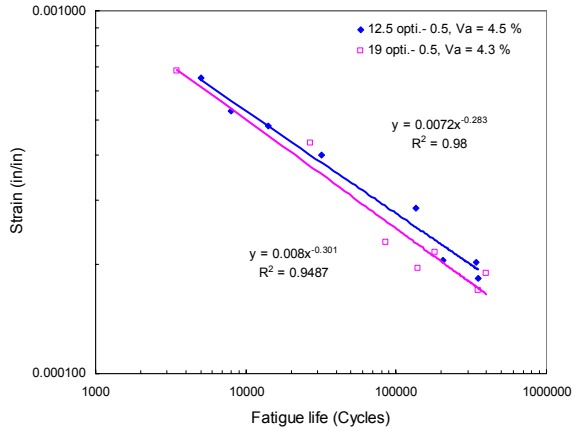


(b).T=25°C, Va≈5.7%, Optimum AC

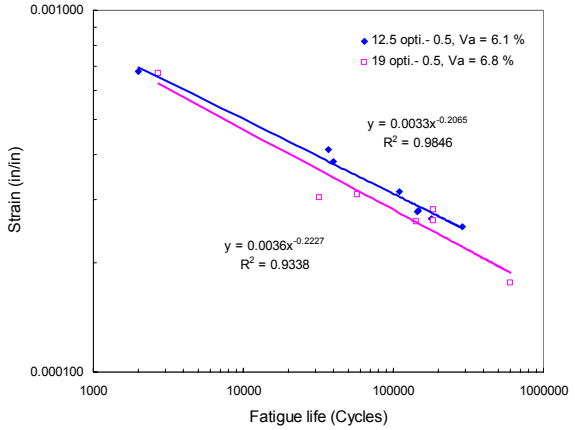


(c).T=25°C, Va≈6.6%, Optimum AC

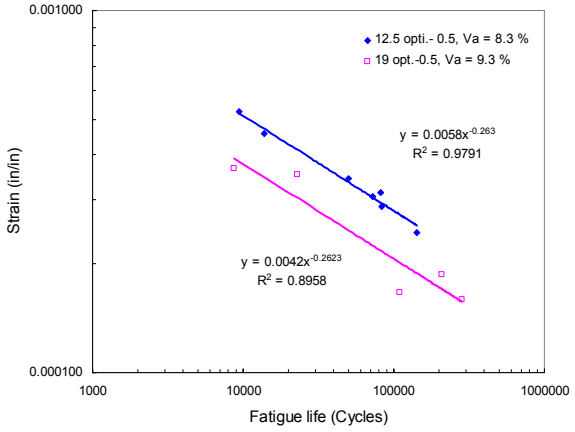
Figure 3-9 (a)-(c) Effect of gradation on fatigue life for optimum asphalt content, T=25°C



(a).T=15°C, Va≈4.4%, Optimum-0.5% AC

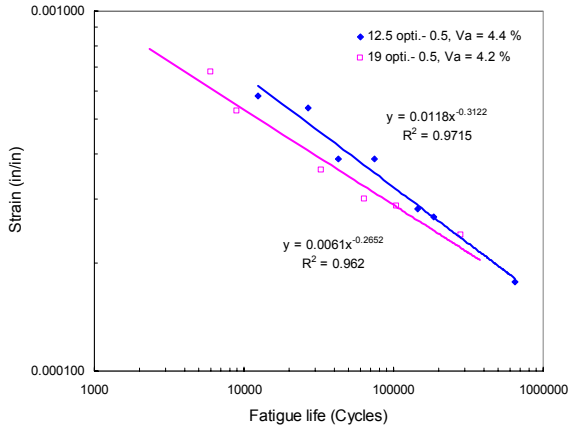


(b).T=15°C, Va≈6.5%, Optimum-0.5% AC

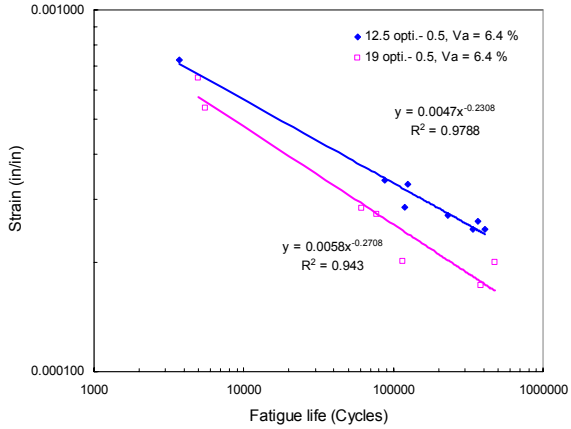


(c).T=15°C, Va≈8.8%, Optimum-0.5% AC

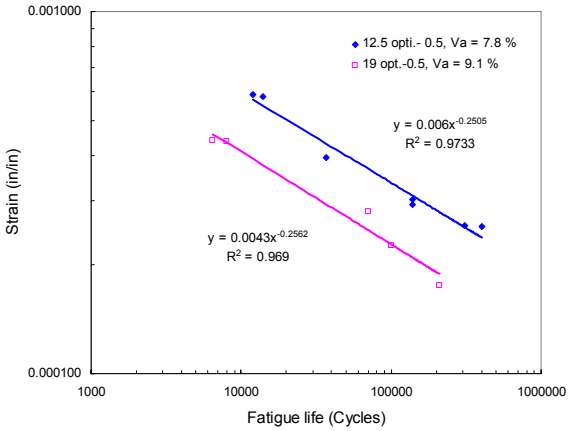
Figure 3-10 (a)-(c) Effect of gradation on fatigue life for optimum-0.5% asphalt content, T=15°C



(a).T=20°C, Va≈4.3%, Optimum-0.5% AC

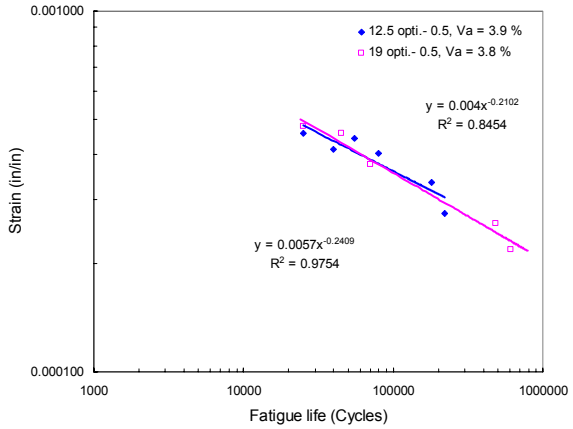


(b).T=20°C, Va≈6.4%, Optimum-0.5% AC

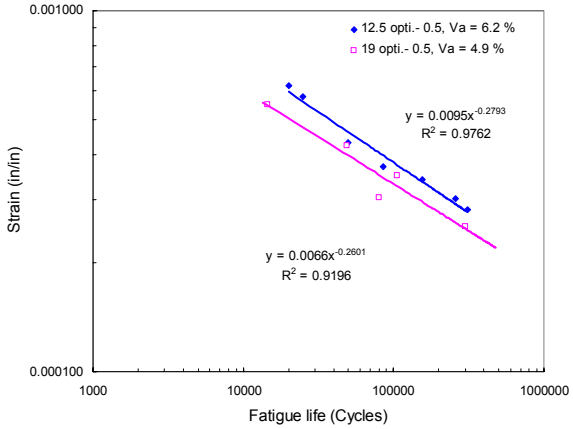


(c).T=20°C, Va≈7.8, 9.1%, Optimum-0.5% AC

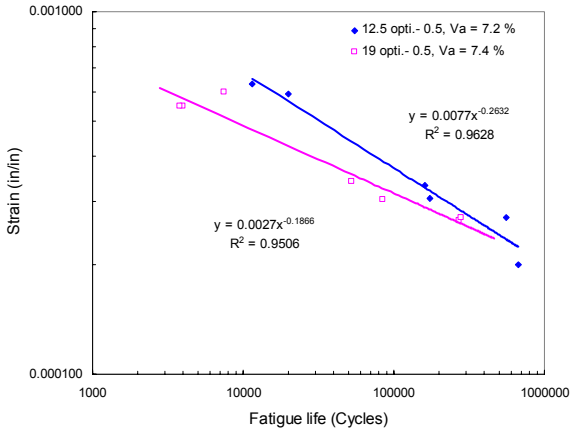
Figure 3-11 (a)-(c) Effect of gradation on fatigue life for optimum-0.5% asphalt content, T=20°C



(a).T=25°C, Va≈3.85%, Optimum-0.5% AC

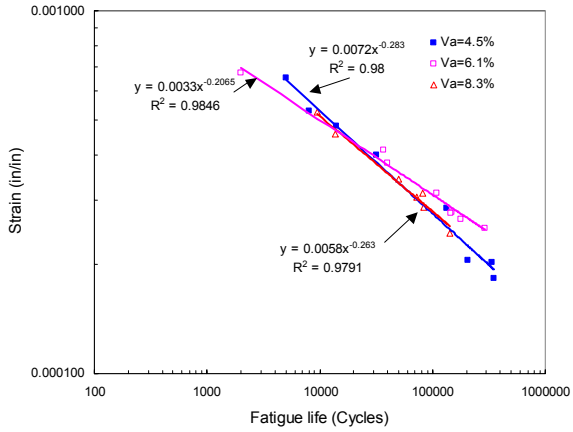


(b).T=25°C, Optimum-0.5% AC

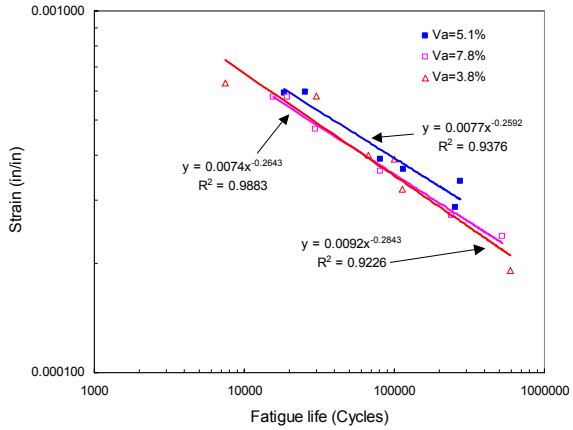


(c).T=25°C, Va≈7.3%, Optimum-0.5% AC

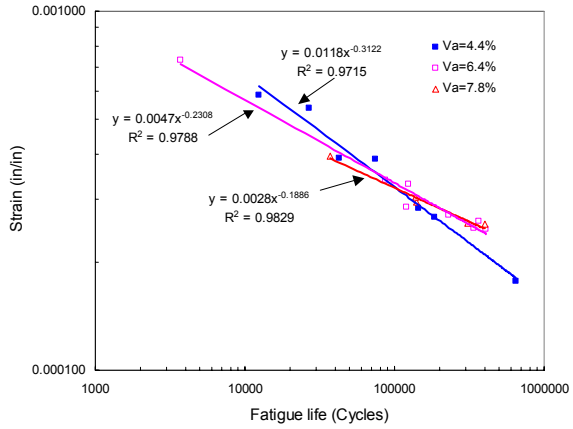
Figure 3-12 (a)-(c) Effect of gradation on fatigue life for optimum-0.5% asphalt content, T=25°C



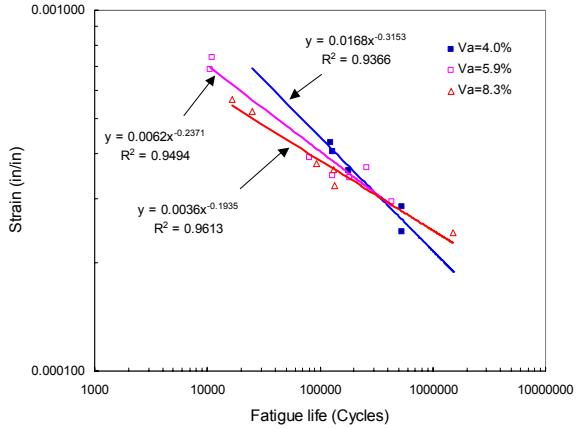
12.5-mm, T=15°C, Optimum-0.5



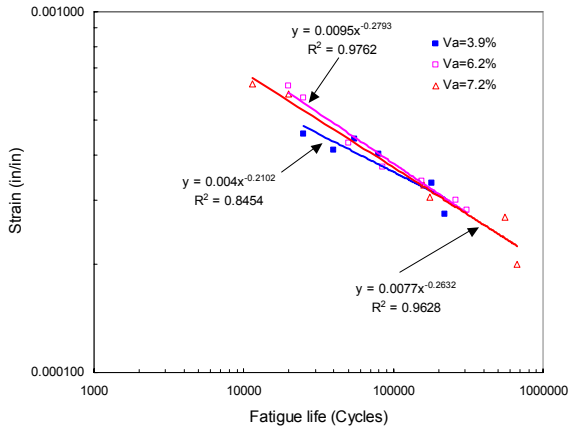
12.5-mm, T=15°C, Optimum



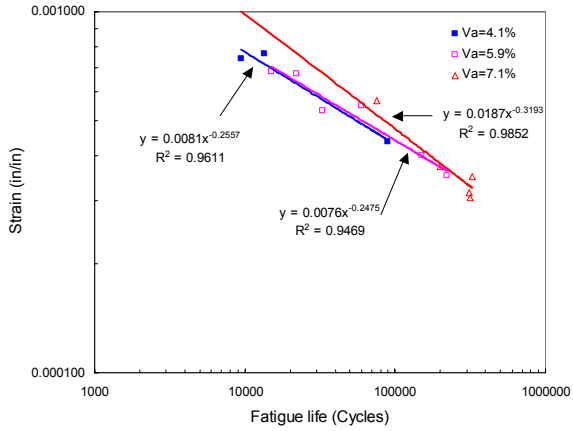
12.5-mm, T=20°C, Optimum-0.5



12.5-mm, T=20°C, Optimum

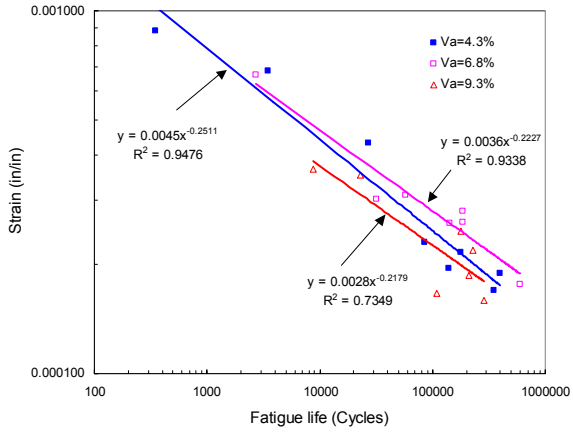


12.5-mm, T=25°C, Optimum-0.5

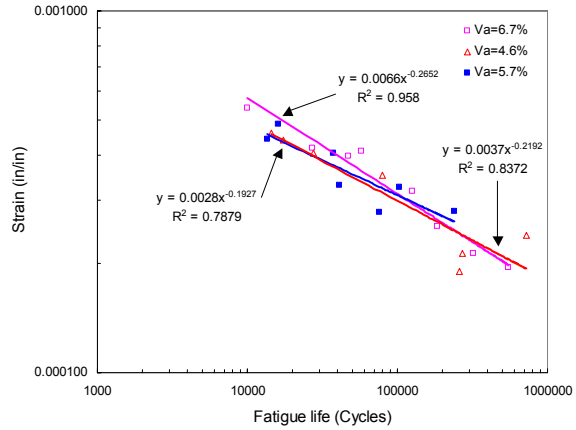


12.5-mm, T=25°C, Optimum

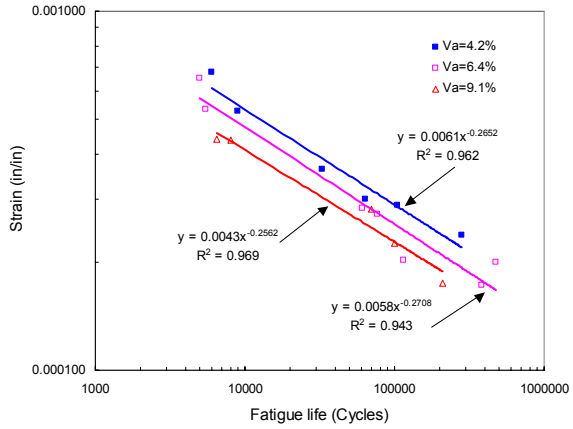
Figure 3-13 Effect of air voids on fatigue life for 12.5-mm mixes



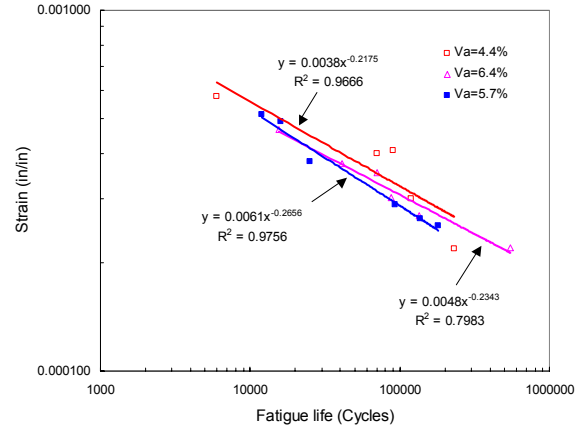
19-mm, T=15°C, Optimum-0.5



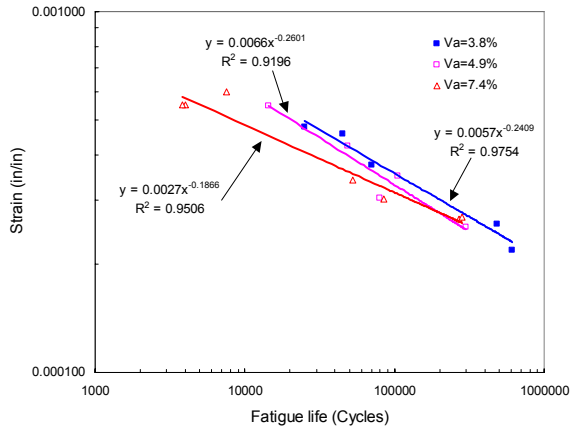
19-mm, T=15°C, Optimum



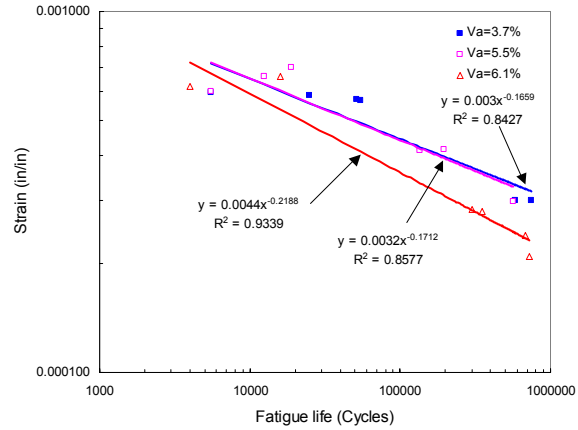
19-mm, T=20°C, Optimum-0.5



19-mm, T=20°C, Optimum

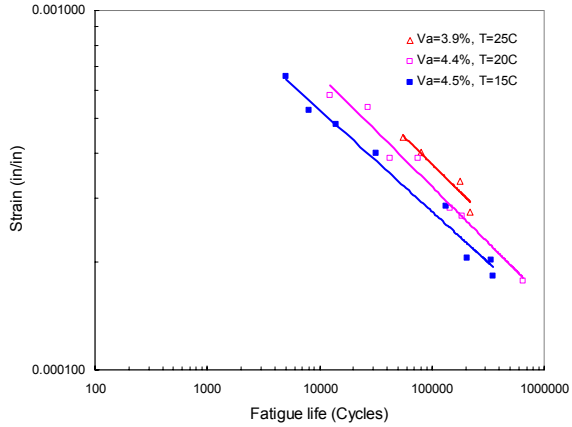


19-mm, T=25°C, Optimum-0.5

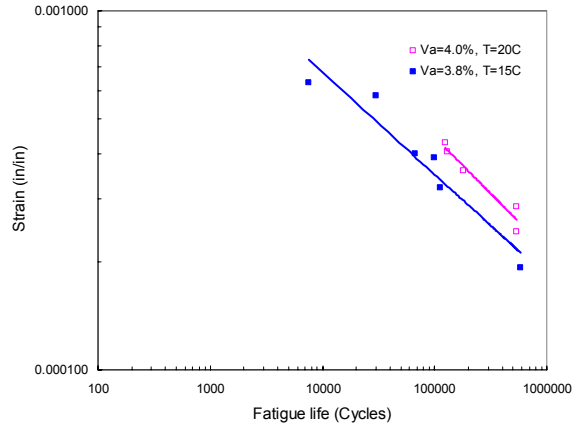


19-mm, T=25°C, Optimum

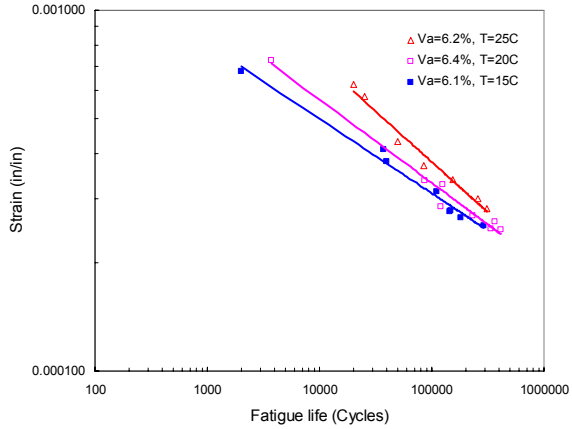
Figure 3-14 Effect of air voids on fatigue life for 19-mm mixes



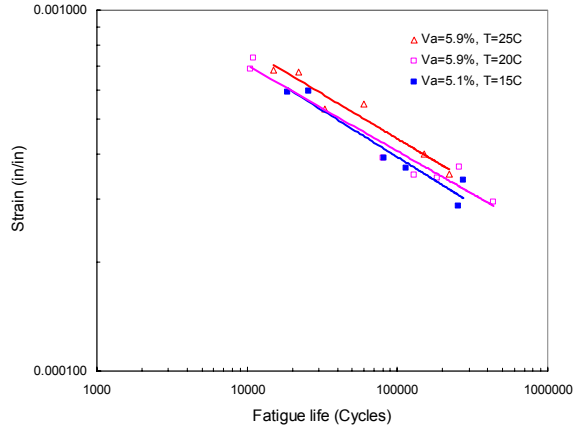
12.5-mm, V_a≈4.3%, Optimum-0.5%



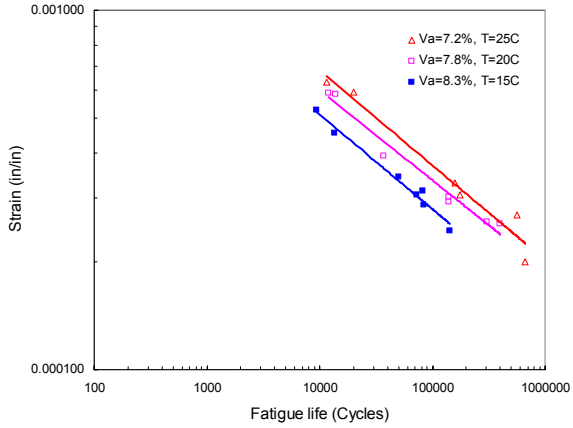
12.5-mm, V_a≈4.0%, Optimum



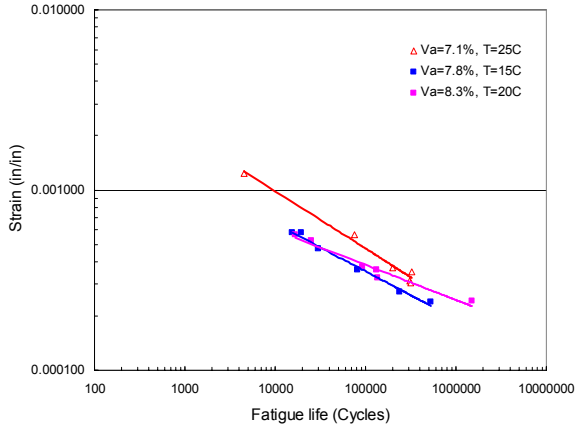
12.5-mm, V_a≈6.2%, Optimum-0.5%



12.5-mm, V_a≈5.6%, Optimum

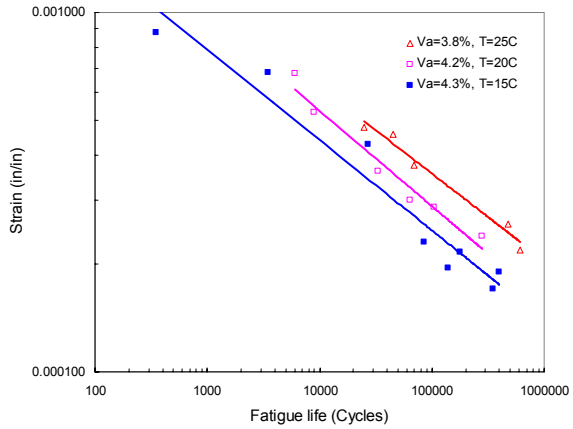


12.5-mm, V_a≈7.7%, Optimum-0.5%

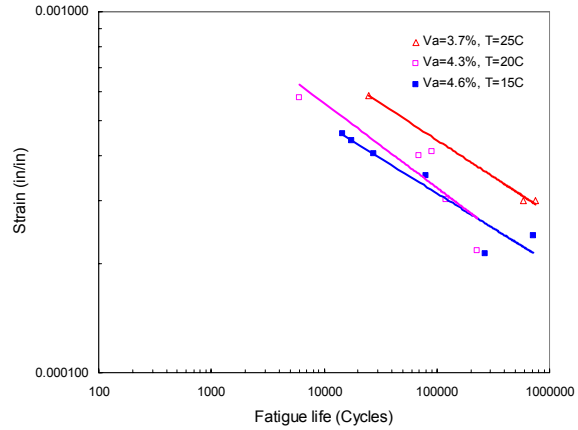


12.5-mm, V_a≈7.7%, Optimum

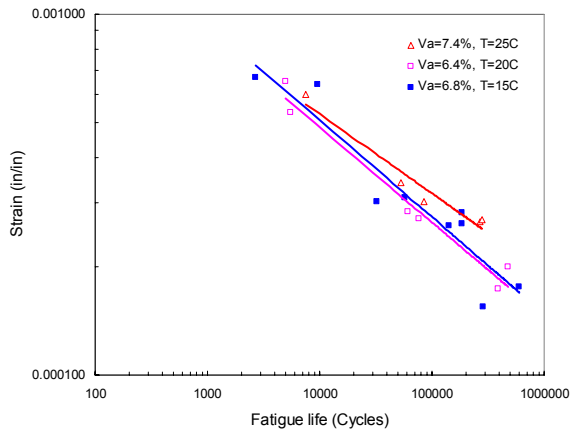
Figure 3-15 Effect of temperature on fatigue life for 12.5-mm mixes



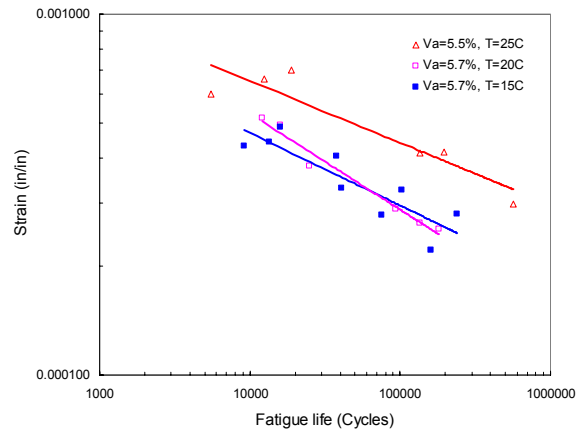
19-mm, V_a≈4.1%, Optimum-0.5%



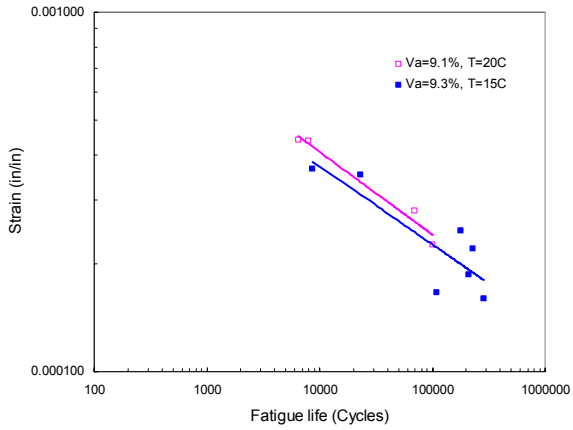
19-mm, V_a≈4.2%, Optimum



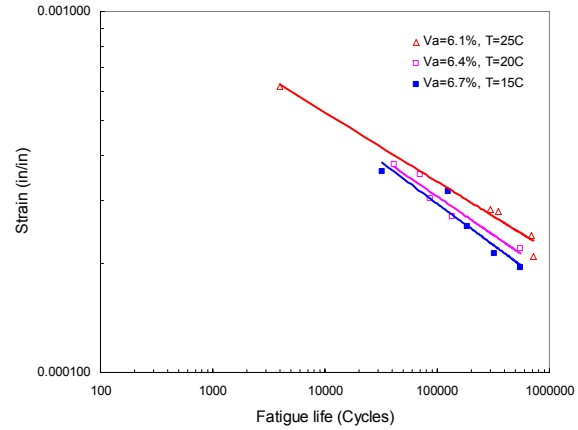
19-mm, V_a≈6.8%, Optimum-0.5%



19-mm, V_a≈5.6%, Optimum



19-mm, V_a≈9.2%, Optimum-0.5%



19-mm, V_a≈6.4%, Optimum

Figure 3-16 Effect of temperature on fatigue life for 19-mm mixes

4. Statistical Analysis of fatigue Test Results

4.1 Introduction

In this section, general linear model (GLM) and regression analysis procedure were used to investigate the individual effect of each independent factor (such as temperature, air void, gradation, and strain level as well as asphalt content) on the response variables (initial flexural stiffness S_0, fatigue life N_f). One of the assumptions necessary for GLM is that the dependent and independent variables are normally distributed. From past research [SHRP-A-404, Tayebali et al, 2], distribution for strain, stiffness, cycles to failure were log-normally distributed. In this study, log transformed data were used for GLM. The analysis was conducted with full model. It included all the effects and two-factor interactions in the following general form:

$$\begin{aligned}\ln(Y) &= \mu + \alpha_1 \cdot AC + \alpha_2 \cdot GR + \alpha_3 \cdot Temp + \alpha_4 \cdot V_a + \alpha_5 \cdot \ln(\varepsilon_0) \\ &+ \alpha_6 \cdot AC \cdot GR + \alpha_7 \cdot AC \cdot Temp + \alpha_8 \cdot AC \cdot V_a + \alpha_9 \cdot AC \cdot \ln(\varepsilon_0) \\ &+ \alpha_{10} \cdot GR \cdot Temp + \alpha_{11} \cdot GR \cdot V_a + \alpha_{12} \cdot GR \cdot \ln(\varepsilon_0) + \alpha_{13} \cdot Temp \cdot Va \\ &+ \alpha_{14} \cdot Temp \cdot \ln(\varepsilon_0) + \alpha_{15} \cdot Va \cdot \ln(\varepsilon_0) + error\end{aligned} \tag{4.1}$$

where,

Y	=	response variable N_f, S_0,
μ	=	constant,
α_i	=	regression coefficients,
AC	=	asphalt content,
GR	=	gradation,
Temp	=	temperature,
V_a	=	Air void,

ε_0 = strain level,

error = higher order interactions plus experiment error.

The GLM analysis was conducted using three typical regression methods---forward selection, backward elimination and stepwise selection. The forward selection procedure is as follows: consider the individual t test for each parameter and choose the single best one-variable model. For the other parameters, choose the one that when adds to the model gives a greatest decrease in SSE (sum square of error) based on SLE (significant level entry) criteria. Continue the process until no remaining variables significantly give rise to reduction in SSE. Once a variable has entered the model, it must remain in the model.

Backward elimination is a contrast to forward selection method. Its follows the procedure that starts from full model and drop parameter that has the largest p_value. Continue the dropping process based upon SLS (significant level stay) criteria. Stop the elimination process when no parameter in the model has greater p_value than SLS.

Stepwise selection method works as follows: begin like forward selection, and add the variable that gives the greatest decreased SSE. Then go back and consider everything again. Drop everything that is not significant at the current time. Continue the process until no more addition and/or elimination in variables occur by using SLE and SLS criteria.

As compared to forward selection and backward elimination method, stepwise selection method is more flexible. The variable that enters into the model earlier may be

eliminated later on. The opposite is also true, i.e., the variable that was eliminated from the model earlier may reenter the model in the later stage of regression process.

Before starting the analysis, the correlation coefficient among variables was examined to guard against multicollinearity. Pearson correlation matrix for the dependent and independent variables is shown in Table 4-1.

Table 4-1 shows that there are two interactions with high correlation coefficients---fatigue life (N_f) versus strain (ε_0); and stiffness (S_0) versus temperature. The first correlation is expected and is of great concern as N_f is the dependent variable, whereas ε_0 is an independent variable. The second one is of concern as both independent variables Temp and S_0 cannot simultaneously be included in the regression equation. As the stiffness S_0 depends on both temperature and air void content, for the GLM analysis Temp and voids will be included in the analysis.

4.2 GLM analysis for fatigue life (N_f)

In this section, the effects of main factors (such as AC, GR ,Temp and Va as well as strain level) and their interaction terms on fatigue life were investigated. The analysis of Nf was conducted using full model as shown in equation (4.1). It included all the main effects and two-factor interactions. Since many parameters are not significant under 5-percent significant level in the full model regression analysis, then forward selection, backward elimination and stepwise selection methods were employed to do the regression.

Table 4-2 provides the regression results by using forward and stepwise selection method. Table 4-3 gives the regression results by using backward elimination method. R^2 value for both models is greater than 0.85 and each parameter in both models is significant under 0.5% significant level. Variance inflation factors for all the parameters in each model are much less than 10. Therefore, both models are acceptable.

The two models resulted in Table 4-2 and Table 4-3 are almost identical except that the last term is different. Note that the R^2 values are identical. By using either of the two models, the mean value of fatigue life (N_f) can be determined for given values of the independent variables---AC, GR, Temp, V_a and ε_0. For the following section, the effect of each of the individual variable is further explored.

4.2.1 Effect of asphalt content and aggregate gradation

Figure 4-1 to Figure 4-9 show the effect of both asphalt content and gradation on fatigue life under different combinations of air void content level and temperature. These figures indicate that fatigue life at optimum asphalt content is significantly higher than that at optimum minus 0.5-percent asphalt content for both SP 12.5-mm and SP 19-mm mixes. It is also clear that the aggregate gradation has a significant and pronounced effect on the fatigue life for each of air void level and temperature level. In general, SP 12.5-mm mixes appear to be more resistant to fatigue as compared to SP 19-mm mixes. This is some what expected as the 12.5-mm mixes have a 0.5-percent more asphalt compared to the 19-mm mixes. When air void content is at 6-percent (as shown in Figure 4-2, Figure 4-5, and Figure 4-8), the fatigue resistance of SP 12.5-mm mix with optimum minus 0.5-

percent asphalt content is almost equal to the fatigue resistance of SP 19-mm mix with optimum asphalt content.

Assuming other factors such as strain amplitude, temperature, and gradation as well as air void content remain the same, it is possible to quantitatively compute the difference in fatigue life due to the change in asphalt content from optimum to optimum minus 0.5-percent.

As shown in Table 4-2, since there is no interaction term for AC, one can obtain

$$\ln(N_{f\_opti}) - \ln(N_{f\_opti-0.5}) = 0.30902 \cdot (1-(-1)) = 0.61804 \quad (4.2)$$

$$N_{f\_opti} / N_{f\_opti-0.5} = \exp(0.61804) = 1.855 \quad (4.3)$$

That is, with the other factors remaining the same, the fatigue life of specimen with optimum asphalt content is 1.855 times as that of specimen with optimum minus 0.5-percent asphalt content.

Because GR interacts with V_a, the effect of GR on fatigue life is different under different air void content. In the same manner, one is able to quantitatively calculate the effect of gradation under different air void content level. Table 4-4 provides the effect of GR on fatigue life. It shows that effect of gradation increases with the increase of air void content.

4.2.2 The effect of temperature on fatigue life

Figure 4-10, through Figure 4-12 shows the effect of temperature on fatigue resistance at 4, 6 and 8-percent air void content, respectively. The straight lines presented in the figures represent the average fatigue life across gradation and asphalt content at

given temperature and air void content. That is, the value of a point on a line represents the average fatigue life of SP 12.5 and SP 19-mm mixes with optimum and optimum minus 0.5-percent AC. These figures indicate that for the same mix and strain level, the higher the temperature, the longer the fatigue life. This is expected in controlled strain mode of loading.

4.2.3 Effect of air void on fatigue life

Figure 4-13 and 4-14 shows the effect of air void content on fatigue life for SP12.5--mm, SP19--mm mix, respectively. The number plotted in the figures is the average fatigue life across all temperatures and asphalt. The results presented in Figure 4-13 are indeed surprising. It shows that for 12.5-mm mix, air voids do not have any effect on fatigue life. This result is contrary to the general accepted norm based on past studies. One of the reasons for this contrary behavior could be high dispersion (variability) in the data as noted in chapter 3. However, what is truly puzzling is the fact that this mix shows significant changes in fatigue life with respect to all other variables such as asphalt content, gradation, and temperature. The fatigue behavior of the 19-mm mix shown in Figure 4-14, however, seems to be in line with the expectations--increase in air void content leads to reduction in fatigue life with all the other variables being constant.

With regards to air voids, there are two terms in the model shown in Table 4-2. One represents the main effect of the air void content and the other stands for interaction term of air void content with gradation. Since GR only takes on two numeric values, -1 and +1, the final coefficient of air void content is definitely negative. It implies that with

the other factors the same, fatigue life is inversely proportional to the air void. However, to what extent air void content affects fatigue life, depends on the gradation. Table 4-5 shows fatigue life ratio between different air void contents for two different gradation. For the 12.5-mm mix, there is very little difference in fatigue life with increase in voids. For the 19-mm mix, there is an average 20-percent reduction in life for 2-percent increase in void content.

4.2.4 Effect of strain level

Strain level is the most important factor to affect the fatigue life of a given mix. In general, the greater the strain level, the shorter the fatigue life is. The coefficient k_2 for strain level in this study takes on the values 3.635, 3.691, and 3.747 at temperature of 15, 20 and 25°C, respectively. This compares well with the k_2 of 3.291 reported for the Asphalt Institute (AI) equation. And a value of 3.624 reported for the SHRP equation [2].

4.3 Analysis of Initial Flexural Stiffness S_0

In the last section, the effects of various factors on fatigue life were investigated and fatigue life model in terms of those factors were established. In this section, the goal is to investigate the effect of those factors on initial flexural stiffness.

Regression analysis was carried out with the full model (as shown in equation (1)). The result of an analysis of variance (ANOVA) on the full model is given in Table 4-6. Although adjusted R^2 is 0.84698, estimated parameters such as asphalt content, gradation, air void content, strain and a lot of interaction terms (shown in Table 4-6) are not significant under 5-percent significance level. From statistical point of view, we are

not able to reject null hypothesis. This means that those parameters are not necessary in the model.

Thus, forward selection, backward elimination and stepwise selection methods were used to eliminate those unnecessary variables from the full model.

The R^2 for forward, stepwise selection, and backward elimination model is 0.8175 and 0.818, respectively. The variance inflation factor of each parameter is around 1.0, which is much less than 10. Moreover, both models have the same number of parameters. The result of forward, stepwise selection and backward elimination of parameters are shown in Table 4-7 and Table 4-8.The results presented in Table 4-7 and Table 4-8 imply that temperature, air void content and strain level are the three main factors that affects the initial flexural stiffness. Asphalt content and gradation also playing a minor role. The stiffness dependence on strain level is not a desirable effect. It indicates that stiffness is not being measured in linear elastic range and therefore is not a true measure of stiffness. The effect of the various factors is discussed briefly in the following section using the model provided in Table 4-7.

4.3.1 Effect of temperature, air void content and gradation and asphalt content on S_0

Figure 4-15 to Figure 4-18 compare the initial flexural stiffness at different air void contents for both 12.5-mm and 19-mm mixes with optimum and optimum minus 0.5-percent asphalt content. First, these figures indicate that initial flexural stiffness decreases with increase in temperature. Nevertheless, for different gradation the effect of temperature is slightly different. Secondly, the initial flexural stiffness is inversely

proportional to air void content. Roughly, increase in 2-percent air void will cause 20-percent decrease in initial flexural stiffness.

Figure 4-19 shows the overall comparison of S_0 for the four different mixes. The number presented in the figure is the average across air void contents and temperature level. At optimum asphalt content, the stiffness of 19-mm mix is 10-percent greater than that of 12.5-mm mix. However, at optimum minus 0.5-percent asphalt content, the stiffness of 12.5-mm mix is 10-percent greater than that of 19-mm mix.

As for 19-mm mix, the initial flexural stiffness at optimum asphalt content is about10-percent more than that at optimum minus 0.5-percent asphalt content. As a contrast, for SP12 mm mix, the initial stiffness at optimum asphalt content is about 10-percent less than that at optimum minus 0.5-percent asphalt content.

4.3.2 Effect of strain level on S_0

Fatigue testing data indicates that strain amplitude has impact on initial flexural stiffness. The greater the strain amplitude, the less the initial flexural stiffness is. This indicates as mentioned earlier that the specimen being tested is already undergoing damage in as little as the first 50 cycles during which the initial stiffness is measured. This is also probably the reason that stiffness is not directly dependent on asphalt content or gradation. The model described in Table 4-7 showed that the effect of strain amplitude on initial flexural stiffness could be computed as follows:

$$S_{0\_\varepsilon_1} / S_{0\_\varepsilon_2} = \left(\varepsilon_1 / \varepsilon_2\right)^{-0.1975} \tag{4.4}$$

For instance, for the same mix, the initial flexural stiffness at 100 micron is about 1.5 times as that at 600 micron. For this reason the model development for fatigue life based on stiffness and strain level will be based on axial stiffness data (Chapter 5) rather than S_0 determined from fatigue testing.

4.4 Regenerating data

Because of the variability associated with specimen preparation, it was not possible to exactly control the air-void contents for each specimen. Moreover, it was also not possible to control strain amplitude to an exact number during fatigue testing. By using fatigue and stiffness models (as shown in Table 4-2 and Table 4-7, respectively) developed, one is able to adjust the response variables (fatigue life, stiffness and loss stiffness) of each specimen corresponding to its target air void content (4, 6, or 8-percent) and target strain amplitude. The adjusted data is provided in Appendix C.

Based on the adjusted data, the average effect of each test variable can be obtained as shown in Table 4-9. Note that percent difference is the difference expressed as a percentage of the higher value for two-level variables or of the highest value for three-level variables. Table 4-9 indicated that, although asphalt content and gradation do not have much impact on initial stiffness (S_0), they do have significant impact on fatigue life. The percent difference in fatigue life between optimum and optimum minus 0.5-percent asphalt content is 46-percent. In addition, the percent difference in fatigue life between 12.5-mm mix and 19-mm mix is 48-percent. As for temperature and air void content, they both not only have impact on fatigue life, but also affect initial stiffness (S_0).

4.5 Summary

Based on the analysis of fatigue data, the following conclusion may be made.

(1) Both asphalt content and gradation have significant impact on fatigue life of Superpave 12.5-mm and 19-mm mixes. A change in asphalt content from optimum to optimum minus 0.5-percent asphalt content will decrease fatigue life about 50-percent. As for gradation, 12.5-mm mix seems to be more resistant to fatigue distress.

(2) In general, at the same strain level, increase in temperature will increase fatigue life. For instance, at 200 micron, the fatigue life at 20°C is about 1.7 times as that at 15°C.

(3) Strain level has significant impact on initial stiffness. This result is expected but very undesirable as the so-called initial stiffness is no longer a true measure of the mix property.

(4) Asphalt content or gradation does not seem to have an effect on initial stiffness. This is again attributed to the damage caused by large strain level that may mask any effect of asphalt content or gradation on initial stiffness.

Table 4-1 Pearson correlation coefficient (r) matix

	AC	GR	Temp	Va	Ln(ε_0)	Ln(S_0)	Ln(N_f)
AC	1						
GR	0.06244	1					
Temp	0.00563	-0.03008	1				
Va	-0.17459	-0.04526	-0.12202	1			
Ln(ε_0)	0.19371	-0.12281	0.23924	-0.16347	1		
Ln(S_0)	0.08896	0.05009	-0.70659	-0.35586	-0.31371	1	
Ln(N_f)	0.02407	-0.10121	0.03124	0.03513	-0.84571	0.10691	1

Table 4-2 Results of forward and stepwise selection method on Nf

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	5	447.408	89.48159	320.05	<.0001	
Error	235	65.70227	0.27958			
Corrected Total	240	513.1102				
Root MSE		0.52876	R-Square	0.872		
Dependent Mean		11.15383	Adj R-Sq	0.8692		
Coeff Var		4.74059				
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	1	-17.7213	0.73428	-24.13	<.0001	0
Strain	1	-3.69093	0.09291	-39.73	<.0001	1.14763
Temp∗Strain	1	-0.05596	0.00548	-10.21	<.0001	1.07759
GR∗Va	1	-5.6255	0.56183	-10.01	<.0001	1.02943
AC	1	0.30902	0.03524	8.77	<.0001	1.06909
Va	1	-6.39159	2.27116	-2.81	0.0053	1.06321

Table 4-3 Results of backward elimination method on Nf

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	5	447.3636	89.47272	319.8	<.0001	
Error	235	65.74666	0.27977			
Corrected Total	240	513.1102				
Root MSE		0.52894	R-Square	0.8719		
Dependent Mean		11.15383	Adj R-Sq	0.8691		
Coeff Var		4.74219				
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	1	-18.0926	0.73735	-24.54	<.0001	0
AC	1	0.30889	0.03527	8.76	<.0001	1.07
Strain	1	-3.73687	0.09625	-38.82	<.0001	1.23083
Temp∗Strain	1	-0.05596	0.00549	-10.2	<.0001	1.0778
GR∗Va	1	-5.61141	0.56178	-9.99	<.0001	1.02858
Strain∗Va	1	0.78946	0.28347	2.78	0.0058	1.1659

Table 4-4 Gradation effect on fatigue life

V_a	$N_{f\_GR=-1}/N_{f\_GR=1}$
4%	1.56
6%	1.96
8%	2.46

Table 4-5 The effect of air void content on fatigue life

GR	$\frac{N_{f\_6\%}}{N_{f\_4\%}}$	$\frac{N_{f\_8\%}}{N_{f\_4\%}}$
-1 (12.5-mm)	0.985	0.969
+1 (19-mm)	0.786	0.618

Table 4-6 Results of GLM for initial flexural stiffness S_0 in full model

Source	DF	Sum of Square	Mean Square	F Value	Pr > F
Model	15	23.36163	1.557442	76.75	<.0001
Error	208	4.220637	0.020292		
Corrected Total	223	27.58227	223		
R-Square	0.84698	Coeff Var	1.044389	Root MSE	0.142448
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	12.96641	0.833195	15.56	<.0001
AC	1	-0.16679	0.219206	-0.76	0.4476
GR	1	-0.28864	0.209026	-1.38	0.1688
Temp	1	-0.49107	0.255743	-1.92	0.0562
Va	1	-15.995	13.71894	-1.17	0.245
Strain	1	-0.15635	0.105278	-1.49	0.139
Temp∗AC	1	0.010341	0.012646	0.82	0.4145
Temp∗GR	1	-0.03515	0.012473	-2.82	0.0053
Temp∗Strain	1	-0.02086	0.032578	-0.64	0.5226
Temp∗Va	1	0.137153	0.837429	0.16	0.8701
AC∗GR	1	0.055032	0.010251	5.37	<.0001
AC∗Strain	1	0.005614	0.027614	0.2	0.8391
AC∗Va	1	3.89648	0.731896	5.32	<.0001
GR∗Strain	1	-0.02418	0.026625	-0.91	0.3648
GR∗Va	1	1.68021	0.679602	2.47	0.0142
Strain∗Va	1	-0.78139	1.72777	-0.45	0.6516

Table 4-7 Results of forward and stepwise selection method on S_0

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	22.6622	4.53244	200.83	<.0001
Error	218	4.92006	0.02257		
Corrected Total	223	27.58227			
R-Square	0.8175			C(p)	3.429
Variable	Parameter Estimate	Standard Error	F Value	Pr > F	Variance Inflation
Intercept	12.71624	0.20943	60.72	<.0001	0
Temp	-0.31859	0.01268	-25.12	<.0001	1.0561
Va	-11.2828	0.6577	-17.16	<.0001	1.06192
Strain	-0.1975	0.02678	-7.37	<.0001	1.07856
Temp∗GR	-0.04708	0.01233	-3.82	0.0002	1.01006
AC∗GR	0.04373	0.01011	4.33	<.0001	1.01157

Table 4-8 Results of backward elimination method on S_0

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	22.67514	4.53503	201.47	<.0001
Error	218	4.90712	0.02251		
Corrected Total	223	27.58227			
R-Square	0.818			C(p)	2.8624
Variable	Parameter Estimate	Standard Error	F Value	Pr > F	Variance Inflation
Intercept	12.04275	0.212	56.81	<.0001	0
Temp	-0.31911	0.01267	-25.19	<.0001	1.05654
Strain	-0.28196	0.02797	-10.08	<.0001	1.17992
Temp∗GR	-0.04808	0.01232	-3.9	0.0001	1.01097
AC∗GR	0.0432	0.0101	4.28	<.0001	1.01217
Strain∗Va	1.41172	0.0821	17.19	<.0001	1.17258

Table 4-9 Average effects of test variables

		N_f		S_0	
		Magnitude (cycle)	% diff	Magnitude (psi)	% diff
Asphalt content	Opt.	350,907		856,073	
	Opt.-0.5%	189,137	46%	855,333	0%
Gradation	12.5-mm	355,541		847,291	2%
	19-mm	184,502	48%	864,115	
Temperature	15°C	156,397	61%	1,138,332	
	20°C	250,946	38%	826,849	27%
	25°C	402,723		601,927	47%
Air void	4%	295,591		1,054,348	
	6%	268,255	9%	841,366	20%
	8%	246,220	17%	671,395	36%
Strain amplitude (micron)	200	740,743		958,948	
	400	56,705	92%	836,259	13%
	600	12,617	98%	771,902	19%

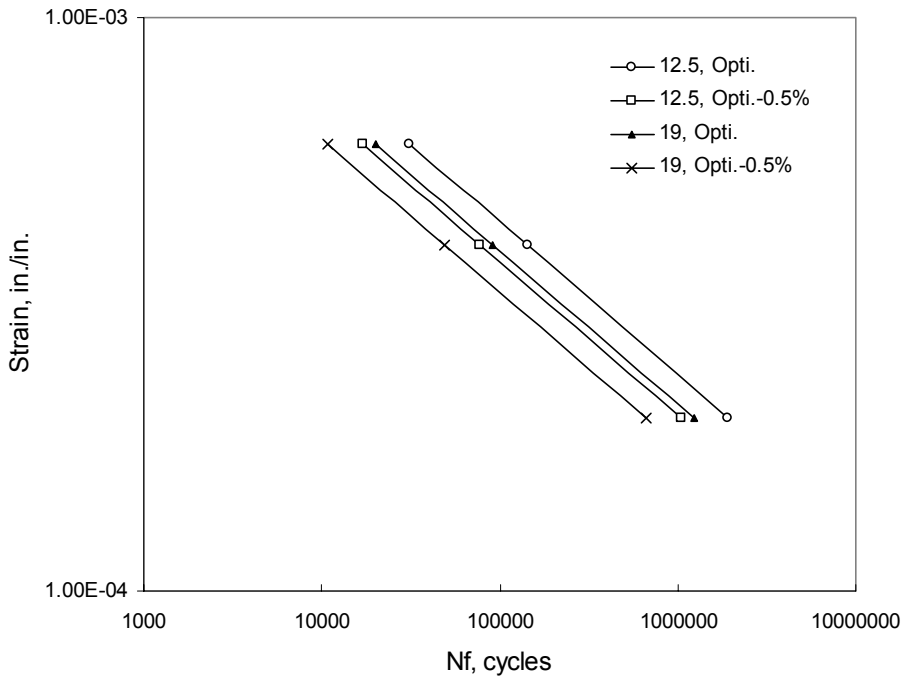


Figure 4-1 Effect of asphalt content and gradation on N_f, Va=4%, T=25°C

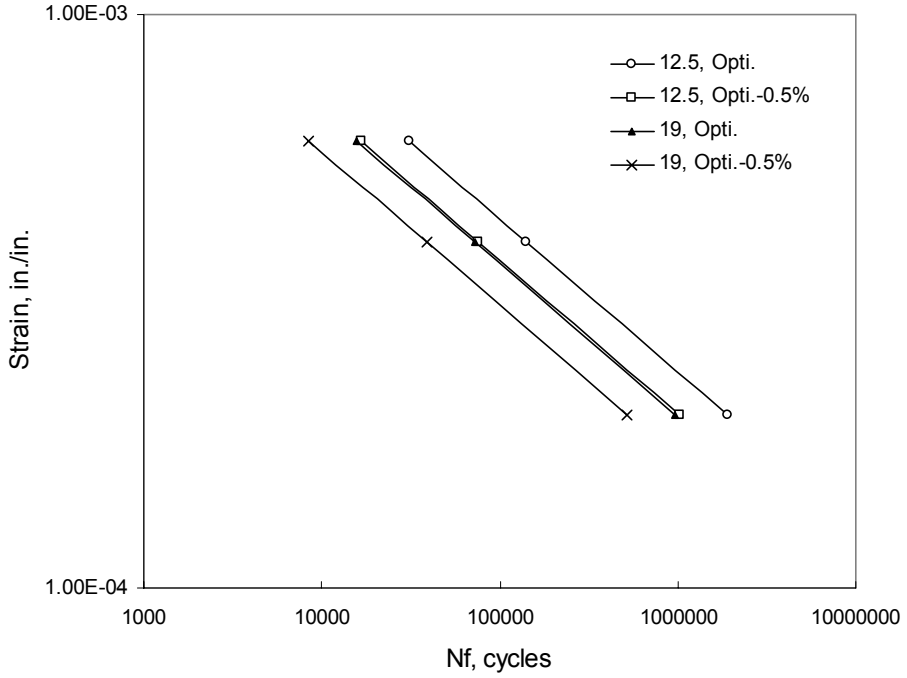


Figure 4-2 Effect of asphalt content and gradation on N_f, Va =6%, T=25°C

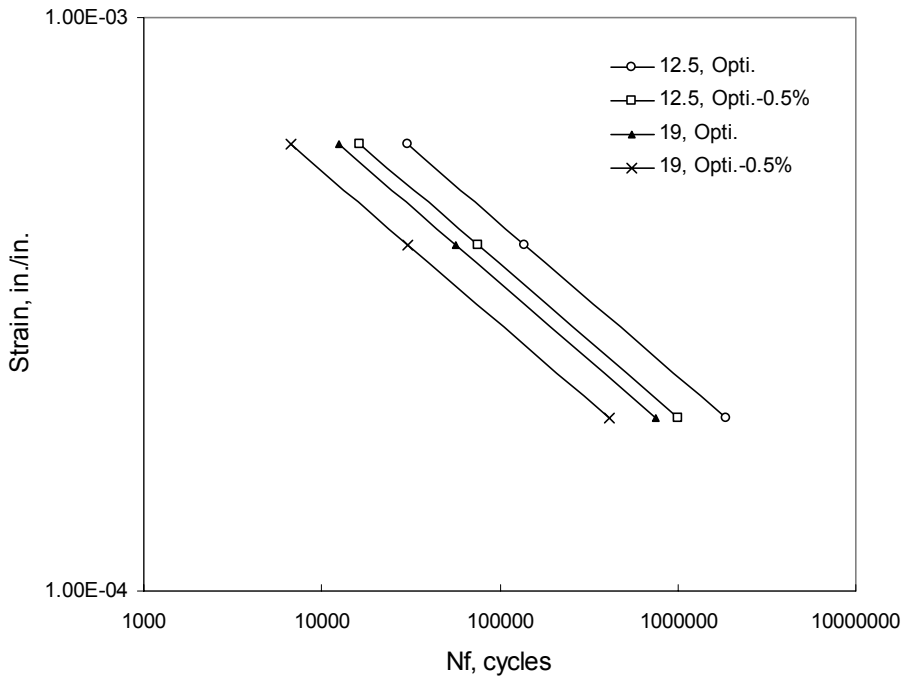


Figure 4-3 Effect of asphalt content and gradation on N_f, Va =8%, T =25°C

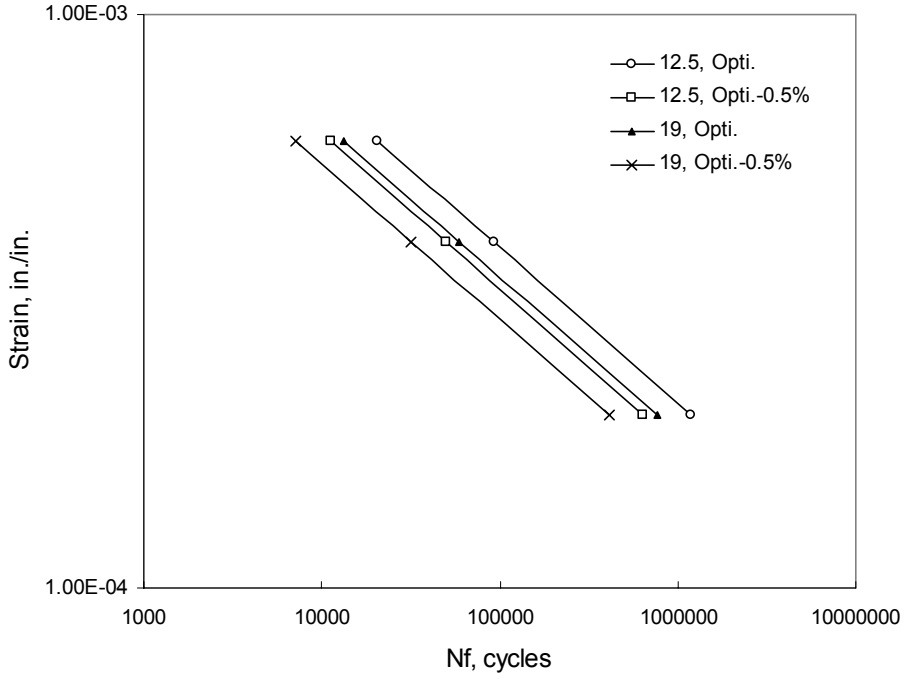


Figure 4-4 Effect of asphalt content and gradation on N_f, Va =4%, T=20°C

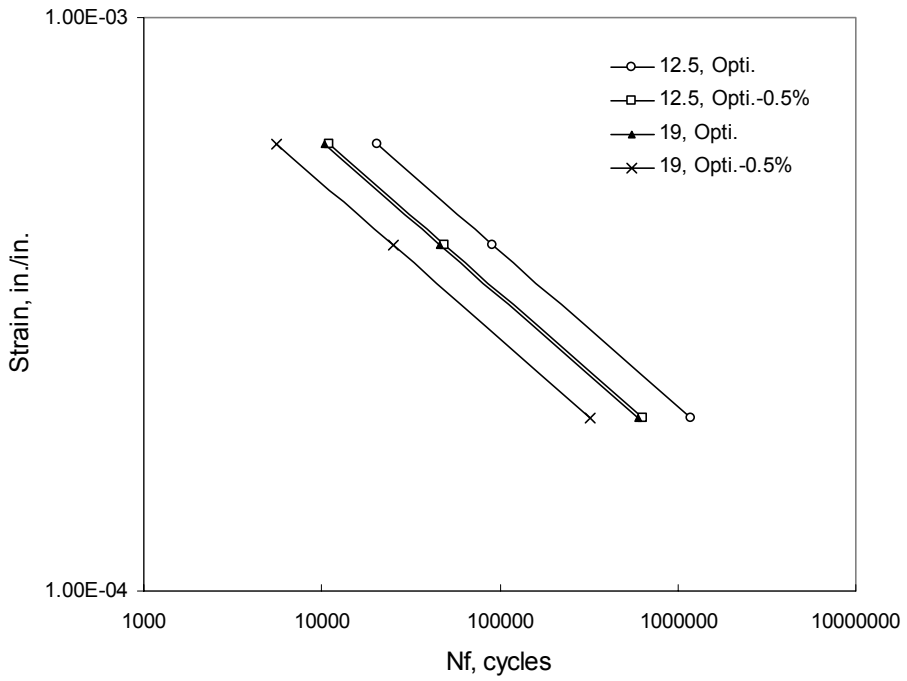


Figure 4-5 Effect of asphalt content and gradation on N_f, Va =6%, T =20°C

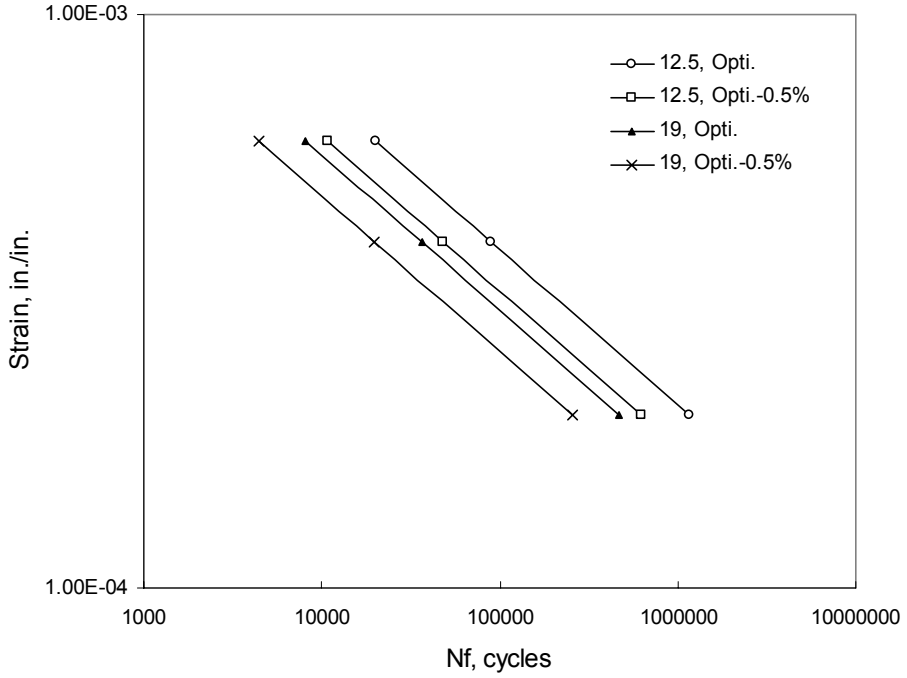


Figure 4-6 Effect of asphalt content and gradation on N_f, Va =8%, T=20°C

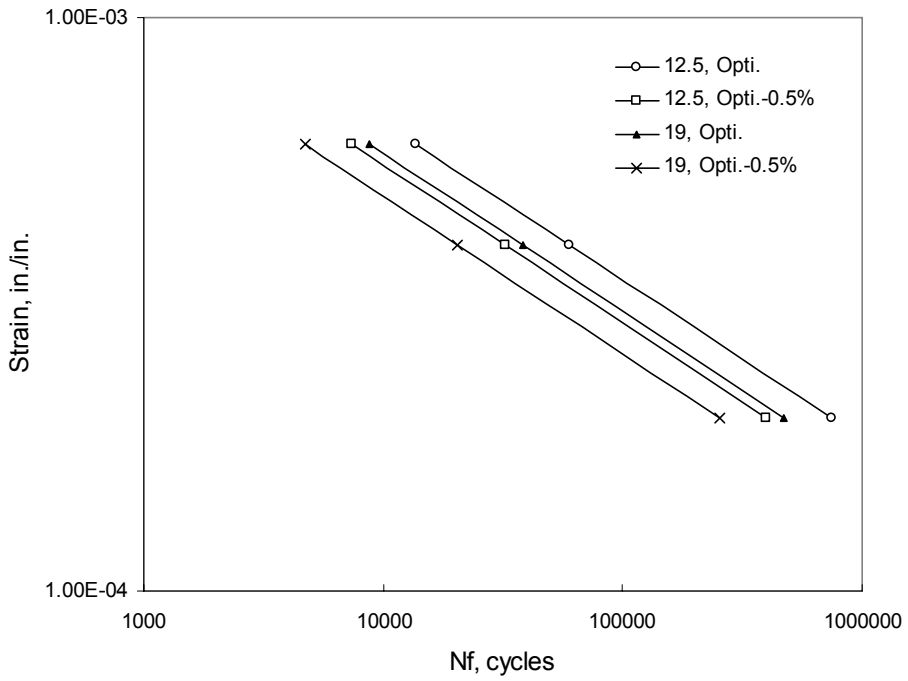


Figure 4-7 Effect of asphalt content and gradation on N_f, Va =4%, T=15°C

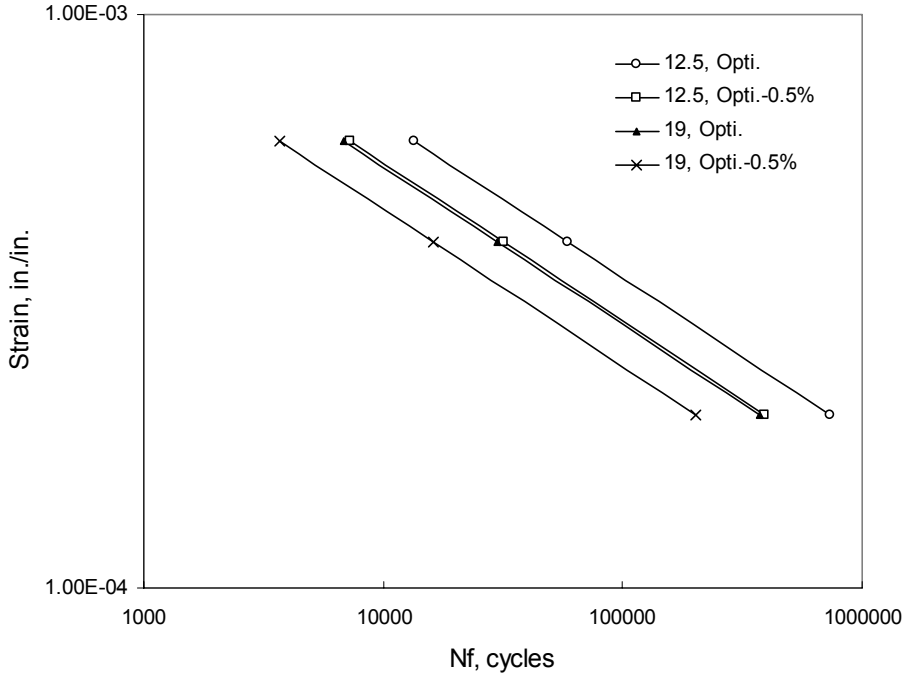


Figure 4-8 Effect of asphalt content and gradation on N_f, Va =6%, T=15°C

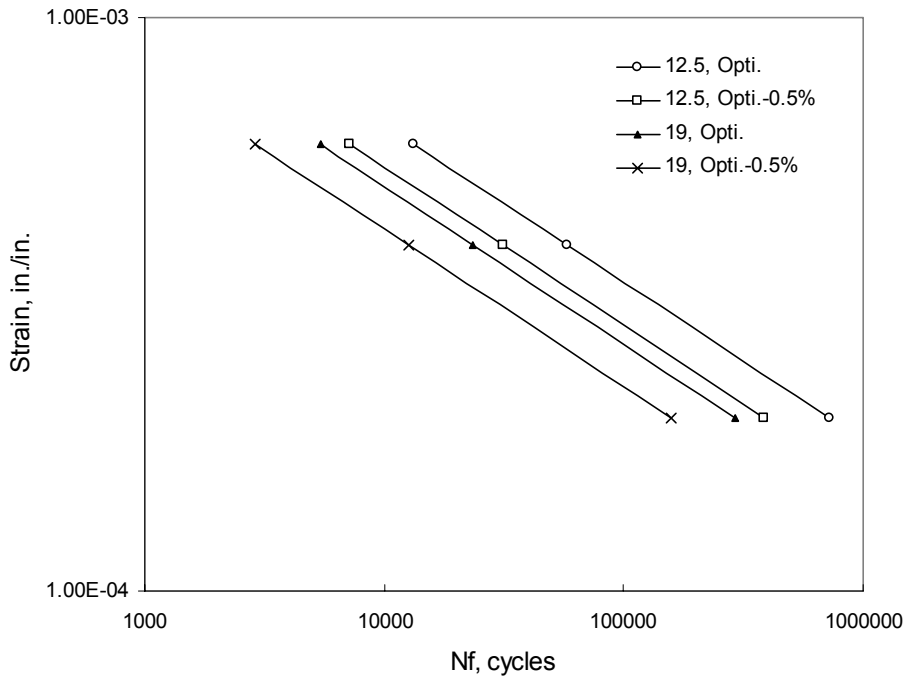


Figure 4-9 Effect of asphalt content and gradation on N_f, Va =8%, T=15°C

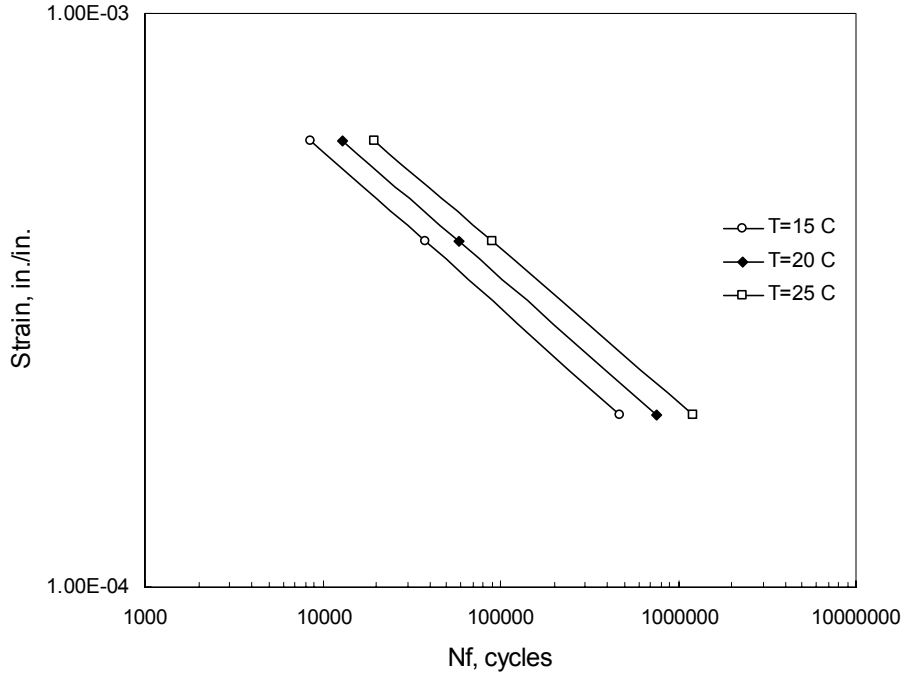


Figure 4-10 Effect of temperature on N_f, Va = 4%

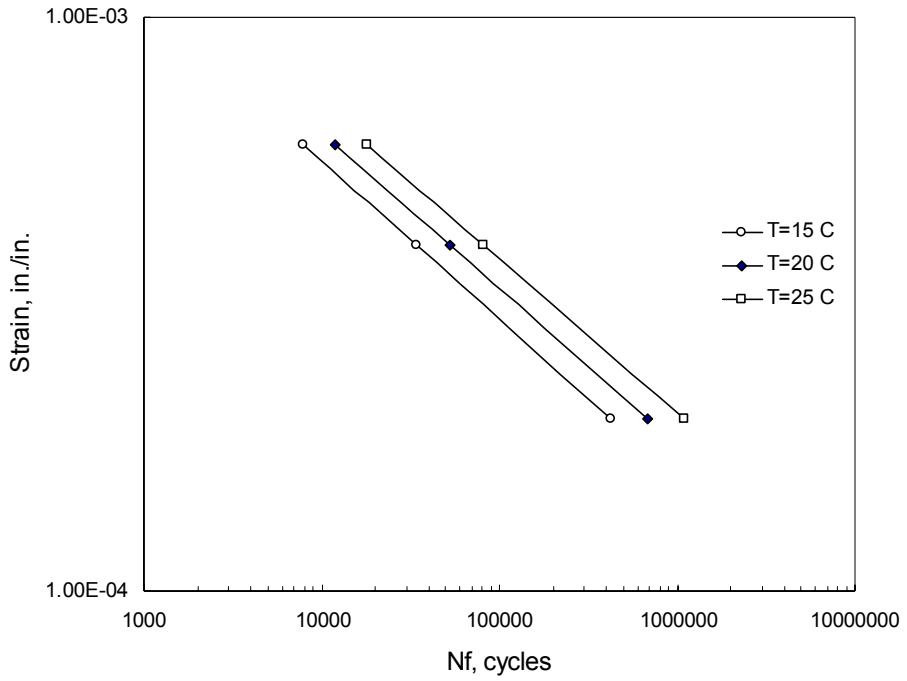


Figure 4-11 Effect of temperature on N_f, Va = 6%

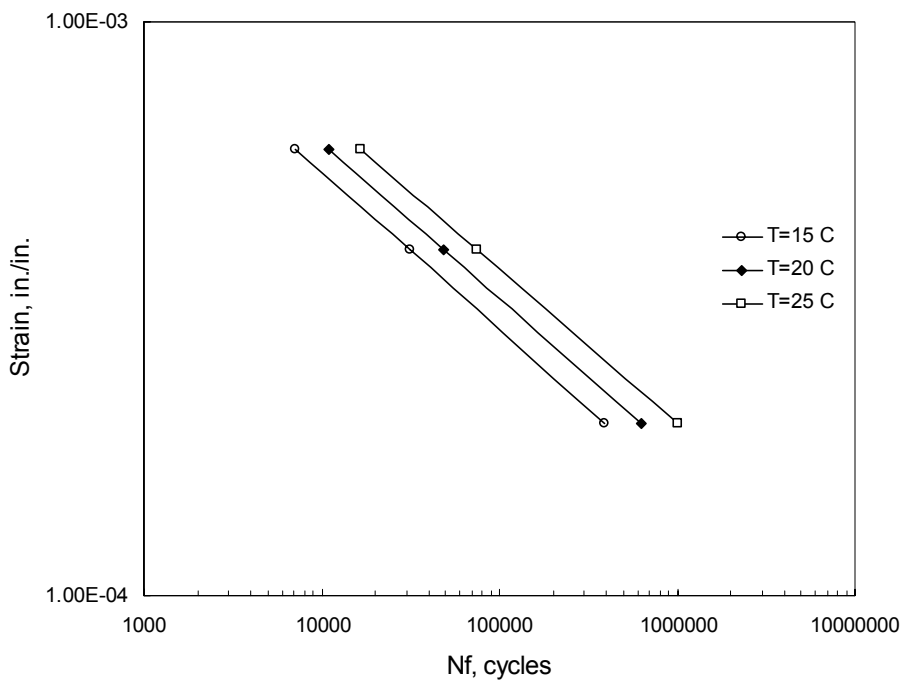


Figure 4-12 Effect of temperature on N_f, Va = 8%

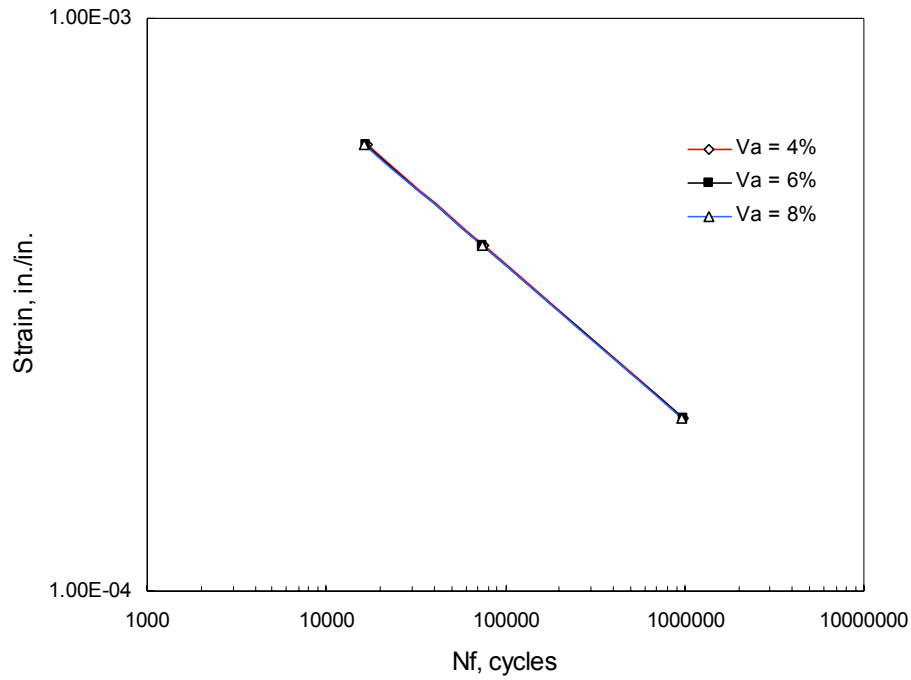


Figure 4-13 Effect of air void content on N_f for SP 12.5-mm mix

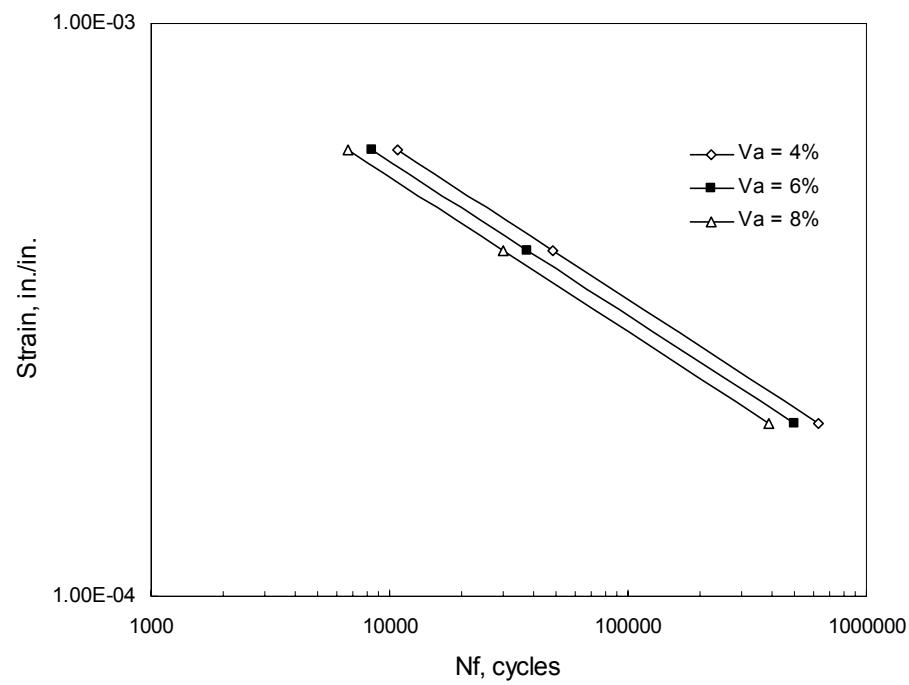


Figure 4-14 Effect of air void content on N_f for SP 19-mm mix

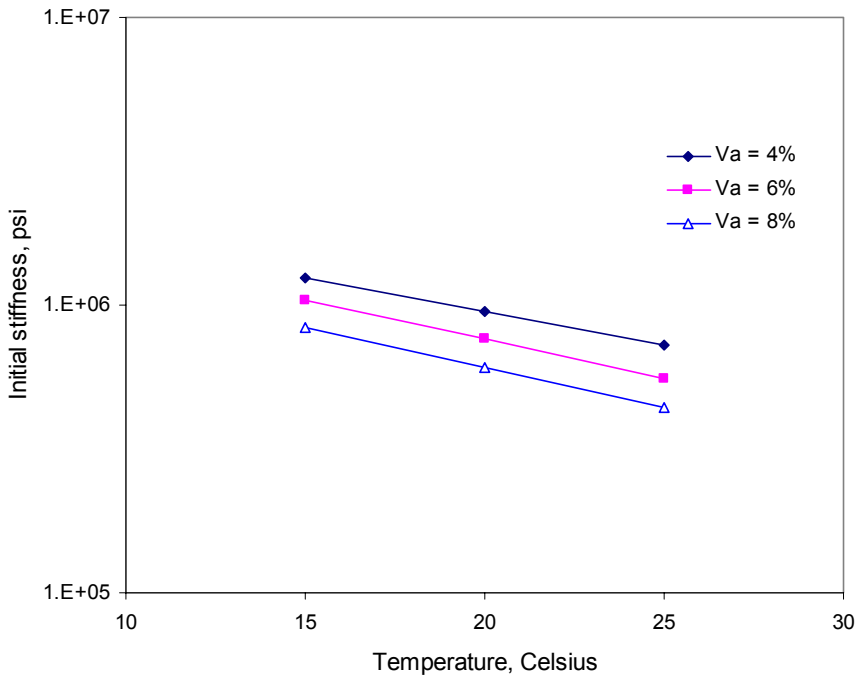


Figure 4-15 Effect of air void content and temperature on initial stiffness for SP 12.5-mm mix with optimum AC, initial strain is 400 microns

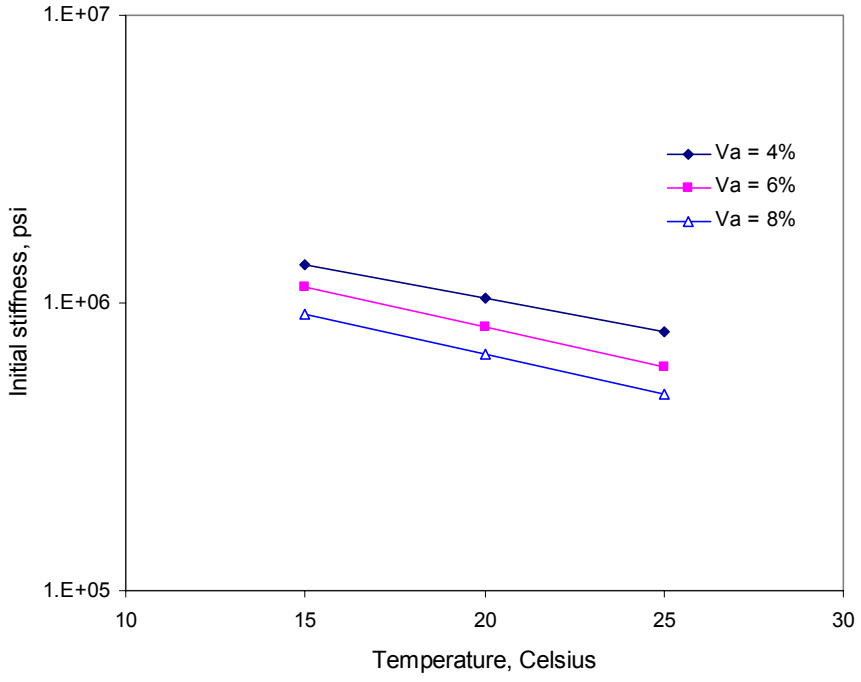


Figure 4-16 Effect of air void content and temperature on initial stiffness for SP 12.5-mm mix with optimum minus 0.5-percent AC, initial strain is 400 microns

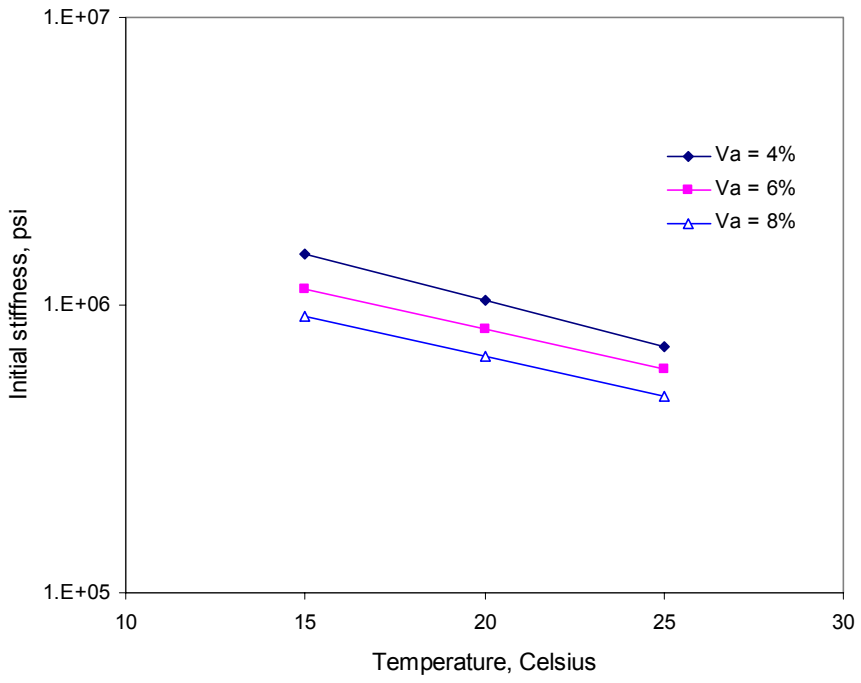


Figure 4-17 Effect of air void content and temperature on initial stiffness for SP 19-mm mix with optimum AC, initial strain is 400 microns

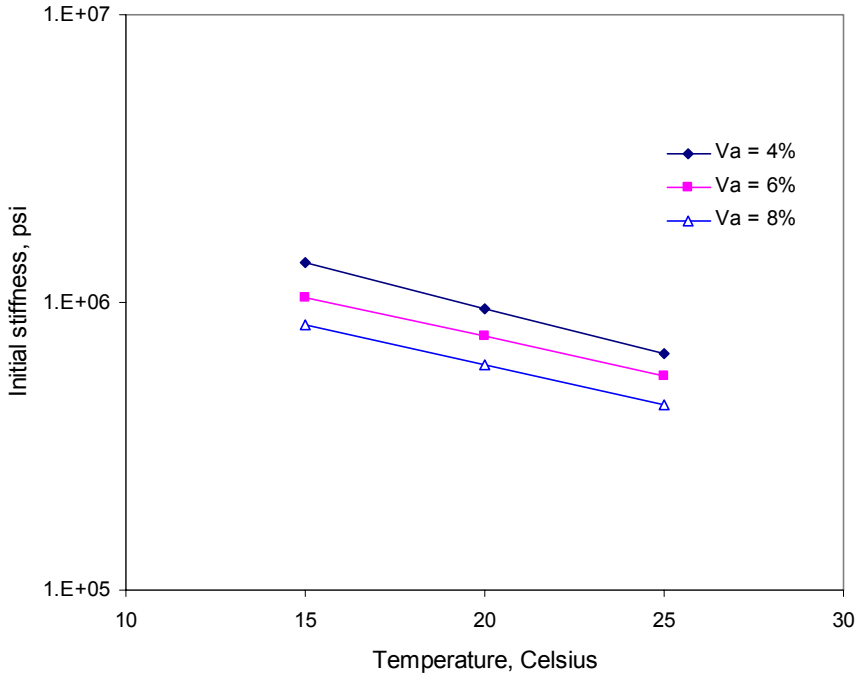


Figure 4-18 Effect of air void content and temperature on initial stiffness for SP 19-mm mix with optimum minus 0.5-percent AC, initial strain is 400 microns

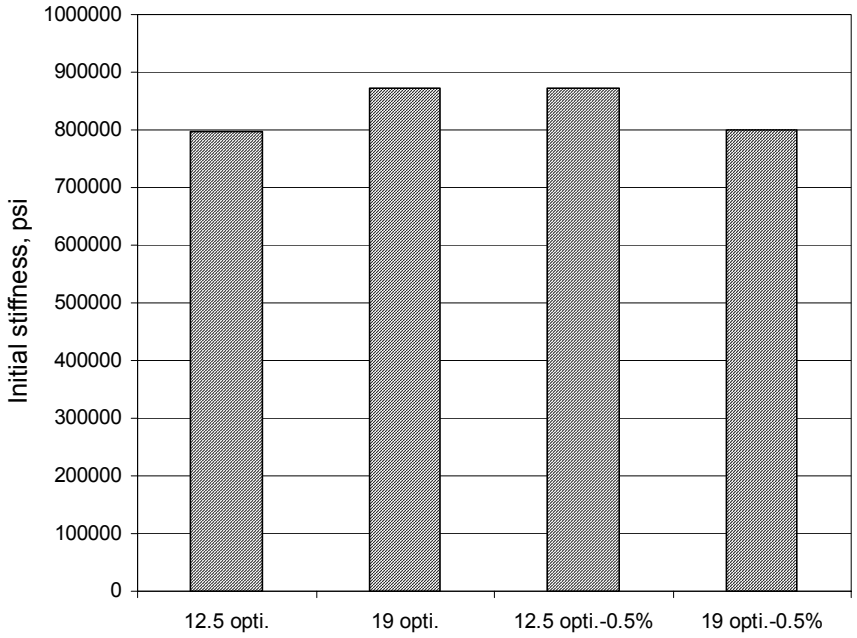


Figure 4-19 Comparison of initial stiffness for different mixtures

5. Axial Frequency Sweep Testing

5.1 Introduction

The axial frequency sweep test (AFST) is similar to FSCH test except that a dynamic uniaxial loading is applied as opposed to shear. The shape of specimen in this experimental study is prismatic. The dimension of the specimen is 6 in by 2.5 in by 2 in (as shown in Figure 5-1). This test measures the axial viscoelastic properties (dynamic axial modulus, |E*| and the phase shift, ϕ) over a range of testing frequencies and at different temperatures.

This test can be conducted in a controlled stress or strain mode of loading. In this study, testing was conducted in accordance with AASHTO TP7 Procedure E [4] in which a sinusoidal axial strain of amplitude +-0.005-percent (0.0001 mm/mm peak-to-peak strain) is applied at frequencies of 15, 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02, and 0.01 Hz. At each frequency, the stress response is measured along with the phase shift between the stress and strain. The dynamic axial modulus (|E*|) is computed as the ratio of the stress over strain. Since it is nondestructive test, the same specimen can be tested under different temperature. By using time-temperature superposition technique, master curves for the mix can be obtained. Those properties can be used as input to evaluate the response and performance of the mixes subjected to traffic loads. Complex modulus of the HMA can also be extracted from master curves by using nonlinear regression and optimization techniques.

Variables that affect the axial stiffness of asphalt mixes are asphalt type and grade, aggregate type and gradation, air void content, temperature, loading frequency, and stress/strain level, aging and moisture conditioning, etc. The significant variables included in this study are asphalt content, air void content, temperature and gradation. The specific objective of this study were as follows:

1. Investigating how the various factors influence the axial dynamic modulus, and providing 95% confidence interval of axial stiffness at 10 Hz for 12 types of mixes under three levels of temperature.

2. Developing an axial dynamic predicative model based on these various factors for the mixes studied in this experiment program.

3. Comparing the lab axial stiffness with the estimated axial stiffness by Witczak model and proposing a modified Witczak axial stiffness model for NCDOT mixes involved in this study.

4. Developing a phase angel predicative model for NCDOT mixes involved in this study.

5.2 Experiment design

Table 5-1 shows the experimental design for shear frequency testing. There are 12 types of mixture (i.e. 2 gradations, 2 asphalt content and 3 air void). Each mixture was tested under three different temperatures. The total number of axial tests is supposed to 72. All those axial specimens were cores from the slabs compacted by roller compactor.

5.3 Test Result

Figure 5-2 and Figure 5-3 presented the dynamic axial modulus versus frequency for SP 19, 12.5-mm mixes under different temperatures and air void contents, respectively. The curves from top to bottom in each figure represents the mixes at 15°C, 20°C and 25°C/28°C, respectively.

It is seen that the same modulus value can be obtained either at low temperature and low frequency or at high test temperature and high frequency. This equivalence is often used to generate |E*| versus $\log(f)$ curves. Since such curves extend over a wide range of frequencies, they may not be determined conveniently from direct laboratory measurements. Instead, dynamic axial stiffness data are obtained at different temperatures over a convenient frequency scale. Then, after choosing one temperature as the reference temperature, the remaining curves are shifted horizontally to lower or higher frequencies to generate a single master curve. Assuming that the viscoelastic response of the material is to be controlled by a single function of temperature (i.e., a single rate controlling mechanism), time shift factor can be given as

$$\log(\alpha_T) = \log(\frac{t_T}{t_{T_0}}) = \log(\frac{f_{T_0}}{f_T}) \tag{5.1}$$

where,

α_T = shift factor that is dependent on the difference between the reference and datum temperatures;

f_T, f_{T_0} = frequency required to reach a specific |E*| at temperature T and T_0.

By using time-temperature superposition technique, Master curve for each mix can be obtained. Figure 5-4 and Figure 5-5 provides master curves for SP 12.5-mm mix

with optimum and optimum minus 0.5-percent asphalt content, respectively. Master curves for SP 19-mm mixes with optimum and optimum minus 0.5-percent asphalt content are shown in Figure 5-6 and Figure 5-7, respectively. Each figure shows a fairly consistent trend, i.e., the lower the air void of the mix, the higher dynamic modulus is.

Table 5-2 provided the time-temperature shift factors obtained by constructing the dynamic axial modulus master curve at 20°C. At 15°C, shift factor ranges from 2.6 to 5.5 and average value is about 3.35. At 25°C, shit factor is varying between 0.2 and 0.45, with the average of 0.298.

5.4 Analysis of axial stiffness

In this section, the effect of temperature, air void content, and asphalt content as well as gradation on axial stiffness at 10 Hz will be investigated based on statistical analysis. The reasons why stiffness data at 10 Hz are chose are partly because the stiffness at 10 Hz is the typical stiffness used in pavement design and partly because stiffness at 10 Hz is representative.

Figure 5-8 presents the evolution of axial stiffness with temperature for SP 12.5-mm mix and SP 19-mm mix. The stiffness value of each data points in Figure 5-8 represents the average stiffness value at 10 Hz under certain temperature and air void content. Figure 5-8 shows that the effect of air void content and temperature on axial stiffness is pronounced. Axial stiffness decreases dramatically with a 5°C increase in temperature. The higher the air void content, the lower the axial stiffness is.

Figure 5-9 gives the variation of axial stiffness with air void content under different temperatures for various mixes. The stiffness value of each data point in the figure is average stiffness value at 10 Hz for a certain air void content. This figure implies that axial stiffness is inversely proportional to the air void content.

With regard to effect of gradation and asphalt content on axial stiffness, it is very hard to tell only based on raw testing data. Since there is variation in air void content in each air void group, the air void content of each air void group should be brought to a single air void content and axial stiffness should be adjusted accordingly. For example, both 3.8 and 4.5 percent are in 4 percent air void group. To make the comparison of axial stiffness between groups more compatible, both axial stiffness of 3.8 and 4.5 percent mixes needs to be normalized to 4 percent.

Because axial stiffness seems to be linear to air void content and temperature (as shown in Figure 5-8 and Figure 5-9), it is quite obvious to suggest that axial stiffness of each type of mixes involved in this study may be related to air void content and temperature in the following form:

$$\ln(|E^*|) = \mu + a \cdot V_a + b \cdot Temp \tag{5.2}$$

where,

$|E^*|$ = dynamic axial modulus at 10 Hz;

μ = constant;

V_a = air void content of the mix, and

$Temp$ = temperature at which the axial test was conducted.

Statistical analyses were done in SAS program. Trial-and-error technique is utilized to determine if quadratic terms of air void content and temperature are needed. If the presence of quadratic term(s) increase the adjusted coefficient of determination (R^2) dramatically, then the quadratic term(s) will be included.

5.4.1 Analysis of axial data from SP 12.5-mm mix with optimum asphalt content

In this section, axial testing data at 10 Hz from SP 12.5-mm mix with optimum asphalt content was analyzed statistically by using equation (5.2) in SAS program.

Figure 5-10 and Figure 5-11 give the partial regression residual plot of temperature and air void content, respectively. A partial regression plot displays the relationship between the response variable, y, and an explanatory variable, x_i, after removing the effect of the other explanatory variables. The purpose of partial regression residual plot is to determine if there is linear relationship. Figure 5-10 and Figure 5-11 indicate that log axial stiffness is linear to temperature and air void content. They help further justify the model described in equation (5-2).

Table 5-3 presents the statistical analysis result for SP 12.5-mm mix with optimum asphalt content. The adjusted R_Sq is as high as 0.9415. P values for the overall model and each parameter are less than 0.0001. Table 5-3 implies that equation (5-2) describes this data set fairly well.

Then, SAS program is used to calculate the 95% confidence interval for the mean axial stiffness at 4, 6 and 8 percent air void content. The result of the analysis is shown in Table 5-4.

5.4.2 Analysis of data of SP 12.5-mm mix with optimum minus 0.5-percent AC and SP 19-mm mixes

In this section, the testing data of SP 12.5-mm mix with optimum minus 0.5-percent asphalt content, SP 19-mm mixes with optimum and optimum minus 0.5-percent asphalt content were analyzed in the same manner as in last section. 95% confidence interval (CL) will be obtained for each type of mixes.

Figure 5-12 provides partial regression residual plots in terms of temperature and air void content for SP 12.5-mm mix with optimum minus 0.5-percent asphalt content, and SP 19-mm mixes with optimum and optimum minus 0.5-percent asphalt content. All those partial regression residual plots appear to be linear either to temperature or to air void content.

Statistical analysis results for SP 12.5-mm mix with optimum minus 0.5-percent asphalt content is summarized in Table 5-5. Table 5-6 and Table 5-7 summarized analysis result for SP 19-mm mixes with optimum and optimum minus 0.5-percent asphalt content, respectively. The adjusted coefficients of determination for SP 12.5-mm mix with optimum minus 0.5-percent asphalt content, SP 19-mm mixes with optimum and optimum minus 0.5-percent asphalt content are 0.97, 0.9689, and 0.9099, respectively. Estimated parameters are statistically significant under 0.01% significance level. These tables statistically reinforced that the model described in equation (4-2) is appropriate and adequate to be used in the data analysis.

Table 5-8 to Table 5-10 provides the adjusted |E*| and its 95% confidence interval for SP 12.5-mm mix with optimum minus 0.5-percent asphalt content, SP 19-mm with optimum and optimum minus 0.5-percent asphalt content, respectively.

5.4.3 Effects of temperature and air void content

In previous two sections, axial testing data were analyzed by using SAS program. In this section, the effect of temperature and air void content on axial stiffness will be quantitatively investigated based on the analysis result from last two sections.

Table 5-11 summarized the estimated parameters for SP 12.5-mm mixes and SP 19-mm mixes. The coefficients of temperature range from -0.29734 to -0.35032, with the average value -0.31642. It means that increase in temperature from 15°C to 20°C (or from 20°C to 25°C) will decrease the axial stiffness to 73 percent. In the other word, the axial stiffness at 15°C(20°C) is about 1.37 times as the stiffness at 20°C(25°C).

The coefficients of V_a (as shown in Table 5-11) range from -0.07861 to -0.1206, with the average value of -0.106355. Basically, it means that 1-percent increase in air void content will cause 10-percent decrease in axial stiffness. That is to say, if the stiffness at certain air void content is known, the stiffness at other air void content can be obtained by shifting the known stiffness curve vertically (downward or upward). For instance, suppose the stiffness at 6-percent air void content of a certain mix is known, stiffness at 8-percent air void content can be obtained by shifting the known stiffness downward. In the same fashion, the stiffness at 4-percent air void content can be obtained by shifting the know stiffness upward. The bottom line is that stiffness is roughly shiftable with respect to air void content in the test data we conducted.

5.4.4 Effect of asphalt content (AC) and gradation (GR)

In the previous sections, the adjusted axial stiffness and its 95% confidence interval were obtained based upon statistical analysis. In this section, the comparison of stiffness between groups can be made by using hypothesis test (t test).

Assume $\overline{Y_1}$, s_1^2 and $\overline{Y_2}$, s_2^2 are based on independent random samples of size n_1 and n_2 from population 1 and 2, where the distribution of Y in populations 1 and 2 are $N(\mu_1, \sigma_1^2)$ and $N(\mu_2, \sigma_2^2)$, respectively. The difference between sample means $\overline{Y_1} - \overline{Y_2}$ is an estimator of $\mu_1 - \mu_2$. If samples are independent, the variance of $\overline{Y_1} - \overline{Y_2}$ is $\sigma_1^2 / n_1 + \sigma_2^2 / n_2$, and the standard error of $\overline{Y_1} - \overline{Y_2}$ is $\sqrt{\sigma_1^2 / n_1 + \sigma_2^2 / n_2}$. This standard error is estimated by $s_{\overline{Y_1} - \overline{Y_2}} = \sqrt{s_1^2 / n_1 + s_2^2 / n_2}$.

Combining estimator and standard error suggests the hypothesis test procedure as follows.

1. Setting up the hypothesis test:

For two sided test, H_0: $\mu_1 - \mu_2 = 0$ vs. H_1: $\mu_1 - \mu_2 \neq 0$;

For one-sided test, H_0: $\mu_1 - \mu_2 \leq 0$ vs. H_1: $\mu_1 - \mu_2 > 0$.

2. Calculating the test statistical: $t' = \dfrac{\overline{Y_1} - \overline{Y_2}}{s_{\overline{Y_1} - \overline{Y_2}}}$,

3. Computing the degree of freedom (df) for test statistical:

$$v = \frac{[s_1^2/n_1 + s_2^2/n_2]^2}{\frac{(s_1^2/n_1)^2}{n_1 - 1} + \frac{(s_2^2/n_2)^2}{n_2 - 1}}, \text{ and}$$

4. Choosing significance level α, and determining rejection region (RR):

For two sided test, $|t'| > t_{\alpha/2,v}$.

For one sided test, $t' > t_{\alpha,v}$.

If t' falls in the rejection region, then under the chosen significance level α, H_1 is true. Because of two replicates, n_1, n_2 are equal two in this study.

Table 5-12 provides the comparison of axial stiffness of SP 12.5-mm mixes with optimum and optimum minus 0.5-percent asphalt content. The percentage of difference in stiffness between mixes with optimum asphalt content and those with optimum minus 0.5-percent asphalt content ranges from -2.1 to 5.4 percent (as shown in Table 5-12). However, since t' value is less than both $t_{\alpha/2,v}$ and $t_{\alpha,v}$ in Table 5-12, it indicates that under 90% significance level, the stiffness of SP 12.5-mm mixes with optimum asphalt content is not significantly different from those of SP 12.5-mm mixes with optimum minus 0.5-percent asphalt content.

Table 5-13 compares the stiffness of SP 19-mm mixes with optimum and optimum minus 0.5-percent asphalt content. For SP 19-mm mixes, asphalt content does make difference on axial stiffness. For 19-mm mixes, the difference in stiffness between optimum asphalt content and optimum minus 0.5-percent ranges from 2.6 to 25.2 percent

(as given in Table 5-13). When the air void content is 6 or 8-percent, statistical analysis shows that with 90% confidence, the stiffness of SP 19-mm mix with optimum asphalt content is significantly greater than that of SP 19-mm mix with optimum minus 0.5-percent.

Table 5-14 describes the effect of gradation on axial stiffness when the mixes are at optimum asphalt content. Firstly, the percent difference in stiffness between SP 19 and 12.5-mm mixes ranges from 3 to 18.1 percent, with the stiffness of SP 19-mm mix with optimum asphalt content being greater. Secondly, statistical analysis shows that when air void content is 6 or 8-percent, under 90% confidence, the stiffness of SP 19-mm mix with optimum asphalt content is significantly greater than that of SP 12-mm mix with optimum asphalt content.

Table 5-15 illustrates the effect of gradation on axial stiffness when the mixes are at optimum minus 0.5 percent asphalt content. The statistical analysis proves that under 90% confidence, the stiffness of SP 12.5-mm mix with optimum minus 0.5-percent asphalt content is not significantly different from that of SP 19-mm mix with optimum minus 0.5-percent asphalt content.

During the testing, there are many variations, such as variation caused by testing machine, and variation involved in batching, mixing and compaction. In order to discern the effect of asphalt content and gradation on axial stiffness, the variations should be controlled as small as possible. However, since variation is inevitable, one way to decrease the variation is to increase the replicates of testing samples. Ideally, the more the replicates are, the greater the chances are to tell the differences.

5.5 Surrogate model for axial stiffness

There are several avenues to get the axial stiffness, such as by doing lab testing, by using some kind of empirical equation(s) or normagraph(s) based upon test data on a broad range of mixes. Those empirical equations usually take a variety of variables into account and always provide good prediction of axial stiffness. However, sometimes some variables required by the empirical equations may not be available immediately. Therefore, that mix-specific empirical stiffness equation is still desirable under some circumstances. This section is to provide an empirical axial stiffness equation for both SP 12.5-mm and SP 19-mm mixes at various frequencies. It will only take variables such as temperature, air void content, and gradation as well as asphalt content into account in the following form:

$$\ln|E^*| = \mu + a \cdot AC + b \cdot GR + c \cdot Temp + d \cdot V_a \tag{5.3}$$

Analysis was done by SAS program. Table 5-16 summarizes the coefficients for the empirical models (as described in equation (5.3)) at 0.01 through 15 Hz. Table 5-16 showed that the adjusted R^2 for each frequency is either equal or greater than 0.90.

Table 5-17 provides the summary of regression analysis on $|E^*|$ at 10 Hz. By plugging coefficients corresponding to 10 Hz into equation (5.3), one can obtain axial stiffness predicative model at 10 Hz in the following form:

$$\left|E^*\right| = 17.5153 \times 10^5 \exp(0.03956AC + 0.01256GR - 0.11671V_a - 0.31472Temp) \qquad R^2 = 0.94 \tag{5.4a}$$

$$\left|E''\right| = 8.93132 \times 10^5 \exp(0.0425AC + 0.37743GR - 0.09232V_a - 0.20671Temp) \qquad R^2 = 0.81 \tag{5.4b}$$

where,

$\left|E^*\right|$, $|E''|$ = axial stiffness, and loss stiffness in psi;

AC = asphalt content: -1 and +1 for optimum minus 0.5-percent and optimum;

GR = aggregate gradation: -1 and +1 for SP 12.5-mm and SP 19-mm;

V_a = air void content in percent;

Temp = test temperature: -1,0 and +1 for 15, 20 and 15°C, respectively;

exp = e: base of natural log.

The axial stiffness predicative model at other frequency can be obtained by substituting corresponding coefficients (as shown in Table 5-16) into equation (5.3).

5.6 Comparison of Witczak model with lab measured data

The 1999 version of Witczak et al dynamic modulus predicative equation is in the following form:

$$\begin{aligned}\log\left|E^*\right| &= -1.249937 + 0.029232 \cdot P_{200} - 0.001767 \cdot (P_{200})^2 - 0.002841 \cdot P_4 \\ &- 0.058097 \cdot V_a - 0.802208 \cdot \frac{V_{beff}}{V_{beff} + V_a} \\ &+ \frac{3.871977 - 0.0021 \cdot P_4 + 0.003958 \cdot P_{38} - 0.000017 \cdot (P_{38})^2 + 0.005470 \cdot P_{34}}{1 + \exp(-0.603313 - 0.313351 \cdot \log(f) - 0.393532 \cdot \log(\eta))}\end{aligned} \tag{5.5}$$

where,

$\left|E^*\right|$ = Asphalt mix dynamic modulus, in 10^5 psi;

η = Bitumen viscosity in 10^6 poise (at any temperature, degree of aging);

f = Load frequency in Hz;

V_a = % air void in the mix, by volume;

V_{beff} = % effective bitumen content, by volume;

P_{34} = % retained on the 3/4 inch sieve, by total aggregate weight (cumulative);

P_{38} = % retained on the 3/8 inch sieve, by total aggregate weight (cumulative);

P_{38} = % retained on the No. 4 sieve, by total aggregate weight (cumulative);

P_{200} = % passing on the No. 4 sieve, by total aggregate weight.

Bitumen viscosity can be obtained by converting penetration data to viscosity units based upon the following model developed at the University of Maryland as a part of a SHRP study [6]. It should be noted the following equation is applicable to a very wide range of penetration from 3 to 300.

$$\log \eta = 10.5012 - 2.2601 \cdot \log(pen) + 0.00389 \cdot \log(pen)^2 \quad (5.6)$$

Note that the viscosity obtained from equation (5.6) is in poise. Table 5-18 summaries the viscosity-consistency test result for PG 64-22 binder. As shown in the Table, the penetration of PG 64-22 binder at 15 and 25°C is 15 and 44, respectively.

Figure 5-13 provides viscosity-temperature relationship for PG 64-22 binder. The linear regression equation takes the following form:

$$\log(\log(\eta)) = -3.6766 \cdot \log(T) + 10.977 \quad (5.7)$$

where,

η = bitumen viscosity in cp,

T = temperature in Rankine.

So, the viscosity at any temperature can be determined by using equation (5.7). The viscosity of PG 64-22 at 15, 20, and 25°C is listed in Table 5-19. Once gradation information and viscosity are known, the axial stiffness at various frequency and temperature can be estimated by using Witczak model. Figure 5-14 compares the lab

measured axial stiffness with those estimated by Witczak model (1999 version). It shows that lab measured and estimated axial stiffness at 20°C is not in very good agreement.

By using solver program in Excel, a model for both SP 19-mm and SP 12.5-mm mixes has been proposed in the following form:

$$\begin{aligned}\log\left|E^*\right| &= -1.249937 + 0.029232 \cdot P_{200} - 0.001767 \cdot (P_{200})^2 - 0.002841 \cdot P_4 \\ &\quad - 0.058097 \cdot V_a - 0.802208 \cdot \frac{V_{beff}}{V_{beff} + V_a} \\ &\quad + \frac{3.871977 - 0.0021 \cdot P_4 + 0.003958 \cdot P_{38} - 0.000017 \cdot (P_{38})^2 + 0.005470 \cdot P_{34}}{0.9696 + \exp(-0.40823 - 0.46825 \cdot \log(f) - 0.39813 \cdot \log(\eta))}\end{aligned} \tag{5.8}$$

5.7 Analysis of phase angle

Phase angle is a very important property of hot mixed asphalt concrete. It reflects viscoelastic behavior. Theoretically, phase angle is needed in both viscoelastic modeling of asphalt concrete and viscoelastic analysis of HMA pavement system. In practice, there is also a need to predict or estimate phase angle. For example, the fatigue prediction model developed in Strategic Highway Research Program (SHRP_A_404) considered loss modulus as a predictor variable, which is a function of both dynamic modulus and phase angle.

This study found that a good empirical relationship between the log of the axial dynamic modulus and phase angle. Table 5-20 provides the summary of statistical analysis on axial phase angle. The adjusted R^2 is 0.8747. Every parameter estimated is

significant under 99.9% confidence. Therefore, the phase angle prediction model takes the form as follows:

$$\phi = -379.61 + 177.85 \cdot \log|E^*| - 18.5 \cdot (\log|E^*|)^2 + 1.942 \cdot \log(f) \qquad (5.9)$$

Where,

ϕ = Phase angle in degree,

$|E^*|$ = Axial dynamic modulus, and

f = Frequency in Hz.

Figure 5-15 and Figure 5-16 compared the measured and predicted phase angle for SP 12.5-mm and SP 19-mm mixes, respectively. The equation (5.9), though not highly accurate in some cases, is useful for estimating phase angle for HMA. It should be kept in mind that the measurement of phase angle is particularly difficult, so the amount o scatter in Figure 5-15 and Figure 5-16 is not surprising. Nonetheless, the phase angle predictive model gives pretty good prediction in most of cases.

5.8 Summary

In this chapter, the axial frequency testing data were analyzed and the following conclusion may be drawn.

(1) Analysis showed that the axial dynamic stiffness involved in this study is roughly shiftable with respect to air void content. The shift direction is vertical, either upward or downward.

(2) Increase in temperature from 15°C to 20°C will decrease axial stiffness to 73 percent.

(3) For SP 12.5-mm mixes, this study failed to discern the effect of asphalt content on axial stiffness. One way to circumvent it is to increase the replicates in the testing to reduce the variation. However, for 19 mm mixes, at 6 and 8-percent air void content, under 90% confidence, the stiffness at optimum asphalt content is significantly greater than that at optimum minus 0.5-percent asphalt content.

(4) Based upon the lab stiffness data, surrogate axial dynamic modulus predictive model for the mixes involved in this study was developed in terms of asphalt content, gradation and temperature as well as air void content.

(5) Based upon the comparison between lab axial stiffness data and the estimated axial stiffness by Witczak (1999 version), a modified Witczak model was proposed. It may only be applicable to the mixes involved in this study.

(6) Phase angle predictive model for the mixes involved in this study was established based upon the testing data.

Table 5-1 Mix and test variables for the experiment design

Number of asphalts	1-PG64-22
Number of aggregate gradations	2-12.5 mm and 19-mm intermediate
Asphalt Contents	2-Superpave opti. and opti. minus 0.5-percent
Air Void Levels	3- About 4, 6, and 8-percent
Temperatures	3- 15°C, 20°C, and 25°C
Test Frequency	0.1 to 15 Hz for axial frequency sweep test
Specimen Size	6-in by 2.5 by 2 in prismatic specimen
Replicates	2- for axial tests
Total Number of Mixes	12- 2 gradations, 2 asphalt content, 3 air void
Number of Axial Tests	2 replicates x 12 mixes x 3 = 72

Table 5-2 Time-temperature shift factors, T_0 =20°C

Mix type		T=15°C	T=25°C	T=28°C	T=30°C	T=33°C
SP 12.5-mm mix with opti AC	V_a=3.80%	4	0.35		0.075	
	V_a=6.0%	5.5	0.45			
	V_a=7.0%	3.05	0.35		0.05	
SP 12.5-mm mix with opti minus 0.5-percent AC	V_a=4.5%	3	0.25			0.04
	V_a=6.1%	3.15	0.3			0.04
	V_a=7.8%	3.15	0.285			
SP 19-mm mix with opti AC	V_a=3.4%	3.6	0.275			0.05
	V_a=6.0%	2.6	0.225			0.035
	V_a=7.1%	3.6	0.2			
SP 19-mm mix with opti minus 0.5-percent AC	V_a=3.7%	3.3	0.22	0.15		
	V_a=7.4%	2.25	0.275	0.1		
	V_a=9.4%	3.1	0.4	0.125		

Table 5-3 Analysis of data for SP 12.5-mm mix with optimum AC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3.17493	1.58746	170.05	<.0001
Error	19	0.17737	0.00934		
Corrected Total	21	3.35229			
Root MSE	0.09662	Coeff. Var	0.70658	R_Square	0.9471
Dependent Mean	13.67403			Adj R_Sq	0.9415
Variable	Parameter Estimate	Standard Error	F Value	Pr > F	Variance Inflation
Intercept	14.38103	0.07155	201	<.0001	0
Temp	-0.29734	0.01929	-15.42	<.0001	1.00001
V_a	-0.11818	0.01163	-10.16	<.0001	1.00001

Table 5-4 Adjusted |E*| and its 95% CL for SP 12.5-mm mix with optimum AC

V_a	Temperature (°C)	|E*| (psi)	95% CL of mean |E*|		Standard Deviation
			Lower limit (psi)	Upper limit (psi)	
4%	15	1.48E+06	1.37E+06	1.59E+06	0.0362
	20	1.10E+06	1.03E+06	1.17E+06	0.0301
	25	8.15E+05	7.57E+05	8.78E+05	0.0354
6%	15	1.17E+06	1.10E+06	1.24E+06	0.0287
	20	8.66E+05	8.30E+05	9.05E+05	0.0207
	25	6.43E+05	6.07E+05	6.82E+05	0.0278
8%	15	9.21E+05	8.51E+05	9.96E+05	0.0377
	20	6.84E+05	6.40E+05	7.31E+05	0.0320
	25	5.08E+05	4.70E+05	5.49E+05	0.0371

Table 5-5 Analysis of data for SP 12.5-mm mix with optimum minus 0.5-percent AC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3.70337	1.85169	323.83	<.0001
Error	18	0.10293	0.00572		
Corrected Total	20	3.8063			
Root MSE	0.07562	Coeff. Var	0.55455	R_Square	0.973
Dependent Mean	13.63608			Adj R_Sq	0.97
Variable	Parameter Estimate	Standard Error	F Value	Pr > F	Variance Inflation
Intercept	14.30253	0.0793	180.37	<.0001	0
Temp	-0.31532	0.01299	-24.27	<.0001	1.00118
Va	-0.10803	0.01274	-8.48	<.0001	1.00118

Table 5-6 Analysis of data for SP 19-mm mix with optimum AC mixes

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.83387	0.91693	203.48	<.0001
Error	11	0.04957	0.00451		
Corrected Total	13	1.88343			
Root MSE	0.06713	Coeff. Var	0.48952	R_Square	0.9737
Dependent Mean	13.71307			Adj R_Sq	0.9689
Variable	Parameter Estimate	Standard Error	F Value	Pr > F	Variance Inflation
Intercept	14.25888	0.07316	194.9	<.0001	0
Temp	-0.30269	0.01553	-19.49	<.0001	1.00273
Va	-0.07861	0.01265	-6.22	<.0001	1.00273

Table 5-7 Analysis of data for SP 19-mm mix with optimum minus 0.5-percent AC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3.43006	1.71503	96.91	<.0001
Error	17	0.30086	0.0177		
Corrected Total	19	3.73092			
Root MSE	0.13303	Coeff. Var	0.9934	R_Square	0.9194
Dependent Mean	13.39104			Adj R_Sq	0.9099
Variable	Parameter Estimate	Standard Error	F Value	Pr > F	Variance Inflation
Intercept	14.35235	0.10489	136.83	<.0001	0
Temp	-0.35032	0.03043	-11.51	<.0001	1.00868
Va	-0.1206	0.0136	-8.87	<.0001	1.00868

Table 5-8 95% CL for SP 12.5-mm mix with optimum minus 0.5-percent AC

Va	Temperature (°C)	|E*| (psi)	95% CL of mean |E*|		Standard Deviation
			Lower limit (psi)	Upper limit (psi)	
4%	15	1.45E+06	1.35E+06	1.56E+06	0.0344
	20	1.06E+06	9.89E+05	1.13E+06	0.0313
	25	7.71E+05	7.18E+05	8.27E+05	0.0334
6%	15	1.17E+06	1.12E+06	1.22E+06	0.0213
	20	8.51E+05	8.22E+05	8.81E+05	0.0165
	25	6.21E+05	5.94E+05	6.49E+05	0.0208
8%	15	9.40E+05	8.79E+05	1.01E+06	0.0320
	20	6.86E+05	6.45E+05	7.29E+05	0.0294
	25	5.00E+05	4.67E+05	5.36E+05	0.0324

Table 5-9 95% CL for SP 19-mm mix with optimum AC

Va	Temperature (°C)	|E*| (psi)	95% CL of mean |E*|		Standard Deviation
			Lower limit (psi)	Upper limit (psi)	
4%	15	1.54E+06	1.43E+06	1.66E+06	0.0347
	20	1.14E+06	1.07E+06	1.21E+06	0.0275
	25	8.40E+05	7.90E+05	8.94E+05	0.0282
6%	15	1.32E+06	1.24E+06	1.40E+06	0.0280
	20	9.72E+05	9.31E+05	1.01E+06	0.0195
	25	7.18E+05	6.85E+05	7.53E+05	0.0214
8%	15	1.12E+06	1.03E+06	1.23E+06	0.0406
	20	8.31E+05	7.68E+05	8.99E+05	0.0358
	25	6.14E+05	5.65E+05	6.66E+05	0.0374

Table 5-10 95% CL for SP 19-mm mix with optimum minus 0.5-percent AC

Va	Temperature (°C)	|E*| (psi)	95% CL of mean |E*|		Standard Deviation
			Lower limit (psi)	Upper limit (psi)	
4%	15	1.50E+06	1.30E+06	1.73E+06	0.0680
	20	1.06E+06	9.40E+05	1.19E+06	0.0551
	25	7.44E+05	6.59E+05	8.40E+05	0.0575
6%	15	1.18E+06	1.06E+06	1.31E+06	0.0521
	20	8.30E+05	7.69E+05	8.95E+05	0.0358
	25	5.84E+05	5.36E+05	6.37E+05	0.0412
8%	15	9.25E+05	8.37E+05	1.02E+06	0.0478
	20	6.52E+05	6.10E+05	6.97E+05	0.0316
	25	4.59E+05	4.22E+05	4.99E+05	0.0396

Table 5-11 Summary of coefficients of temperature and V_a (10 Hz)

Parameters	SP 12.5-mm mix		SP19-mm mix	
	optimum	Optimum minus 0.5-percent	optimum	Optimum minus 0.5-percent
Intercept	14.38103	14.30253	14.25888	14.3525
Temp	-0.29734	-0.31532	-0.30269	-0.35032
Va	-0.11818	-0.10803	-0.07861	-0.1206
Adj R_sq	0.9415	0.97	0.9689	0.9099

Table 5-12 Comparison of stiffness between mix with optimum and mix with optimum minus 0.5-percent AC for 12.5-mm, $\alpha = 0.1$

V_a (%)	Temp (°C)	12.5 opti.		12.5 opti.-0.5%		% diff	$s_{\overline{Y_1}-\overline{Y_2}}$	t'	v	$t_{\alpha/2,v}$	$t_{\alpha,v}$
		Ln|E*|	s_1	Ln|E*|	s_2						
4	15	14.20755	0.0362	14.18707	0.0344	2.0%	0.035311	0.58	2	2.92	1.886
	20	13.91082	0.0301	13.87378	0.0313	3.6%	0.030706	1.21	2	2.92	1.886
	25	13.61094	0.0354	13.55544	0.0334	5.4%	0.034415	1.61	2	2.92	1.886
6	15	13.97251	0.0287	13.97251	0.0213	0.0%	0.025272	0.00	2	2.92	1.886
	20	13.67164	0.0207	13.65417	0.0165	1.7%	0.018718	0.93	2	2.92	1.886
	25	13.3739	0.0278	13.33909	0.0208	3.4%	0.024551	1.42	2	2.92	1.886
8	15	13.73322	0.0377	13.75364	0.0213	-2.1%	0.030618	-0.67	1.5	4.622	2.982
	20	13.43571	0.032	13.43863	0.0165	-0.3%	0.025458	-0.11	1.5	4.622	2.982
	25	13.13824	0.0371	13.12236	0.0208	1.6%	0.030075	0.53	1.5	4.622	2.982

Table 5-13 Comparison of stiffness between mix with optimum and mix with optimum minus 0.5-percent AC for 19-mm, $\alpha = 0.1$

V_a (%)	Temp (°C)	19 opti.		19 opti.-0.5%		% diff	$s_{\overline{Y_1}-\overline{Y_2}}$	t'	v	$t_{\alpha/2,v}$	$t_{\alpha,v}$
		Ln|E*|	s_1	Ln|E*|	s_2						
4	15	14.2471	0.0347	14.2203	0.0680	2.6%	0.053982	0.50	1.5	4.622	2.982
	20	13.9444	0.0275	13.8699	0.0551	7.2%	0.043545	1.71	1.5	4.622	2.982
	25	13.6417	0.0282	13.5196	0.0575	11.5%	0.045285	2.70	1.5	4.622	2.982
6	15	14.0899	0.0280	13.9791	0.0521	10.5%	0.041823	2.65	1.5	4.622	2.982
	20	13.7872	0.0195	13.6287	0.0358	14.7%	0.028826	**5.50**	1.5	4.622	2.982
	25	13.4845	0.0214	13.2784	0.0412	18.6%	0.032828	**6.28**	1.5	4.622	2.982
8	15	13.9327	0.0406	13.7379	0.0478	17.7%	0.044346	**4.39**	2	2.92	1.886
	20	13.63	0.0358	13.3875	0.0316	21.5%	0.033765	**7.18**	2	2.92	1.886
	25	13.3273	0.0374	13.0372	0.0396	25.2%	0.038516	**7.53**	2	2.92	1.886

Table 5-14 Comparison of stiffness between 19-mm and 12.5-mm mixes at optimum AC, $\alpha = 0.1$

V_a (%)	Temp (°C)	19 opti.		12.5 opti.		% diff	$s_{\overline{Y_1}-\overline{Y_2}}$	t'	v	$t_{\alpha/2,v}$	$t_{\alpha,v}$
		Ln|E*|	s_1	Ln|E*|	s_2						
4	15	14.2471	0.0347	14.20755	0.0362	3.9%	0.035458	1.12	2	2.92	1.886
	20	13.9444	0.0275	13.91082	0.0301	3.3%	0.028829	1.16	2	2.92	1.886
	25	13.6417	0.0282	13.61094	0.0354	3.0%	0.032003	0.96	2	2.92	1.886
6	15	14.0899	0.0280	13.97251	0.0287	11.1%	0.028352	**4.14**	2	2.92	1.886
	20	13.7872	0.0195	13.67164	0.0207	10.9%	0.020109	**5.75**	2	2.92	1.886
	25	13.4845	0.0214	13.3739	0.0278	10.5%	0.024807	**4.46**	2	2.92	1.886
8	15	13.9327	0.0406	13.73322	0.0377	18.1%	0.039177	**5.09**	2	2.92	1.886
	20	13.63	0.0358	13.43571	0.0320	17.7%	0.033953	**5.72**	2	2.92	1.886
	25	13.3273	0.0374	13.13824	0.0371	17.2%	0.03725	**5.08**	2	2.92	1.886

Table 5-15 Comparison of stiffness between 19-mm and 12.5-mm mixes at optimum minus 0.5-percent AC, $\alpha = 0.1$

V_a (%)	Temp (°C)	12.5 opti.-0.5%		19 opti.-0.5%		% diff	$s_{\overline{Y_1}-\overline{Y_2}}$	t'	v	$t_{\alpha/2,v}$	$t_{\alpha,v}$
		Ln|E*|	s_1	Ln|E*|	s_2						
4	15	14.18707	0.0344	14.2203	0.0680	-3.3%	0.053886	-0.62	1.5	4.622	2.982
	20	13.87378	0.0313	13.8699	0.0551	0.4%	0.044809	0.09	1.5	4.622	2.982
	25	13.55544	0.0334	13.5196	0.0575	3.6%	0.04702	0.76	1.5	4.622	2.982
6	15	13.97251	0.0213	13.9791	0.0521	-0.7%	0.0398	-0.17	1.5	4.622	2.982
	20	13.65417	0.0165	13.6287	0.0358	2.6%	0.027874	0.91	1.5	4.622	2.982
	25	13.33909	0.0208	13.2784	0.0412	6.3%	0.032635	1.86	1.5	4.622	2.982
8	15	13.75364	0.0213	13.7379	0.0478	1.6%	0.037004	0.43	1.5	4.622	2.982
	20	13.43863	0.0165	13.3875	0.0316	5.2%	0.025207	2.03	1.5	4.622	2.982
	25	13.12236	0.0208	13.0372	0.0396	8.9%	0.031629	2.69	1.5	4.622	2.982

Table 5-16 Summary of coefficients for empirical axial model at different frequency

Frequency (Hz)	Intercept	AC	GR	V_a	Temp	R^2
0.01	12.19377	0.13318	0.04649	-0.17904	-0.51822	0.90
0.02	12.4790	0.14188	0.05115	-0.18054	-0.55334	0.92
0.05	12.78785	0.13570	0.05364	-0.17914	-0.55626	0.92
0.1	13.10556	0.12205	0.05079	-0.17361	-0.56172	0.94
0.2	13.35991	0.10739	0.04132	-0.16981	-0.53917	0.95
0.5	13.66088	0.09251	0.04038	-0.15902	-0.50333	0.95
1	13.86837	0.07094	0.04304	-0.15104	-0.46856	0.95
2	14.05081	0.05863	0.036	-0.14102	-0.42246	0.94
5	14.24576	0.04762	0.02099	-0.1268	-0.36057	0.94
10	14.37603	0.03956	0.01256	-0.11671	-0.31472	0.94
15	14.44706	0.03458	0.00844	-0.11118	-0.28822	0.94

Table 5-17 Summary of regression analysis on |E*| at 10 Hz

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	13.17039	3.2926	295.53	<.0001
Error	72	0.80219	0.01114		
Corrected Total	76	13.97257			
Root MSE	0.10555	Coeff. Var	0.77628	R_Square	0.9426
Dependent Mean	13.59728			Adj R_Sq	0.9394
Variable	Parameter Estimate	Standard error	F Value	Pr > F	Variance Inflation
Intercept	14.37603	0.04448	323.21	<.0001	14.37603
AC	0.03956	0.01248	3.17	0.0022	0.03956
GR	0.01256	0.01239	1.01	0.3141	0.01256
Va	-0.11671	0.00681	-17.13	<.0001	-0.11671
Temp	-0.31472	0.01072	-29.35	<.0001	-0.31472

Table 5-18 Summary of viscosity-consistency test result for PG 64-22

Temp (°C)	Temp (°F)	Log(Temp) (°Rankine)	Pen. (0.1 mm)	Viscosity (poise)	Viscosity (cp)	Log Log Visc (cp)
15	59	2.714916	15	7.12E+07	7.12E+09	0.993546
25	77	2.729732	44	6.30E+06	6.30E+08	0.94445
80	176	2.803252			4.30E+04	0.665906
100	212	2.827175			6.35E+03	0.5801
135	275	2.86611			5.90E+02	0.442613
175	347	2.906712			1.04E+02	0.304713

Table 5-19 Viscosity of PG 64-22 at 15, 20, and 25°C

Temp (°C)	Viscosity (10^6 poise)
15	71.2
20	45.1
25	6.3

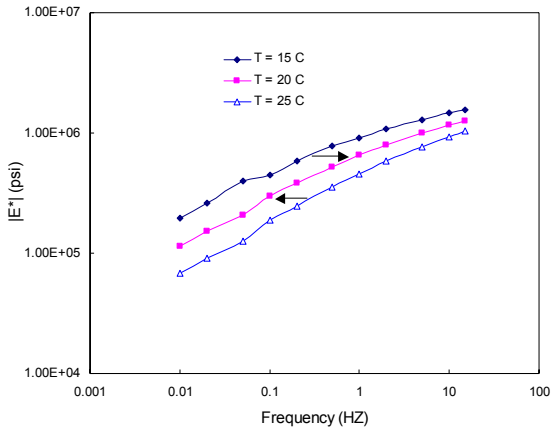
Table 5-20 Summary of regression analysis on phase angle

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	63162	21054	1968.92	<.0001
Error	843	9014.3	10.69132		
Corrected Total	846	72176			
Root MSE	3.27003	Coeff. Var	9.16978	R_Square	0.8751
Dependent Mean	35.66099			Adj R_Sq	0.8747
Variable	Parameter Estimate	Standard error	F Value	Pr > F	Variance Inflation
Intercept	-379.612	13.25439	-28.64	<.0001	0
Log|E*|	177.8555	5.0517	35.21	<.0001	464.8846
Log|E*|*log|E*|	-18.5134	0.48026	-38.55	<.0001	476.152
Log(frequency)	1.94148	0.19392	10.01	<.0001	3.19285

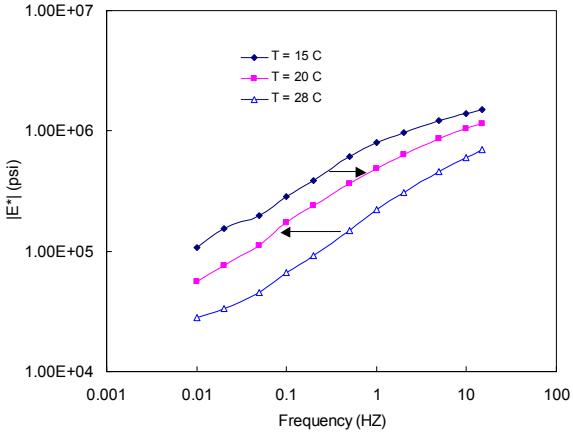
(a) After gluing

(b) Before gluing

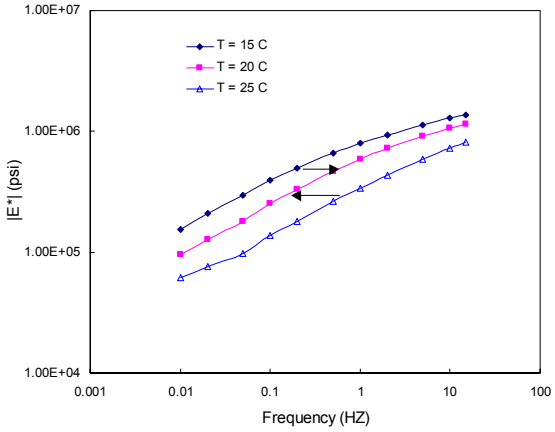
Figure 5-1 The dimension of specimen of axial frequency sweep test



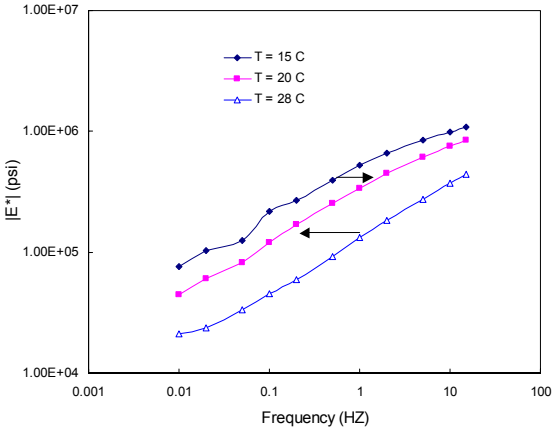
19-mm mix with optimum asphalt content, V_a=3.4%



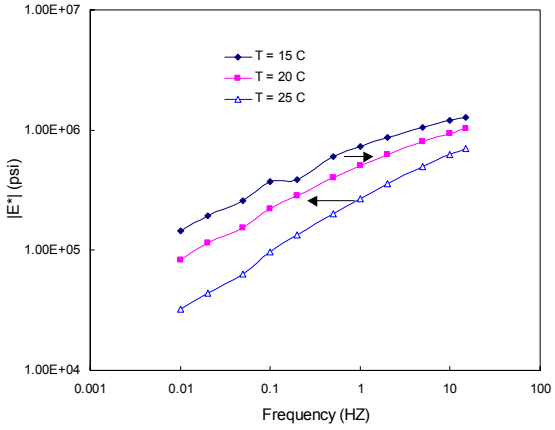
19-mm mix with optimum minus 0.5-percent AC, V_a=3.8%



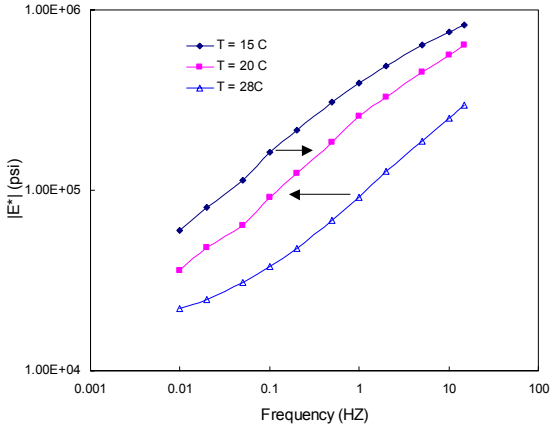
19-mm mix with optimum asphalt content, V_a=6%



19-mm mix with optimum minus 0.5-percent AC, V_a=7.5%

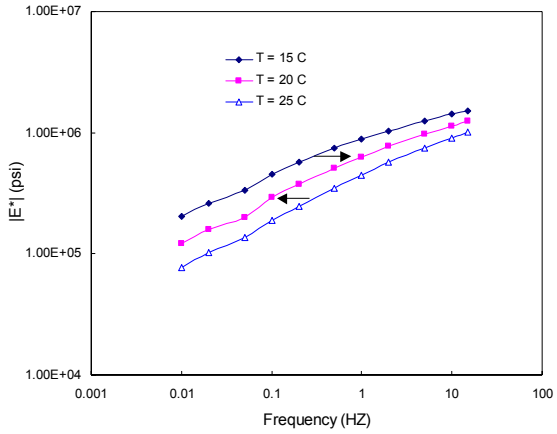


19-mm mix with optimum asphalt content, V_a=7%

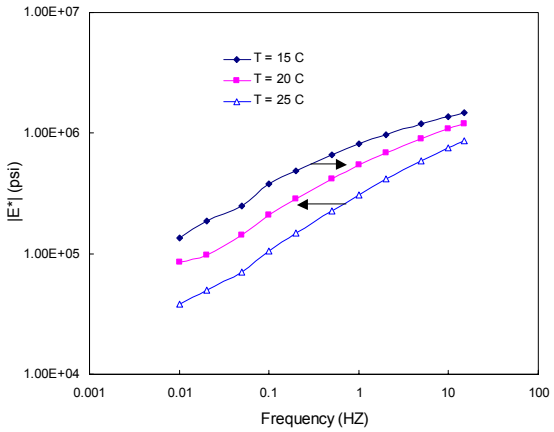


19-mm mix with optimum minus 0.5-percent AC, V_a=9.4%

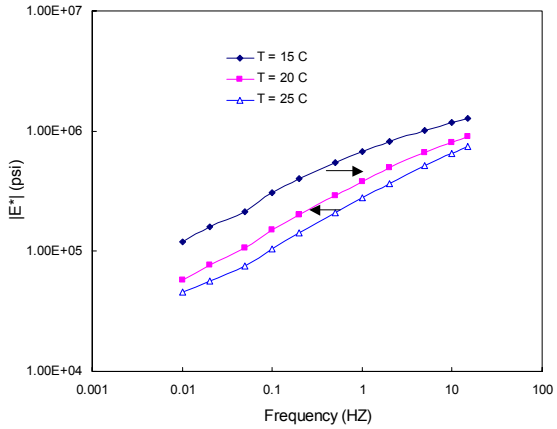
Figure 5-2 Axial stiffness versus frequency for SP 19-mm mixes



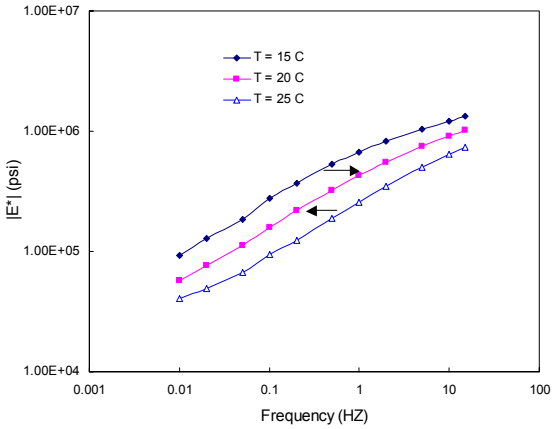
12.5-mm mix with optimum AC, V_a=3.8%



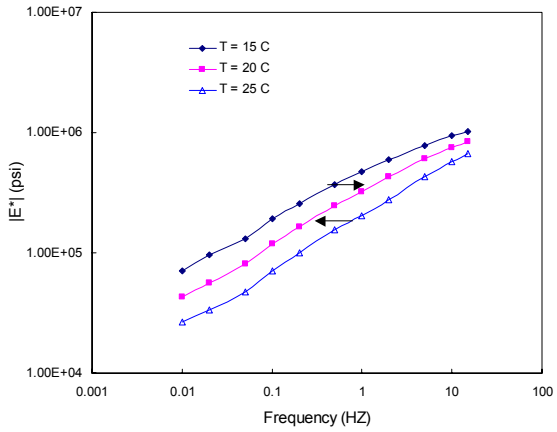
12.5-mm mix with optimum minus 0.5-percent AC, V_a=4.5%



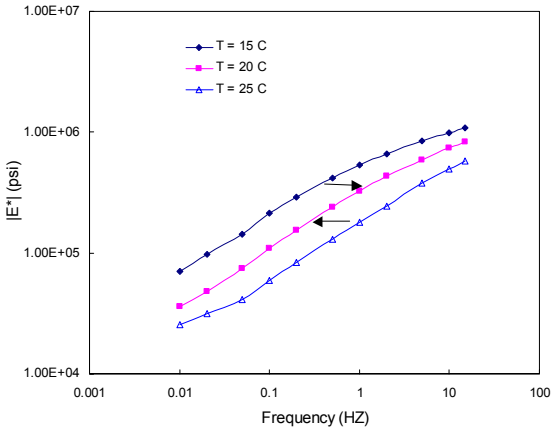
12.5-mm mix with optimum AC, V_a=6%



12.5-mm mix with optimum minus 0.5-percent AC, V_a=6.1%



12.5-mm mix with optimum AC, V_a=7%



12.5-mm mix with optimum minus 0.5-percent AC, V_a=7.8%

Figure 5-3 Axial stiffness versus frequency for SP 12.5-mm mixes

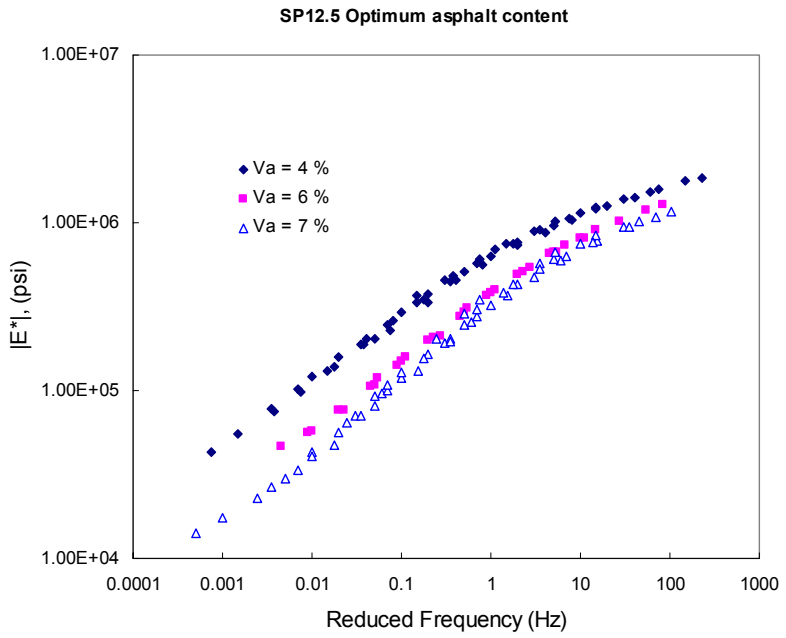


Figure 5-4 Master curves for SP 12.5-mm mix with optimum AC

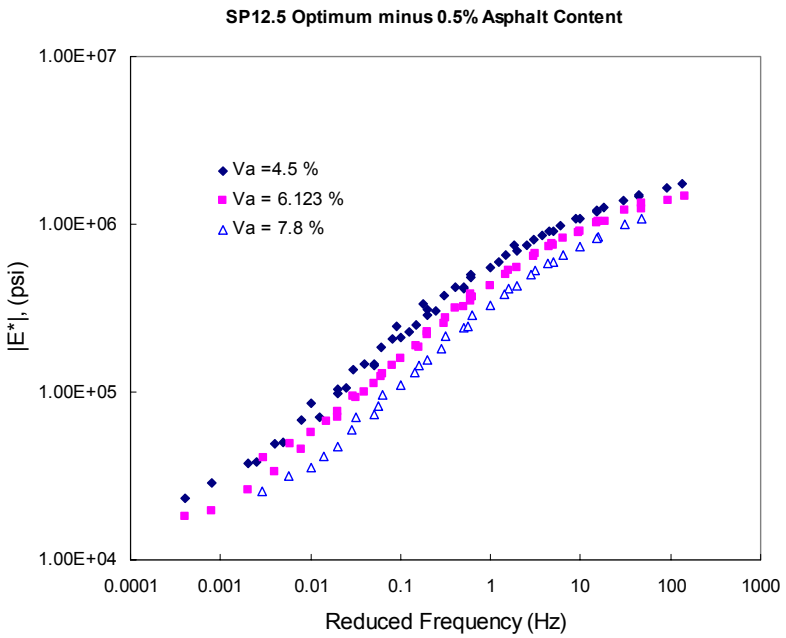


Figure 5-5 Master curves for SP 12.5-mm mix with optimum minus 0.5-percent AC

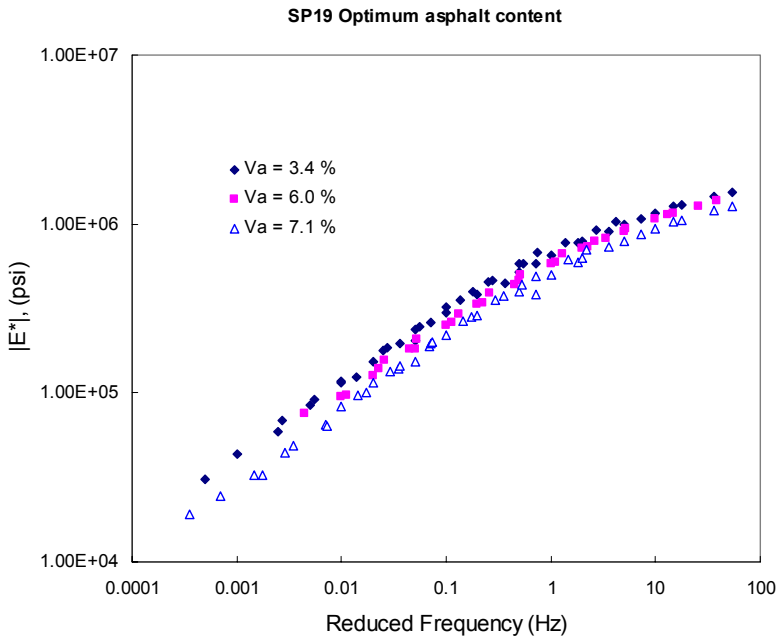


Figure 5-6 Master curves for SP 19-mm mix with optimum AC

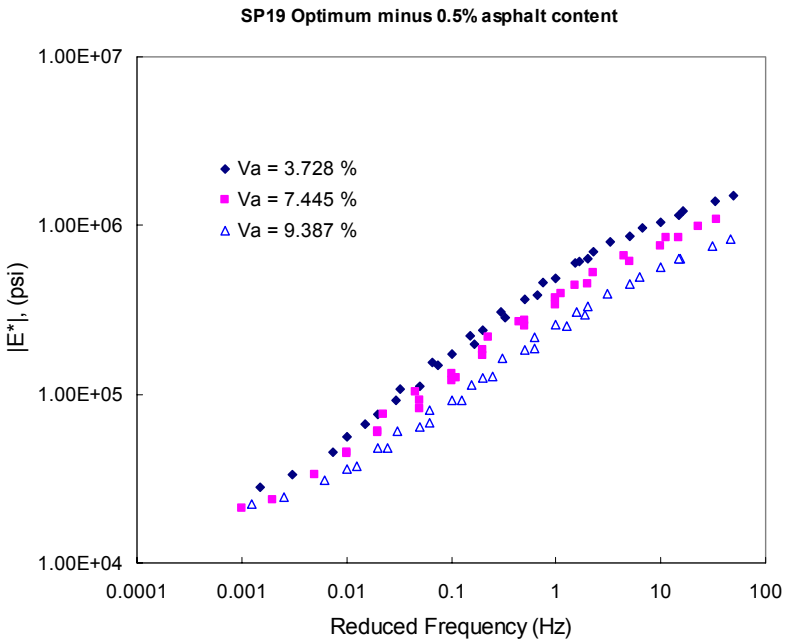
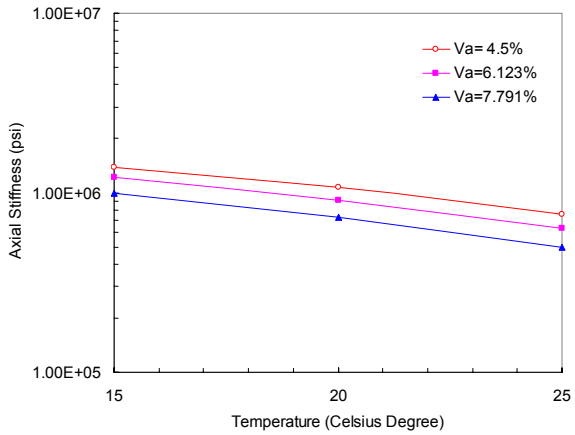
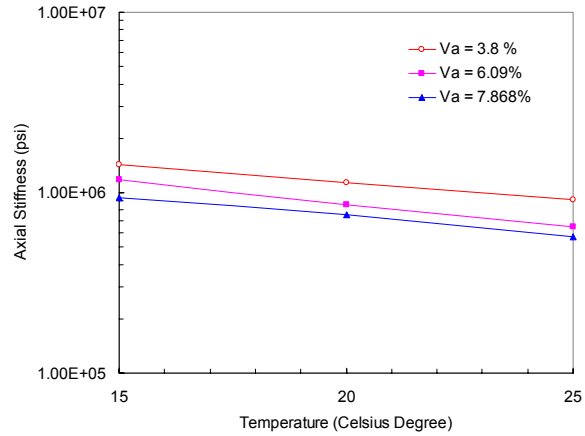


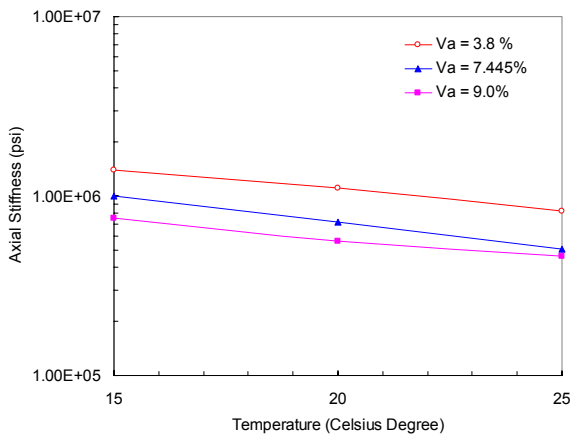
Figure 5-7 Master curves for SP 19-mm mix with optimum minus 0.5% AC



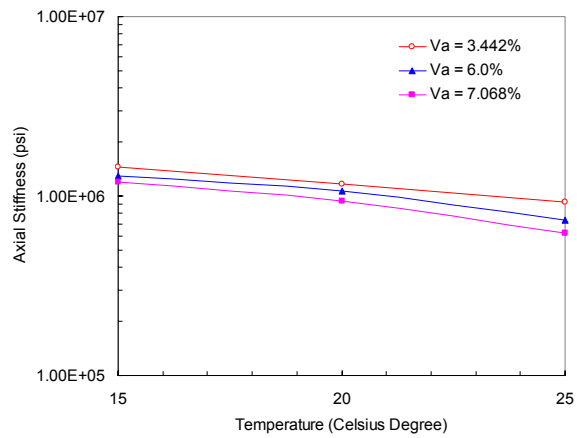
SP 12.5-mm mix with optimum minus 0.5-percent asphalt content



SP 12.5-mm mix with optimum asphalt content

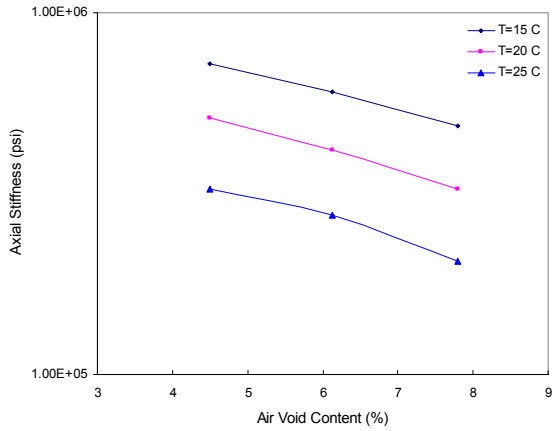


SP 19-mm mix with optimum minus 0.5-percent asphalt content

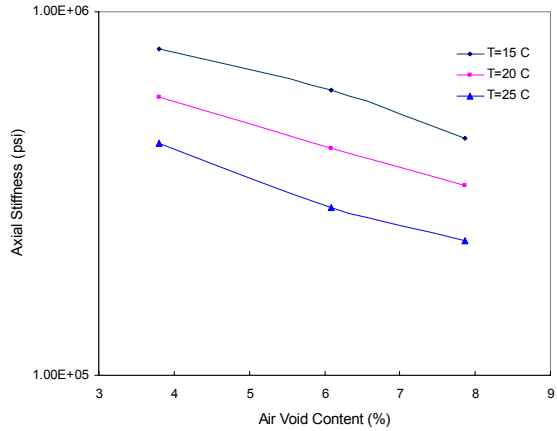


SP 19-mm mix with optimum asphalt content

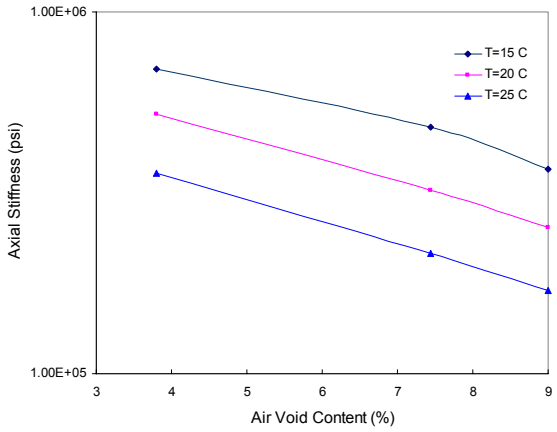
Figure 5-8 Evolution of axial stiffness with temperature



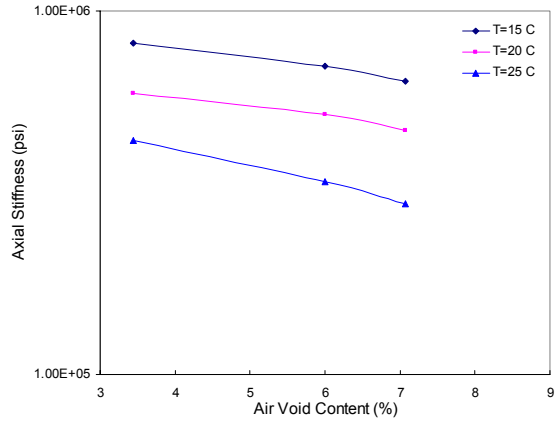
SP 12.5-mm mix with optimum minus 0.5-percent asphalt content



SP 12.5-mm mix with optimum asphalt content



SP 19-mm mix with optimum minus 0.5-percent asphalt content



SP 19-mm mix with optimum asphalt content

Figure 5-9 Evolution of axial stiffness with air void content

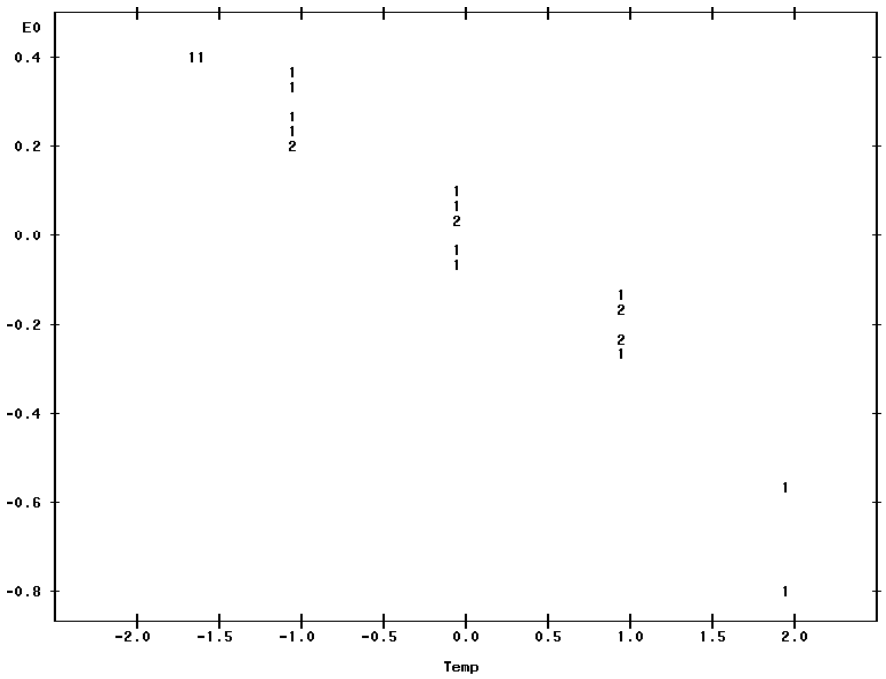


Figure 5-10 Partial regression residual plot of Temp for SP 12.5-mm mix with optimum AC

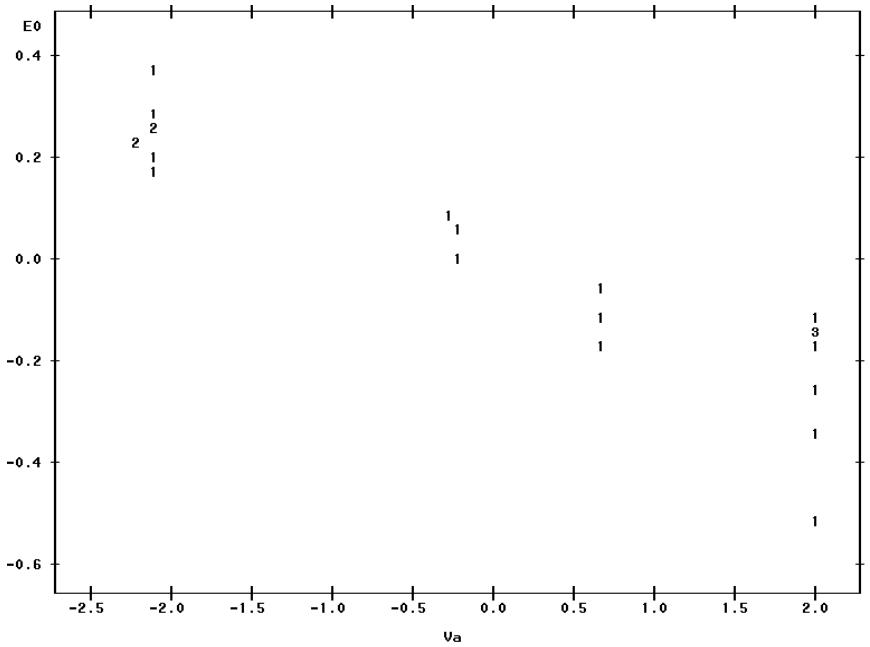
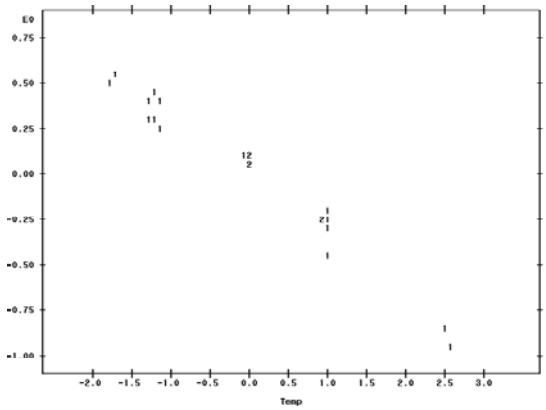
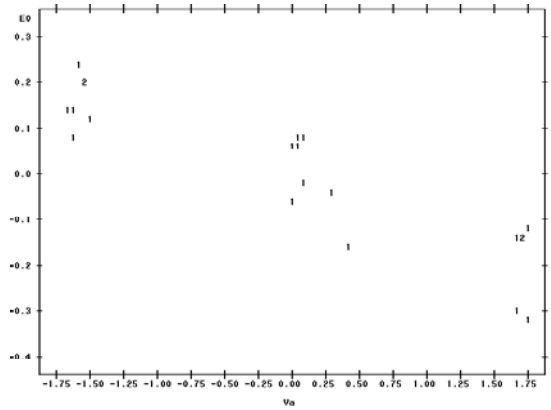


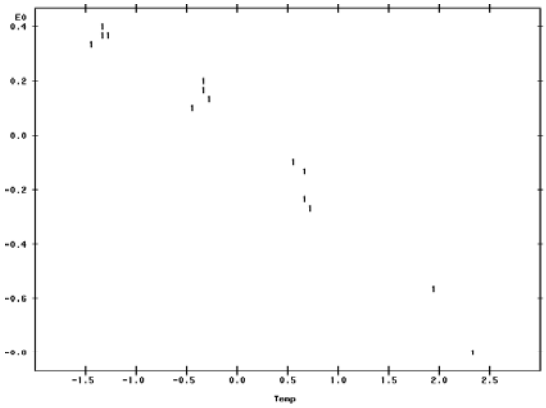
Figure 5-11 Partial regression residual plot of V_a for SP 12.5-mm with optimum AC



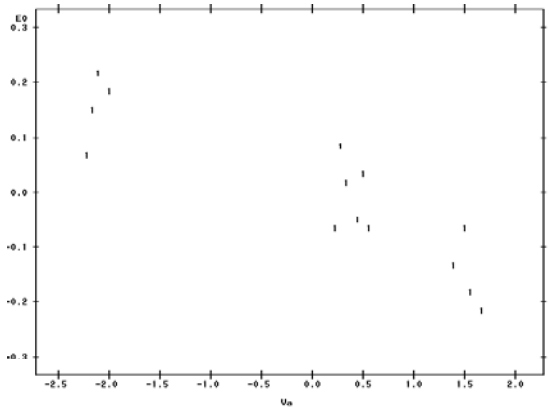
SP 12.5-mm mix with optimum minus 0.5-percent AC



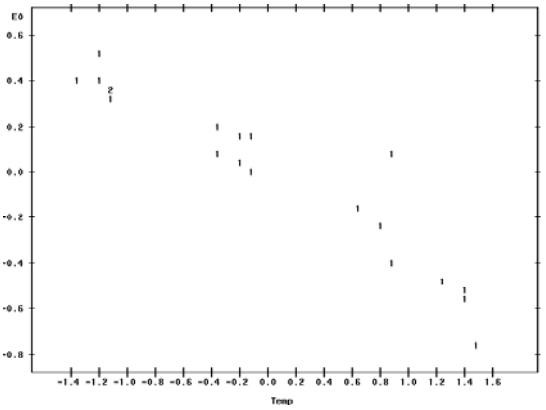
SP 12.5-mm mix with optimum minus 0.5-percent AC



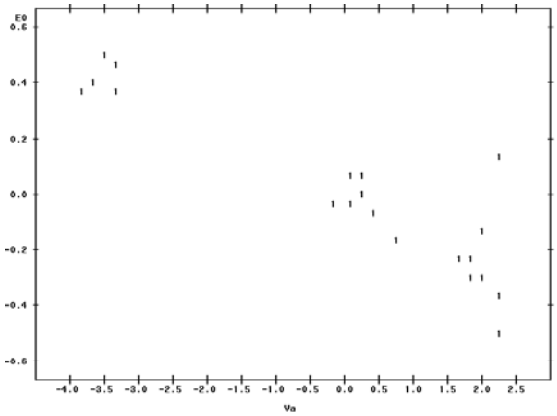
SP 19-mm mix with optimum AC



SP 19-mm mix with optimum AC



SP 19-mm mix with optimum minus 0.5-percent AC



SP 19-mm mix with optimum minus 0.5-percent AC

Figure 5-12 Partial regression residual plot of temperature and air void content

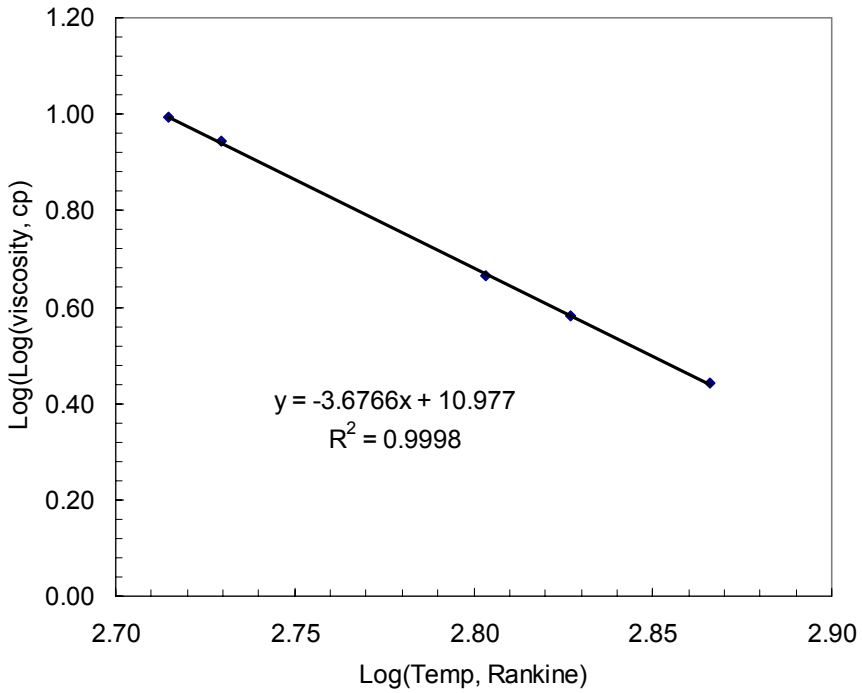
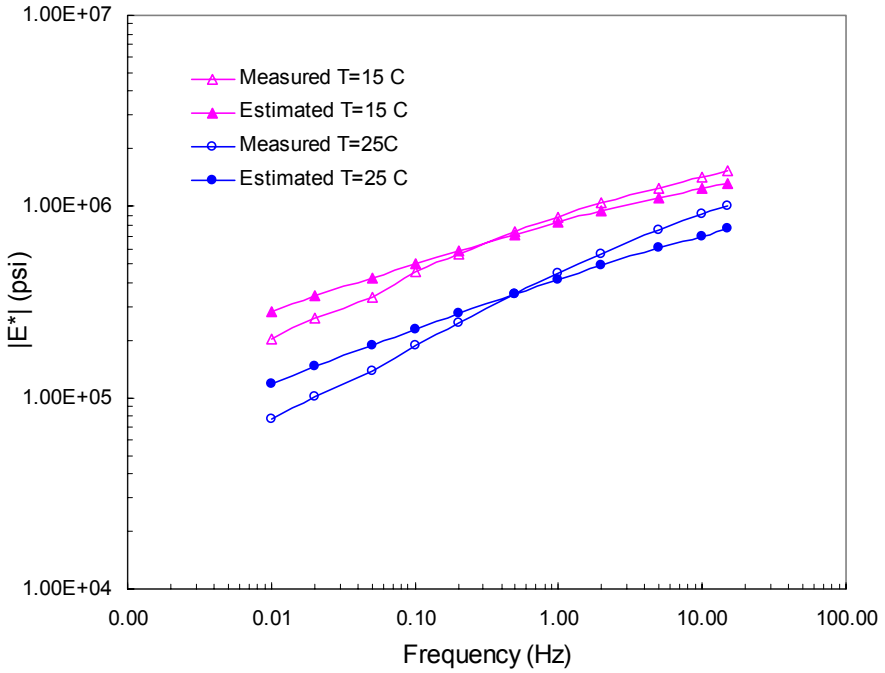
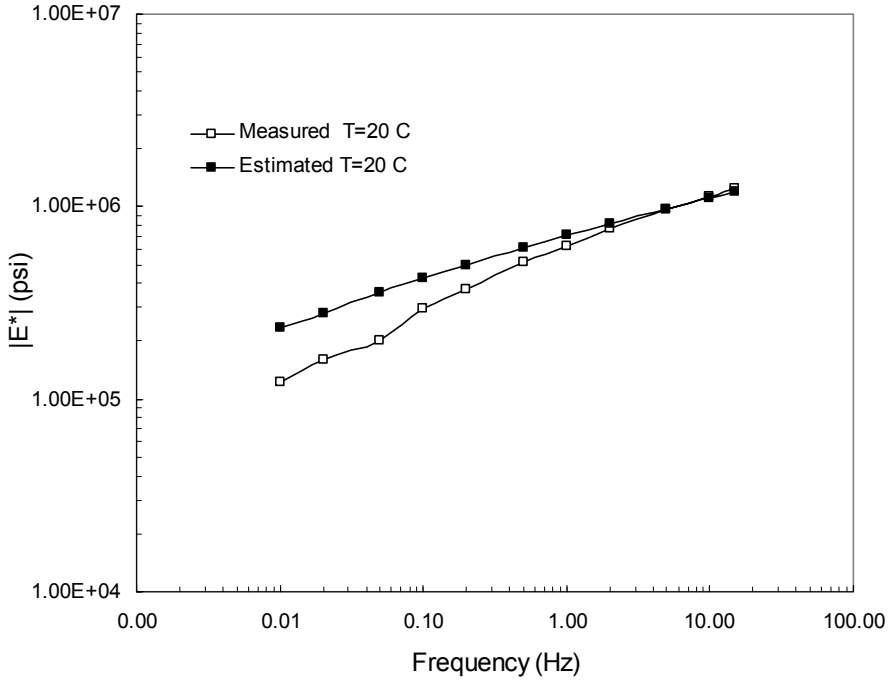


Figure 5-13 Viscosity-temperature relationship

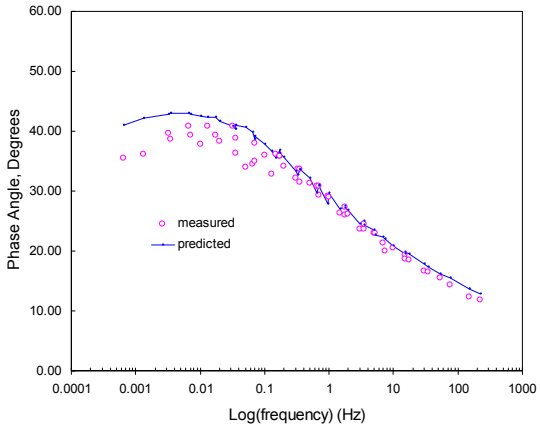


(a) T=15, 25°C

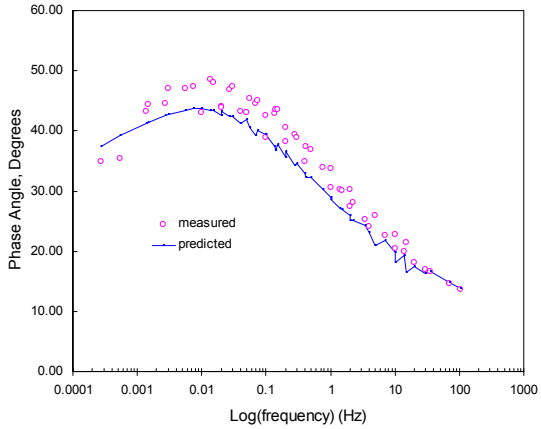


(b) T=20°C

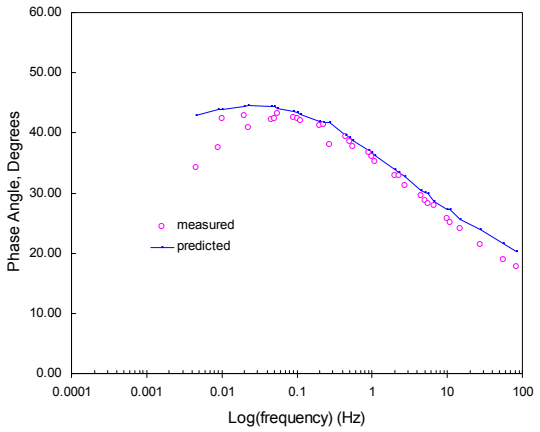
Figure 5-14 Comparison of axial stiffness between lab measured and estimated by Witczak model, V_a = 3.8%, SP 12.5-mm mix with optimum AC



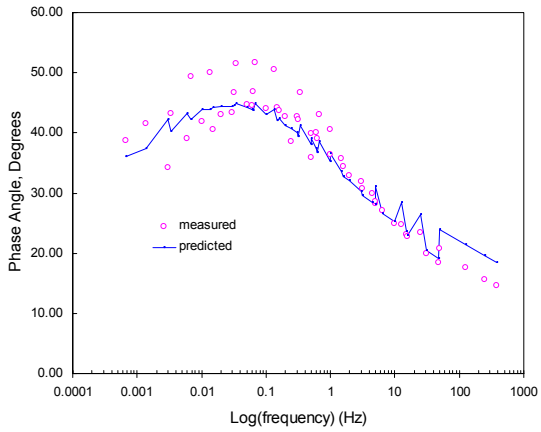
optimum AC, V_a=4%



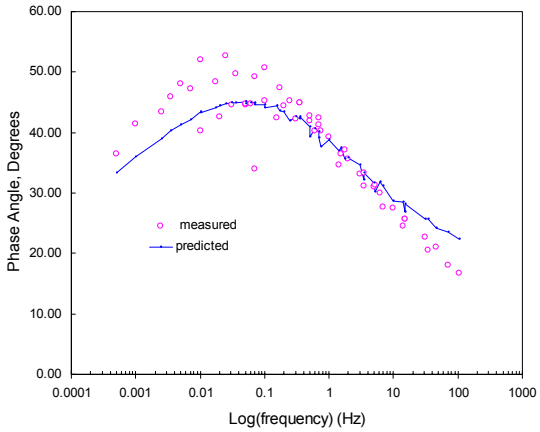
optimum minus 0.5-percent AC, V_a=4.5%



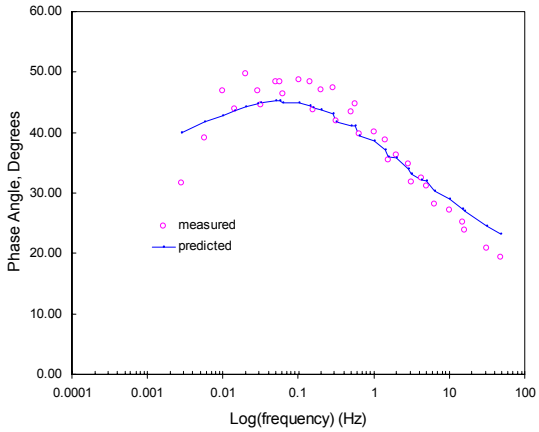
optimum AC, V_a=6%



optimum minus 0.5-percent AC, V_a=6%

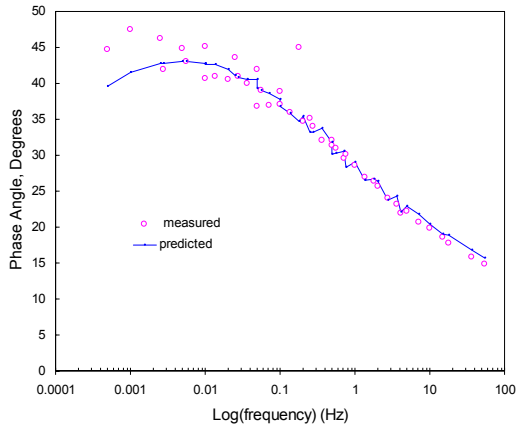


optimum AC, V_a=7%

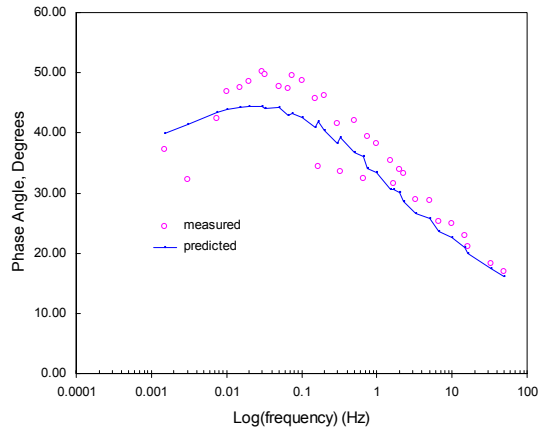


optimum minus 0.5-percent AC, V_a=7.8%

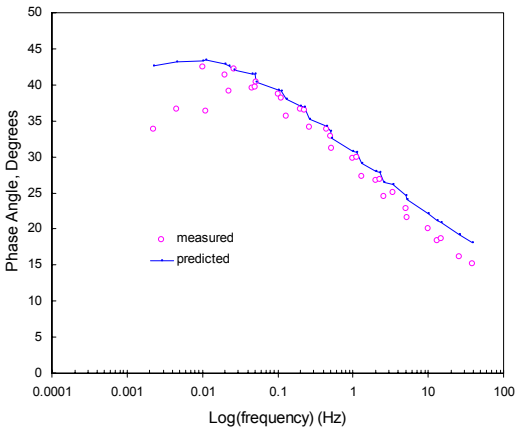
Figure 5-15 Comparison between calculated and measured phase angle for 12.5-mm mixes



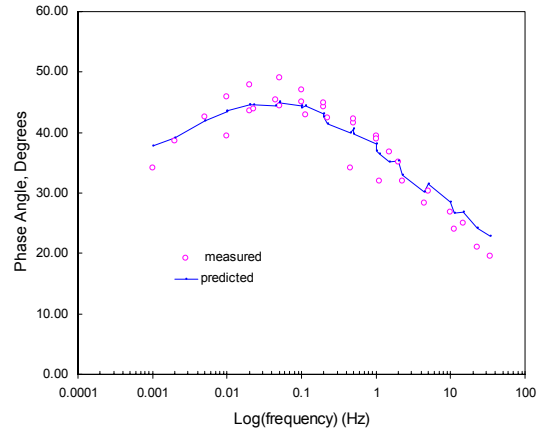
optimum AC, V_a=3.4%



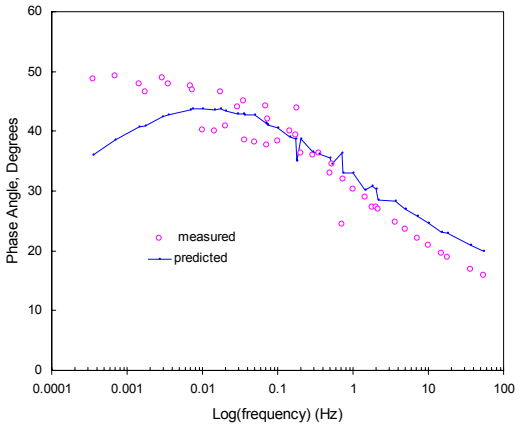
optimum minus 0.5-percent AC, V_a=3.7%



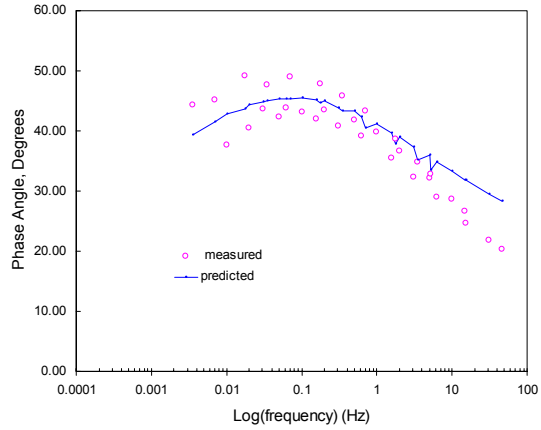
optimum AC, V_a=6%



optimum minus 0.5-percent AC, V_a=7.4%



optimum AC, V_a=7%



optimum minus 0.5-percent AC, V_a=9.4%

Figure 5-16 Comparison between calculated and measured phase angle for 19-mm mixes

6. Shear Frequency Sweep Testing

6.1 Introduction

For shear frequency sweep test (FSCH), horizontal loading is applied at different temperature and frequencies. A cylinder specimen was used in this study with 6 in diameter by 2 in height. This test measures the shear viscoelastic properties (dynamic shear modulus, |G*| and the phase shift (ϕ)) over a range of testing frequencies and at temperatures.

This test can be conducted in a controlled stress or strain mode of loading. In this study, testing was conducted in accordance with AASHTO TP7 Procedure E [4] in which a sinusoidal shear strain of amplitude ±0.005% (0.0001 mm/mm peak-to-peak strain) is applied at frequencies of 15, 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02, and 0.01 Hz. At each frequency, the stress response is measured along with the phase shift between the stress and strain. The dynamic shear stiffness (|G*|) is computed as the ratio of the stress over strain. Since this test is considered to be nondestructive, the same specimen was tested under different temperature. By using time-temperature superposition technique, master curves for the mix was obtained. The |G*| and phase angle can be used as input to evaluate the response and performance of the mixes subjected to traffic loads. Complex shear modulus of the HMA can also be extracted from master curves by using nonlinear regression and optimization techniques.

Variables that may affect the shear stiffness of asphalt mixes are considered to be asphalt type and grade, aggregate type and gradation, air void content, temperature,

loading frequency, aging and moisture conditioning. The significant variables included in this study are asphalt content, air void content, temperature and gradation. The specific objectives of this task was to investigate how the various factors influence the dynamic shear stiffness, and develop a predicative model based on various factors for the mixes studied in this study.

6.2 Experiment design

Table 6-1 shows the experimental design for shear frequency sweep testing. This design parallels the fatigue test and axial frequency test. Each of 12 mixes was tested under three different temperatures. The total number of shear tests conducted was 72.

6.3 Shear frequency sweep test results

Figure 6-1 and Figure 6-2 shows the dynamic shear modulus versus frequency for SP 12.5-mm and 19-mm mixes for different temperatures and air void contents, respectively.

The time-temperature superposition principal was applied to the data to obtain master curve at 20°C. Assuming that the viscoelastic response of the material is to be controlled by a single function of temperature (i.e., a single rate controlling mechanism), time shift factor can be evaluated as

$$\log(\alpha_T) = \log(\frac{t_T}{t_{T_0}}) = \log(\frac{f_{T_0}}{f_T}) \tag{6-1}$$

where,

α_T = shift factor that is dependent on the difference between the reference temperature and data temperatures;

f_T, f_{T_0} = frequency required to reach a specific |G*|at temperature T and T_0.

By using time-temperature superposition technique, master curve for each mix was obtained. Figure 6-3 to Figure 6-6 show master curves for SP 12.5-mm mix with optimum AC, SP 12.5-mm mix with optimum minus 0.5-percent AC, SP 19-mm mix with optimum AC, and SP 19-mm mix with optimum minus 0.5-percent AC, respectively. Each figure shows a fairly consistent trend, i.e., the lower the air void contents of the mix, the higher the dynamic modulus is.

6.4 Analysis of shear stiffness

This section deals with analysis of shear stiffness data. The sensitivity of shear stiffness to various mix and test parameters is investigated using statistical analysis, and surrogate models are developed for the prediction of shear stiffness and shear loss stiffness.

6.4.1 Surrogate model for shear stiffness

The shear stiffness model development procedure followed is similar to that employed for fatigue characterization. The models presented in this section are the general models for shear stiffness (|G*|), shear loss stiffness (G"), and shear stiffness $\left|G^*\right|_{10Hz}$ at 10 Hz.

Table 6-2 through Table 6-4 provides summary of regression analysis for the various models. The shear stiffness models based on GLM are as follows:

At 10 Hz frequency

$$\left|G^*\right|_{10Hz} = 10.7313\times10^5 \exp(-0.04504AC + 0.05947GR - 0.34265Temp - 0.1564V_a) \qquad R^2 = 0.71 \qquad (6.2)$$

For varying frequency, the general models are

$$\left|G^*\right| = 4.297\times10^5 \exp(0.05805AC + 0.08957GR - 0.57338Temp - 0.1703V_a)\cdot(Freq)^{0.4775} \qquad R^2 = 0.91 \qquad (6.3)$$

$$G'' = 1.496\times10^5 \exp(-0.0195AC + 0.04779GR - 0.32727Temp - 0.13927V_a)\cdot(Freq)^{0.3091} \qquad R^2 = 0.71 \qquad (6.4)$$

where,

$|G^*|$, G''= shear stiffness, and loss stiffness in psi;

AC = asphalt content: -1 and +1 for optimum minus 0.5-percent and optimum;

GR = aggregate gradation: -1 and +1 for SP 12.5-mm and SP 19-mm;

V_a = air void content in percent;

Temp = test temperature: -1, 0 and 1 for 15, 20 and 25°C;

$Freq$ = frequency in Hz;

exp = e: base of natural log.

It can be seen from these models that shear stiffness as well as loss stiffness is sensitive to all mix and test variables considered in this study.

6.4.2 Surrogate models for phase angle

The summary of regression analysis for shear phase angle is given in Table 6-5. It was found in this study that the phase angle is dependent on |G*| and the frequency. The model at variable frequency is:

$$\phi = -58.75 + 58.45\cdot\log|G^*| - 7.87\cdot(\log|G^*|)^2 - 1.41\cdot\log(f) \qquad R^2 = 0.77 \qquad (6.5)$$

where,

ϕ = phase angle in degree,

$|G^*|$ = shear dynamic modulus, and

f = frequency in Hz, and

log = logarithm to base 10.

For the phase angle at 10 Hz frequency, equation 6.5 reduces to:

$$\phi = -59.86 + 58.45 \cdot \log|G^*| - 7.87 \cdot (\log|G^*|)^2 \qquad R^2 = 0.77 \tag{6.6}$$

6.5 Relationships between axial and shear modulus

The summary of regression analysis between axial and shear stiffness is given in Table 6-6 and Table 6-7. For mixes considered in this study, the axial stiffness can reliably be estimated from shear stiffness through the following regression equations:

$$\left|E^*\right|_{10Hz} = 37.6 \cdot \left|G^*\right|_{10Hz}^{0.78114} \qquad R^2 = 0.96 \tag{6.7}$$

$$E''_{10Hz} = 79.28 \cdot (G'')_{10Hz}^{0.71735} \qquad R^2 = 0.93 \tag{6.8}$$

where,

$|E^*|$, $|G^*|$ = axial and shear dynamic stiffness, respectively; and

E'', G'' = axial and shear loss-stiffness, respectively.

The use of equations 6.7 and 6.8 will be elaborated in the following section.

6.6 Shear frequency sweep test for field cores

In the previous section, a relationship between axial stiffness and shear stiffness was presented. This relationship presents a useful tool for forensic analysis of pavement sections.

For mechanistic analysis, it is required either to evaluate the axial stiffness in laboratory or to evaluate it using models. However, laboratory evaluation of axial stiffness for field sample is often a difficult task, especially for pavement sections with thin layers. An alternative method is to obtain field cores that are tested in shear mode of loading to evaluate the shear stiffness $|G^*|$. Once the shear stiffness of a mix is known, the axial stiffness can be estimated using equations 6.7 and 6.8. Then, the procedure outlined in chapter 7 can be used for mechanistic analysis and for determining the fatigue resistance of pavement section under consideration.

In this study, six in diameter field cores were obtained to conduct shear frequency sweep test. From each core a 2 in height specimen was obtained for both 12.5-mm and 19-mm mixes. Tests were conducted at 15, 20 and 25°C. Four specimens were tested for each mix. The data are presented in Appendix F. The average air void content for these mixes varied between 7.5 to 8.1-percent for both mixes.

Table 6-8 and Table 6-9 show the average test results for the 12.5-mm and 19-mm aggregate size cores, respectively, as function of temperature and frequency. Figure 6-7 and Figure 6-8 show the $|G^*|$ value as a function of reduced frequency at 20°C.

The comparison between the field $|G^*|$ and lab $|G^*|$ at 10 Hz frequency is presented in Table 6-9 and Table 6-10. It can be seen that there is a fair amount of scatter

in the data for both field $|G^*|$ values and the corresponding phase angle. The field $|G^*|$ value at 10 Hz is less than the lab evaluated values.

6.7 Summary

In this chapter, the shear frequency sweep test data were analyzed and the following conclusion may be drawn based on the results.

(1) Analysis shows that the shear stiffness data follow the time-temperature superposition principle.

(2) Regression models developed show that shear stiffness is sensitive to all mix and test variables considered in this study.

(3) There is a good correlation between axial and shear stiffness.

(4) The shear stiffness of field cores was found to be lower as compared to the lab evaluated shear stiffness.

Table 6-1 Mix and test variables for FSCH experiment design

Number of asphalts	1-PG64-22
Number of aggregate gradations	2-12.5-mm and 19-mm intermediate
Asphalt Contents	2-Superpave opti. and opt. minus 0.5-percent
Air Void Levels	3- About 4, 6, and 8-percent
Temperatures	3- 15°C, 20°C, and 25°C
Test Frequency	0.1 to 15 Hz for shear frequency sweep test
Specimen Size	6-in diam. x 2-in high shear test specimen
Replicates	2- for shear tests
Total Number of Mixes	12- 2 gradations, 2 asphalt content, 3 air void
Number of Shear Tests	2 replicates x 12 mixes x 3 = 72

Table 6-2 Summary of statistical analysis for $|G^*|$ at 10 Hz

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	13.40945	3.35236	57.25	<.0001
Error	88	5.15268	0.05855		
Corrected Total	92	18.56213			
Root MSE	0.24198	Coeff. Var	1.86294	R_Square	0.7224
Dependent Mean	12.98899			Adj R_Sq	0.7098
Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	13.88609	0.09095	152.68	<.0001	0
Temp	-0.34265	0.03089	-11.09	<.0001	1.0001
AC	-0.04504	0.02568	-1.75	0.0829	1.01234
GR	0.05947	0.02577	2.31	0.0234	1.01945
V_a	-0.1564	0.01568	-9.98	<.0001	1.00718

Table 6-3 Summary of statistical analysis for $|G^*|$ at variable frequency

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1631.958	326.3915	2189.29	<.0001
Error	1022	152.3657	0.14909		
Corrected Total	1027	1784.323			
Root MSE	0.38612	Coeff. Var	3.32337	R_Square	0.9146
Dependent Mean	11.61821			Adj R_Sq	0.9142
Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	12.97083	0.04393	295.28	<.0001	0
Temp	-0.57338	0.0148	-38.73	<.0001	1.00017
AC	0.05805	0.01233	4.71	<.0001	1.0111
GR	0.08957	0.01235	7.25	<.0001	1.01824
Va	-0.1703	0.00754	-22.58	<.0001	1.00702
Log(f)	1.09948	0.01163	94.55	<.0001	1.00009

Table 6-4 Summary of statistical analysis for |G"| at variable frequency

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	681.1776	136.2355	497.02	<.0001
Error	1022	280.1376	0.27411		
Corrected Total	1027	961.3152			
Root MSE	0.52355	Coeff. Var	4.81559	R_Square	0.7086
Dependent Mean	10.87203			Adj R_Sq	0.7072
Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	11.91586	0.05956	200.06	<.0001	0
Temp	-0.32727	0.02007	-16.3	<.0001	1.00017
AC	-0.0195	0.01671	-1.17	0.2435	1.0111
GR	0.04779	0.01674	2.85	0.0044	1.01824
Va	-0.13927	0.01023	-13.62	<.0001	1.00702
Log(f)	0.71177	0.01577	45.14	<.0001	1.00009

Table 6-5 Summary of statistical analysis for phase angle

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	168128	56043	1160.49	<.0001
Error	1024	49451	48.29217		
Corrected Total	1027	217580			
Root MSE	6.94926	Coeff. Var	20.71	R_Square	0.7727
Dependent Mean	33.55484			Adj R_Sq	0.7721
Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	-58.7491	16.22962	-3.62	0.0003	
Log|G*|)	58.45281	6.56387	8.91	<.0001	
Log|G*|)* Log|G*|)	-7.87732	0.6645	-11.85	<.0001	
Log(f)	-1.41069	0.41435	-3.4	0.0007	

Table 6-6 Summary of statistical analysis for |E*| versus |G*|

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	3.21452	3.21452	780.3	<.0001
Error	34	0.14007	0.00412		
Corrected Total	35	3.35459			
Root MSE	0.06418	Coeff. Var	0.4685	R_Square	0.9582
Dependent Mean	13.70003			Adj R_Sq	0.957
Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	3.62685	0.36077	10.05	<.0001	0
Ln(G)	0.78114	0.02796	27.93	<.0001	1

Table 6-7 Summary of statistical analysis for |E"| versus |G"|

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.34649	0.34649	431.1	<.0001
Error	34	0.02733	0.000804		
Corrected Total	35	0.37382			
Root MSE	0.02835	Coeff. Var	0.22112	R_Square	0.9269
Dependent Mean	12.82133			Adj R_Sq	0.9247
Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	4.37294	0.40693	10.75	<.0001	0
Ln(G)	0.71735	0.03455	20.76	<.0001	1

Table 6-8 Average shear test data for field samples, SP 12.5-mm mix

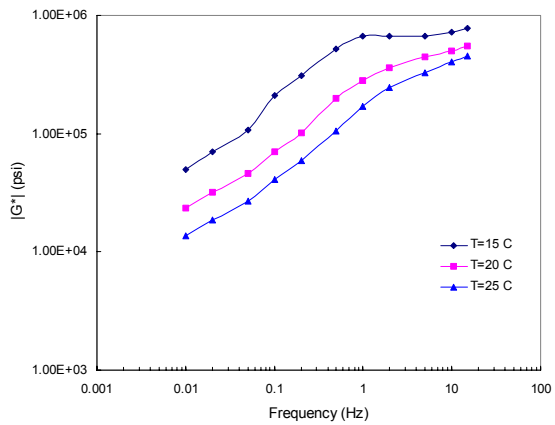
Frequency (Hz)	T=15°C		T=20°C		T=25°C	
	|G*| (psi)	ϕ (Degree)	|G*| (psi)	ϕ (Degree)	ϕ (Degree)	|G*| (psi)
15	3.41E+05	17	1.89E+05	25	1.97E+05	26
10	3.14E+05	18	1.69E+05	26	1.72E+05	27
5	2.61E+05	21	1.35E+05	29	1.32E+05	31
2	2.06E+05	23	1.00E+05	33	9.09E+04	34
1	1.67E+05	28	7.65E+04	35	6.89E+04	38
0.5	1.30E+05	30	5.79E+04	38	4.93E+04	40
0.2	9.30E+04	33	3.94E+04	40	3.05E+04	43
0.1	7.21E+04	35	2.93E+04	41	2.12E+04	45
0.05	5.20E+04	36	2.07E+04	40	1.42E+04	45
0.02	3.75E+04	38	1.48E+04	42	9.97E+03	45
0.01	2.77E+04	39	1.13E+04	41	7.28E+03	43

Table 6-9 Average shear test data for field samples, SP 19-mm mix

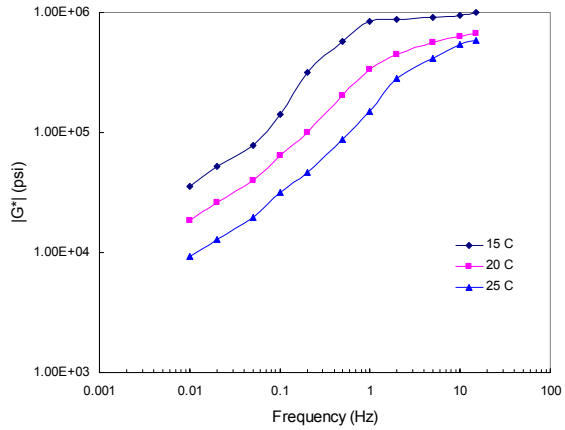
Frequency (Hz)	T=15°C		T=20°C		T=25°C	
	|G*| (psi)	ϕ (Degree)	|G*| (psi)	ϕ (Degree)	ϕ (Degree)	|G*| (psi)
15	4.86E+05	18	2.54E+05	21	2.84E+05	27
10	4.47E+05	19	2.31E+05	23	2.45E+05	29
5	3.89E+05	20	1.91E+05	26	1.84E+05	33
2	2.96E+05	25	1.42E+05	30	1.25E+05	38
1	2.85E+05	27	1.10E+05	35	8.93E+04	43
0.5	2.10E+05	31	8.21E+04	38	6.21E+04	46
0.2	1.27E+05	36	5.44E+04	42	3.74E+04	50
0.1	9.57E+04	39	3.94E+04	43	2.47E+04	51
0.05	6.65E+04	40	2.64E+04	45	1.55E+04	51
0.02	4.72E+04	43	1.83E+04	46	1.03E+04	50
0.01	3.28E+04	45	1.35E+04	46	7.53E+03	47

Table 6-10 Comparison of test data between lab and field samples

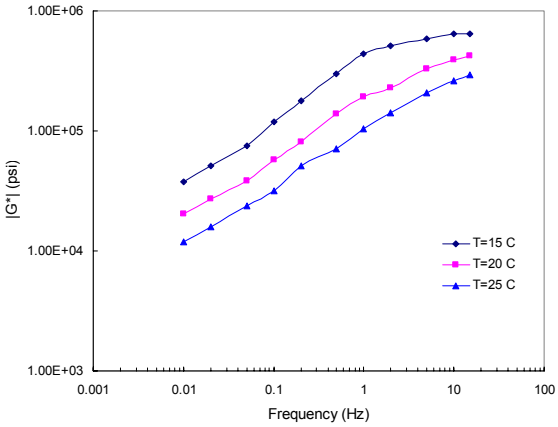
	GR	Temp	V_a	Frequency	Lab $\|G^*\|$	Lab ϕ	Field $\|G^*\|$	Field ϕ
			(%)	(Hz)	(psi)	(degree)	(psi)	(degree)
1	-1	-1	7.7	10	408378.68	20.03	280660.38	20.98
1	-1	-1	7.8	10	399534.01	20.31	316883.73	18.43
1	-1	-1	7.9	10	396421.84	20.41	320151.32	16.68
1	-1	-1	8.1	10	383613.25	20.83	337009.67	16.03
1	-1	0	7.7	10	289902.57	24.30	158321.01	25.51
1	-1	0	7.8	10	283623.85	24.56	165229.88	28.30
1	-1	0	7.9	10	281414.56	24.65	171670.78	25.57
1	-1	0	8.1	10	272321.92	25.04	179017.40	25.02
1	-1	1	7.7	10	205797.96	28.22	157229.88	29.66
1	-1	1	7.8	10	201340.78	28.46	140019.89	27.81
1	-1	1	7.9	10	199772.43	28.54	189186.85	27.65
1	-1	1	8.1	10	193317.69	28.90	202680.93	24.01
1	1	-1	7.9	10	444400.81	18.92	371397.39	18.06
1	1	-1	7.2	10	498148.83	17.39	578948.03	22.95
1	1	-1	7.3	10	491954.82	17.56	420409.23	18.62
1	1	-1	7.4	10	480547.89	17.88	459916.85	16.40
1	1	-1	7.5	10	473831.08	18.07	404731.93	16.68
1	1	0	7.9	10	315474.20	23.28	206634.28	26.23
1	1	0	7.3	10	349232.15	22.02	229184.92	22.78
1	1	0	7.4	10	341134.52	22.31	271434.61	23.62
1	1	0	7.5	10	336366.35	22.49	263734.83	20.88
1	1	1	7.9	10	223950.91	27.28	229282.09	30.39
1	1	1	7.20	10	251036.64	25.99	281716.46	34.53
1	1	1	7.3	10	247915.23	26.13	210263.96	27.48
1	1	1	7.4	10	242166.84	26.40	254903.31	25.88
1	1	1	7.5	10	238781.97	26.56	249171.38	25.70



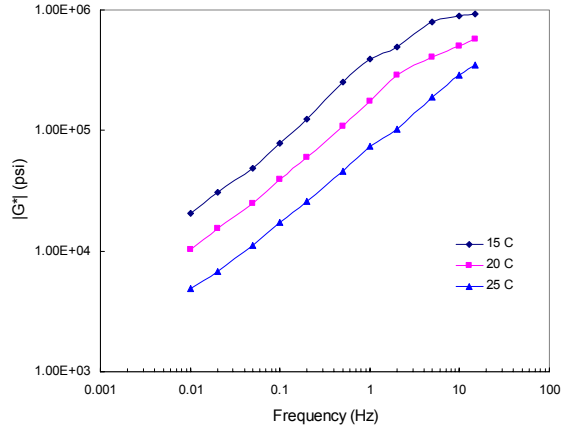
12.5-mm mix with optimum AC, V_a=3.65%



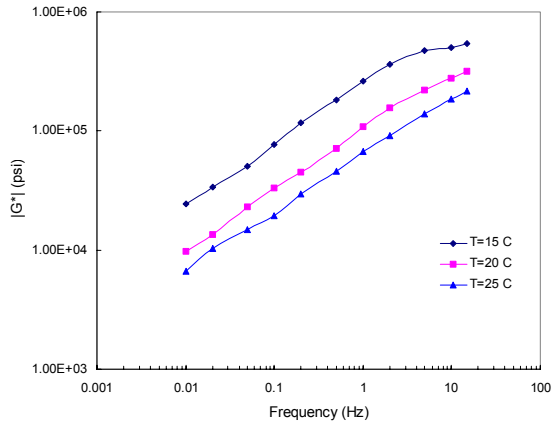
12.5-mm mix with optimum minus 0.5-percent AC, V_a=3.6%



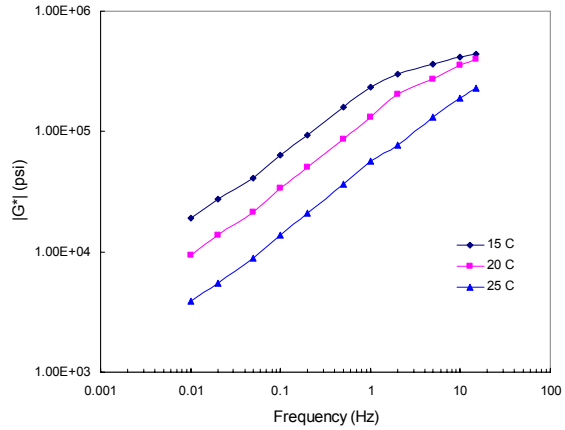
12.5-mm mix with optimum AC, V_a=6.2%



12.5-mm mix with optimum minus 0.5-oercent AC, V_a=5.9%

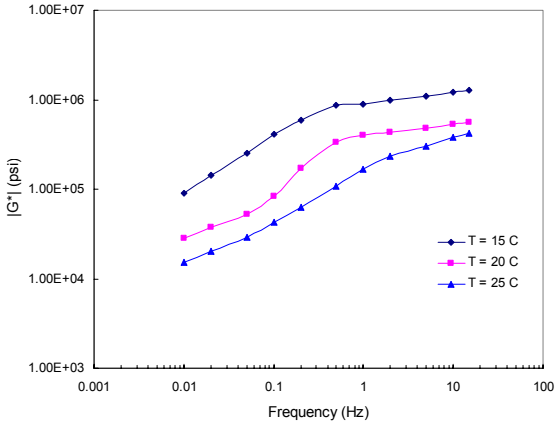


19-mm mix with optimum AC, V_a=7%

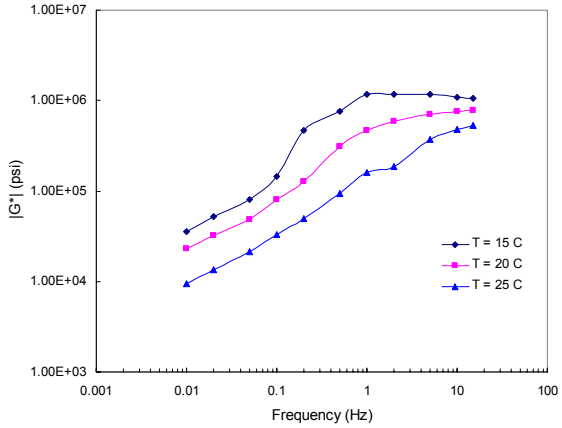


12.5-mm mix with optimum minus 0.5-percent AC, V_a=7.8%

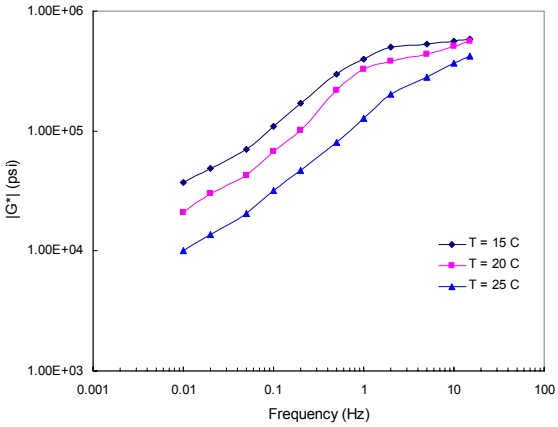
Figure 6-1 Shear stiffness versus frequency for SP 12.5-mm mixes



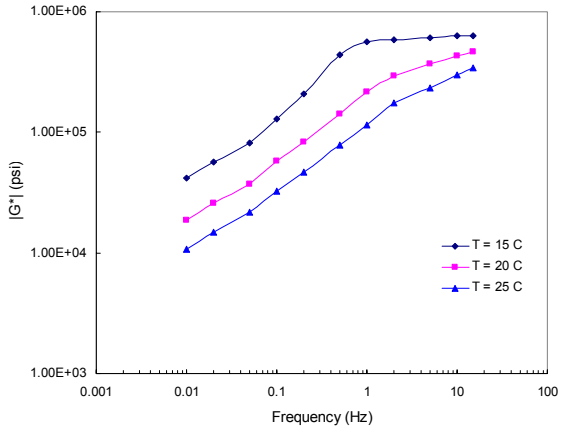
19-mm mix with optimum asphalt content, V_a=3.96%



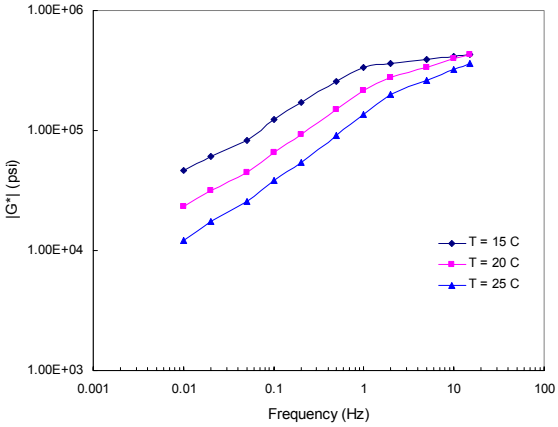
19-mm mix with opti.-0.5% asphalt content, V_a=3.96%



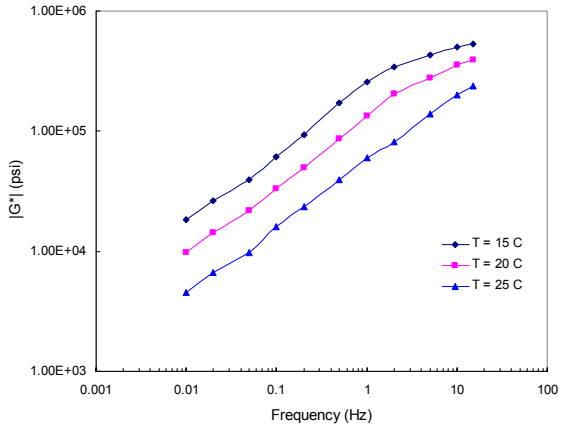
19-mm mix with optimum asphalt content, V_a=5.54%



19-mm mix with opti.-0.5% asphalt content, V_a=5.66%



19-mm mix with optimum asphalt content, V_a=6.33%



19-mm mix with opti.-0.5% asphalt content, V_a=8.06%

Figure 6-2 Shear stiffness versus frequency for SP 19-mm mixes

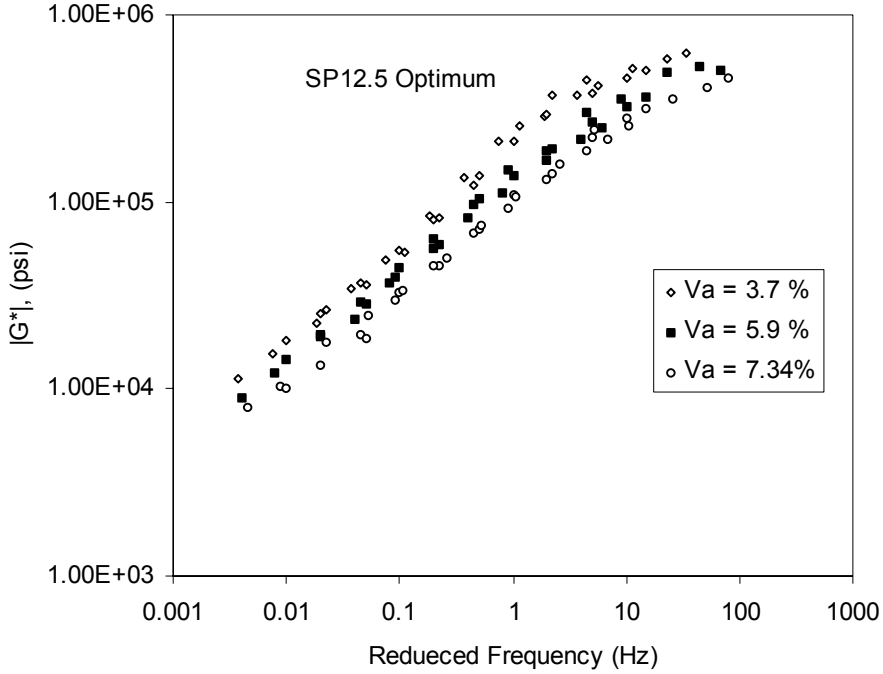


Figure 6-3 Master curves for SP 12.5-mm mix with optimum AC, 20°C

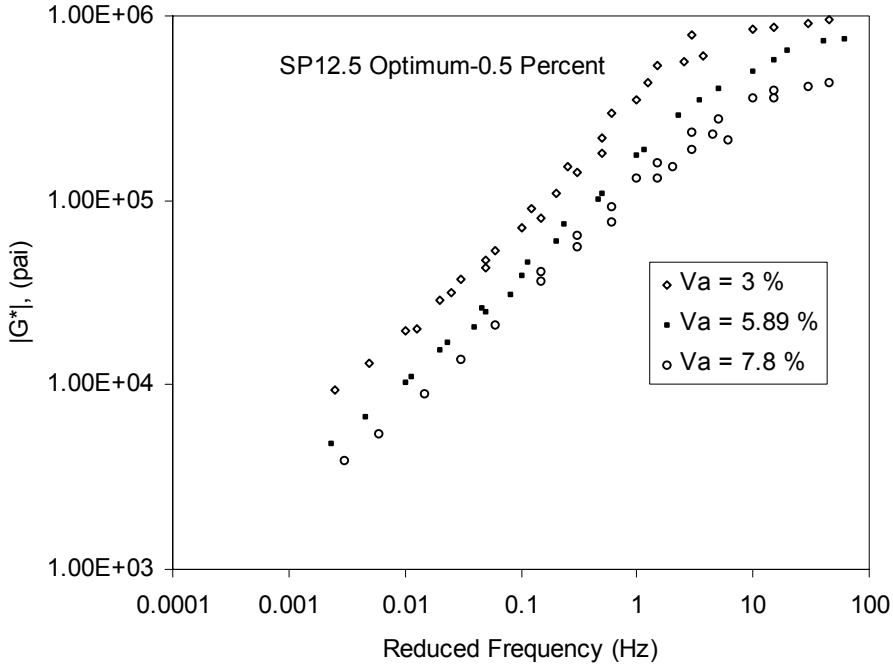


Figure 6-4 Master curves for SP 12.5-mm mix with optimum minus 0.5-percent AC, 20°C

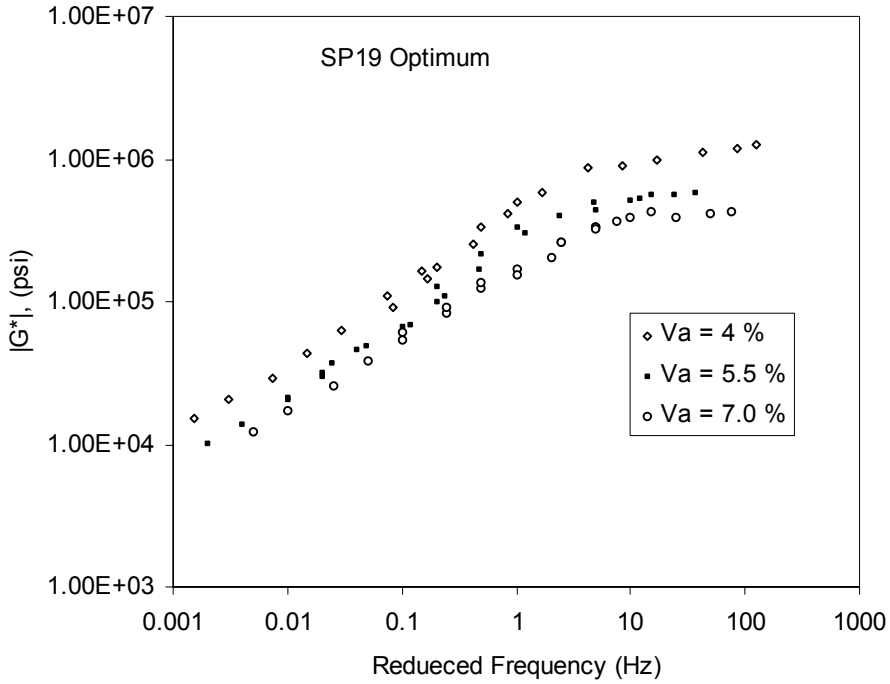


Figure 6-5 Master curves for SP 19-mm mix with optimum AC, 20°C

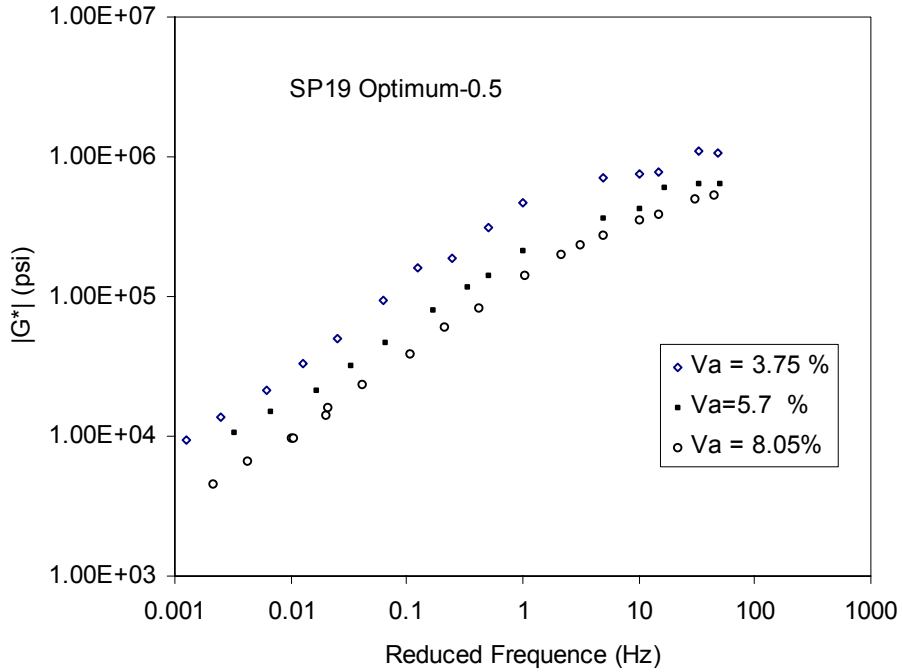


Figure 6-6 Master curves for SP 19-mm with optimum minus 0.5-percent AC, 20°C

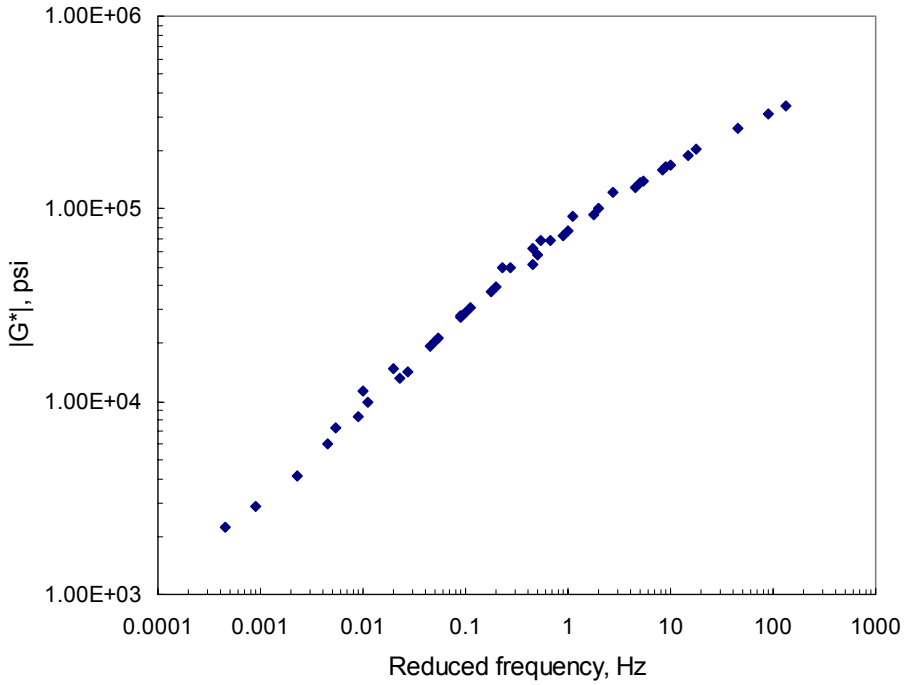


Figure 6-7 Master curve for SP 12.5-mm mix with average V_a = 7.5%, 20°C

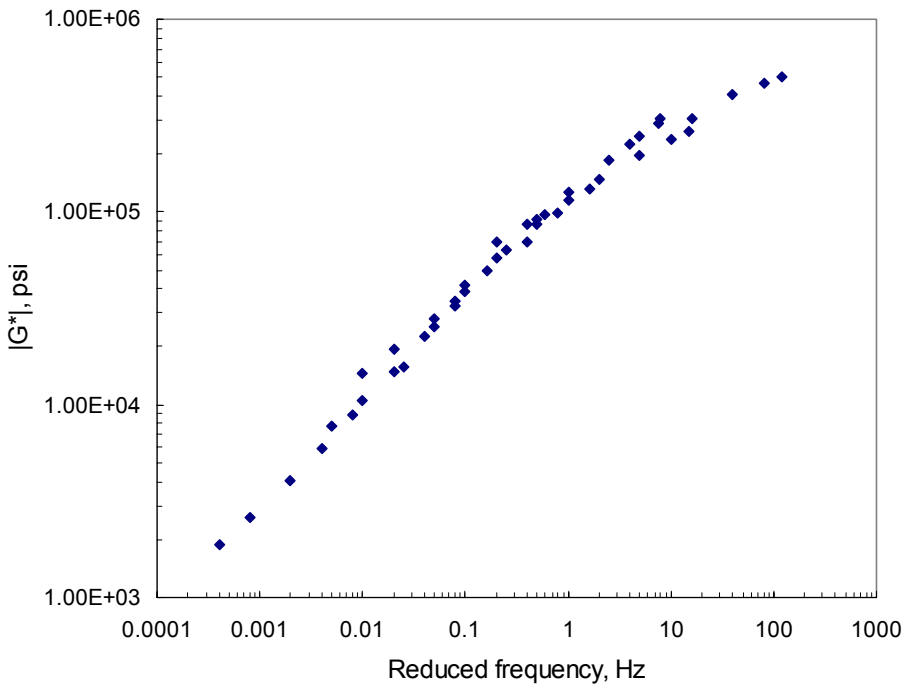


Figure 6-8 Master curve for SP 19-mm mix with average V_a = 7.9%, 20°C

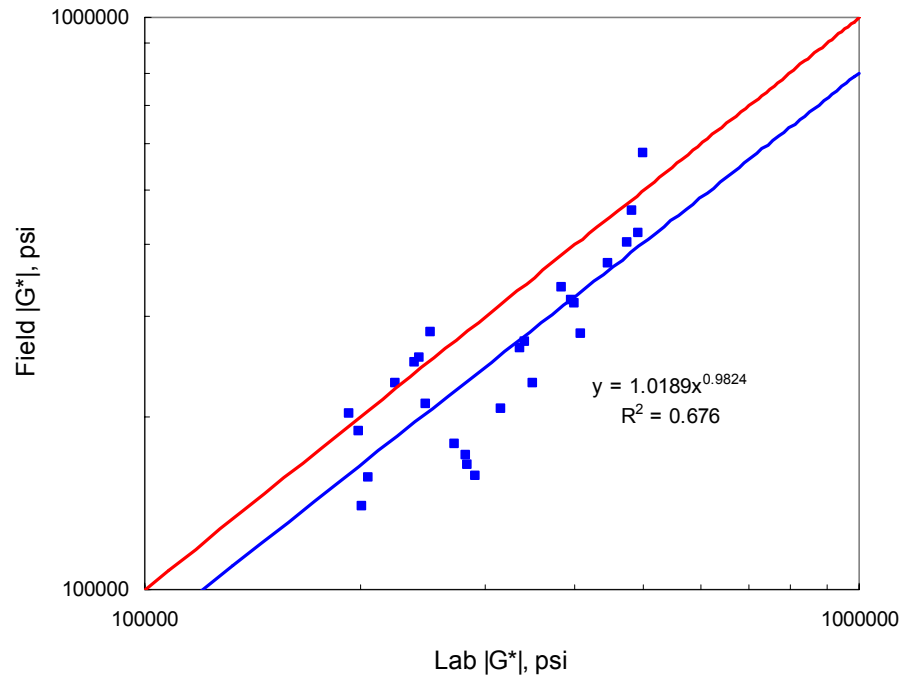


Figure 6-9 Field $|G^*|$ versus lab $|G^*|$ at 10 Hz

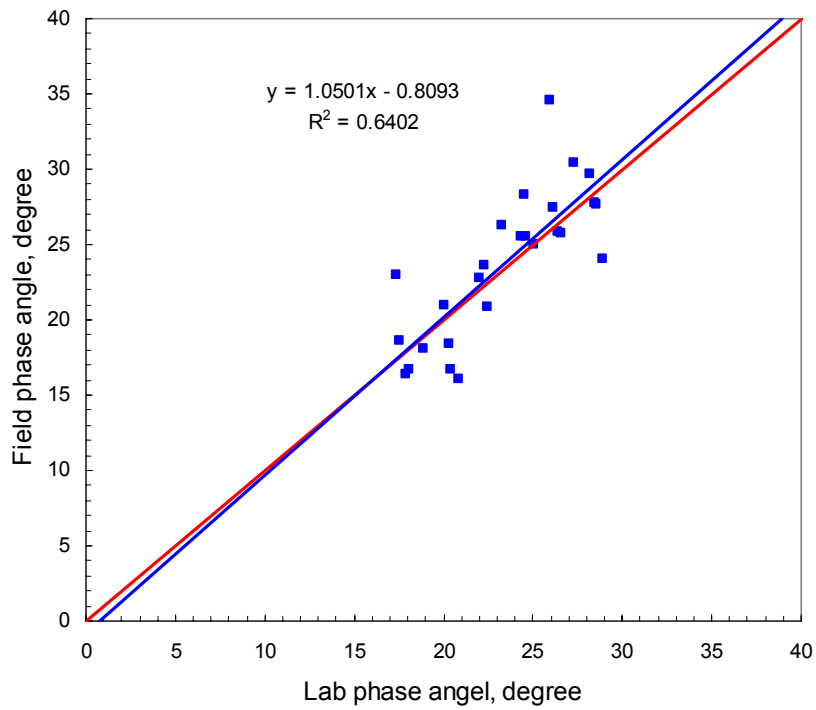


Figure 6-10 Field phase angle versus lab phase angle at 10 Hz

7. Fatigue models and procedure for fatigue analysis

7.1 Introduction

In chapters 4 to 6, the effect of various mix and test variables on fatigue life, stiffness and shear stiffness was presented. The objective of this section is to present the result of an effort to calibrate the strain and stiffness based fatigue models, and present procedure for fatigue analysis of typical asphalt pavement sections.

In chapter 4, it was shown that the flexural stiffness (S_0) is not a true measure of initial stiffness of the mix as it is influenced by the strain level, especially at higher temperatures. That is, at higher strain levels and higher temperatures, the flexural beam is subjected to damage from the beginning. Therefore, in the following sections, the fatigue models developed are based on the axial stiffness, which has been evaluated at lower strain levels so as not to subject given mix to undue damage.

7.2 Fatigue models

In this study, the asphalt content and air void content were both variables. The generally accepted norm in literature for taking into account the effect of asphalt content and air void content on fatigue life is through the use of VFA (voids filled with asphalt). In this study, the fatigue models are therefore, based on VFA rather than asphalt content and air void content.

There are three sets of fatigue models presented herein First, the two data sets present the equations separately for the SP 12.5-mm and SP 19-mm mixes, based on

initial axial stiffness and axial loss stiffness, respectively. Second, generalized fatigue models are presented that includes the aggregate gradation as a variable.

Table 7-1 through Table 7-6 showed the results of the regression analysis. It may be noted that the R^2 in general, is approximately 0.8, with a coefficient of variation of 95%. These results are in line with those presented in the SHRP-A-003A fatigue study [4].

The fatigue models are the following:

<u>12.5-mm mix</u>

$$N_f = 4.9016 \times 10^{-2} \cdot (e)^{0.03029 \cdot VFA} \cdot \varepsilon_0^{-3.28034} \cdot \left|E^*\right|^{-0.98505} \qquad R^2 = 0.81 \tag{7.1}$$

$$N_f = 2.31 \times 10^{10} \cdot e^{0.0221 \cdot VFA} \cdot \varepsilon_0^{-3.27807} \cdot (E'')^{-3.11293} \qquad R^2 = 0.82 \tag{7.2}$$

<u>19-mm mix</u>

$$N_f = 1.54 \times 10^{-3} \cdot e^{0.07007 \cdot VFA} \cdot \varepsilon_0^{-3.65657} \cdot \left|E^*\right|^{-1.17087} \qquad R^2 = 0.81 \tag{7.3}$$

$$N_f = 1.13 \times 10^{4} \cdot e^{0.05741 \cdot VFA} \cdot \varepsilon_0^{-3.58427} \cdot (E'')^{-2.38231} \qquad R^2 = 0.78 \tag{7.4}$$

<u>Generalized models</u>

$$N_f = 1.13 \times 10^{-2} \cdot e^{0.04789 \cdot VFA} \cdot \varepsilon_0^{-3.44019} \cdot \left|E^*\right|^{-1.07005} \cdot (e^{GR})^{-0.26812} \qquad R^2 = 0.81 \tag{7.5}$$

$$N_f = 1.09 \times 10^{7} \cdot e^{0.03759 \cdot VFA} \cdot \varepsilon_0^{-3.39963} \cdot (E'')^{-2.68589} \cdot (e^{GR})^{-0.27449} \qquad R^2 = 0.79 \tag{7.6}$$

where,

N_f = fatigue life;

VFA = void filled with asphalt in percent;

ε_0 = initial strain, in/in;

$|E^*|$, E'' = initial axial stiffness, and loss stiffness;

GR = -1 for 12.5-mm, and 1 for 19-mm mix; and

e = exponent of the natural logarithm.

7.3 Fatigue analysis of typical pavement sections

The objective of this section is to present a step-by-step procedure for fatigue analysis of in-situ pavement sections.

The analysis assumes that a trial mix has been proportioned and that the approximate pavement cross-section has been designed. The several steps of the analysis are as follows:

1. Determine the expected distribution of in-situ pavement temperature.
2. Estimate design traffic demand (N_{demand} = ESALs).
3. Design pavement structural section.
4. Determine design strain under standard axle load.
5. Determine the resistance of trial mix to fatigue (N_{supply}) using regression estimate.
6. Apple shift factor to fatigue resistance to account for differences between estimated fatigue resistance and in-situ conditions (such as traffic wander and crack propagation).
7. Compare the N_{demand} (ESALs) to pavement fatigue resistance (N_{supply}).
8. If N_{demand} exceeds N_{supply}, re-analyze current trial mix by altering the trial mix and/or structural section as appropriate and reiterate.

7.3.1 Traffic loading and temperature consideration

Traffic loading is typically expressed as the number of ESALs that is expected during the pavement design life. This can be estimated using the AASHTO load equivalency factors.

For analysis purpose, temperature regime for pavement section under consideration will be necessary. Typically, most fatigue damage is expected to occur under moderate temperatures near or around 20°C. As will be shown later, the NCDOT fatigue models for both 12.5-mm and 19-mm mixes are sensitive to temperature between 15°C and 25°C.

7.3.2 Design pavement structure

The analysis procedure described herein can be used for new design, overlay design, or for forensic analysis of existing pavement section that may have failed prematurely. For analysis purpose, in this study, two hypothetical pavement sections were selected based on data available from Rutherford County, NC. The sections are shown in Figure 7-1 and Figure 7-2. The pavement section shown in Figure 7-1 constitutes 12.5-mm mix asphalt layer of varying thickness between 3 in and 8 in, underlain by an 8 in layer of ABC, and 7 in layer of CT subbase over the subgrade. The pavement section shown in Figure 7-2 consists of 3.5 in 19-mm mix asphalt concrete overlaid with a surface layer of 2.5 in 12.5-mm mix asphalt concrete, with underlying layers consisting of 8 in ABC, and 7 in CT subbase over subgrade.

7.3.3 Analysis procedure

The maximum principal tensile strain at underside of the asphalt layer governs the initiation of fatigue cracking in-situ. For analysis purposes, a multilayered elastic analysis provides a convenient means for estimating the maximum strain anticipated at given temperature under the standard axle load. The standard axle load (ESAL) is an 18 kip loading on an axle with dual set of tires. In this study, it is assumed that the wheel spacing is 12 in with tire pressure of 100 psi. Given the pavement structure and the loading condition, the following procedure is used to find the maximum tensile strain, and the corresponding fatigue life of the pavement:

1. Select the temperature at which the analysis is to be conducted;
2. For given temperature and mix properties, estimate the axial stiffness $|E^*|$ at 10 Hz frequency using equation 5-4a. Note, the loss-stiffness can also be evaluated at this point using equation 5-4b if it is desirable to use the fatigue equation based on loss-stiffness.
3. Assume a value for the Poisson's ration. This value will vary from 0.35 to 0.45 for asphalt mixes. At moderate temperatures, a value of 0.35 to 0.4 is reasonable.
4. Conduct the analysis using any available computer program and determine the maximum principal tensile strain under the layer of interest.
5. Calculate fatigue life of pavement section (N_{supply}) using appropriate model from equations 7.1 to 7.6.
6. Apply appropriate shift factor (SF) to N_{supply}. Generally, a shift factor of 10 to 18 has been reported in literature. However, each department of transportation needs to determine a shift factor appropriate for the site under consideration. The shift factor can be determined based on experience of individual DOT. For this study, a shift factor of 1.0 has been assumed.

7. Compare N_{supply} to N_{demand}, ($SF \cdot N_{\sup ply} \geq N_{demand}$). If the factored N_{supply} is greater than N_{demand}, the pavement section will perform adequately. If not, alter the mix selected, and/or increase the design thickness and reiterate analysis.
8. If the analysis is conducted at different temperatures, then fatigue life supply versus traffic demand may be compared using the damage ratios:

$$\frac{N_{demand\_15°C}}{SF \cdot N_{\sup ply\_15°C}} + \frac{N_{demand\_20°C}}{SF \cdot N_{\sup ply\_20°C}} + \frac{N_{demand\_25°C}}{SF \cdot N_{\sup ply\_25°C}} + \cdots \leq 1.0 \qquad (7.7)$$

The above procedure was used to evaluate the pavement sections shown in Figure 7-1and Figure 7-2 for varying mix and temperature variables. The effect of the mix and temperature variables is discussed in the following section.

7.4 Effect of mix variables and temperature on fatigue life of pavement section

One of main objective of this study was to determine the sensitivity of Superpave mixes to mix variables and temperature with regards to fatigue distress. In this section, the two hypothetical pavement sections presented in Figure 7-1and Figure 7-2 are used to determine the sensitivity of the 12.5-mm and 19-mm mixes.

7.4.1 Effect of asphalt concrete layer thickness

The mechanistic analysis procedure outlined in section 7.3 was used to investigate the effect of layer thickness.

Table 7-7 shows the results of the analysis for 12.5-mm mix at optimum asphalt content (5.2-percent by weight of mix) and at 4-percent voids and 20°C.

As expected, the fatigue life (N_{supply}) of the pavement section under consideration increases as the layer thickness increases. Figure 7-3 shows the relationship between the layer thicknesses versus the fatigue life. The results indicate that an increase of 1 in layer thickness will increase the fatigue life of pavement section by approximately 100%.

7.4.2 Effect of mix variables and temperature

To evaluate the effect of mix variables and temperature on fatigue life, the layer thickness for the 12.5-mm mix was selected to be 6 in for the pavement section shown in Figure 7-1. The 6 in layer thickness was selected to equal the combined layer thickness of 12.5-mm and 19-mm mixes in Figure 7-2. For both pavement sections, the mix variables were the air void content (4, 6 and 8-percent), asphalt contents (optimum and optimum minus 0.5-percent), and temperature (15, 20 and 25°C). The results of the analysis are presented in Table 7-8 to Table 7-11. Summary of the comparisons are presented in Table 7-12 to Table 7-14.

7.4.2.1 Effect of asphalt content

Table 7-12 summarizes the effect of asphalt content on pavement fatigue life. For both mixes, the fatigue life reduces with decrease in asphalt content. However, the effect of lower asphalt content on the two mixes is different. The reduction in life for 12.5-mm mix is about 18-percent compared to the 19-mm mix for which the reduction is about 24-percent. The slightly more sensitivity of the 19-mm mix is expected as it contains 0.5-percent less asphalt compared to the 12.5-mm mix.

7.4.2.2 Effect of air void content

Table 7-13 shows the effect of air void content on fatigue life. It may be noted that the values shown in the table are averages over all temperatures. The effect of air voids is quite pronounced for both mixes. For the 12.5-mm mix, an increase of 2-percent air void content results in a decrease of 35 to 40-percent fatigue life. For 19-mm mix, an increase of 2-percent air void content results in a decrease of 55 to 60-percent in fatigue life.

7.4.2.3 Effect of temperature

Table 7-14 shows the effect of temperature on fatigue life of the mixes. The fatigue life shown is an average across all air voids. In general, an increase of 5°C temperature will result in a decrease of fatigue life by about 25 to 29-percent. The 19-mm mixes are slightly more sensitive to temperature compared to the 12.5-mm mixes. This is probably the result of the lower asphalt content.

In chapter 3 and 4, the lab fatigue data showed that the laboratory fatigue life of mixes to be lower at lower temperature in controlled-strain mode-of-loading (reverse trend is expected in control stress mode of loading). However, it is interesting to note that the fatigue life of the pavement sections will increase with decrease in temperature. This is in line with general norm expected for in-situ field condition.

7.4.2.4 Comparison of NCDOT models with SHRP model

During the Strategic Highway Research Program (SHRP), a major study was undertaken [2] to develop a fatigue model based on testing of 44 mixes. This model reported in SHRP Report SHRP-404 [2] is following:

$$N_f = 2.738 \times 10^5 \cdot e^{0.077 \cdot VFA} \cdot (\varepsilon_0)^{-3.624} \cdot (S_0^{''})^{-2.720} \qquad R^2 = 0.79 \qquad (7.8)$$

where,

N_f = fatigue life,

e = base of the natural logarithms,

ε_0 = critical tensile strain,

$S_0^{''}$ = the initial flexural loss stiffness in psi and,

VFA = the voids filled with asphalt in percent.

Table 7-8 to Table 7-11 also shows the fatigue life of NCDOT mixes evaluated using the above model. In general, the results show that the fatigue life of pavement sections evaluated using NCDOT model is fairly comparable to the fatigue life evaluated using the SHRP model. However, there is one major difference, which is, that the SHRP model is not sensitive to temperature; i.e., for a given mix with fixed parameters (air void content, and asphalt content), change in temperature does not result in change in fatigue life. This is not surprising considering that the SHRP model was developed based on fatigue testing at a single temperature of 20°C.

7.5 Summary

In this section, fatigue models for NCDOT mixes were developed. A mechanistic analysis procedure is outlined for evaluating the fatigue life of a given pavement section. Based on the results of the analysis for the pavement sections considered, the following conclusions may be drawn:

(1) Fatigue models developed for NCDOT mixes are sensitive to the mix variable and test temperature considered in this study.

(2) NCDOT fatigue models yield fatigue life similar to those obtained using SHRP fatigue model. However, NCDOT models are sensitive to temperature in comparison to the SHRP model.

(3) Increase in temperature results in decrease in fatigue life of pavement section under consideration. A 5°C increase in temperature results in about 25-percent reduction in life. This trend is opposite to the trend shown by laboratory fatigue data where increase in temperature will result in increase in laboratory fatigue life.

(4) NCDOT mixes are sensitive to asphalt content. Decrease in AC by 0.5-percent (by wt. of mix) results in decrease of 18 to 25-percent fatigue life.

(5) NCDOT mixes are also sensitive to air void content as expected. An increase in 2-percent air void content will reduce pavement life by about 40-percent for 12.5-mm mixes, and by almost 60-percent for 19-mm mixes.

(6) Based on the overall result of analysis, it appears that 19-mm mixes are more sensitive to mix variables as compared to the 12.5-mm mixes.

Table 7-1 Summary of analysis of N_f with $|E^*|$, 12.5-mm mix

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	176.0097	58.66989	174.67	<.0001
Error	116	38.96326	0.33589		
Corrected Total	119	214.9729			
Root MSE	0.57956	Coeff. Var	5.12789	R_Square	0.8188
Dependent Mean	11.30212			Adj R_Sq	0.8141
Variable	Parameter Estimate	Standard error	t Value	Pr > |t|	Variance Inflation
Intercept	-3.01561	2.64317	-1.14	0.2563	0
VFA	0.03029	0.00871	3.48	0.0007	1.39458
Strain	-3.28034	0.14355	-22.85	<.0001	1.02754
$\|E^*\|$	-0.98505	0.20455	-4.82	<.0001	1.40385

Table 7-2 Summary of analysis of N_f with E'', 12.5-mm mix

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	176.4375	58.81249	177.04	<.0001
Error	116	38.53545	0.3322		
Corrected Total	119	214.9729			
Root MSE	0.57637	Coeff. Var	5.09966	R_Square	0.8207
Dependent Mean	11.30212			Adj R_Sq	0.8161
Variable	Parameter Estimate	Standard error	t Value	Pr > |t|	Variance Inflation
Intercept	23.86466	7.76406	3.07	0.0026	0
VFA	0.02221	0.00788	2.82	0.0057	1.15353
Strain	-3.27807	0.14261	-22.99	<.0001	1.02531
E"	-3.11293	0.62589	-4.97	<.0001	1.16523

Table 7-3 Summary of regression analysis of N_f with $|E^*|$, 19-mm mix

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	236.448	78.81601	163.41	<.0001
Error	117	56.43302	0.48233		
Corrected Total	120	292.881			
Root MSE	0.6945	Coeff. Var	6.30978	R_Square	0.8073
Dependent Mean	11.00675			Adj R_Sq	0.8024
Variable	Parameter Estimate	Standard error	t Value	Pr > |t|	Variance Inflation
Intercept	-6.47814	3.20091	-2.02	0.0453	0
VFA	0.07007	0.01116	6.28	<.0001	1.45865
Strain	-3.65657	0.16546	-22.1	<.0001	1.12729
$\|E^*\|$	-1.17087	0.24914	-4.7	<.0001	1.35617

Table 7-4 Summary of regression analysis of N_f with E'', 19-mm mix

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	229.6826	76.56085	141.74	<.0001
Error	117	63.19848	0.54016		
Corrected Total	120	292.881			
Root MSE	0.73495	Coeff. Var	6.6773	R_Square	0.7842
Dependent Mean	11.00675			Adj R_Sq	0.7787
Variable	Parameter Estimate	Standard error	t Value	Pr > |t|	Variance Inflation
Intercept	9.32855	10.91001	0.86	0.3943	0
VFA	0.05741	0.01144	5.02	<.0001	1.36805
Strain	-3.58427	0.1745	-20.54	<.0001	1.11963
E''	-2.38231	0.88797	-2.68	0.0084	1.27248

Table 7-5 Summary of general regression analysis of N_f with $|E^*|$

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	413.4471	103.3618	244.76	<.0001
Error	236	99.66317	0.4223		
Corrected Total	240	513.1102			
Root MSE	0.64985	Coeff. Var	5.82623	R_Square	0.8058
Dependent Mean	11.15383			Adj R_Sq	0.8025
Variable	Parameter Estimate	Standard error	t Value	Pr > |t|	Variance Inflation
Intercept	-4.48682	2.10273	-2.13	0.0339	0
VFA	0.04789	0.0071	6.75	<.0001	1.41289
Strain	-3.44019	0.11077	-31.06	<.0001	1.08002
$\|E^*\|$	-1.07005	0.16345	-6.55	<.0001	1.3942
GR	-0.26812	0.04249	-6.31	<.0001	1.03005

Table 7-6 Summary of general regression analysis of N_f with E'

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	406.4466	101.6117	224.82	<.0001
Error	236	106.6636	0.45196		
Corrected Total	240	513.1102			
Root MSE	0.67228	Coeff. Var	6.02738	R_Square	0.7921
Dependent Mean	11.15383			Adj R_Sq	0.7886
Variable	Parameter Estimate	Standard error	t Value	Pr > |t|	Variance Inflation
Intercept	16.20155	6.69834	2.42	0.0163	0
VFA	0.03759	0.00687	5.47	<.0001	1.23595
Strain	-3.39963	0.11418	-29.77	<.0001	1.07228
E''	-2.68589	0.54199	-4.96	<.0001	1.22516
GR	-0.27449	0.04397	-6.24	<.0001	1.03094

Table 7-7 Surface layer thickness vs. N_{supply}, 12.5-mm mix

Thickness (in)	Temp (Celsius)	VFA	|E*| (psi)	Strain (in/in).	N_{opt-AC}
3	20	72.46	1,130,000	1.93E-04	7.41E+05
4				1.53E-04	1.59E+06
5				1.23E-04	3.22E+06
6				1.01E-04	6.17E+06
7				8.42E-05	1.12E+07
8				7.15E-05	1.91E+07

Table 7-8 Fatigue life of SP 12.5-mm mix with optimum AC

Temp (Celsius)	V_a (%)	VFA (%)	Strain (in/in)	|E*| (psi)	$S''=E''$ (psi)	Nsupply	
						Equ. (7.1)	SHRP
15	4	72.46412	8.29E-05	1.55E+06	6.17E+05	8.63E+06	7.99E+06
15	6	63.20644	9.63E-05	1.22E+06	5.04E+05	5.01E+06	3.94E+06
15	8	55.77154	1.11E-04	9.69E+05	4.12E+05	3.19E+06	2.32E+06
20	4	72.46412	1.01E-04	1.13E+06	4.87E+05	6.17E+06	7.47E+06
20	6	63.20644	1.16E-04	8.93E+05	3.98E+05	3.69E+06	3.80E+06
20	8	55.77154	1.33E-04	7.07E+05	3.25E+05	2.39E+06	2.29E+06
25	4	72.46412	1.22E-04	8.24E+05	3.84E+05	4.55E+06	7.22E+06
25	6	63.20644	1.39E-04	6.52E+05	3.14E+05	2.80E+06	3.80E+06
25	8	55.77154	1.57E-04	5.16E+05	2.56E+05	1.87E+06	2.36E+06

Table 7-9 Fatigue life of SP 12.5-mm mix with optimum-0.5% AC

Temp (Celsius)	V_a (%)	VFA (%)	Strain (in/in)	|E*| (psi)	S"=E" (psi)	Nsupply	
						Equ. (7.1)	SHRP
15	4	70.20736	8.72E-05	1.50E+06	6.35E+05	7.00E+06	5.17E+06
15	6	60.60344	1.01E-04	1.19E+06	5.19E+05	4.08E+06	2.52E+06
15	8	53.03339	1.16E-04	9.43E+05	4.24E+05	2.59E+06	1.47E+06
20	4	70.20736	1.06E-04	1.10E+06	5.01E+05	5.02E+06	4.85E+06
20	6	60.60344	1.22E-04	8.70E+05	4.09E+05	3.01E+06	2.44E+06
20	8	53.03339	1.39E-04	6.89E+05	3.34E+05	1.96E+06	1.47E+06
25	4	70.20736	1.27E-04	8.02E+05	3.95E+05	3.75E+06	4.76E+06
25	6	60.60344	1.45E-04	6.35E+05	3.23E+05	2.32E+06	2.47E+06
25	8	53.03339	1.64E-04	5.03E+05	2.64E+05	1.55E+06	1.53E+06

Table 7-10 Fatigue life of SP 19-mm mix with optimum AC

Temp (Celsius)	V_a (%)	VFA (%)	Strain (in/in)	|E*| (psi)	S"=E" (psi)	Nsupply	
						Equ. (7.3)	SHRP
15	4	71.26469	8.04E-05	1.58E+06	6.61E+05	1.17E+07	6.74E+06
15	6	61.81624	9.33E-05	1.25E+06	5.40E+05	4.61E+06	3.28E+06
15	8	54.30352	1.07E-04	9.94E+05	4.42E+05	2.14E+06	1.92E+06
20	4	71.26469	9.78E-05	1.16E+06	5.22E+05	8.30E+06	6.32E+06
20	6	61.81624	1.13E-04	9.16E+05	4.26E+05	3.33E+06	3.15E+06
20	8	54.30352	1.29E-04	7.25E+05	3.48E+05	1.58E+06	1.88E+06
25	4	71.26469	1.18E-04	8.45E+05	4.11E+05	5.99E+06	6.06E+06
25	6	61.81624	1.35E-04	6.69E+05	3.36E+05	2.49E+06	3.13E+06
25	8	54.30352	1.53E-04	5.30E+05	2.75E+05	1.22E+06	1.92E+06

Table 7-11 Fatigue life of SP 19-mm mix with optimum-0.5% AC

Temp (Celsius)	V_a (%)	VFA (%)	Strain (in/in)	|E*| (psi)	S"=E" (psi)	Nsupply	
						Equ. (7.3)	SHRP
15	4	68.78089	8.46E-05	1.46E+06	6.80E+05	8.98E+06	4.29E+06
15	6	58.98576	9.78E-05	1.16E+06	5.56E+05	3.50E+06	2.07E+06
15	8	51.35438	1.13E-04	9.18E+05	4.54E+05	1.61E+06	1.19E+06
20	4	68.78089	1.03E-04	1.07E+06	5.37E+05	6.37E+06	4.03E+06
20	6	58.98576	1.18E-04	8.46E+05	4.38E+05	2.53E+06	1.98E+06
20	8	51.35438	1.35E-04	6.70E+05	3.58E+05	1.20E+06	1.18E+06
25	4	68.78089	1.24E-04	7.80E+05	4.23E+05	4.65E+06	3.91E+06
25	6	58.98576	1.41E-04	6.18E+05	3.46E+05	1.91E+06	1.98E+06
25	8	51.35438	1.60E-04	4.89E+05	2.83E+05	9.30E+05	1.21E+06

Table 7-12 Comparison of fatigue life for opt. AC and opt.-0.5% AC

Temp (Celsius)	Va (%)	SP 12.5-mm mix			SP 19-mm mix		
		Nsupply at opti. AC	Nsupply at opti.-0.5% AC	Percent difference	Nsupply at opti. AC	Nsupply at opti.-0.5% AC	Percent difference
15	4	8.63E+06	7.00E+06	-18.91%	1.17E+07	8.98E+06	-23.45%
15	6	5.01E+06	4.08E+06	-18.53%	4.61E+06	3.50E+06	-24.09%
15	8	3.19E+06	2.59E+06	-18.92%	2.14E+06	1.61E+06	-24.94%
20	4	6.17E+06	5.02E+06	-18.67%	8.30E+06	6.37E+06	-23.27%
20	6	3.69E+06	3.01E+06	-18.45%	3.33E+06	2.53E+06	-24.17%
20	8	2.39E+06	1.96E+06	-18.04%	1.58E+06	1.20E+06	-24.23%
25	4	4.55E+06	3.75E+06	-17.46%	5.99E+06	4.65E+06	-22.40%
25	6	2.80E+06	2.32E+06	-17.38%	2.49E+06	1.91E+06	-23.45%
25	8	1.87E+06	1.55E+06	-17.23%	1.22E+06	9.30E+05	-23.51%

Table 7-13 Effect of air void content on fatigue life

Va (%)	12.5 opt.		12.5 opt.-0.5%		19 opt.		19 opt.-0.5%	
	N_f	Percent difference	N_f	Percent difference	N_f	Percent difference	N_f	Percent difference
4	6.45E+06		5.26E+06		8.68E+06		6.67E+06	
6	3.84E+06	-40%	3.14E+06	-40%	3.48E+06	-60%	2.65E+06	-60%
8	2.48E+06	-36%	2.03E+06	-35%	1.65E+06	-55%	1.25E+06	-53%

Note: The percent difference is the difference expressed as a percentage of the higher value.

Table 7-14 Effect of temperature on fatigue life

Temp (°C)	12.5 opt.		12.5 opt.-0.5%		19 opt.		19 opt.-0.5%	
	N_f	Percent difference	N_f	Percent difference	N_f	Percent difference	N_f	Percent difference
15	5.61E+06		4.56E+06		6.16E+06		4.70E+06	
20	4.08E+06	-27%	3.33E+06	-27%	4.40E+06	-29%	3.36E+06	-29%
25	3.07E+06	-25%	2.54E+06	-24%	3.23E+06	-27%	2.50E+06	-26%

Note: The percent difference is the difference expressed as a percentage of the higher value.

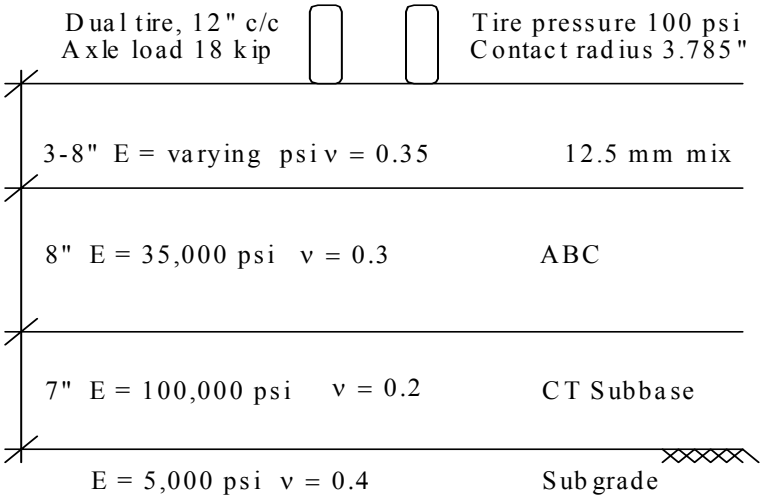


Figure 7-1 Pavement structure for SP 12.5-mm mix

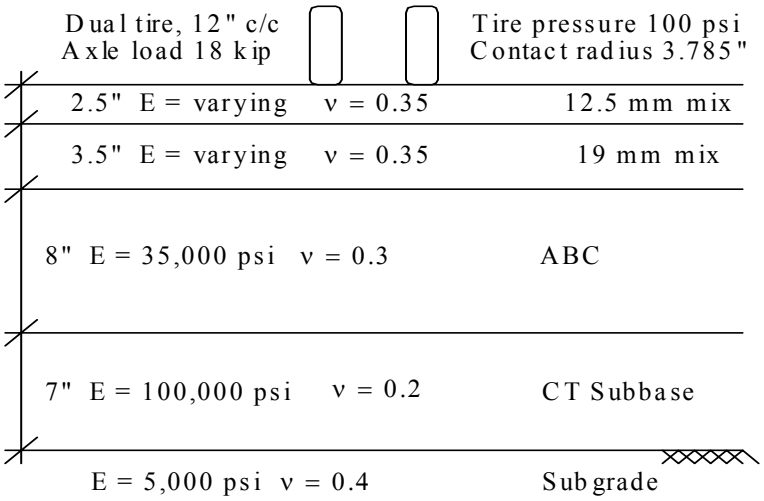


Figure 7-2 Pavement structure for SP 19-mm mix

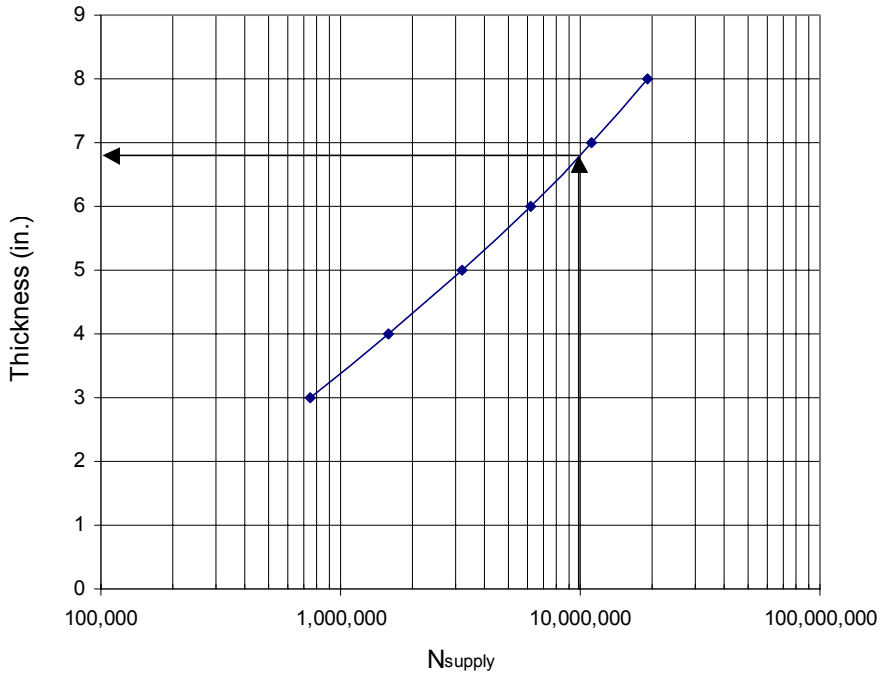


Figure 7-3 Surface layer thickness vs. N_{supply}

8. Effect of frequency on fatigue life

8.1 Introduction

In chapter 4, the effect of asphalt content, aggregate gradation, and air void content on laboratory fatigue life was investigated. It should be noted that those tests were performed at a single frequency (i.e. 10Hz). However, asphalt concrete is a visco-elastic material, which means the mechanical response of asphalt concrete depends on both loading frequency and temperature. It is well known that the stiffness of asphalt concrete can be characterized in terms of a common frequency and temperature parameter using time-temperature superposition principle. However, it is not known how exactly frequency and temperature affect the fatigue life of asphalt concrete.

The main objective of this chapter is to investigate the effect of frequency on fatigue life based upon both multiple frequency fatigue test data and analysis of pavement section.

This section consists of four parts. First, multiple frequency fatigue test data at 20°C will be presented. Then, a fatigue life prediction procedure, incorporating the effect of frequency on fatigue life, will be introduced based on observing test data. Thirdly, new test data is used to verify the procedure. Finally, the effect of load frequency on the fatigue life of pavement section was studied based on the result of structural analysis of typical pavement section under various frequency loading.

8.2 Multiple frequency test data

Table 8-1 gives the layout of this experiment design. Figure 8-1 to Figure 8-4 shows the effect of frequency on laboratory fatigue life of mixes. It can be seen from these figures, frequency has distinct impact on the fatigue life of mixes. Lower loading frequency results in longer fatigue life provided strain level, temperature and air void content remain the same. The increase in fatigue life with decreasing load frequency may attribute to the decrease in stiffness with decreasing load frequency. Furthermore, the strain-fatigue life lines at various frequencies are almost paralleled to each other. In statistical sense, it indicates that there is no interaction between load frequency and strain level. In other words, it means that the strain-fatigue life relationship at one frequency can be obtained by shifting that at the other frequency.

8.3 Development of fatigue life prediction procedure

First, let's introduce "fatigue life frequency shift factor"(from now on, we will call it frequency shift factor), which is defined in the following way:

$$\alpha_{N_f} = \frac{N_{f\_f_0}}{N_{f\_f}} \tag{8.1}$$

where,

α_{N_f} = frequency shift factor at a given temperature and for a given mix;

$N_{f\_f_0}$ = fatigue life at reference frequency f_0;

N_{f_f} = fatigue life at frequency f provided except for frequency, the other conditions (such as strain level, temperature and air void content, etc.) remain the same as those at reference frequency.

Next, let's define "stiffness ratio" in the following sense:

$$S_r = \frac{E_{f_0}}{E_f} \tag{8.2}$$

where,

S_r = stiffness ratio;

E_{f_0} = axial stiffness at reference frequency f_0;

E_f = axial stiffness at frequency f provided except for frequency, the other conditions are the same as those at reference frequency.

Now, we are able to proceed to find out both frequency shift factors for the fatigue test data (shown in Figure 8-1 through Figure 8-4) and their corresponding stiffness ratios. Figure 8-5 illustrates how to obtain frequency shift factor from Figure 8-1. In addition, corresponding stiffness ratio can be obtained from Figure 8-6. In the exactly the same fashion, both the frequency shift factor and stiffness ratio for Figure 8-2 through Figure 8-4 can also be obtained. Table 8-2 summarizes the stiffness ratio and frequency shift factor for this study.

Then, it is desirable to establish a relationship between frequency shift factor and stiffness ratio. Figure 8-7 showed graphically the evolution of frequency shift factor with stiffness ratio. As shown in this figure, the relationship between frequency shift factor and stiffness ratio can be expressed as follows:

$$\alpha_{N_f} = 0.95 \cdot S_r^{-2.4619} \qquad R^2 = 0.95 \tag{8.3}$$

Finally, it is ready to introduce a fatigue life prediction procedure, which incorporates the effect of frequency on fatigue life. This procedure involves both fatigue tests and axial frequency sweep tests. The specific procedure is as follows:

Preparing six flexural beam specimens with dimension of 15-in by 2.5-in by 2-in and two axial specimens with the height of 6-in. The air void content of those specimens should be in the same level.

Conducting fatigue testing on six flexural beam specimens, each two at a different strain level, in the controlled-strain mode-of-loading at reference frequency (i.e. 10 Hz) and certain temperature (i.e. 20°C). Then, the fatigue life of the mix can be expressed as a function of the applied strain in a simple regression equation: $N_{f\_f_0} = k_1 \varepsilon^{-k_2}$

Conducting axial frequency sweep test on the two axial specimens at the same temperature as that in flexural fatigue testing. Stiffness ratio at the other frequency can be obtained based on the axial test data.

Using equation (8.3) to compute frequency shift factor α_{N_f}.

The fatigue life at the other frequency can be expressed as follows:

$$N_{f\_f} = (\alpha_{N_f})^{-1} \cdot N_{f\_f_0} = 1.05\left(\frac{E_{f_0}}{E_f}\right)^{2.4619} \cdot k_1 \cdot \varepsilon^{-k_2}$$

8.4 Verification of the fatigue life prediction procedure

Three more tests at 20°C have been done to verify the fatigue life prediction procedure. One sample (S16b11) with SP 19-mm gradation and 7.3-percent air void

content was tested at 1Hz. The other two (S26b12 and S5b2) are in SP 12.5-mm gradation with air void content of 5.4, 8.3-percent, respectively. Those two samples were tested at 2 and 7 Hz, respectively. The detailed information of those three samples are shown in Table 8-3.

Figure 8-8 through Figure 8-10 provides stiffness versus number of cycles for those three samples. As you can see from those three figures, the measured fatigue life at 20°C for S16b11 at 1Hz, S5b2 at 7Hz and S26b12 at 2Hz is 123,000, 20,000, and 400,000, respectively.

Figure 8-11 illustrates how to obtain fatigue life at reference frequency for beam 11 in slab 16. The reference frequency is 10Hz. It should be noted that average air void content is 6.5-percent at reference frequency as compared to 7.3-percent at data frequency (1Hz). As shown in the figure, the reference fatigue life for S16b11 at 416 micron strain is 17,800. As shown in Figure 8-12 and Figure 8-13, the reference fatigue life for S5b2 and S26b12 is 13,500 and 91,000, respectively

Table 8-3 compared the predicted and measured fatigue life for those three samples. As you can see, the prediction fatigue life is fairly accurate as compared the measured fatigue life.

8.5 Effect of load frequency on fatigue life of pavement section

One of main objective of this study was to determine the effect of load frequency on fatigue life of pavement section. In order to do so, fatigue distress model that incorporates the effect of load frequency is necessary.

By simple regression analysis on the fatigue test data as shown in Figure 8-1, fatigue distress models at various frequencies (i.e., 2, 5, 7, and 10Hz) for SP 19-mm mix with optimum minus 0.5-percent asphalt content at air void content of 7.2-percent can be obtained as follows:

At 2 Hz:

$$N_f = 3.73 \times 10^{-9} \cdot \varepsilon^{-3.90} \qquad R^2 = 0.99 \tag{8.4}$$

At 5 Hz:

$$N_f = 4.97 \times 10^{-9} \cdot \varepsilon^{-3.81} \qquad R^2 = 0.99 \tag{8.5}$$

At 7 Hz:

$$N_f = 8.17 \times 10^{-9} \cdot \varepsilon^{-3.71} \qquad R^2 = 0.99 \tag{8.6}$$

At 10 Hz:

$$N_f = 2.60 \times 10^{-9} \cdot \varepsilon^{-3.80} \qquad R^2 = 0.97 \tag{8.7}$$

By simple regression analysis on the fatigue test data as shown in Figure 8-2, fatigue distress models at 5, and 10 Hz for SP 19-mm mix with optimum asphalt content at air void content of 6-percent can be obtained as follows:

At 5 Hz:

$$N_f = 1.59 \times 10^{-9} \cdot \varepsilon^{-3.9984} \qquad R^2 = 0.99 \tag{8.8}$$

At 10 Hz:

$$N_f = 2.32 \times 10^{-9} \cdot \varepsilon^{-3.8986} \qquad R^2 = 0.98 \tag{8.9}$$

In this analysis, the pavement section as shown in Figure 7-2 is used to study the effect of frequency. This pavement section consists of five layers. For the two layers, two cases are investigated here. In the first case, 2.5 in 12.5-mm mix layer with optimum minus 0.5-percent asphalt content at air void of 7.4-percent underlaid by 3.5 in 19-mm mixes with optimum minus 0.5-percent asphalt content at air void content of 7.8-percent. In the second case, both 12.5-mm and 19-mm mix layers are at optimum asphalt content and air void content of about 6-percent. Table 8-4 provides the stiffness information for the pavement section as shown in Figure 7-2. The pavement section is subjected to single standard axle load (18 kips). By using Kenpave program, the tensile strain at the bottom of SP 19-mm mix layer can be obtained as shown in Table 8-5. Then, fatigue life at various frequencies, computed by correspondingly using equations (8.4) through (8.9), is shown in Table 8-5.

As you can see from Table 8-5, the predicted fatigue life at various frequencies is fairly close to each other. That implies that no matter at which load frequency the fatigue tests are done, the corresponding fatigue distress model will still give a fairly accurate prediction of fatigue life as long as tensile strain is computed based on the same load frequency. In general, lower frequency will give you better control over strain amplitude, in turn, produce more accurate test result. However, lower frequency means longer testing time. Therefore, there is tradeoff between accuracy and time.

8.6 Summary

Based on analyzing the fatigue test data involved in this study, a fatigue life prediction procedure, incorporating the effect of load frequency on fatigue life, is proposed and verified.

Analysis also suggested that prediction of fatigue life of pavement section is independent of load frequency used in fatigue test as long as tensile strain is computed based on the same load frequency.

Fatigue test can be done at any frequency. However, there is tradeoff between time and accuracy. Lower load frequency gives more accurate result, but needs longer test time.

Table 8-1 The layout of the experiment study

Mix type	Asphalt content	Air void content (%)	Test temperature (°C)	Test frequency (Hz)
SP 19-mm mix	Opti-0.5%	7.2	20	2, 5,7, and 10
	Opti.	6.0	20	5, 10
SP 12-mm mix	Opti-0.5%	8.0	20	2, 10
	Opti-0.5%	4.5	20	2, 10

Table 8-2 Summary of stiffness ratio and frequency shift factor, f_0=10Hz

Mix type	Frequency (Hz)	Va (%)	S_r	α_{N_f}
SP 19-mm mix w/ opti-0.5% AC	2	7.3	1.698	0.300
	5	7.2	1.239	0.500
	7	7.3	1.108	0.649
	10	6.5	1.0	1.0
SP 19-mm mix w/ opti AC	5	6.1	1.17	0.5
	10	5.7	1.0	1.0
SP 12.5-mm mix w/ opti-0.5% AC	2	4.5	1.558	0.3374
	10	4.45	1.0	1.0
	2	7.8	1.7	0.25
	10	7.6	1.0	1.0

Table 8-3 Comparison between predicted and measured fatigue life, T=20°C

ID	GR	AC	Va %	f_0 Hz	f Hz	ε Micron	S_r	α_{N_f}	N_{f-f_0}	N_{f_f}	
										Predicted	Measured
S16b11	19-mm	Opti-0.5%	7.3	10	1	416	2.23	0.132	17,800	135,000	123,000
S5b2	12.5-mm	Opti	5.4	10	7	663	1.10	0.750	13,500	18,000	20,000
S26b12		Opti	8.3	10	2	390	1.75	0.240	91,000	379,000	400,000

Table 8-4 Stiffness information for the pavement section, T=20°C

Frequency (Hz)	Layer 1: SP 12.5 mm mix		Layer 2: SP19-mm mix	
	First case, Va=7.8%, opt-0.5% (psi)	Second case, Va=6.0%, opt (psi)	First case, Va=7.4%, opt-0.5% (psi)	Second case, Va=6.0%, opt (psi)
10	7.34E+05	8.11E+05	7.2E+05	1.07E+06
7	6.5E+05		6.3E+05	
5	5.85E+05	6.64E+05	5.81E+05	9.11E+05
2	4.31E+05		4.24E+05	

Table 8-5 Fatigue life at various frequency for SP 19-mm mix

Freq (Hz)	First case		Second case	
	Tensile strain (in/in)	Fatigue life (ESALs)	Tensile strain (in/in)	Fatigue life (ESALs)
10	1.02E-04	3.78E+06	81.4E-06	20.3E+06
7	1.12E-04	3.76E+06		
5	1.18E-04	4.60E+06	90.86E-06	23.0E+06
2	1.45E-04	3.45E+06		

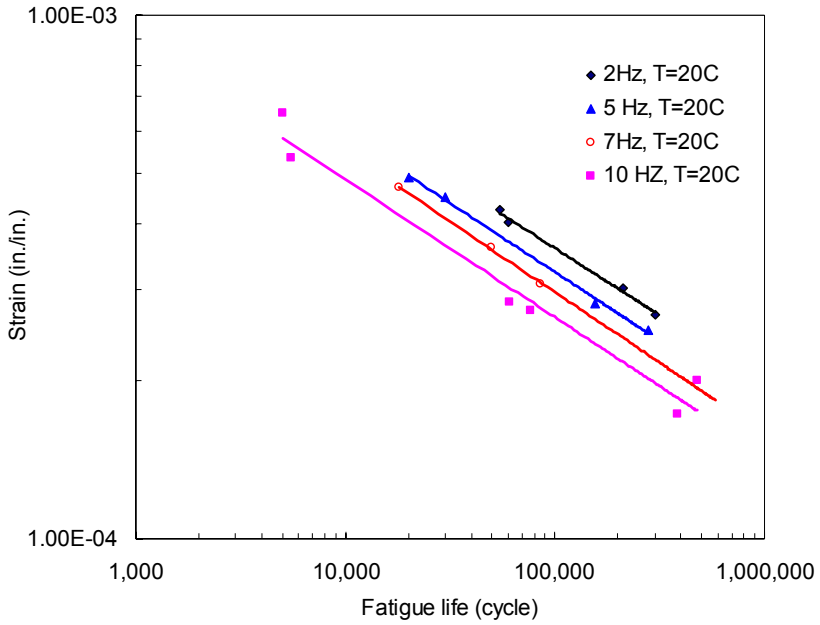


Figure 8-1 Effect of frequency on N_f for SP 19-mm mix with optimum minus 0.5-percent AC, Va=7.2%

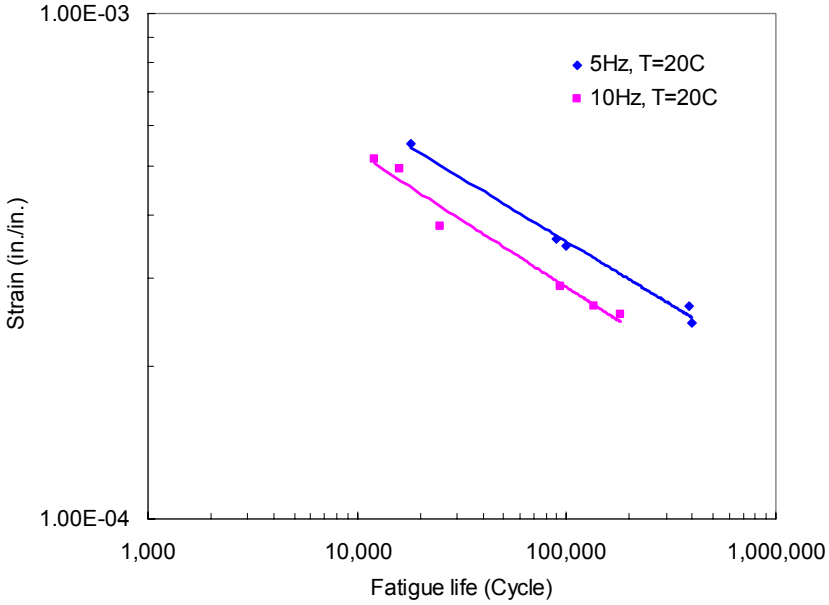


Figure 8-2 Effect of frequency on N_f for SP 19-mm mix with optimum AC, Va=6.0%

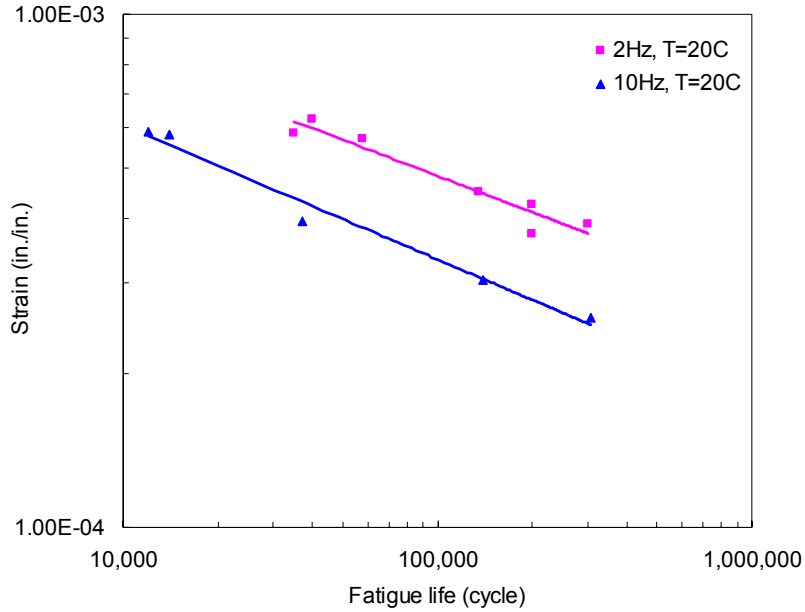


Figure 8-3 Effect of frequency on N_f for SP 12.5-mm mix w/ optimum minus 0.5% AC, Va=8%

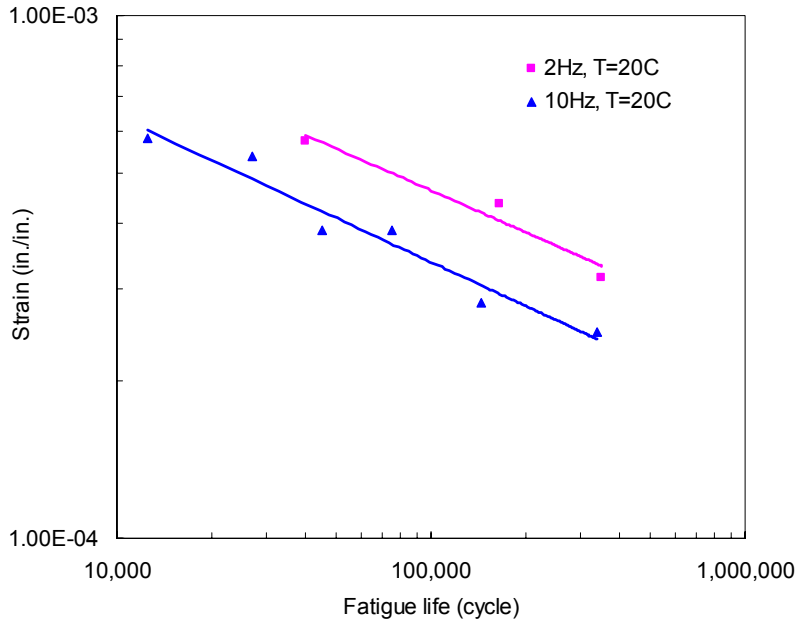


Figure 8-4 Effect of frequency on N_f for SP 12.5-mm mix w/ optimum minus 0.5% AC, Va=4.5%

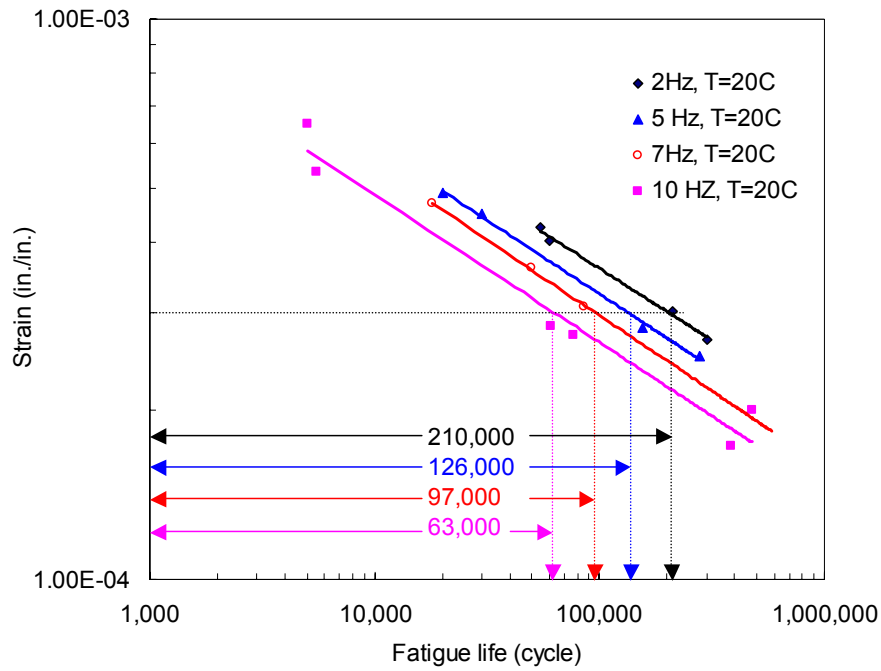


Figure 8-5 Illustration for obtaining frequency shift factor

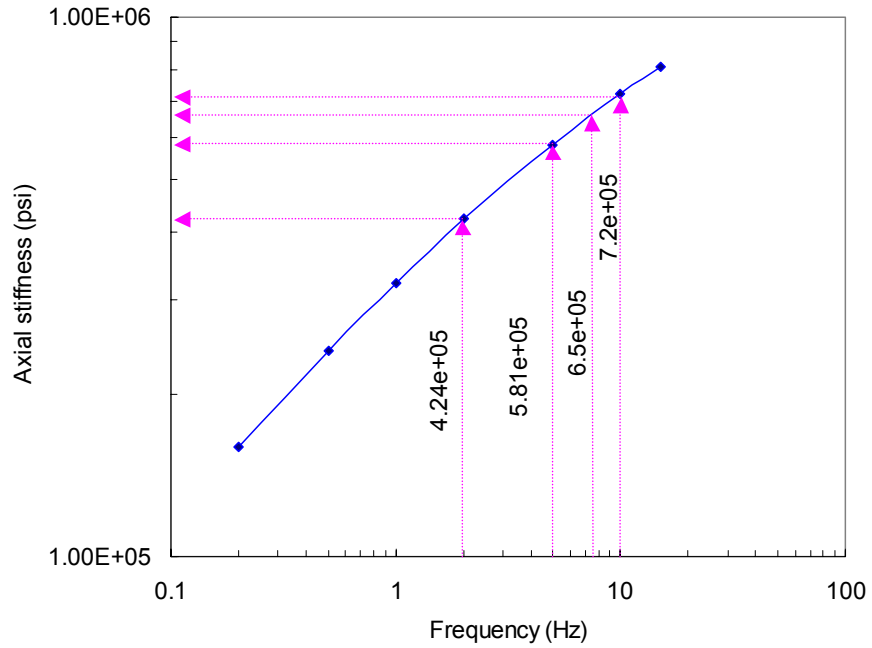


Figure 8-6 Axial frequency sweep test data for SP 19-mm w/ optimum minus 0.5-percent AC, T=20°C, Va=7.4%

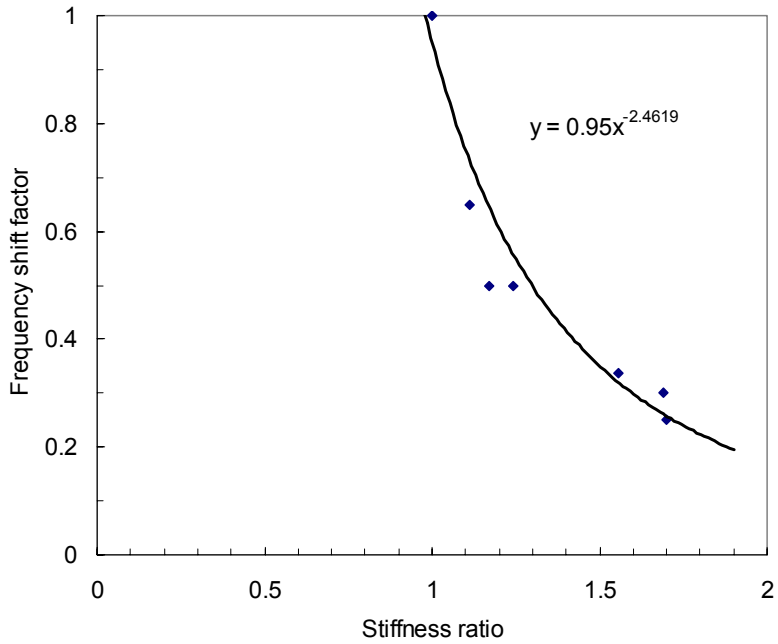


Figure 8-7 Frequency shift factor versus stiffness ratio

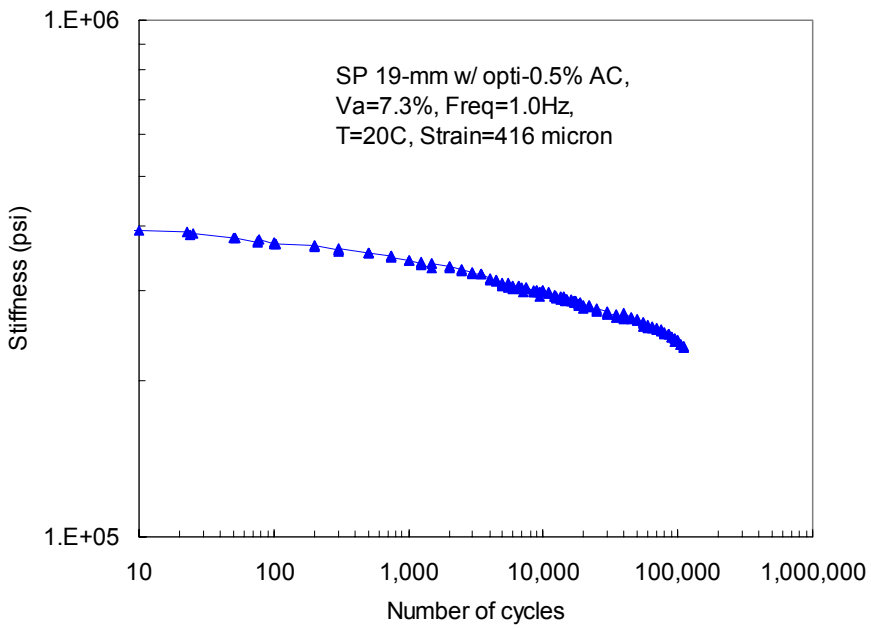


Figure 8-8 Stiffness vs. number of cycles for beam 11 in slab 16 at 1Hz, T=20°C

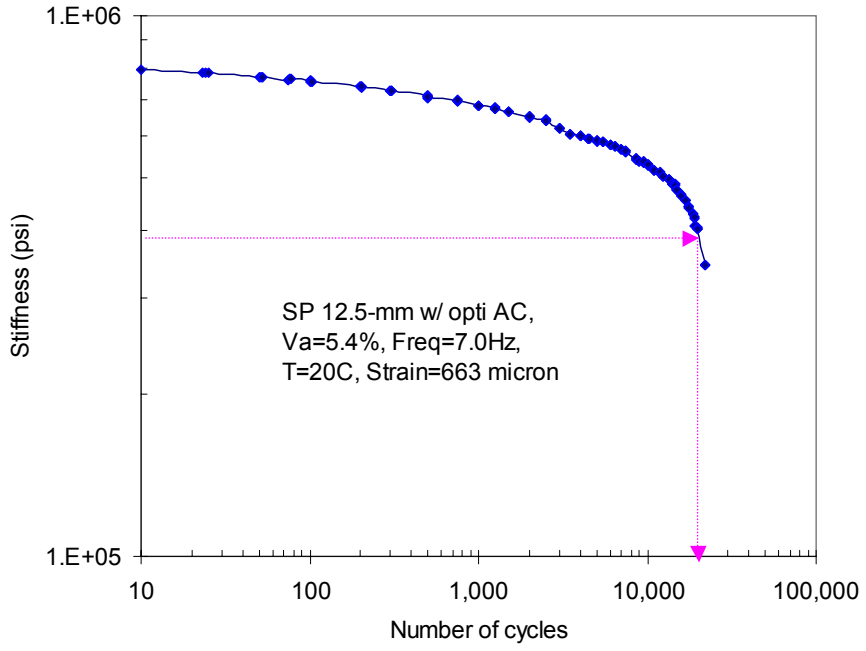


Figure 8-9 Stiffness vs. number of cycles for beam 2 in slab 5 at 7Hz, T=20°C

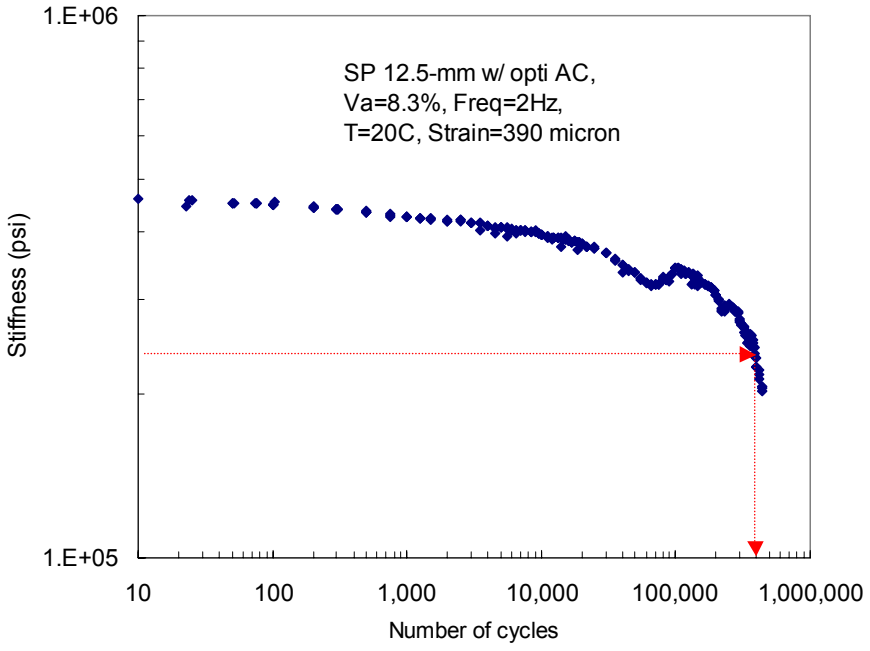


Figure 8-10 Stiffness vs. number of cycles for beam 12 in slab 26 at 2Hz, T=20°C

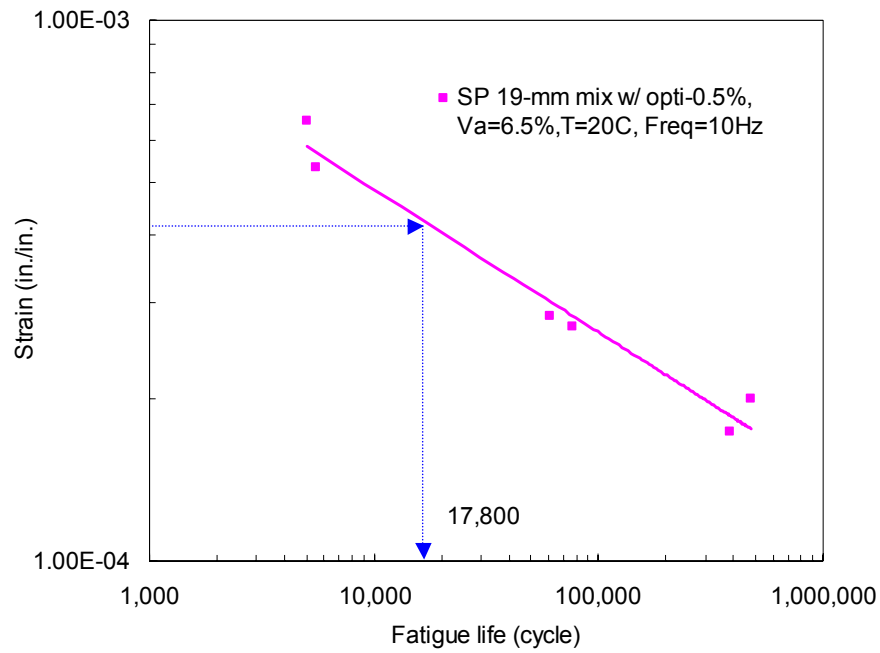


Figure 8-11 Illustration of obtaining reference fatigue life for beam 11 in slab 16

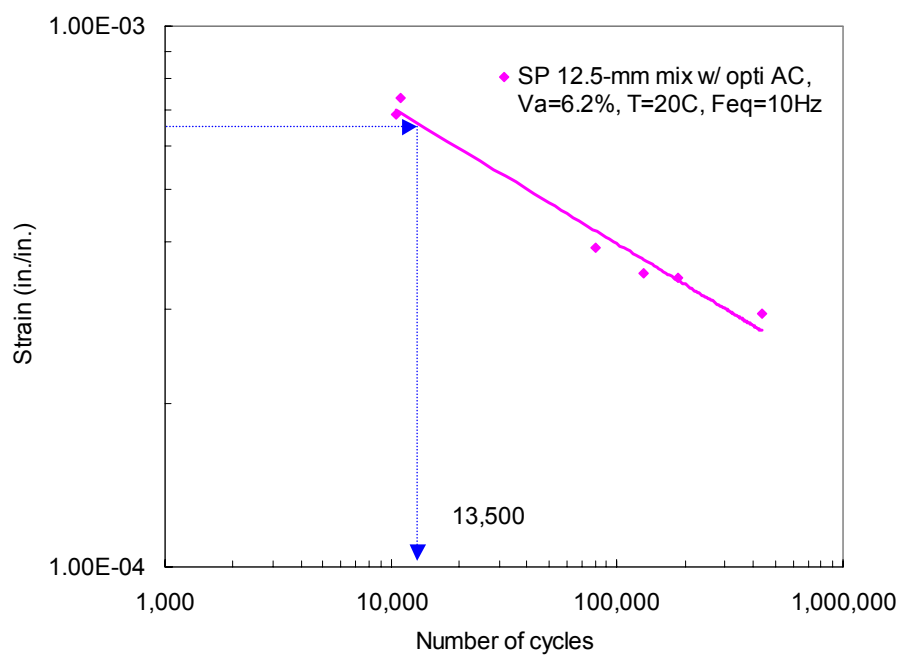


Figure 8-12 Illustration of obtaining reference fatigue life for beam 2 in slab 5

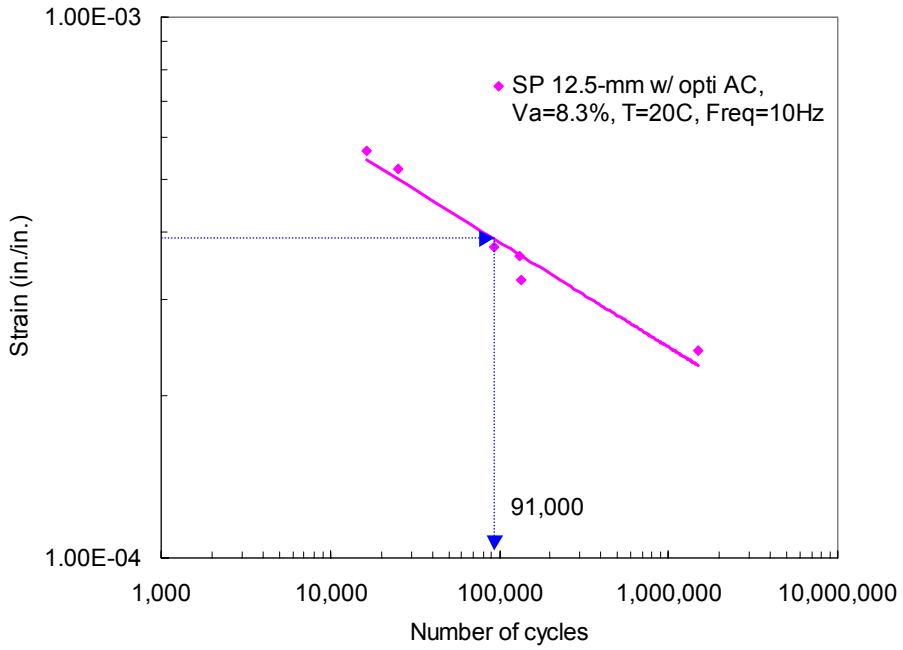


Figure 8-13 Illustration of obtaining reference fatigue life for beam 12 in slab 26

9. Characterization of visco-elastic parameters

9.1 Introduction

Asphalt concrete is a typical visco-elastic material even at moderate temperature. The behavior of asphalt concrete can be modeled by visco-elastic model. There are two basic components (linear springs and linear viscous dashpots) for linear visco-elastic model. The linear spring obeys Hooker's law when it is subjected to a force. The dashpot is an ideal viscous element whose stress is proportional to the strain rate. Visco-elastic models can be built up by putting the springs and dashpots in series, parallel, or various combinations of these. For example, Maxwell model consists of one spring and one dashpot in series (as shown in Figure 9-1). In order to use visco-elastic model to compute the response of the asphalt concrete pavement, it is usually necessary to have available an explicit equation for the relaxation modulus in the time domain or dynamic modulus in the frequency domain.

The objectives of this section are to obtain visco-elastic parameters by fitting generalized Maxwell model with axial frequency sweep test data, and compare pavement fatigue life between elastic and visco-elastic analysis.

9.2 Characterization of visco-elastic parameters

The generalized Maxwell model is composed of springs and dashpots connected in parallel as shown in Figure 9-2. For the single spring component, the stress-strain relationship can be written as

$$\sigma_0 = E_0 \varepsilon \tag{9.1}$$

For each Maxwell component, we have

$$\frac{\dot{\sigma}_i}{E_i} + \frac{\sigma_i}{\eta_i} = \dot{\varepsilon} \tag{9.2}$$

Because the single spring and every Maxwell component are connected in parallel, the total stress is

$$\sigma = \sigma_0 + \sum_{i=1}^{n} \sigma_i \tag{9.3}$$

For the case of relaxation under a constant ε_0 applied at t=0, we have

$$\sigma = \left(E_0 + \sum_{i=1}^{n} E_i e^{-\frac{E_i t}{\eta_i}} \right) \varepsilon_0 = E(t) \varepsilon_0 \tag{9.4}$$

In which $E(t) = \left(E_0 + \sum_{i=1}^{n} E_i e^{-(\frac{E_i t}{\eta_i})} \right)$ is the relaxation modulus for the generalized Maxwell model. Using Fourier Transform, the storage moduli and lose moduli, E' and E'', become

$$E'(w) = E_0 + \sum_{i=1}^{N} E_i \frac{(w\lambda_i)^2}{1 + (w\lambda_i)^2} \tag{9.5}$$

$$E'(w) = \sum_{i=1}^{N} E_i \frac{w\lambda_i}{1 + (w\lambda_i)^2} \tag{9.6}$$

where, $\lambda_i = \dfrac{\eta_i}{E_i}$

From equations (9.5) and (9.6), it can be seen that E_i and λ_i may be determined from measured loss and storage modulus or vice versa. However, this is an ill-posed problem and is not at all a straightforward curve-fitting operation. This means that without consideration of the physical meaning and some restrictions, infinitely many parameter sets can be found that are equally satisfactory. In the general Maxwell model, the parameters for all the springs and dashpots must be positive to have physical meaning. To best fit the testing data, negative moduli $\boldsymbol{E_i}$ might be produced as the number of relaxation time N increases, which are generally thought to be physically unrealistic (Tanner RI, 1968; Friedrich G, Hoffmann B, 1983).

In the literature, various techniques have been proposed to determine the parameters of the dynamic modulus. Laun (1986) presented the linear regression method, Honerkamp (1989) proposed the linear regression with regularization method, and Baumgaertel and Winter (1989) used a nonlinear regression method. The linear regression method may lead to negative moduli (ill-posed problem) when N is high. Linear regression with regularization can give reasonable fitting curve but usually with a large N value. Nonlinear regression is found to give a good fit of the data with a minimum number of parameters. For the simplicity of numerical calculation, we want a constitutive model with a good fit with experimental data and having the few possible parameters. Therefore, nonlinear regression method is the best one.

In this study, parameters for the general Maxwell model is developed through experimental dynamic modulus data by using the software IRIS (nonlinear regression method) developed by Winter (2000).

Table 9-1 and Table 9-2 presents visco-elastic parameters for SP 12.5-mm mix with optimum asphalt content and with optimum minus 0.5-percent asphalt content, respectively. Visco-elastic parameters for SP 19-mm mix with optimum and optimum minus 0.5-percent asphalt content are shown in Table 9-3 and Table 9-4.

Figure 9-3 compared the calculated and measured E', E" for SP 12.5-mm mix with air void of 4-percent at 20°C. Figure 9-4 showed the comparison between calculated and measured |E*| for SP 12.5-mm mix with optimum asphalt content at 4-percent air void. Moreover, the comparison between measured and calculated phase angle is given in Figure 9-5. These figures imply that the regression model fits well with the measured data.

9.3 Formulation of direct time integration method

For a viscoelastic material under certain loading and/or boundary conditions, the responses can be obtained through direct time domain analysis, Fourier transformed domain analysis or Laplace transformed domain analysis. In this study, only direct time integration method is used to compute visco-elastic tensile strain of asphalt concrete layer under vertical circular loading conditions. Xu [6] presented the formulation of direct time integration method in details. Here, only a brief discussion of formulation is provided. The equilibrium equations for the layered system subjected to axisymmetric loading in cylindrical coordinates can be expressed as

$$\frac{\partial \sigma_r}{\partial r} + \frac{\partial \tau_{rz}}{\partial z} + \frac{\sigma_r - \sigma_\theta}{r} = 0 \tag{9.7}$$

$$\frac{\partial \tau_{rz}}{\partial r} + \frac{\partial \sigma_z}{\partial z} + \frac{\tau_{rz}}{r} = 0 \tag{9.8}$$

Note that each stress component here is time-dependent. Stress - strain relationship for viscoelastic material in time domain is

$$\underset{\sim}{\sigma}(t) = \underset{\approx}{D_A}(0)\,\underset{\sim}{\varepsilon}(t) - \int_0^t \frac{d\,\underset{\approx}{D_A}(t-\tau)}{d\tau}\,\underset{\sim}{\varepsilon}(\tau)\,d\tau \tag{9.9}$$

In equation (9.9), $\underset{\sim}{\sigma}(t)$ and $\underset{\sim}{\varepsilon}(t)$ are the vectors of time-dependent stress components and strain components respectively, and $\underset{\approx}{D_A}(t)$ is the stress-strain relationship matrix for axial-symmetric problems.

$$\underset{\approx}{D_A}(t) = \begin{bmatrix} a(t) & c(t) & c(t) & 0 \\ c(t) & a(t) & c(t) & 0 \\ c(t) & c(t) & a(t) & 0 \\ 0 & 0 & 0 & f(t) \end{bmatrix} \tag{9.10}$$

where,

$$a(t) = K(t) + \frac{4}{3}G(t)$$

$$c(t) = K(t) - \frac{2}{3}G(t)$$

$$f(t) = G(t)$$

Strain-displacement relationship is as follows:

$$\begin{bmatrix} \varepsilon_r \\ \varepsilon_\theta \\ \varepsilon_z \\ \gamma_{rz} \end{bmatrix} = -\begin{bmatrix} \frac{\partial}{\partial r} & 0 & 0 \\ \frac{1}{r} & 0 & 0 \\ 0 & 0 & \frac{\partial}{\partial z} \\ \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial r} \end{bmatrix} \begin{bmatrix} u_r \\ u_\theta \\ u_z \end{bmatrix} \tag{9.11}$$

Apply the Hankel transformations with respect to spatial coordinate r to the displacement components as follows:

$$U_z = \int_0^\infty r u_z J_0(\alpha r) dr \tag{9.12}$$

$$(U_r, U_\theta) = \int_0^\infty r(u_r, u_\theta) J_1(\alpha r) dr \tag{9.13}$$

Where J_0 and J_1 are zero order and first order Bessel functions of the first type, respectively. The corresponding inverse transforms are

$$u_z = \int_0^\infty \alpha U_z J_0(\alpha r) d\alpha \tag{9.14}$$

$$(u_r, u_\theta) = \int_0^\infty \alpha U_r J_1(\alpha r) d\alpha \tag{9.15}$$

By substituting equations (9.14) and (9.15) into the strain-displacement relationship (9.11), one can get the expression of each strain component (ε_r, ε_θ, ε_z, γ_{rz}) in term of U_z, U_r. Then, substituting those strain components into the stress-strain law in equation (9.9), the stress components can be expressed in terms of transformed

displacement components. If these values of stress are used in the equilibrium equations (9.7) and (9.8), we get

$$\underset{\approx}{R}\,\underset{\approx}{D}(0)\underset{\approx}{V}\,\underset{\sim}{W}(t)-\underset{\approx}{R}\int_0^t \frac{d\,\underset{\approx}{D}(t-\tau)}{d\tau}\underset{\approx}{V}\,\underset{\sim}{W}(\tau)d\tau=0 \tag{9.16}$$

where,

$$\underset{\approx}{R}=\begin{bmatrix} \alpha & 0 & -\dfrac{\partial}{\partial z} \\ 0 & -\dfrac{\partial}{\partial z} & -\alpha \end{bmatrix}$$

$$\underset{\approx}{D}(t)=\begin{bmatrix} a(t) & c(t) & 0 \\ c(t) & a(t) & 0 \\ 0 & 0 & f(t) \end{bmatrix}$$

$$\underset{\approx}{V}=\begin{bmatrix} \alpha & 0 & \dfrac{\partial}{\partial z} \\ 0 & \dfrac{\partial}{\partial z} & -\alpha \end{bmatrix}^T$$

$$\underset{\sim}{W}=(U_r,U_z)^T$$

Consistent with the associated boundary and continuity equations, the solution of equation (9.16) can be obtained by the finite element approximation.

$$\underset{\approx}{K}^e(0)\left\{\underset{\sim}{W}^e(t)\right\}-\int_0^t \frac{d\,\underset{\approx}{K}^e(t-\tau)}{d\tau}\left\{\underset{\sim}{W}^e(\tau)\right\}d\tau=\underset{\sim}{F}^e \tag{9.17}$$

where,

$$\underset{\approx}{K}^e(t)=\int_{\Omega^e}\underset{\approx}{N}^T\underset{\approx}{V}^T\underset{\approx}{D}(t)\underset{\approx}{V}\,\underset{\approx}{N}dz \tag{9.18}$$

$$\underset{\sim}{F}^{e} = \int_{\Omega^e} \underset{\approx}{N}^T \underset{\sim}{p} dz - \int_{\Omega^e} \underset{\approx}{N}^T \underset{\sim}{q} dz \tag{9.19}$$

During the assembly of the elemental equations, it is assumed that the stresses and displacements are continuous at the layer interface, which yields the following set of equations:

$$\underset{\approx}{K}(0)\left\{\underset{\sim}{W}(t)\right\} - \int_0^t \frac{d\,\underset{\approx}{K}(t-\tau)}{d\tau}\left\{\underset{\sim}{W}(\tau)\right\} d\tau = \underset{\sim}{F} \tag{9.20}$$

Discretizing the convolution integral in equation (9.20) by the finite difference method leads to the following equation:

$$\left(\underset{\approx}{K}(0) - \theta\Delta t \left.\frac{d\,\underset{\approx}{K}(t-\tau)}{d\tau}\right|_{\tau=t+\Delta t}\right)\left\{\underset{\sim}{W}(t+\Delta t)\right\} = \underset{\sim}{F}(t+\Delta t) + (1-\theta)\Delta t \left.\frac{d\,\underset{\approx}{K}(t-\tau)}{d\tau}\right|_{\tau=t}\left\{\underset{\sim}{W}(t)\right\} \tag{9.21}$$

Therefore, the solutions at any time can be solved by a forward marching process. However, it is observed that there is an accumulation of history terms on the right-hand-side of equation (9.21) as time increases. Thus, the demand on computer storage and computer time will increase as time increases. This problem can be overcome if each component of $\underset{\approx}{D}(t)$ can be expressed as a Prony series, which bypasses the need to store the entire history of displacements, strains and stresses.

9.4 Analyze pavement section using direct time integration method

In this section, visco-elastic analysis approach is employed to study the effect of load frequency and air void content on tensile strain at the bottom of asphalt concrete

layer. In the mean time, the comparison of fatigue life between elastic and visco-elastic analysis will be made.

9.4.1 Effect of load frequency

The pavement section used in this analysis is shown in Figure 9-6. The first layer consists of SP 12.5-mm mix with optimum minus 0.5-percent asphalt content at air void content of 4.5%. Once again, the pavement section is subjected to single standard axle load (i.e.,18 kips). Haversine loading with various frequencies (50, 20, 10, 5, 2, and 1 Hz) was used in the computation. Figure 9-7 shows the haversine loading with frequency of 10 Hz. Visco-elastic parameters needed in this analysis are given in Table 9-2.

Table 9-5 summarizes the computation result at various frequencies. It shows that the ratio of elastic strain to visco-elastic strain decreases with the decrease of load frequency. In turn, the ratio of fatigue life based on elastic analysis to that based on visco-elastic analysis increases with the decrease of load frequency. At frequency of 10 and 5 Hz, fatigue life computed by elastic analysis is about 1.6 and 2 times as that by visco-elastic analysis, respectively.

9.4.2 The effect of air void content

The pavement structure used in this analysis is still as shown in Figure 9-6. Here, the first layer consists of SP 12.5-mm mix with optimum minus 0.5-percent asphalt content at varying air void content (i.e., 4.5, 6.1, and 7.8-percent). The frequency of load is 10 Hz. Visco-elastic parameters are shown in Table 9-2.

Tensile strain and fatigue life computed based on both elastic and visco-elastic analysis are summarized in Table 9-6. It shows that the percent difference based on vico-elastic analysis is fairly close to that based on elastic analysis.

9.5 Summary

This chapter obtained visco-elastic parameters of the general Maxwell model for SP 12.5-mm and SP 19-mm mixes. Those parameters can be used in visco-elastic analysis.

Table 9-1 Parameters of SP 12.5-mm mix with optimum AC, T=20°C

	Va =4.0%		Va = 6%		Va = 7.8%	
	E_i (psi)	λ_i	E_i (psi)	λ_i	E_i (psi)	λ_i
0	20,000		10,000		5,000	
1	7.61E+05	0.0013	6.75E+05	0.0021	6.37E+05	0.0023
2	5.89E+05	0.0159	4.79E+05	0.0193	4.70E+05	0.0236
3	4.42E+05	0.1476	2.88E+05	0.1480	2.54E+05	0.2116
4	2.32E+05	1.1730	1.14E+05	1.1860	7.85E+04	2.08
5	1.01E+05	12.50	3.58E+04	6.94	2.22E+04	20.45
6	3.47E+04	191.90	3.02E+04	58.43	1.00E+04	320.20

Table 9-2 Parameters of SP 12.5-mm mix with optimum minus 0.5-percent AC, T=20°C

	Va =4.5%		Va = 6%		Va = 8%	
	E_i (psi)	λ_i	E_i (psi)	λ_i	E_i (psi)	λ_i
0	15,000		10,000		4,000	
1	8.02E+05	0.0027	7.59E+05	0.0017	6.89E+05	0.0031
2	6.95E+05	0.0324	5.74E+05	0.0212	4.41E+05	0.0211
3	4.39E+05	0.3451	3.45E+05	0.2071	3.15E+05	0.1179
4	1.47E+05	3.2640	1.13E+05	1.8280	1.60E+05	0.6805
5	4.13E+04	30.33	3.38E+04	20.53	8.11E+04	7.0190
6	1.21E+04	385.80	9.50E+03	327.40		

Table 9-3 Parameters of SP 19-mm mix with optimum AC, T=20°C

	Va =3.4%		Va = 6%		Va = 7%	
	E_i (psi)	λ_i	E_i (psi)	λ_i	E_i (psi)	λ_i
0	20,000		15,000		5,000	
1	6.83E+05	0.0034	6.06E+05	0.0047	6.63E+05	0.0045
2	4.83E+05	0.0284	4.29E+05	0.0354	4.40E+05	0.0499
3	3.86E+05	0.1894	2.98E+05	0.1947	2.91E+05	0.4122
4	2.29E+05	1.2310	1.79E+05	0.9735	1.12E+05	3.2390
5	9.80E+04	8.807	9.81E+04	5.871	4.77E+04	26.460
6	4.43E+04	73.790	4.79E+04	97.270	1.61E+04	373.100

Table 9-4 Parameters of SP 19-mm mix with optimum minus 0.5-percent AC, T=20°C

	Va =3.8%		Va = 7.5%		Va =9.3 %	
	E_i (psi)	λ_i	E_i (psi)	λ_i	E_i (psi)	λ_i
0	20,000		7,500		4,000	
1	6.96E+05	0.0028	6.76E+05	0.006	4.89E+05	0.0028
2	5.30E+05	0.0192	4.03E+05	0.066	3.66E+05	0.0239
3	4.20E+05	0.1192	1.65E+05	0.519	1.96E+05	0.2147
4	1.59E+05	0.8276	4.34E+04	3.674	5.56E+04	2.1850
5	5.79E+04	4.85	2.13E+04	12.87	2.21E+04	27.98
6	1.59E+04	42.79	1.41E+04	185.20		

Table 9-5 Comparison of N_f at various frequency between elastic and visco-elastic analysis, T=20°C

Frequency (Hz)	$\lvert E^* \rvert$ (psi)	E_t (psi)	ε_e (in/in)	ε_{ve} (in/in)	$\frac{\varepsilon_e}{\varepsilon_{ve}}$	$\frac{N_{f\_e}}{N_{f\_ve}}$
50	1.55E+06	1.00E+06	77.53E-06	83.7E-06	0.93	1.29
20	1.38E+06	7.41E+05	83.63E-06	95.0E-06	0.88	1.52
10	1.20E+06	5.71E+05	91.54E-06	105E-06	0.87	1.57
5	1.11E+06	4.54E+05	96.25E-06	120E-06	0.80	2.06
2	8.47E+06	2.97E+05	111.5E-06	142E-06	0.79	2.21
1	6.59E+06	1.99E+05	134.0E-06	180E-06	0.74	2.63

Note: Mix type is SP 12.5-mm mix with optimum minus 0.5-percent AC at air void content of 4.5%.

Table 9-6 Comparison of N_f at various air void content between elastic and visco-elastic analysis at 10 Hz, T=20°C

Va (%)	VFA (%)	|E*| (psi)	Elastic Analysis			Visco-elastic Analysis			$\frac{N_{f\_e}}{N_{f\_ve}}$
			Strain (in/in)	N_{supply} (ESALs)	% diff	Strain (in/in)	N_{supply} (ESALs)	% diff	
4.5	69.01	1.20E+06	9.15E-05	7.20E+06		1.05E-04	4.59E+06		1.57
6.1	61.67	9.08E+05	1.09E-04	4.23E+06	-41	1.30E-04	2.40E+06	-48	1.76
7.8	55.4	7.34E+05	1.25E-04	2.77E+06	-34	1.48E-04	1.60E+06	-33	1.73

Note: 1. The percent difference is the difference expressed as a percentage of the higher value;
2. Mix type is SP 12.5-mm mix with optimum minus 0.5-percent AC at 10 Hz.

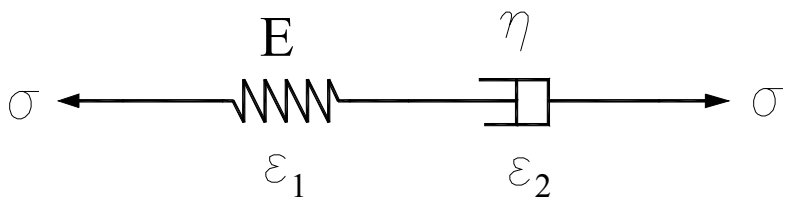


Figure 9-1 Maxwell model

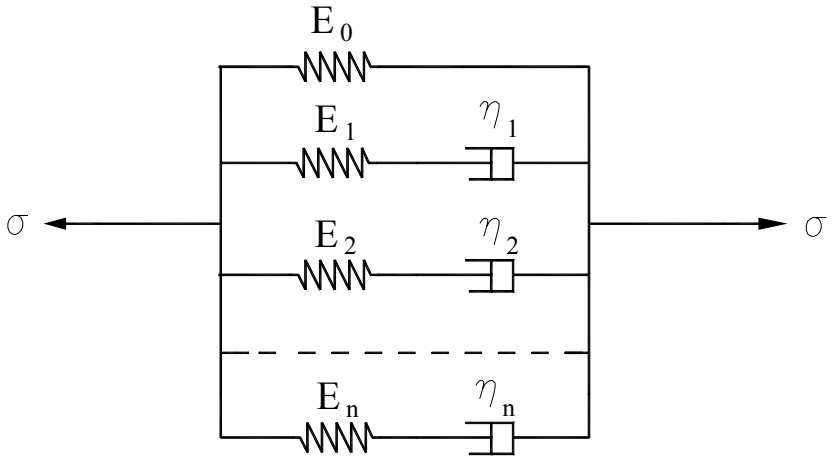


Figure 9-2 Generalized Maxwell model

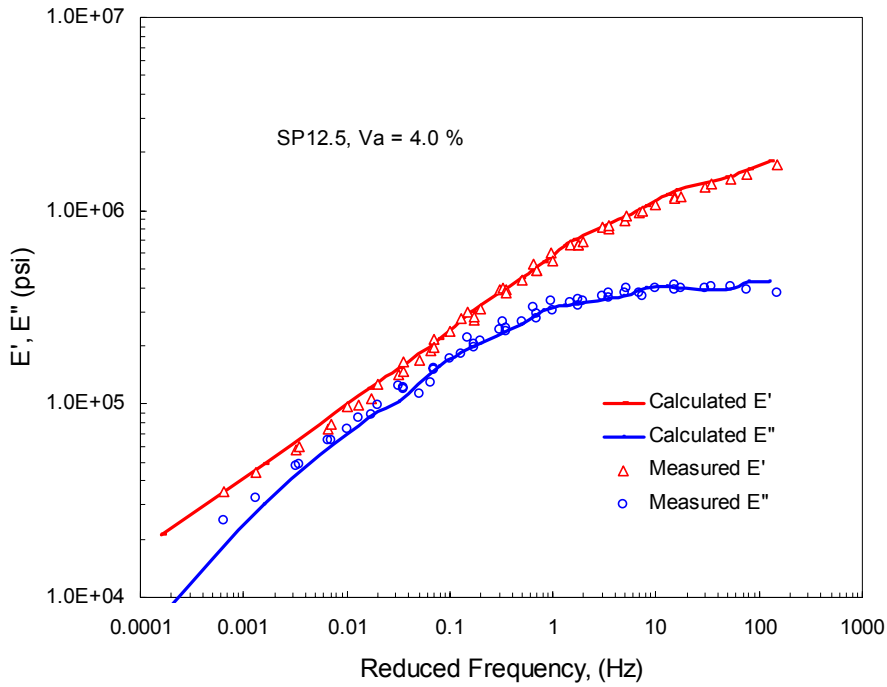


Figure 9-3 E', E" of SP 12.5-mm mix with optimum AC, V_a=4%, T=20°C

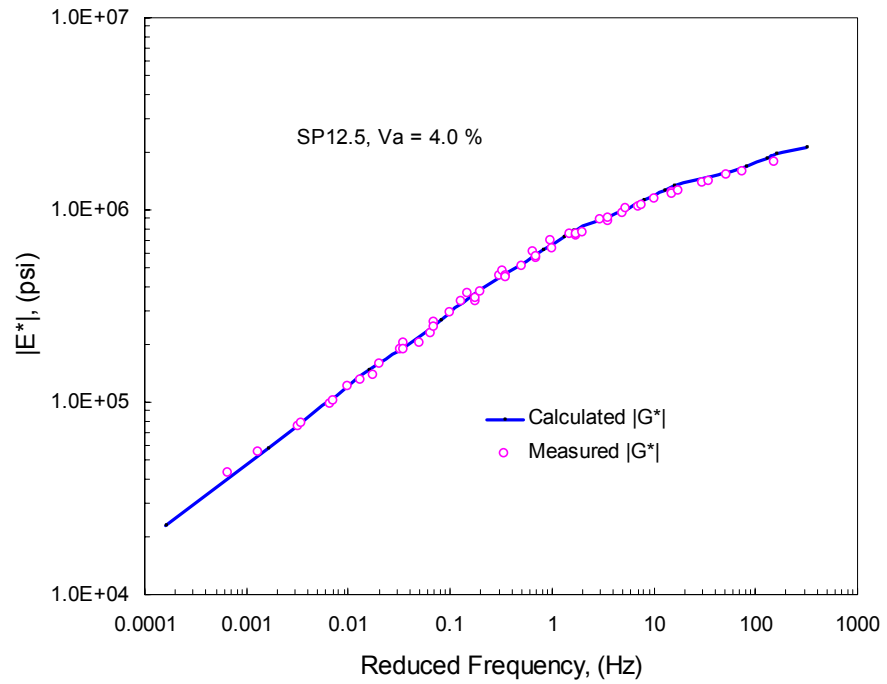


Figure 9-4 Comparison of calculated and measured |E*| for SP12.5-mm mix with optimum AC, V_a=4%

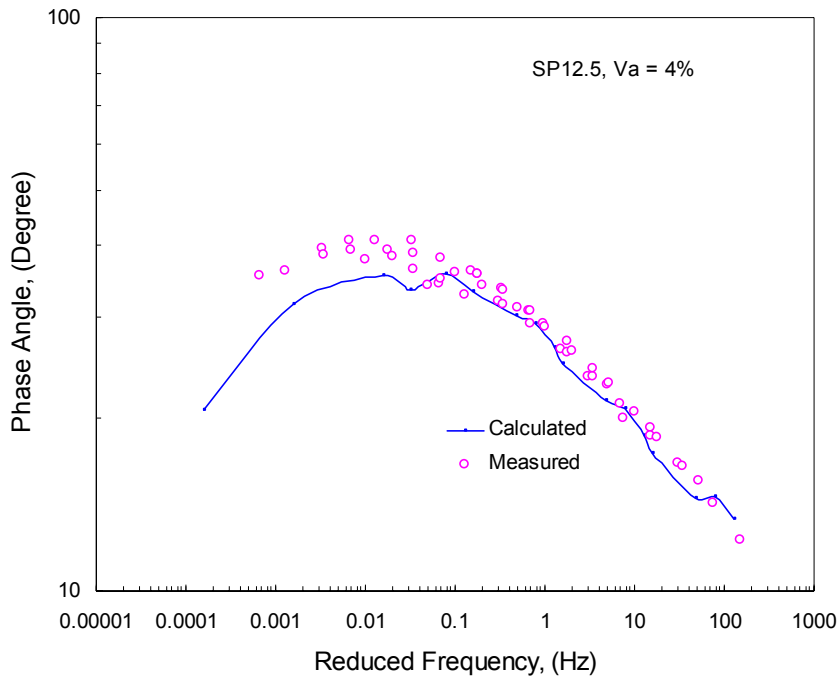


Figure 9-5 Comparison of calculated and measured phase angle for SP12.5-mm mix with optimum AC, V_a=4%

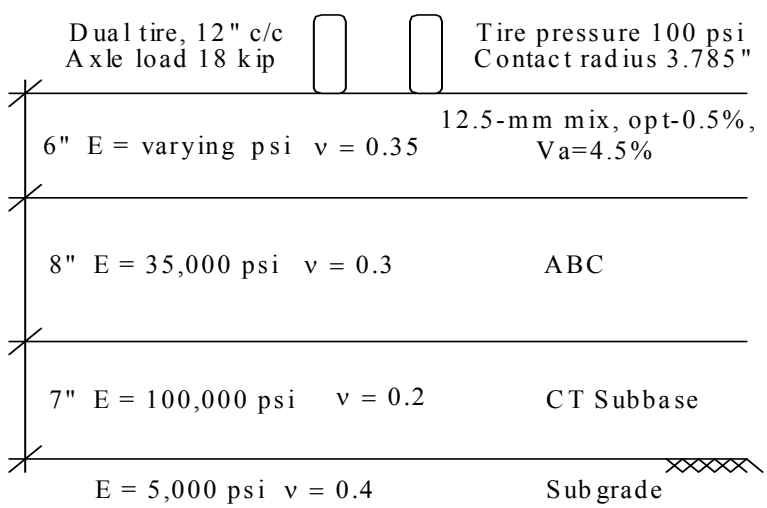


Figure 9-6 Pavement structure for studying effect of frequency on tensile strain

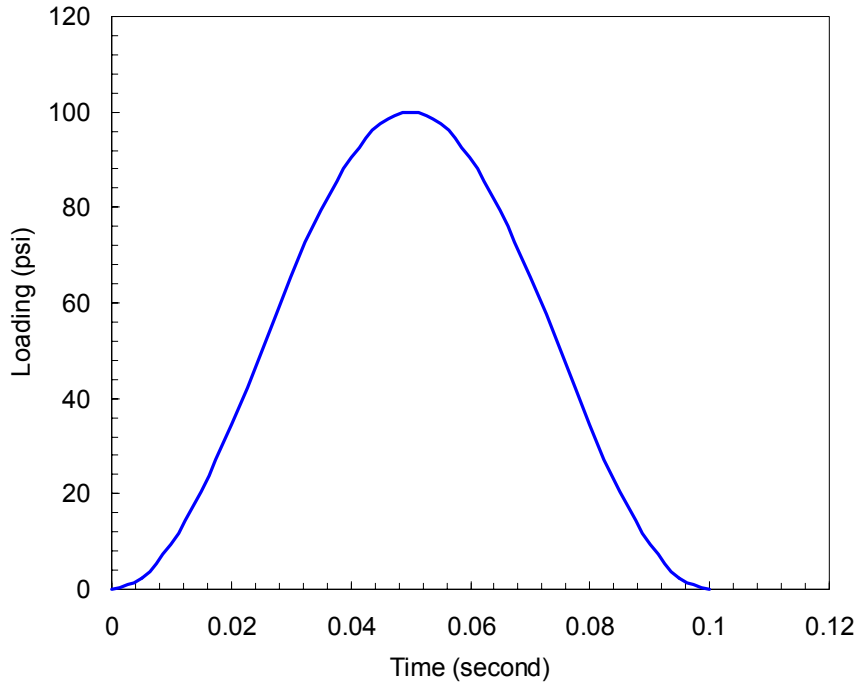


Figure 9-7 Haversine loading with frequency of 10 Hz

10. Summary and conclusions

The primary objectives of this research study was to characterize properties of two NCDOT Superpave mixes, and to develop phenomenological fatigue relationships for these mixes based on various levels of strain, asphalt content, air voids content, and temperatures. Of particular importance was the sensitivity of the Superpave mixes to asphalt content and air void content that are usually expected in-situ. This study included laboratory investigation of a 12.5-mm and a 19-mm mixes at moderate temperatures of 15°C, 20°C and 25°C where predominant fatigue cracking is expected to be significant.

Specific work tasks that were considered are the following:

- Verification of the JMF,
- Specimen fabrication for the fatigue and stiffness testing,
- Flexural fatigue testing of beam specimens at 15°C, 20°C and 25°C, and at 3 different strain levels,
- Axial and shear frequency sweep testing,
- Shear frequency sweep testing on field cores, and
- Analysis of test results and development of fatigue and stiffness models along with mechanistic analysis procedure for fatigue distress.
- Studying the effect of frequency on fatigue distress.
- Characterization of visco-elastic parameters for SP 12.5-mm and 19-mm mixes.

Materials used in this study were the same as those used for the SPS-9A Project 370900, Highway US-1 in Sanford, NC. Based on the raw materials obtained, verification of the JMF was conducted for both 12.5-mm and 19-mm mixes. It was found that both

mixes confirmed to the JMF volumetric requirements. Based on the mix design, laboratory specimens were fabricated using a rolling wheel compactor. A 2 ft. by 2 ft. slabs were compacted at target air void contents of 4, 6, and 8-percent; and at optimum and optimum minus 0.5-percent asphalt content. Flexure beam specimens (2 in x 2.5 in x 15 in) and core specimens (6 in diameter x 2 in height) were then sawn and cored for fatigue testing and for determination of shear stiffness. Prismatic specimens for the axial stiffness testing were obtained by sawing the flexure beam specimens to 6 in height with a cross section of 2 in by 2.5 in

In all, more than 280 fatigue tests and 144 frequency sweep tests were conducted. Statistical analysis of fatigue data indicates the following:

- Both asphalt content and gradation have significant impact on laboratory fatigue life of Superpave 12.5-mm and 19-mm mixes. On an average, change in asphalt content from optimum to optimum minus 0.5-percent decreased the laboratory fatigue life by about 50-percent. For the gradation, 12.5-mm mix appears to be more resistant to fatigue compared to the 19-mm mix. This could partly be due to the lower asphalt content in 19-mm mixes.
- In general, for the same strain level, increase in temperature increased laboratory fatigue life. This behavior is typical for the controlled-strain mode-of-loading applied in laboratory. However, conventional wisdom generally suggest that fatigue life of in-situ pavement section should increase with decrease in temperature. This was shown to be the case during the mechanistic analysis of typical pavement sections.
- In fatigue testing, strain level had a significant impact on initial stiffness, especially at higher temperature. This result is somewhat expected as high strain levels and high temperatures will induce damage during fatigue testing early on. However, this result is very undesirable as the so called “initial stiffness” is no longer a true measure of the initial mix property. It is therefore suggested that when conducting laboratory fatigue testing for a given specimen, a two step procedure be followed: first, the

initial flexure stiffness should be measured at strain level small enough so as not to induce damage to the specimen; and second, subject the specimen to fatigue testing at the desired strain level.

- Asphalt content or gradation does not seem to have an effect on "initial flexural stiffness" as defined in this study to correspond to 50th loading cycle. This can again be attributed to the damage caused by large strain levels at high temperature that may mask any effect of asphalt content or gradation.
- For the same mix at the same air void content and temperature, decrease in frequency always results in increase in fatigue life. This is also a typical behavior of controlled-strain mode-of-testing.

Following fatigue testing, axial and shear frequency sweep testing was conducted. The analysis of the results indicated that for both axial and shear stiffness are sensitive to mix parameters and test temperatures, including the asphalt content and gradation. The regression models calibrated for dynamic axial and shear stiffness at 10 Hz are:

$$\left|E^*\right|_{10Hz} = 17.5153 \times 10^5 \cdot \exp(0.03956 \cdot AC + 0.01256 \cdot GR - 0.31472 \cdot Temp - 0.11671 \cdot V_a) \qquad R^2 = 0.94$$

$$\left|G^*\right|_{10Hz} = 10.7313 \times 10^5 \cdot \exp(-0.04504 \cdot AC + 0.05947 \cdot GR - 0.34265 \cdot Temp - 0.1564 \cdot V_a \qquad R^2 = 0.71$$

where,

$|E^*|$ = axial stiffness, and loss stiffness in psi;

$|G^*|$ = shear stiffness, and loss stiffness in psi;

AC = asphalt content: -1 for opt.-0.5%, +1 for opt.;

GR = aggregate gradation: -1 for SP 12.5-mm, +1 for SP 19-mm;

V_a = air void content in percent; and

Temp = test temperature: -1, 0, +1 for 15°C, 0 is 20°C, +1 is 25°C.

The relationship between the dynamic axial and shear stiffness for the mixes considered in this study was found to be the following:

$$\left|E^*\right|_{10Hz} = 37.6 \cdot \left|G^*\right|_{10Hz}^{0.78114} \qquad R^2 = 0.96$$

Based on the fatigue test results, the laboratory fatigue life model that could be used for pavement analysis is the following:

$$N_f = 1.13 \times 10^{-2} \cdot \exp(0.04789 \cdot VFA - 0.26812 \cdot GR) \cdot \varepsilon_0^{-3.44019} \cdot \left|E^*\right|^{-1.07005} \qquad R^2 = 0.81$$

where,

N_f = laboratory fatigue life;
VFA = void filled with asphalt in percent;
ε0 = initial strain, in/in;
|E*| = initial axial stiffness, and loss stiffness;
GR = -1 for 12.5-mm, and 1 for 19-mm mix; and
e = exponent of the natural logarithm.

Mechanistic analysis of typical pavement sections was conducted to evaluate the effect of mix and temperature variables on pavement fatigue life using the laboratory fatigue relationship developed for NCDOT mixes. The results of the analysis suggest the following:

- Pavement fatigue life based on NCDOT fatigue models is sensitive to the mix variables and test temperatures considered in this study.

- NCDOT fatigue models yields fatigue life similar to those obtained using SHRP fatigue model. However, NCDOT models are sensitive to temperature, whereas the SHRP fatigue model per-se is not sensitive to temperature.
- An increase in temperature results in decrease in fatigue life of pavement section under consideration. A 5°C increase in temperature results in about 25-percent reduction in life. This trend is opposite to the trend shown by laboratory fatigue data where increase in temperature will result in increase in laboratory fatigue life.
- NCDOT mixes are sensitive to asphalt content. A decrease in asphalt content by 0.5-percent (by wt. of mix) results in decrease of 18 to 25-percent fatigue life.
- NCDOT mixes are also sensitive to air void content as expected. An increase in 2-percent air void content will reduce pavement life by about 40-percent for 12.5-mm mixes, and by almost 60-percent for 19-mm mixes.
- Based on the overall result of analysis, it appears that 19-mm mixes are more sensitive to mix variables as compared to the 12.5-mm mixes.
- Pavement fatigue life seemingly can be predicted using fatigue model at any load frequency as long as the stiffness at the same load frequency is used to compute tensile strain. Fatigue test can be done at any frequency. In general, lower frequency gives more accurate result, but takes longer time.
- The ratio of fatigue life based on elastic analysis to that based on visco-elastic analysis increases with the decrease in frequency. At 10 Hz, fatigue life computed by elastic analysis is about 1.6 times as that computed by visco-elastic analysis.

Based on the fatigue test to study the effect of frequency on fatigue life, a fatigue life prediction procedure, incorporating the effect of load frequency on fatigue life, is proposed and verified.

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Appendix A. Job formula

CORRECTED COPY

NORTH CAROLINA DEPARTMENT OF TRANSPORATION
RALEIGH, NORTH CAROLINA 27611

SUPERPAVE HOT MIX ASPHALT JOB MIX FORMULA

LEE PAVING COMPANY

SANFORD NC

PLANT CERTIFICATION NO.: B-033

TYPE MIX: ACBC, TYPE SP 12.5

JOB MIX FORM NO: 97-442-021

EFFECTIVE DATE: 05-09-97

PROJECT NO: 6.549001T

COUNTY: LEE-CHATHAM

AGGREGATE SOURCES AND BLEND PERCENTAGES

SUPPLIER	LOCATION/SOURCE	MATERIAL	BLEND (%)
MARTIN MARIETTA	LEMON SPRINGS QUARRY	#67	15.0
MARTIN MARIETTA	LEMON SPRINGS QUARRY	#78M	55.0
MARTIN MARIETTA	LEMON SPRINGS QUARRY	REG. SCRGS.	20.0
LEE PAVING COMPANY	RAMBEAUT PIT	N. SAND	10.0
		TOTAL	100.0%

JMF COMBINED GRADATION

SIEVE SIZE		% PASSING
2 "	(50.0 mm)	
1 1/2"	(37.5 mm)	
1"	(25.0 mm)	
3/4"	(19.0 mm)	100
1/2"	(12.5 mm)	94
3/8"	(9.5 mm)	84
No. 4	(4.75 mm)	43
No. 8	(2.36 mm)	29
No. 16	(1.18 mm)	23
No. 30	(0.600 mm)	17
No. 50	(0.300 mm)	9
No. 100	(0.150 mm)	7
No. 200	(0.075 mm)	4.4

*ASPHALT BINDER % (TOT)	5.2
GRADE	PG 64-22
MAX. SP. GR.	2.464
GYRATORY SP. GR.: $G_{mb}@N_d$	2.356
VOIDS IN TOTAL MIX %	4.0
VOIDS IN MIN. AGG. %	14.8
VOIDS FILLED W/ASPH %	73
MIN. % COMPACTION % G_{mm}	92.0
MIX TEMPERATURE F.	300
NON-STRIP ADDITIVE %	0.25
MODIFIER %	0.00
$N_{ini}/N_{des}/N_{max}$	8/106/169

ASPHALT CEMENT SUPPLIER : CITGO WILMINGTON
TACK COAT SUPPLIER : SEACO, COLUMBIA, SC CRS-1
NON-STRIP ADD. SUPPLIER : AD-HERE - ARR MAZ LOF 65-00
COMMENTS:

APPROVED BY:
J. E. GRADY, JR., PE
PAVEMENT CONSTRUCTION ENGINEER

DATE JMF VOID:

CORRECTED COPY

NORTH CAROLINA DEPARTMENT OF TRANSPORATION
RALEIGH, NORTH CAROLINA 27611

SUPERPAVE HOT MIX ASPHALT JOB MIX FORMULA

LEE PAVING COMPANY

SANFORD NC

PLANT CERTIFICATION NO.: B-033

TYPE MIX: ACBC, TYPE SP 19.0

JOB MIX FORM NO: 97-441-021

EFFECTIVE DATE: 05-09-97

PROJECT NO: 6.549001T

COUNTY: LEE-CHATHAM

AGGREGATE SOURCES AND BLEND PERCENTAGES

SUPPLIER	LOCATION/SOURCE	MATERIAL	BLEND (%)
MARTIN MARIETTA	LEMON SPRINGS QUARRY	#67	50.0
MARTIN MARIETTA	LEMON SPRINGS QUARRY	#78M	22.0
MARTIN MARIETTA	LEMON SPRINGS QUARRY	REG. SCRGS.	18.0
LEE PAVING COMPANY	RAMBEAUT PIT	N. SAND	10.0
		TOTAL	100.0%

JMF COMBINED GRADATION

SIEVE SIZE		% PASSING
2 "	(50.0 mm)	
1 1/2"	(37.5 mm)	
1"	(25.0 mm)	100
3/4"	(19.0 mm)	99
1/2"	(12.5 mm)	80
3/8"	(9.5 mm)	62
No. 4	(4.75 mm)	35
No. 8	(2.36 mm)	27
No. 16	(1.18 mm)	22
No. 30	(0.600 mm)	16
No. 50	(0.300 mm)	9
No. 100	(0.150 mm)	6
No. 200	(0.075 mm)	4.2

*ASPHALT BINDER % (TOT)	4.7
GRADE	PG 64-22
MAX. SP. GR.	2.483
GYRATORY SP. GR.: $G_{mb}@N_d$	2.384
VOIDS IN TOTAL MIX %	4.0
VOIDS IN MIN. AGG. %	14.0
VOIDS FILLED W/ASPH %	70
MIN. % COMPACTION % G_{mm}	92.0
MIX TEMPERATURE F.	300
NON-STRIP ADDITIVE %	0.25
MODIFIER %	0.00
$N_{ini}/N_{des}/N_{max}$	8/106/169

ASPHALT CEMENT SUPPLIER : CITGO WILMINGTON
TACK COAT SUPPLIER : SEACO, COLUMBIA, SC CRS-1
NON-STRIP ADD. SUPPLIER : AD-HERE - ARR MAZ LOF 65-00
COMMENTS:

APPROVED BY:
J. E. GRADY, JR., PE
PAVEMENT CONSTRUCTION ENGINEER

DATE JMF VOID:

Appendix B. Fatigue test data

AC	GR	RT	Temp.	Air void	strain	|E*|	Phase Angle	E"	Fatigue life	VFA	Vb/(Va+Vb)
				%	in/in	psi	degree	psi	cycles	%	
1	-1	-1	-1	7.62	2.38E-04	1013348	22.72	391405	522000	50.55	0.611
1	-1	1	-1	7.87	2.73E-04	983863	23.29	388992	238955	49.44	0.603
1	-1	-1	-1	7.98	3.60E-04	971427	23.53	387852	81052	48.50	0.600
1	-1	1	-1	7.87	4.70E-04	983749	23.29	388982	29811	48.87	0.603
1	-1	-1	-1	7.67	5.77E-04	1006864	22.85	390909	19481	50.61	0.609
1	-1	1	-1	7.73	5.78E-04	999838	22.98	390350	15502	50.22	0.607
1	-1	-1	-1	4.98	5.94E-04	1378538	16.44	390145	18500	67.67	0.706
1	-1	1	-1	5.17	5.98E-04	1348778	16.91	392259	25500	66.81	0.698
1	-1	-1	-1	5.09	3.89E-04	1361589	16.71	391390	81052	67.18	0.702
1	-1	1	-1	4.97	3.65E-04	1379826	16.42	390046	115000	67.70	0.707
1	-1	-1	-1	5.13	3.39E-04	1354615	16.82	391871	274000	66.97	0.700
1	-1	1	-1	5.13	2.86E-04	1354615	16.82	391871	255909	66.97	0.700
1	-1	-1	-1	3.65	1.92E-04	1610022	13.02	362758	590000	74.33	0.769
1	-1	-1	-1	3.79	3.22E-04	1584854	13.38	366639	112500	73.60	0.762
1	-1	-1	-1	3.65	3.90E-04	1610022	13.02	362758	100002	74.33	0.769
1	-1	1	-1	3.76	4.00E-04	1590412	13.30	365800	67000	73.76	0.764
1	-1	-1	-1	3.88	5.80E-04	1567379	13.62	369208	30000	73.10	0.757
1	-1	1	-1	3.79	6.31E-04	1584854	13.38	366639	7500	73.60	0.762
-1	-1	-1	-1	8.18	2.00E-04	876412	25.45	376679	144273	54.08	0.561
-1	-1	1	-1	7.79	2.22E-04	917440	24.61	382046	800000	55.40	0.574
-1	-1	-1	-1	8.37	2.43E-04	857392	25.85	373904	142047	53.46	0.555
-1	-1	1	-1	8.50	2.87E-04	845073	26.12	372008	83504	53.06	0.551
-1	-1	-1	-1	8.18	3.07E-04	876412	25.45	376679	72500	54.08	0.561
-1	-1	1	-1	8.50	3.15E-04	845073	26.12	372008	82000	53.06	0.551
-1	-1	-1	-1	8.18	3.43E-04	876412	25.45	376679	50000	54.08	0.561
-1	-1	-1	-1	8.62	4.56E-04	832834	26.38	370046	13705	52.67	0.547
-1	-1	-1	-1	7.97	5.26E-04	898787	24.99	379710	9453	54.80	0.568
-1	-1	-1	-1	6.12	2.52E-04	1114609	20.85	396681	290000	61.67	0.636
-1	-1	1	-1	5.52	2.66E-04	1195459	19.43	397686	180000	64.23	0.661
-1	-1	-1	-1	6.42	2.77E-04	1077013	21.53	395256	145002	60.48	0.624
-1	-1	1	-1	6.24	2.79E-04	1099236	21.13	396173	147000	61.19	0.631
-1	-1	-1	-1	5.52	3.15E-04	1195459	19.43	397686	110000	64.23	0.661
-1	-1	-1	-1	6.42	3.81E-04	1077013	21.53	395256	40000	60.48	0.624
-1	-1	1	-1	6.24	4.12E-04	1099621	21.12	396187	37000	61.20	0.631
-1	-1	-1	-1	6.50	6.76E-04	1067253	21.71	394784	2000	60.17	0.621
-1	-1	-1	-1	4.34	1.83E-04	1372451	16.54	390605	350000	69.99	0.715
-1	-1	1	-1	4.32	2.02E-04	1376140	16.48	390328	340000	69.94	0.716
-1	-1	-1	-1	4.32	2.05E-04	1376140	16.48	390328	205000	69.94	0.716
-1	-1	1	-1	4.50	2.85E-04	1347060	16.93	392371	135000	68.99	0.707
-1	-1	-1	-1	4.50	4.01E-04	1347060	16.93	392371	32000	69.02	0.707
-1	-1	-1	-1	4.34	4.81E-04	1372451	16.54	390605	14000	69.99	0.715
-1	-1	1	-1	4.86	5.28E-04	1291635	17.82	395368	8000	67.25	0.690
-1	-1	-1	-1	4.50	6.55E-04	1347060	16.93	392371	5000	68.99	0.707
1	1	-1	-1	4.90	1.90E-04	1426533	15.70	386040	260000	66.72	0.689
1	1	1	-1	4.46	2.14E-04	1502053	14.57	377885	270000	68.88	0.710
1	1	-1	-1	4.36	2.40E-04	1518977	14.32	375779	720000	69.37	0.715
1	1	-1	-1	4.63	3.46E-04	1472373	15.01	381333	15002	68.03	0.702

AC	GR	RT	Temp.	Air void	strain	|E*|	Phase Angle	E"	Fatigue life	VFA	Vb/(Va+Vb)
				%	in/in	psi	degree	psi	cycles	%	
1	1	1	-1	4.43	3.51E-04	1507849	14.49	377175	80001	69.05	0.712
1	1	-1	-1	4.62	4.04E-04	1474437	14.98	381104	27500	68.09	0.703
1	1	1	-1	4.94	4.40E-04	1420718	15.79	386583	17500	66.55	0.688
1	1	1	-1	4.51	4.60E-04	1492791	14.71	378994	14501	68.62	0.708
1	1	-1	-1	5.74	2.22E-04	1294223	17.78	395254	160000	62.94	0.653
1	1	-1	-1	5.50	2.77E-04	1330988	17.19	393362	75600	64.41	0.663
1	1	1	-1	5.87	2.79E-04	1274438	18.11	396054	240000	62.37	0.647
1	1	-1	-1	5.74	3.26E-04	1293317	17.80	395294	102500	62.91	0.653
1	1	1	-1	5.97	3.30E-04	1260091	18.34	396537	41000	61.63	0.644
1	1	-1	-1	5.31	4.04E-04	1360038	16.73	391499	37500	64.82	0.671
1	1	1	-1	5.74	4.30E-04	1294223	17.78	395254	9200	62.94	0.653
1	1	-1	-1	5.88	4.42E-04	1272060	18.14	396140	13500	62.31	0.647
1	1	1	-1	5.75	4.86E-04	1292111	17.82	395347	16000	62.88	0.652
1	1	-1	-1	6.56	1.95E-04	1175831	19.77	397696	550000	59.55	0.620
1	1	1	-1	6.64	2.14E-04	1164768	19.96	397630	320000	59.24	0.617
1	1	-1	-1	6.81	2.53E-04	1141619	20.37	397326	185002	58.57	0.610
1	1	1	-1	6.58	3.18E-04	1172269	19.83	397680	125002	59.45	0.619
1	1	-1	-1	6.73	3.60E-04	1153135	20.16	397506	32002	58.90	0.613
1	1	1	-1	6.71	3.97E-04	1154886	20.13	397528	47000	58.95	0.614
1	1	-1	-1	7.07	4.10E-04	1107885	20.97	396472	57500	57.60	0.601
1	1	1	-1	6.80	4.18E-04	1142552	20.35	397342	27000	58.60	0.610
1	1	-1	-1	6.73	5.38E-04	1153135	20.16	397506	10000	58.90	0.613
-1	1	-1	-1	4.20	1.70E-04	1431216	15.63	385594	350000	69.25	0.700
-1	1	1	-1	4.41	1.89E-04	1396075	16.17	388744	400000	68.14	0.689
-1	1	-1	-1	5.23	1.95E-04	1268958	18.20	396248	140000	61.67	0.652
-1	1	1	-1	4.33	2.16E-04	1409665	15.96	387580	180000	68.57	0.693
-1	1	-1	-1	4.08	2.30E-04	1451571	15.32	383563	85000	69.89	0.706
-1	1	-1	-1	4.17	4.31E-04	1436403	15.55	385091	27000	69.41	0.702
-1	1	-1	-1	3.70	6.81E-04	1517219	14.35	376002	3500	71.99	0.727
-1	1	-1	-1	4.13	8.80E-04	1442620	15.46	384475	350	69.61	0.704
-1	1	-1	-1	7.08	1.54E-04	1021698	22.56	392015	285000	56.40	0.573
-1	1	1	-1	6.58	1.76E-04	1083725	21.41	395556	600000	58.34	0.592
-1	1	-1	-1	6.83	2.60E-04	1053053	21.97	394022	142000	56.80	0.583
-1	1	1	-1	6.66	2.62E-04	1074155	21.58	395122	185001	58.04	0.589
-1	1	-1	-1	6.83	2.81E-04	1053053	21.97	394022	185000	57.38	0.583
-1	1	1	-1	6.78	3.03E-04	1058845	21.87	394344	32000	57.56	0.584
-1	1	-1	-1	6.87	3.10E-04	1047537	22.08	393701	57500	57.21	0.581
-1	1	-1	-1	6.58	6.39E-04	1083725	21.41	395556	9500	58.34	0.592
-1	1	1	-1	6.68	6.67E-04	1071151	21.64	394978	2700	57.95	0.588
-1	1	-1	-1	9.50	1.59E-04	770662	27.75	358863	286000	47.47	0.494
-1	1	1	-1	9.39	1.66E-04	780893	27.52	360846	110000	48.77	0.497
-1	1	-1	-1	9.41	1.86E-04	778799	27.57	360445	210000	48.70	0.496
-1	1	1	-1	9.67	2.19E-04	755610	28.09	355843	230001	47.96	0.489
-1	1	-1	-1	9.59	2.46E-04	762787	27.93	357299	180000	48.19	0.491
-1	1	-1	-1	9.27	3.52E-04	792091	27.27	362951	23000	49.13	0.500
-1	1	1	-1	8.63	3.67E-04	853422	25.94	373301	8750	51.09	0.520
1	-1	-1	0	4.06	2.43E-04	1120259	20.75	396842	537500	72.15	0.748
1	-1	1	0	3.84	2.85E-04	1149798	20.22	397459	535000	73.31	0.759
1	-1	-1	0	3.82	3.59E-04	1152889	20.17	397502	180000	73.44	0.761
1	-1	-1	0	4.28	4.05E-04	1091607	21.26	395883	130000	71.02	0.738
1	-1	1	0	3.76	4.29E-04	1160990	20.03	397596	125000	73.76	0.764

AC	GR	RT	Temp.	Air void	strain	|E*|	Phase Angle	E"	Fatigue life	VFA	Vb/(Va+Vb)
				%	in/in	psi	degree	psi	cycles	%	
1	-1	-1	0	5.43	2.33E-04	954502	23.87	386183	385000	66.76	0.685
1	-1	1	0	6.29	2.43E-04	863651	25.72	374837	100000	62.03	0.652
1	-1	-1	0	6.29	2.61E-04	863651	25.72	374837	42000	61.51	0.653
1	-1	1	0	6.30	2.94E-04	862342	25.75	374644	435000	61.98	0.652
1	-1	-1	0	6.32	3.43E-04	860833	25.78	374420	185000	61.92	0.651
1	-1	1	0	5.43	3.48E-04	954502	23.87	386183	130000	66.76	0.685
1	-1	-1	0	5.76	3.67E-04	918760	24.58	382205	260000	64.21	0.673
1	-1	1	0	5.09	3.90E-04	993951	23.09	389863	80000	67.18	0.702
1	-1	-1	0	6.27	6.86E-04	865972	25.67	375179	10500	62.12	0.653
1	-1	1	0	5.99	7.38E-04	894739	25.07	379180	11000	63.26	0.664
1	-1	-1	0	8.31	2.41E-04	682342	29.82	339330	1500000	54.75	0.582
1	-1	1	0	8.18	3.26E-04	692855	29.57	341887	135002	55.18	0.586
1	-1	-1	0	8.30	3.61E-04	683139	29.80	339526	131800	54.78	0.582
1	-1	1	0	8.10	3.76E-04	698865	29.42	343321	92500	55.43	0.588
1	-1	-1	0	8.49	5.24E-04	668079	30.17	335756	25000	54.17	0.576
1	-1	1	0	8.22	5.65E-04	689547	29.65	341089	16500	55.05	0.584
-1	-1	-1	0	4.46	1.77E-04	987946	23.21	389350	648607	69.21	0.709
-1	-1	1	0	5.04	2.48E-04	923391	24.49	382756	339612	66.42	0.682
-1	-1	-1	0	4.48	2.67E-04	985873	23.25	389170	185002	69.13	0.708
-1	-1	1	0	4.46	2.82E-04	987946	23.21	389350	145000	69.21	0.709
-1	-1	-1	0	4.04	3.88E-04	1037459	22.26	393080	75000	71.37	0.730
-1	-1	1	0	4.56	3.89E-04	976825	23.43	388356	42500	68.73	0.705
-1	-1	-1	0	4.18	5.38E-04	1021003	22.58	391966	27000	70.65	0.723
-1	-1	1	0	4.32	5.82E-04	1003870	22.90	390674	12500	69.91	0.716
-1	-1	-1	0	6.54	2.47E-04	775187	27.65	359747	410000	61.38	0.618
-1	-1	1	0	6.41	2.60E-04	787222	27.38	362044	365002	64.05	0.620
-1	-1	-1	0	6.50	2.70E-04	779087	27.56	360500	230000	62.99	0.618
-1	-1	1	0	6.64	2.85E-04	766372	27.85	358015	120000	62.22	0.612
-1	-1	-1	0	6.62	3.29E-04	767714	27.82	358282	125000	63.64	0.611
-1	-1	1	0	6.60	3.38E-04	769778	27.77	358690	87000	62.17	0.614
-1	-1	-1	0	6.47	7.28E-04	781090	27.52	360884	3700	62.68	0.619
-1	-1	-1	0	7.65	2.55E-04	680599	29.86	338899	400000	53.02	0.582
-1	-1	1	0	7.76	2.57E-04	671917	30.08	336729	308000	52.67	0.578
-1	-1	-1	0	8.62	2.93E-04	607963	31.69	319358	140000	47.51	0.552
-1	-1	1	0	7.90	3.03E-04	661568	30.33	334085	138889	51.96	0.574
-1	-1	-1	0	7.88	3.94E-04	662804	30.30	334404	37000	51.68	0.575
-1	-1	-1	0	7.19	5.84E-04	718556	28.96	347872	14000	56.03	0.597
-1	-1	1	0	7.44	5.89E-04	697730	29.45	343052	12002	54.16	0.589
1	1	-1	0	4.84	2.18E-04	1049412	22.04	393812	230000	67.03	0.692
1	1	1	0	4.13	3.01E-04	1140075	20.39	397297	120000	70.60	0.727
1	1	-1	0	4.37	4.00E-04	1107937	20.97	396474	70000	69.33	0.715
1	1	1	0	4.09	4.09E-04	1145009	20.31	397385	90000	70.79	0.729
1	1	-1	0	4.28	5.77E-04	1119636	20.76	396825	6002	69.79	0.719
1	1	1	0	4.04	6.39E-04	1151710	20.19	397486	8000	71.06	0.731
1	1	-1	0	5.67	2.53E-04	951636	23.92	385887	180000	63.21	0.655
1	1	1	0	5.43	2.64E-04	979125	23.38	388566	136065	64.80	0.665
1	1	-1	0	5.68	2.89E-04	951302	23.93	385852	93000	63.45	0.655
1	1	1	0	5.80	3.80E-04	938182	24.19	384444	25000	62.42	0.651
1	1	-1	0	5.68	4.93E-04	951080	23.93	385829	16000	62.64	0.656
1	1	1	0	5.68	5.14E-04	951302	23.93	385852	12000	63.19	0.655
1	1	-1	0	6.43	2.20E-04	870861	25.57	375888	550000	59.87	0.625

AC	GR	RT	Temp.	Air void	strain	|E*|	Phase Angle	E"	Fatigue life	VFA	Vb/(Va+Vb)
				%	in/in	psi	degree	psi	cycles	%	
1	1	1	0	6.49	2.70E-04	865289	25.69	375078	135000	59.72	0.623
1	1	-1	0	6.38	3.03E-04	876469	25.45	376687	87000	60.26	0.627
1	1	1	0	6.41	3.54E-04	873712	25.51	376296	70000	60.16	0.626
1	1	-1	0	6.44	3.77E-04	870048	25.59	375771	41000	60.12	0.624
1	1	1	0	6.36	4.66E-04	878825	25.40	377018	15500	60.53	0.627
-1	1	-1	0	4.46	2.38E-04	1012841	22.73	391367	280000	67.86	0.686
-1	1	1	0	4.07	2.88E-04	1060750	21.83	394446	105000	69.94	0.707
-1	1	-1	0	4.93	3.00E-04	959115	23.77	386652	64000	65.55	0.664
-1	1	1	0	3.70	3.62E-04	1107560	20.97	396461	33000	71.99	0.727
-1	1	-1	0	4.34	5.26E-04	1027606	22.45	392427	9000	68.50	0.693
-1	1	1	0	3.92	6.76E-04	1078854	21.50	395340	6002	70.73	0.715
-1	1	-1	0	6.53	1.73E-04	795464	27.20	363572	385000	58.53	0.594
-1	1	-1	0	6.59	2.00E-04	790374	27.31	362633	475000	58.31	0.592
-1	1	1	0	6.36	2.02E-04	811593	26.84	366457	115000	59.22	0.601
-1	1	-1	0	6.57	2.72E-04	791943	27.28	362924	77000	58.38	0.592
-1	1	1	0	6.56	2.83E-04	792961	27.25	363112	61000	58.42	0.593
-1	1	-1	0	5.92	5.34E-04	854658	25.91	373490	5500	61.06	0.619
-1	1	1	0	6.52	6.50E-04	796578	27.17	363776	5000	58.68	0.594
-1	1	-1	0	8.91	1.75E-04	602681	31.83	317811	210000	50.20	0.511
-1	1	-1	0	9.12	2.26E-04	588158	32.21	313469	100000	49.57	0.505
-1	1	1	0	9.57	2.80E-04	558131	33.01	304067	70000	48.24	0.491
-1	1	-1	0	8.91	4.38E-04	602752	31.82	317832	8000	50.21	0.511
-1	1	1	0	8.99	4.40E-04	597429	31.96	316256	6500	49.98	0.509
1	-1	-1	1	4.12	7.65E-04	811791	26.84	366491	13500	71.82	0.745
1	-1	1	1	4.24	7.40E-04	800454	27.09	364479	9500	71.56	0.739
1	-1	-1	1	3.84	4.36E-04	839639	26.23	371147	90000	73.33	0.760
1	-1	-1	1	6.12	3.51E-04	643018	30.79	329185	220000	62.71	0.659
1	-1	1	1	6.42	3.98E-04	621184	31.35	323152	150000	60.97	0.648
1	-1	-1	1	6.27	5.33E-04	632154	31.07	326220	33000	60.42	0.655
1	-1	1	1	5.22	5.48E-04	714068	29.06	346854	60000	66.56	0.696
1	-1	-1	1	5.64	6.72E-04	679830	29.88	338709	22000	64.71	0.678
1	-1	1	1	5.62	6.84E-04	681658	29.84	339161	15000	64.80	0.679
1	-1	-1	1	7.33	3.06E-04	558658	33.00	304237	317600	58.11	0.614
1	-1	1	1	6.91	3.15E-04	586656	32.25	313012	310000	59.65	0.629
1	-1	-1	1	7.19	3.50E-04	567596	32.75	307093	325000	58.61	0.619
1	-1	1	1	7.40	3.71E-04	553854	33.13	302680	200000	57.86	0.612
1	-1	-1	1	7.29	5.68E-04	561010	32.93	304993	75000	58.24	0.616
1	-1	-1	1	6.70	1.24E-03	600791	31.87	317253	4500	60.42	0.637
-1	-1	-1	1	3.68	2.75E-04	790297	27.31	362618	220000	73.33	0.749
-1	-1	1	1	3.90	3.36E-04	769814	27.77	358697	180000	72.11	0.737
-1	-1	-1	1	3.97	4.02E-04	763907	27.91	357523	80000	71.76	0.734
-1	-1	1	1	3.98	4.15E-04	763105	27.92	357363	40000	71.71	0.733
-1	-1	-1	1	3.74	4.43E-04	784324	27.45	361498	55000	72.98	0.746
-1	-1	1	1	4.10	4.59E-04	751790	28.18	355057	25000	71.03	0.727
-1	-1	-1	1	6.10	2.81E-04	595491	32.01	315678	310000	61.77	0.637
-1	-1	1	1	5.86	3.01E-04	612407	31.57	320645	260000	62.77	0.646
-1	-1	-1	1	6.46	3.70E-04	571190	32.66	308227	85000	60.32	0.623
-1	-1	1	1	5.89	4.32E-04	610409	31.62	320068	50000	62.65	0.645
-1	-1	-1	1	6.11	5.77E-04	594797	32.03	315470	25000	61.72	0.636
-1	-1	1	1	6.04	6.21E-04	599676	31.90	316923	20000	62.01	0.639
-1	-1	-1	1	7.03	2.00E-04	534303	33.67	296190	668000	58.12	0.601

AC	GR	RT	Temp.	Air void	strain	|E*|	Phase Angle	E"	Fatigue life	VFA	Vb/(Va+Vb)
				%	in/in	psi	degree	psi	cycles	%	
-1	-1	1	1	7.62	2.70E-04	499041	34.66	283839	560000	56.01	0.580
-1	-1	-1	1	7.17	3.06E-04	525644	33.91	293234	174000	57.61	0.596
-1	-1	1	1	7.08	3.31E-04	531318	33.75	295177	160000	57.94	0.599
-1	-1	-1	1	6.83	3.40E-04	546922	33.32	300408	155000	58.87	0.608
-1	-1	-1	1	7.09	5.93E-04	530575	33.77	294924	20000	57.90	0.599
-1	-1	1	1	7.00	6.31E-04	536177	33.61	296823	11500	58.25	0.602
1	1	-1	1	3.55	3.00E-04	890118	25.17	378566	585000	73.73	0.757
1	1	1	1	3.44	3.00E-04	901409	24.94	380049	750000	75.84	0.761
1	1	-1	1	3.96	5.67E-04	848825	26.04	372594	55000	71.49	0.735
1	1	1	1	3.52	5.72E-04	893344	25.10	378996	51000	73.91	0.758
1	1	-1	1	4.33	5.86E-04	813141	26.81	366726	25000	69.57	0.717
1	1	1	1	3.54	5.96E-04	891262	25.15	378719	5500	73.80	0.757
1	1	-1	1	6.14	2.10E-04	657992	30.42	333156	720000	61.24	0.636
1	1	1	1	6.14	2.40E-04	658222	30.41	333216	685000	61.25	0.636
1	1	-1	1	6.15	2.79E-04	657147	30.44	332936	350000	61.19	0.636
1	1	1	1	6.00	2.83E-04	668753	30.15	335928	300000	61.82	0.642
1	1	-1	1	5.67	2.98E-04	695418	29.51	342501	567000	47.51	0.668
1	1	-1	1	5.21	4.13E-04	733345	28.61	351145	135000	65.27	0.676
1	1	1	1	5.69	4.14E-04	693068	29.56	341938	197000	63.12	0.655
1	1	-1	1	5.41	6.02E-04	716425	29.01	347390	5500	64.36	0.667
1	1	1	1	6.33	6.18E-04	643486	30.78	329312	4000	60.46	0.629
1	1	-1	1	5.49	6.60E-04	710181	29.15	345963	12502	64.04	0.663
1	1	1	1	6.13	6.60E-04	658452	30.41	333276	16000	61.26	0.637
1	1	-1	1	5.74	7.00E-04	689759	29.64	341141	19000	62.94	0.653
-1	1	-1	1	3.70	2.18E-04	808417	26.91	365900	610000	71.98	0.727
-1	1	1	1	3.86	2.58E-04	793276	27.25	363170	482000	71.07	0.718
-1	1	-1	1	3.82	3.77E-04	797174	27.16	363884	70000	71.31	0.720
-1	1	-1	1	3.82	4.59E-04	797360	27.16	363918	45000	71.32	0.720
-1	1	1	1	3.92	4.80E-04	787832	27.37	362158	25000	70.75	0.715
-1	1	-1	1	4.81	2.52E-04	709857	29.16	345889	300000	66.12	0.669
-1	1	-1	1	5.16	3.04E-04	681524	29.84	339128	80000	64.48	0.653
-1	1	1	1	5.12	3.50E-04	684473	29.77	339853	105000	64.62	0.654
-1	1	-1	1	4.80	4.24E-04	711100	29.13	346175	48750	66.19	0.670
-1	1	1	1	4.79	5.49E-04	711349	29.13	346232	14500	66.21	0.670
-1	1	-1	1	7.34	2.66E-04	528488	33.83	294211	270000	55.46	0.563
-1	1	1	1	7.80	2.70E-04	500805	34.61	284477	281000	53.83	0.547
-1	1	-1	1	7.29	3.03E-04	531767	33.74	295330	85000	55.66	0.565
-1	1	1	1	7.18	3.41E-04	538387	33.55	297566	52500	55.87	0.569
-1	1	-1	1	7.45	5.50E-04	521990	34.01	291972	4000	55.08	0.560
-1	1	1	1	7.27	5.50E-04	532575	33.71	295604	3800	55.70	0.566
-1	1	-1	1	7.79	6.00E-04	501682	34.59	284793	7500	53.88	0.548
1	1	1	1	3.52	5.72E-04	893344	25.10	378996	51000	73.91	0.758

Note: AC = Asphalt content. AC = 1 means optimum asphalt content;
AC=-1 means optimum minus 0.5-percent asphalt content.
GR = Gradation. GR = -1 means 12.5-mm mix; GR=1 means 19-mm mix.
RT = Replicates. RT = -1 means only one replicate; RT=1 means two replicates.
Temp = Temperature. Temp = -1 means temperature is 15°C; and
Temp = 0 means temperature is 20°C, and
Temp = 1 means temperature is 25°C.

Appendix C. Adjusted fatigue data based on GLM

Adjusted data for SP 12.5-mm with optimum asphalt content

AC	GR	Temp.	Air void	strain	Nf	S_0	S_0"
			%	in/in	cycles	psi	psi
1	-1	-1	4	0.0002	741774	1432455	646546
1	-1	-1	4	0.0004	59707	1249183	557825
1	-1	-1	4	0.0006	13676	1153026	511703
1	-1	-1	6	0.0002	730511	1143038	528924
1	-1	-1	6	0.0004	58800	996795	456343
1	-1	-1	6	0.0006	13468	920065	418570
1	-1	-1	8	0.0002	719420	912187	432657
1	-1	-1	8	0.0004	57907	795479	373286
1	-1	-1	8	0.0006	13263	734246	342422
1	-1	0	4	0.0002	1194813	1091867	549300
1	-1	0	4	0.0004	92513	952171	482434
1	-1	0	4	0.0006	20715	878877	447173
1	-1	0	6	0.0002	1176554	871264	449324
1	-1	0	6	0.0004	91108	759792	394668
1	-1	0	6	0.0006	20398	701306	365785
1	-1	0	8	0.0002	1158689	695231	367581
1	-1	0	8	0.0004	89725	606282	322836
1	-1	0	8	0.0006	20088	559669	299240
1	-1	1	4	0.0002	1924352	832177	466634
1	-1	1	4	0.0004	143344	725706	417233
1	-1	1	4	0.0006	31373	669911	390780
1	-1	1	6	0.0002	1895134	664108	381742
1	-1	1	6	0.0004	141153	579140	341294
1	-1	1	6	0.0006	30897	534560	319688
1	-1	1	8	0.0002	1866359	529930	312263
1	-1	1	8	0.0004	139010	462129	279205
1	-1	1	8	0.0006	30427	426556	261503

Note: AC = Asphalt content. AC = 1 means optimum asphalt content.
GR = Gradation. GR = -1 means 12.5-mm mix.
RT = Replicates. RT = -1 means only one replicate.
Temp = Temperature. Temp = -1 means temperature is 15°C; and
Temp = 0 means temperature is 20°C, and
Temp = 1 means temperature is 25°C.

Adjusted data for SP 12.5-mm with optimum minus 0.5-percent asphalt content

AC	GR	Temp.	Air void	strain	Nf	S_0	S_0"
			%	in/in	cycles	psi	psi
-1	-1	-1	4	0.0002	399832	1563285	739922
-1	-1	-1	4	0.0004	32183	1363274	635140
-1	-1	-1	4	0.0006	7372	1258461	580880
-1	-1	-1	6	0.0002	393761	1247560	605252
-1	-1	-1	6	0.0004	31695	1087944	519540
-1	-1	-1	6	0.0006	7259	1004198	475157
-1	-1	-1	8	0.0002	387744	995500	495142
-1	-1	-1	8	0.0004	31213	868133	425024
-1	-1	-1	8	0.0006	7149	801307	388714
-1	-1	0	4	0.0002	643965	1191591	628568
-1	-1	0	4	0.0004	49866	1039136	549300
-1	-1	0	4	0.0006	11165	959147	507626
-1	-1	0	6	0.0002	634188	950934	514217
-1	-1	0	6	0.0004	49104	829269	449324
-1	-1	0	6	0.0006	10995	765435	415235
-1	-1	0	8	0.0002	624558	758805	420626
-1	-1	0	8	0.0004	48359	661721	367581
-1	-1	0	8	0.0006	10828	610785	339694
-1	-1	1	4	0.0002	1037267	908273	534026
-1	-1	1	4	0.0004	77258	792066	475014
-1	-1	1	4	0.0006	16911	731096	443610
-1	-1	1	6	0.0002	1021416	724763	436830
-1	-1	1	6	0.0004	76085	632098	388598
-1	-1	1	6	0.0006	16654	583442	362870
-1	-1	1	8	0.0002	1005907	578388	357360
-1	-1	1	8	0.0004	74929	504387	317871
-1	-1	1	8	0.0006	16399	465562	296855

Note: AC = Asphalt content. AC = -1 means optimum minus 0.5-percent asphalt content.
GR = Gradation. GR = -1 means 12.5-mm mix.
RT = Replicates. RT = -1 means only one replicate.
Temp = Temperature. Temp = -1 means temperature is 15°C; and
Temp = 0 means temperature is 20°C, and
Temp = 1 means temperature is 25°C.

Adjusted data for SP 19-mm with optimum asphalt content

AC	GR	Temp.	Air void	strain	Nf	S_0	S_0"
			%	in/in	cycles	psi	psi
1	1	-1	4	0.0002	472976	1717706	777470
1	1	-1	4	0.0004	38071	1497938	670782
1	1	-1	4	0.0006	8720	1382633	615260
1	1	-1	6	0.0002	371907	1370656	635966
1	1	-1	6	0.0004	29938	1195291	548696
1	1	-1	6	0.0006	6857	1103392	503329
1	1	-1	8	0.0002	292465	1093835	520268
1	1	-1	8	0.0004	23541	953887	448830
1	1	-1	8	0.0006	5392	880460	411720
1	1	0	4	0.0002	761770	1191591	590426
1	1	0	4	0.0004	58989	1039136	518554
1	1	0	4	0.0006	13207	959147	480653
1	1	0	6	0.0002	599050	950934	482965
1	1	0	6	0.0004	46384	829269	424217
1	1	0	6	0.0006	10386	765435	393210
1	1	0	8	0.0002	471041	758805	395102
1	1	0	8	0.0004	36476	661721	347007
1	1	0	8	0.0006	8167	610785	321644
1	1	1	4	0.0002	1227021	826702	448382
1	1	1	4	0.0004	91391	720932	400913
1	1	1	4	0.0006	20004	665438	375495
1	1	1	6	0.0002	964823	659673	366810
1	1	1	6	0.0004	71869	575273	327945
1	1	1	6	0.0006	15730	530991	307183
1	1	1	8	0.0002	758729	526391	300049
1	1	1	8	0.0004	56512	459043	268284
1	1	1	8	0.0006	12370	423750	251274

Note: AC = Asphalt content. AC = 1 means optimum asphalt content.
GR = Gradation. GR = 1 means 19-mm mix.
RT = Replicates. RT = -1 means only one replicate.
Temp = Temperature. Temp = -1 means temperature is 15°C; and
Temp = 0 means temperature is 20°C, and
Temp = 1 means temperature is 25°C.

Adjusted data for SP 19-mm with optimum minus 0.5-percent asphalt content

AC	GR	Temp.	Air void	strain	Nf	S_0	S_0"
			%	in/in	cycles	psi	psi
-1	1	-1	4	0.0002	254919	1573794	770042
-1	1	-1	4	0.0004	20521	1372439	660994
-1	1	-1	4	0.0006	4700	1266794	604526
-1	1	-1	6	0.0002	200466	1255946	629890
-1	1	-1	6	0.0004	16136	1095257	540689
-1	1	-1	6	0.0006	3696	1010949	494499
-1	1	-1	8	0.0002	157645	1002192	515298
-1	1	-1	8	0.0004	12689	873969	442325
-1	1	-1	8	0.0006	2906	806694	404538
-1	1	0	4	0.0002	410610	1091867	584785
-1	1	0	4	0.0004	31793	952171	511038
-1	1	0	4	0.0006	7119	878877	472267
-1	1	0	6	0.0002	322868	871264	478399
-1	1	0	6	0.0004	25002	759792	418026
-1	1	0	6	0.0006	5598	701306	386312
-1	1	0	8	0.0002	253901	695231	391327
-1	1	0	8	0.0004	19659	606282	341977
-1	1	0	8	0.0006	4402	559669	316032
-1	1	1	4	0.0002	661325	757440	444142
-1	1	1	4	0.0004	49262	660531	395063
-1	1	1	4	0.0006	10782	609686	368944
-1	1	1	6	0.0002	520060	604405	363306
-1	1	1	6	0.0004	38735	527076	323191
-1	1	1	6	0.0006	8479	486552	301794
-1	1	1	8	0.0002	408930	482338	297212
-1	1	1	8	0.0004	30461	420626	264369
-1	1	1	8	0.0006	6667	388248	246890

Note: AC = Asphalt content. AC = -1 means optimum minus 0.5-percent asphalt content.
GR = Gradation. GR = 1 means 19-mm mix.
RT = Replicates. RT = -1 means only one replicate.
Temp = Temperature. Temp = -1 means temperature is 15°C; and
Temp = 0 means temperature is 20°C, and
Temp = 1 means temperature is 25°C.

Appendix D. Axial frequency sweep test data

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	-1	3.80	15.00	1.50E+06	15.69	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	10.00	1.40E+06	16.69	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	5.00	1.23E+06	18.63	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	2.00	1.02E+06	21.43	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	1.00	8.65E+05	23.84	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.50	7.25E+05	26.10	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.20	5.56E+05	29.21	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.10	4.51E+05	31.41	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.05	3.31E+05	30.79	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.02	2.58E+05	34.75	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.01	2.02E+05	35.42	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	15.00	1.55E+06	15.41	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	10.00	1.44E+06	16.39	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	5.00	1.27E+06	18.37	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	2.00	1.06E+06	21.13	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	1.00	8.97E+05	23.60	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.50	7.54E+05	26.04	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.20	5.78E+05	29.36	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.10	4.66E+05	31.65	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.05	3.37E+05	30.75	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.02	2.65E+05	35.40	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	3.80	0.01	2.06E+05	37.26	2.3750	73.66	0.7611	14.43	12.11
1	-1	-1	6.54	15.00	1.16E+06	18.96	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	6.54	10.00	1.06E+06	20.35	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	6.54	5.00	9.07E+05	23.01	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	6.54	2.00	7.17E+05	26.92	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	6.54	1.00	5.82E+05	30.23	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	6.54	0.50	4.63E+05	33.49	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	6.54	0.20	3.31E+05	37.66	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	6.54	0.10	2.52E+05	40.46	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	6.54	0.05	1.65E+05	40.73	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	6.54	0.02	1.23E+05	45.22	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	6.54	0.01	9.13E+04	46.92	2.3093	61.04	0.6428	16.79	11.77
1	-1	-1	5.64	15.00	1.40E+06	16.48	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	5.64	10.00	1.30E+06	17.65	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	5.64	5.00	1.13E+06	19.92	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	5.64	2.00	9.17E+05	23.31	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	5.64	1.00	7.64E+05	26.15	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	5.64	0.50	6.25E+05	29.12	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	5.64	0.20	4.66E+05	32.83	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	5.64	0.10	3.65E+05	35.06	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	5.64	0.05	2.57E+05	35.32	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	5.64	0.02	1.96E+05	39.00	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	5.64	0.01	1.48E+05	39.64	2.3316	64.71	0.6781	15.99	11.89
1	-1	-1	7.87	15.00	1.12E+06	19.58	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	10.00	1.02E+06	21.01	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	5.00	8.70E+05	23.76	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	2.00	6.78E+05	27.72	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	1.00	5.46E+05	30.64	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.50	4.32E+05	33.89	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.20	3.08E+05	37.28	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.10	2.35E+05	39.07	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.05	1.62E+05	38.96	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.02	1.23E+05	41.17	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.01	9.21E+04	40.66	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	15.00	9.38E+05	22.64	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	10.00	8.46E+05	24.31	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	5.00	6.99E+05	27.57	2.2766	56.22	0.5960	17.97	11.61

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	-1	7.87	2.00	5.22E+05	32.20	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	1.00	4.09E+05	35.56	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.50	3.09E+05	39.16	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.20	2.09E+05	43.27	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.10	1.52E+05	45.50	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.05	9.94E+04	45.86	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.02	6.98E+04	48.46	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1	7.87	0.01	4.88E+04	48.66	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	3.80	15.00	1.25E+06	19.40	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	10.00	1.14E+06	20.62	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	5.00	9.71E+05	22.92	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	2.00	7.73E+05	26.03	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	1.00	6.33E+05	28.63	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.50	5.17E+05	30.80	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.20	3.80E+05	33.52	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.10	3.00E+05	34.99	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.05	2.09E+05	32.58	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.02	1.66E+05	36.70	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.01	1.28E+05	36.04	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	15.00	1.24E+06	19.20	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	10.00	1.13E+06	20.51	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	5.00	9.68E+05	23.00	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	2.00	7.67E+05	26.35	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	1.00	6.26E+05	29.22	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.50	5.07E+05	31.78	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.20	3.69E+05	34.83	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.10	2.87E+05	36.87	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.05	1.95E+05	35.58	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.02	1.54E+05	39.94	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	3.80	0.01	1.15E+05	39.65	2.3750	73.66	0.7611	14.43	12.11
1	-1	0	6.54	15.00	8.36E+05	24.91	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	6.54	10.00	7.45E+05	26.59	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	6.54	5.00	6.05E+05	29.82	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	6.54	2.00	4.44E+05	34.09	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	6.54	1.00	3.40E+05	37.47	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	6.54	0.50	2.58E+05	39.94	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	6.54	0.20	1.75E+05	42.88	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	6.54	0.10	1.28E+05	44.23	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	6.54	0.05	9.03E+04	44.60	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	6.54	0.02	6.29E+04	45.40	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	6.54	0.01	4.52E+04	45.43	2.3093	61.04	0.6428	16.79	11.77
1	-1	0	5.64	15.00	9.74E+05	23.18	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	5.64	10.00	8.77E+05	24.78	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	5.64	5.00	7.22E+05	27.70	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	5.64	2.00	5.41E+05	31.74	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	5.64	1.00	4.23E+05	34.72	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	5.64	0.50	3.27E+05	37.30	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	5.64	0.20	2.28E+05	39.55	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	5.64	0.10	1.71E+05	40.55	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	5.64	0.05	1.25E+05	40.29	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	5.64	0.02	9.03E+04	40.30	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	5.64	0.01	6.98E+04	39.47	2.3316	64.71	0.6781	15.99	11.89
1	-1	0	7.87	15.00	8.61E+05	24.73	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	10.00	7.67E+05	26.55	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	5.00	6.23E+05	29.91	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	2.00	4.54E+05	34.46	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	1.00	3.48E+05	37.64	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.50	2.64E+05	40.56	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.20	1.77E+05	43.16	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.10	1.30E+05	43.69	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.05	8.90E+04	43.47	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.02	6.37E+04	43.08	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.01	5.00E+04	39.67	2.2766	56.22	0.5960	17.97	11.61

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	0	7.87	15.00	8.36E+05	26.73	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	10.00	7.36E+05	28.61	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	5.00	5.80E+05	32.22	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	2.00	4.06E+05	36.96	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	1.00	2.91E+05	41.04	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.50	2.29E+05	43.23	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.20	1.50E+05	45.69	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.10	1.08E+05	46.76	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.05	7.16E+04	45.76	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.02	4.89E+04	42.20	2.2766	56.22	0.5960	17.97	11.61
1	-1	0	7.87	0.01	3.56E+04	40.82	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	3.80	15.00	1.05E+06	22.50	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	10.00	9.49E+05	23.98	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	5.00	7.86E+05	26.72	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	2.00	5.96E+05	30.25	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	1.00	4.72E+05	33.02	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.50	3.69E+05	35.20	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.20	2.62E+05	37.67	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.10	2.00E+05	38.47	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.05	1.46E+05	38.94	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.02	1.09E+05	39.32	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.01	8.29E+04	38.40	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	15.00	9.76E+05	23.54	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	10.00	8.75E+05	25.06	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	5.00	7.19E+05	27.89	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	2.00	5.41E+05	31.37	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	1.00	4.25E+05	34.17	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.50	3.31E+05	36.38	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.20	2.32E+05	38.47	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.10	1.77E+05	39.28	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.05	1.29E+05	39.63	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.02	9.53E+04	39.21	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	3.80	0.01	7.21E+04	38.93	2.3750	73.66	0.7611	14.43	12.11
1	-1	1	6.54	15.00	7.00E+05	28.36	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	6.54	10.00	6.14E+05	30.21	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	6.54	5.00	4.85E+05	33.52	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	6.54	2.00	3.44E+05	37.50	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	6.54	1.00	2.59E+05	39.99	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	6.54	0.50	1.93E+05	42.27	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	6.54	0.20	1.29E+05	43.57	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	6.54	0.10	9.47E+04	43.37	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	6.54	0.05	6.72E+04	42.67	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	6.54	0.02	5.05E+04	38.45	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	6.54	0.01	4.09E+04	35.89	2.3093	61.04	0.6428	16.79	11.77
1	-1	1	5.64	15.00	7.78E+05	27.35	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	5.64	10.00	6.87E+05	29.03	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	5.64	5.00	5.46E+05	32.18	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	5.64	2.00	3.92E+05	35.88	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	5.64	1.00	2.99E+05	38.71	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	5.64	0.50	2.25E+05	40.38	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	5.64	0.20	1.53E+05	41.60	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	5.64	0.10	1.15E+05	40.99	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	5.64	0.05	8.46E+04	39.24	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	5.64	0.02	6.29E+04	36.63	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	5.64	0.01	5.12E+04	32.69	2.3316	64.71	0.6781	15.99	11.89
1	-1	1	7.87	15.00	6.64E+05	29.72	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	10.00	5.79E+05	31.77	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	5.00	4.50E+05	35.42	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	2.00	3.12E+05	39.92	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	1.00	2.29E+05	42.68	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.50	1.68E+05	45.47	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.20	1.09E+05	47.07	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.10	7.82E+04	47.60	2.2766	56.22	0.5960	17.97	11.61

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	1	7.87	0.05	5.24E+04	46.80	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.02	3.71E+04	45.33	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.01	3.02E+04	44.19	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	15.00	6.62E+05	32.85	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	10.00	5.64E+05	34.96	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	5.00	4.10E+05	38.71	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	2.00	2.40E+05	44.87	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	1.00	1.75E+05	47.14	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.50	1.43E+05	49.37	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.20	9.11E+04	51.28	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.10	6.33E+04	51.75	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.05	4.16E+04	50.08	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.02	2.95E+04	49.12	2.2766	56.22	0.5960	17.97	11.61
1	-1	1	7.87	0.01	2.30E+04	47.62	2.2766	56.22	0.5960	17.97	11.61
1	-1	-1.6	3.65	15.00	1.86E+06	11.79	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	3.65	10.00	1.77E+06	12.32	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	3.65	5.00	1.59E+06	14.28	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	3.65	2.00	1.38E+06	16.73	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	3.65	1.00	1.22E+06	18.67	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	3.65	0.50	1.06E+06	20.08	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	3.65	0.20	8.93E+05	23.75	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	3.65	0.10	7.49E+05	26.36	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	3.65	0.05	6.03E+05	29.24	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	3.65	0.02	4.56E+05	32.12	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	3.65	0.01	3.72E+05	36.10	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	15.00	6.98E+05	29.22	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	10.00	6.11E+05	30.89	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	5.00	4.80E+05	33.69	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	2.00	3.32E+05	32.92	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	1.00	2.29E+05	34.48	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	0.50	1.89E+05	40.91	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	0.20	1.31E+05	40.85	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	0.10	9.84E+04	40.83	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	0.05	7.53E+04	39.61	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	0.02	5.53E+04	36.14	2.3807	74.33	0.7688	14.22	12.14
1	-1	2	3.65	0.01	4.30E+04	35.57	2.3807	74.33	0.7688	14.22	12.14
1	-1	-1.6	7.87	15.00	1.17E+06	16.78	2.2765	56.21	0.5959	17.97	11.61
1	-1	-1.6	7.87	10.00	1.08E+06	18.10	2.2765	56.21	0.5959	17.97	11.61
1	-1	-1.6	7.87	5.00	9.41E+05	20.58	2.2765	56.21	0.5959	17.97	11.61
1	-1	-1.6	7.87	2.00	7.67E+05	24.56	2.2765	56.21	0.5959	17.97	11.61
1	-1	-1.6	7.87	1.00	6.30E+05	27.61	2.2765	56.21	0.5959	17.97	11.61
1	-1	-1.6	7.87	0.50	5.30E+05	31.20	2.2765	56.21	0.5959	17.97	11.61
1	-1	-1.6	7.87	0.20	3.80E+05	34.68	2.2765	56.21	0.5959	17.97	11.61
1	-1	-1.6	7.87	0.10	3.05E+05	41.27	2.2765	56.21	0.5959	17.97	11.61
1	-1	-1.6	7.87	0.05	1.96E+05	34.11	2.2765	56.21	0.5959	17.97	11.61
1	-1	-1.6	7.87	0.02	1.88E+05	50.26	2.2765	56.21	0.5959	17.97	11.61
1	-1	-1.6	7.87	0.01	1.09E+05	33.97	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	15.00	3.49E+05	40.30	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	10.00	2.89E+05	42.69	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	5.00	2.05E+05	45.30	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	2.00	1.29E+05	50.70	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	1.00	9.26E+04	52.80	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	0.50	6.38E+04	52.75	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	0.20	4.06E+04	51.99	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	0.10	2.97E+04	48.02	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	0.05	2.27E+04	43.35	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	0.02	1.73E+04	41.40	2.2765	56.21	0.5959	17.97	11.61
1	-1	2	7.87	0.01	1.41E+04	36.50	2.2765	56.21	0.5959	17.97	11.61
-1	-1	-1.2	4.50	15.00	1.44E+06	17.26	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	10.00	1.34E+06	18.51	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	5.00	1.16E+06	20.98	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	2.00	9.38E+05	24.65	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	1.00	7.74E+05	28.06	2.3598	69.01	0.7072	14.52	10.87

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	-1	-1.2	4.50	0.50	6.28E+05	31.25	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.20	4.62E+05	35.74	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.10	3.53E+05	38.37	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.05	2.33E+05	38.28	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.02	1.75E+05	42.42	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.01	1.32E+05	43.59	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	15.00	1.53E+06	16.56	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	10.00	1.42E+06	17.68	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	5.00	1.24E+06	19.99	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	2.00	1.02E+06	23.50	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	1.00	8.48E+05	26.77	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.50	6.91E+05	29.84	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.20	5.02E+05	33.98	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.10	4.00E+05	38.10	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.05	2.66E+05	39.53	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.02	1.98E+05	44.14	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	4.50	0.01	1.40E+05	44.53	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.2	6.12	15.00	1.40E+06	17.90	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	10.00	1.29E+06	19.31	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	5.00	1.11E+06	22.08	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	2.00	8.85E+05	26.20	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	1.00	7.21E+05	29.79	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.50	5.73E+05	33.51	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.20	4.06E+05	38.15	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.10	3.05E+05	41.11	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.05	2.06E+05	42.51	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.02	1.44E+05	45.63	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.01	1.05E+05	46.24	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	15.00	1.25E+06	19.01	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	10.00	1.15E+06	20.52	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	5.00	9.79E+05	23.47	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	2.00	7.67E+05	27.89	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	1.00	6.16E+05	31.61	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.50	4.82E+05	35.44	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.20	3.35E+05	40.13	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.10	2.48E+05	43.18	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.05	1.65E+05	44.90	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.02	1.14E+05	48.06	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	6.12	0.01	7.85E+04	47.08	2.3197	61.67	0.6358	15.98	10.69
-1	-1	-1.2	7.79	15.00	1.16E+06	18.68	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	10.00	1.07E+06	20.15	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	5.00	9.14E+05	23.03	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	2.00	7.18E+05	27.39	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	1.00	5.79E+05	31.09	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.50	4.58E+05	34.78	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.20	3.17E+05	39.59	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.10	2.37E+05	42.01	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.05	1.56E+05	44.31	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.02	1.04E+05	45.52	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.01	7.55E+04	45.03	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	15.00	9.99E+05	20.05	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	10.00	9.13E+05	21.58	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	5.00	7.72E+05	24.54	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	2.00	6.03E+05	28.89	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	1.00	4.83E+05	32.41	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.50	3.77E+05	36.00	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.20	2.61E+05	40.10	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.10	1.93E+05	42.01	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.05	1.30E+05	43.26	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.02	8.92E+04	47.32	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.2	7.79	0.01	6.52E+04	44.18	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	4.50	15.00	1.19E+06	21.35	2.3598	69.01	0.7072	14.52	10.87
-1	-1	0	4.50	10.00	1.08E+06	22.90	2.3598	69.01	0.7072	14.52	10.87

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	-1	0	4.50	5.00	9.04E+05	26.09	2.3598	69.01	0.7072	14.52	10.87
-1	-1	0	4.50	2.00	6.93E+05	30.48	2.3598	69.01	0.7072	14.52	10.87
-1	-1	0	4.50	1.00	5.47E+05	34.12	2.3598	69.01	0.7072	14.52	10.87
-1	-1	0	4.50	0.50	4.21E+05	37.42	2.3598	69.01	0.7072	14.52	10.87
-1	-1	0	4.50	0.20	2.87E+05	41.37	2.3598	69.01	0.7072	14.52	10.87
-1	-1	0	4.50	0.10	2.11E+05	43.63	2.3598	69.01	0.7072	14.52	10.87
-1	-1	0	4.50	0.05	1.44E+05	44.20	2.3598	69.01	0.7072	14.52	10.87
-1	-1	0	4.50	0.02	9.75E+04	46.66	2.3598	69.01	0.7072	14.52	10.87
-1	-1	0	4.50	0.01	7.14E+04	46.17	2.3598	69.01	0.7072	14.52	10.87
-1	-1	0	6.12	15.00	1.00E+06	23.10	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	10.00	9.03E+05	24.86	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	5.00	7.41E+05	28.19	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	2.00	5.52E+05	32.69	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	1.00	4.27E+05	36.15	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.50	3.24E+05	39.40	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.20	2.19E+05	42.03	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.10	1.61E+05	42.97	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.05	1.16E+05	43.40	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.02	8.11E+04	40.75	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.01	5.81E+04	38.04	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	15.00	1.02E+06	23.22	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	10.00	9.13E+05	24.97	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	5.00	7.50E+05	28.45	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	2.00	5.58E+05	33.19	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	1.00	4.34E+05	36.61	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.50	3.25E+05	40.42	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.20	2.17E+05	43.50	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.10	1.58E+05	45.24	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.05	1.09E+05	46.04	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.02	7.21E+04	45.48	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	6.12	0.01	5.65E+04	45.58	2.3197	61.67	0.6358	15.98	10.69
-1	-1	0	7.79	15.00	8.34E+05	25.80	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	10.00	7.40E+05	27.92	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	5.00	5.94E+05	31.91	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	2.00	4.27E+05	37.33	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	1.00	3.20E+05	41.41	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.50	2.32E+05	45.03	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.20	1.46E+05	48.96	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.10	1.02E+05	51.25	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.05	6.73E+04	50.76	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.02	4.17E+04	52.59	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.01	3.11E+04	49.90	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	15.00	8.15E+05	24.66	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	10.00	7.28E+05	26.55	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	5.00	5.92E+05	30.30	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	2.00	4.36E+05	35.23	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	1.00	3.34E+05	38.77	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.50	2.49E+05	41.97	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.20	1.63E+05	45.32	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.10	1.16E+05	46.06	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.05	8.05E+04	45.96	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.02	5.36E+04	46.92	2.2785	55.40	0.5740	17.47	10.50
-1	-1	0	7.79	0.01	4.04E+04	43.78	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	4.50	15.00	8.56E+05	28.14	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	10.00	7.54E+05	30.23	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	5.00	5.92E+05	34.12	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	2.00	4.15E+05	39.26	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	1.00	3.03E+05	43.88	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.50	2.22E+05	45.89	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.20	1.43E+05	48.64	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.10	1.01E+05	49.77	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.05	6.70E+04	48.79	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.02	4.51E+04	48.28	2.3598	69.01	0.7072	14.52	10.87

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	-1	1	4.50	0.01	3.40E+04	46.79	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	15.00	8.59E+05	28.07	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	10.00	7.55E+05	30.01	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	5.00	5.96E+05	33.57	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	2.00	4.20E+05	38.58	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	1.00	3.09E+05	43.07	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.50	2.32E+05	44.24	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.20	1.53E+05	46.24	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.10	1.10E+05	46.30	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.05	7.51E+04	46.05	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.02	5.54E+04	45.67	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	4.50	0.01	4.25E+04	41.82	2.3598	69.01	0.7072	14.52	10.87
-1	-1	1	6.12	15.00	7.67E+05	28.80	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	10.00	6.70E+05	30.90	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	5.00	5.28E+05	34.58	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	2.00	3.71E+05	39.11	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	1.00	2.76E+05	41.96	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.50	2.03E+05	43.66	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.20	1.33E+05	44.39	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.10	1.00E+05	43.08	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.05	7.21E+04	40.55	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.02	5.19E+04	39.49	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.01	4.26E+04	33.21	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	15.00	6.97E+05	30.87	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	10.00	6.06E+05	32.96	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	5.00	4.69E+05	36.73	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	2.00	3.24E+05	41.08	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	1.00	2.39E+05	43.48	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.50	1.76E+05	44.79	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.20	1.16E+05	44.60	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.10	8.69E+04	43.52	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.05	6.24E+04	40.57	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.02	4.74E+04	38.75	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	6.12	0.01	3.93E+04	35.23	2.3197	61.67	0.6358	15.98	10.69
-1	-1	1	7.79	15.00	6.36E+05	31.25	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	10.00	5.51E+05	33.42	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	5.00	4.23E+05	37.42	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	2.00	2.69E+05	41.03	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	1.00	2.03E+05	46.32	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.50	1.47E+05	47.28	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.20	9.45E+04	47.23	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.10	6.85E+04	46.39	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.05	4.69E+04	42.80	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.02	3.60E+04	36.96	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.01	2.94E+04	29.48	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	15.00	5.26E+05	33.69	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	10.00	4.50E+05	36.13	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	5.00	3.39E+05	40.06	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	2.00	2.20E+05	48.37	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	1.00	1.57E+05	48.40	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.50	1.13E+05	49.62	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.20	7.15E+04	49.70	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.10	5.08E+04	47.45	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.05	3.63E+04	45.05	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.02	2.70E+04	41.19	2.2785	55.40	0.5740	17.47	10.50
-1	-1	1	7.79	0.01	2.19E+04	33.88	2.2785	55.40	0.5740	17.47	10.50
-1	-1	-1.7	4.50	15.00	1.74E+06	13.59	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.7	4.50	10.00	1.64E+06	14.55	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.7	4.50	5.00	1.46E+06	16.60	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.7	4.50	2.00	1.25E+06	19.97	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.7	4.50	1.00	1.07E+06	22.55	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.7	4.50	0.50	9.16E+05	25.19	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.7	4.50	0.20	7.44E+05	30.33	2.3598	69.01	0.7072	14.52	10.87

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	-1	-1.7	4.50	0.10	5.98E+05	34.54	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.7	4.50	0.05	4.66E+05	39.06	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.7	4.50	0.02	3.33E+05	43.57	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.7	4.50	0.01	2.46E+05	44.53	2.3598	69.01	0.7072	14.52	10.87
-1	-1	-1.6	6.42	15.00	1.48E+06	14.65	2.3124	60.48	0.6241	16.24	10.66
-1	-1	-1.6	6.42	10.00	1.38E+06	15.69	2.3124	60.48	0.6241	16.24	10.66
-1	-1	-1.6	6.42	5.00	1.23E+06	17.65	2.3124	60.48	0.6241	16.24	10.66
-1	-1	-1.6	6.42	2.00	1.05E+06	20.73	2.3124	60.48	0.6241	16.24	10.66
-1	-1	-1.6	6.42	1.00	8.87E+05	23.41	2.3124	60.48	0.6241	16.24	10.66
-1	-1	-1.6	6.42	0.50	7.72E+05	24.76	2.3124	60.48	0.6241	16.24	10.66
-1	-1	-1.6	6.42	0.20	6.24E+05	28.61	2.3124	60.48	0.6241	16.24	10.66
-1	-1	-1.6	6.42	0.10	5.13E+05	31.06	2.3124	60.48	0.6241	16.24	10.66
-1	-1	-1.6	6.42	0.05	4.05E+05	33.48	2.3124	60.48	0.6241	16.24	10.66
-1	-1	-1.6	6.42	0.02	2.96E+05	35.91	2.3124	60.48	0.6241	16.24	10.66
-1	-1	-1.6	6.42	0.01	2.35E+05	38.49	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	4.50	15.00	5.04E+05	37.44	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	4.50	10.00	4.23E+05	39.38	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	4.50	5.00	3.12E+05	42.93	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	4.50	2.00	2.07E+05	45.39	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	4.50	1.00	1.48E+05	46.92	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	4.50	0.50	1.04E+05	48.47	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	4.50	0.20	6.82E+04	47.08	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	4.50	0.10	4.91E+04	44.60	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	4.50	0.05	3.74E+04	43.25	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	4.50	0.02	2.90E+04	35.38	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	4.50	0.01	2.32E+04	34.92	2.3598	69.01	0.7072	14.52	10.87
-1	-1	2.6	6.42	15.00	3.85E+05	40.50	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	6.42	10.00	3.18E+05	43.11	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	6.42	5.00	2.29E+05	46.66	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	6.42	2.00	1.45E+05	50.46	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	6.42	1.00	1.00E+05	51.70	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	6.42	0.50	7.14E+04	51.60	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	6.42	0.20	4.58E+04	50.01	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	6.42	0.10	3.38E+04	49.38	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	6.42	0.05	2.62E+04	43.21	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	6.42	0.02	1.97E+04	41.62	2.3124	60.48	0.6241	16.24	10.66
-1	-1	2.6	6.42	0.01	1.80E+04	38.67	2.3124	60.48	0.6241	16.24	10.66
1	1	-1	3.44	15.00	1.55E+06	14.81	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	3.44	10.00	1.46E+06	15.80	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	3.44	5.00	1.29E+06	17.74	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	3.44	2.00	1.07E+06	20.71	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	3.44	1.00	9.12E+05	23.15	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	3.44	0.50	7.74E+05	26.35	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	3.44	0.20	5.80E+05	29.58	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	3.44	0.10	4.50E+05	32.03	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	3.44	0.05	4.01E+05	45.07	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	3.44	0.02	2.62E+05	36.99	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	3.44	0.01	1.97E+05	41.00	2.3975	74.35	0.7624	13.42	11.05
1	1	-1	5.88	15.00	1.37E+06	15.67	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	5.88	10.00	1.28E+06	16.80	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	5.88	5.00	1.12E+06	19.03	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	5.88	2.00	9.21E+05	22.31	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	5.88	1.00	7.75E+05	25.17	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	5.88	0.50	6.37E+05	27.79	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	5.88	0.20	4.77E+05	31.74	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	5.88	0.10	3.74E+05	34.72	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	5.88	0.05	2.80E+05	35.69	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	5.88	0.02	1.98E+05	40.53	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	5.88	0.01	1.46E+05	42.07	2.3369	62.31	0.6467	15.61	10.77
1	1	-1	6.09	15.00	1.38E+06	14.66	2.3318	61.45	0.6383	15.79	10.74
1	1	-1	6.09	10.00	1.30E+06	15.63	2.3318	61.45	0.6383	15.79	10.74
1	1	-1	6.09	5.00	1.15E+06	17.66	2.3318	61.45	0.6383	15.79	10.74
1	1	-1	6.09	2.00	9.55E+05	20.74	2.3318	61.45	0.6383	15.79	10.74

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	1	-1	6.09	1.00	8.18E+05	23.77	2.3318	61.45	0.6383	15.79	10.74
1	1	-1	6.09	0.50	6.83E+05	26.77	2.3318	61.45	0.6383	15.79	10.74
1	1	-1	6.09	0.20	5.17E+05	30.67	2.3318	61.45	0.6383	15.79	10.74
1	1	-1	6.09	0.10	4.07E+05	33.54	2.3318	61.45	0.6383	15.79	10.74
1	1	-1	6.09	0.05	3.07E+05	35.74	2.3318	61.45	0.6383	15.79	10.74
1	1	-1	6.09	0.02	2.22E+05	40.24	2.3318	61.45	0.6383	15.79	10.74
1	1	-1	6.09	0.01	1.63E+05	42.25	2.3318	61.45	0.6383	15.79	10.74
1	1	-1	7.07	15.00	1.28E+06	15.84	2.3075	57.60	0.6007	16.67	10.63
1	1	-1	7.07	10.00	1.19E+06	16.93	2.3075	57.60	0.6007	16.67	10.63
1	1	-1	7.07	5.00	1.05E+06	18.99	2.3075	57.60	0.6007	16.67	10.63
1	1	-1	7.07	2.00	8.64E+05	22.17	2.3075	57.60	0.6007	16.67	10.63
1	1	-1	7.07	1.00	7.28E+05	24.72	2.3075	57.60	0.6007	16.67	10.63
1	1	-1	7.07	0.50	5.98E+05	27.26	2.3075	57.60	0.6007	16.67	10.63
1	1	-1	7.07	0.20	3.85E+05	24.52	2.3075	57.60	0.6007	16.67	10.63
1	1	-1	7.07	0.10	3.88E+05	34.24	2.3075	57.60	0.6007	16.67	10.63
1	1	-1	7.07	0.05	3.91E+05	43.96	2.3075	57.60	0.6007	16.67	10.63
1	1	-1	7.07	0.02	1.95E+05	37.77	2.3075	57.60	0.6007	16.67	10.63
1	1	-1	7.07	0.01	1.46E+05	38.49	2.3075	57.60	0.6007	16.67	10.63
1	1	0	3.44	15.00	1.26E+06	18.62	2.3975	74.35	0.7624	13.42	11.05
1	1	0	3.44	10.00	1.16E+06	19.87	2.3975	74.35	0.7624	13.42	11.05
1	1	0	3.44	5.00	9.98E+05	22.27	2.3975	74.35	0.7624	13.42	11.05
1	1	0	3.44	2.00	7.94E+05	25.70	2.3975	74.35	0.7624	13.42	11.05
1	1	0	3.44	1.00	6.50E+05	28.59	2.3975	74.35	0.7624	13.42	11.05
1	1	0	3.44	0.50	5.24E+05	31.39	2.3975	74.35	0.7624	13.42	11.05
1	1	0	3.44	0.20	3.82E+05	34.67	2.3975	74.35	0.7624	13.42	11.05
1	1	0	3.44	0.10	2.96E+05	37.05	2.3975	74.35	0.7624	13.42	11.05
1	1	0	3.44	0.05	2.06E+05	36.87	2.3975	74.35	0.7624	13.42	11.05
1	1	0	3.44	0.02	1.53E+05	40.62	2.3975	74.35	0.7624	13.42	11.05
1	1	0	3.44	0.01	1.15E+05	40.73	2.3975	74.35	0.7624	13.42	11.05
1	1	0	5.88	15.00	1.19E+06	18.71	2.3369	62.31	0.6467	15.61	10.77
1	1	0	5.88	10.00	1.09E+06	20.03	2.3369	62.31	0.6467	15.61	10.77
1	1	0	5.88	5.00	9.36E+05	22.82	2.3369	62.31	0.6467	15.61	10.77
1	1	0	5.88	2.00	7.42E+05	26.60	2.3369	62.31	0.6467	15.61	10.77
1	1	0	5.88	1.00	6.05E+05	29.75	2.3369	62.31	0.6467	15.61	10.77
1	1	0	5.88	0.50	4.83E+05	32.61	2.3369	62.31	0.6467	15.61	10.77
1	1	0	5.88	0.20	3.46E+05	36.28	2.3369	62.31	0.6467	15.61	10.77
1	1	0	5.88	0.10	2.65E+05	38.28	2.3369	62.31	0.6467	15.61	10.77
1	1	0	5.88	0.05	1.90E+05	39.23	2.3369	62.31	0.6467	15.61	10.77
1	1	0	5.88	0.02	1.34E+05	40.47	2.3369	62.31	0.6467	15.61	10.77
1	1	0	5.88	0.01	1.02E+05	41.14	2.3369	62.31	0.6467	15.61	10.77
1	1	0	6.09	15.00	1.13E+06	18.59	2.3318	61.45	0.6383	15.79	10.74
1	1	0	6.09	10.00	1.04E+06	20.02	2.3318	61.45	0.6383	15.79	10.74
1	1	0	6.09	5.00	8.86E+05	22.79	2.3318	61.45	0.6383	15.79	10.74
1	1	0	6.09	2.00	6.99E+05	26.75	2.3318	61.45	0.6383	15.79	10.74
1	1	0	6.09	1.00	5.66E+05	29.99	2.3318	61.45	0.6383	15.79	10.74
1	1	0	6.09	0.50	4.50E+05	33.13	2.3318	61.45	0.6383	15.79	10.74
1	1	0	6.09	0.20	3.21E+05	36.92	2.3318	61.45	0.6383	15.79	10.74
1	1	0	6.09	0.10	2.43E+05	39.08	2.3318	61.45	0.6383	15.79	10.74
1	1	0	6.09	0.05	1.73E+05	40.26	2.3318	61.45	0.6383	15.79	10.74
1	1	0	6.09	0.02	1.21E+05	42.27	2.3318	61.45	0.6383	15.79	10.74
1	1	0	6.09	0.01	9.02E+04	43.96	2.3318	61.45	0.6383	15.79	10.74
1	1	0	7.07	15.00	1.03E+06	19.65	2.3075	57.60	0.6007	16.67	10.63
1	1	0	7.07	10.00	9.42E+05	21.02	2.3075	57.60	0.6007	16.67	10.63
1	1	0	7.07	5.00	7.97E+05	23.67	2.3075	57.60	0.6007	16.67	10.63
1	1	0	7.07	2.00	6.23E+05	27.32	2.3075	57.60	0.6007	16.67	10.63
1	1	0	7.07	1.00	5.04E+05	30.32	2.3075	57.60	0.6007	16.67	10.63
1	1	0	7.07	0.50	4.00E+05	33.01	2.3075	57.60	0.6007	16.67	10.63
1	1	0	7.07	0.20	2.85E+05	36.39	2.3075	57.60	0.6007	16.67	10.63
1	1	0	7.07	0.10	2.21E+05	38.39	2.3075	57.60	0.6007	16.67	10.63
1	1	0	7.07	0.05	1.52E+05	38.16	2.3075	57.60	0.6007	16.67	10.63
1	1	0	7.07	0.02	1.15E+05	40.93	2.3075	57.60	0.6007	16.67	10.63
1	1	0	7.07	0.01	8.26E+04	40.26	2.3075	57.60	0.6007	16.67	10.63

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	1	1	3.44	15.00	1.03E+06	22.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	3.44	10.00	9.26E+05	24.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	3.44	5.00	7.68E+05	27.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	3.44	2.00	5.82E+05	31.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	3.44	1.00	4.59E+05	34.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	3.44	0.50	3.56E+05	36.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	3.44	0.20	2.48E+05	39.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	3.44	0.10	1.87E+05	41.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	3.44	0.05	1.25E+05	41.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	3.44	0.02	9.15E+04	43.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	3.44	0.01	6.86E+04	42.00	2.3975	74.35	0.7624	13.42	11.05
1	1	1	5.88	15.00	8.54E+05	24.88	2.3369	62.31	0.6467	15.61	10.77
1	1	1	5.88	10.00	7.62E+05	26.52	2.3369	62.31	0.6467	15.61	10.77
1	1	1	5.88	5.00	6.19E+05	29.67	2.3369	62.31	0.6467	15.61	10.77
1	1	1	5.88	2.00	4.58E+05	33.32	2.3369	62.31	0.6467	15.61	10.77
1	1	1	5.88	1.00	3.56E+05	35.95	2.3369	62.31	0.6467	15.61	10.77
1	1	1	5.88	0.50	2.76E+05	37.69	2.3369	62.31	0.6467	15.61	10.77
1	1	1	5.88	0.20	1.91E+05	39.01	2.3369	62.31	0.6467	15.61	10.77
1	1	1	5.88	0.10	1.46E+05	38.60	2.3369	62.31	0.6467	15.61	10.77
1	1	1	5.88	0.05	1.04E+05	36.25	2.3369	62.31	0.6467	15.61	10.77
1	1	1	5.88	0.02	8.10E+04	35.92	2.3369	62.31	0.6467	15.61	10.77
1	1	1	5.88	0.01	6.53E+04	34.25	2.3369	62.31	0.6467	15.61	10.77
1	1	1	6.09	15.00	7.86E+05	25.32	2.3318	61.45	0.6383	15.79	10.74
1	1	1	6.09	10.00	6.99E+05	27.16	2.3318	61.45	0.6383	15.79	10.74
1	1	1	6.09	5.00	5.66E+05	30.34	2.3318	61.45	0.6383	15.79	10.74
1	1	1	6.09	2.00	4.16E+05	34.30	2.3318	61.45	0.6383	15.79	10.74
1	1	1	6.09	1.00	3.21E+05	36.94	2.3318	61.45	0.6383	15.79	10.74
1	1	1	6.09	0.50	2.47E+05	38.61	2.3318	61.45	0.6383	15.79	10.74
1	1	1	6.09	0.20	1.70E+05	39.97	2.3318	61.45	0.6383	15.79	10.74
1	1	1	6.09	0.10	1.30E+05	39.69	2.3318	61.45	0.6383	15.79	10.74
1	1	1	6.09	0.05	9.09E+04	36.48	2.3318	61.45	0.6383	15.79	10.74
1	1	1	6.09	0.02	7.09E+04	37.20	2.3318	61.45	0.6383	15.79	10.74
1	1	1	6.09	0.01	5.71E+04	33.41	2.3318	61.45	0.6383	15.79	10.74
1	1	1	7.07	15.00	7.01E+05	27.00	2.3075	57.60	0.6007	16.67	10.63
1	1	1	7.07	10.00	6.21E+05	29.00	2.3075	57.60	0.6007	16.67	10.63
1	1	1	7.07	5.00	4.95E+05	32.00	2.3075	57.60	0.6007	16.67	10.63
1	1	1	7.07	2.00	3.57E+05	36.00	2.3075	57.60	0.6007	16.67	10.63
1	1	1	7.07	1.00	2.67E+05	40.00	2.3075	57.60	0.6007	16.67	10.63
1	1	1	7.07	0.50	2.01E+05	42.00	2.3075	57.60	0.6007	16.67	10.63
1	1	1	7.07	0.20	1.34E+05	44.00	2.3075	57.60	0.6007	16.67	10.63
1	1	1	7.07	0.10	9.73E+04	46.00	2.3075	57.60	0.6007	16.67	10.63
1	1	1	7.07	0.05	6.38E+04	47.00	2.3075	57.60	0.6007	16.67	10.63
1	1	1	7.07	0.02	4.44E+04	49.00	2.3075	57.60	0.6007	16.67	10.63
1	1	1	7.07	0.01	3.26E+04	48.00	2.3075	57.60	0.6007	16.67	10.63
1	1	2.4	3.44	15.00	6.73E+05	30.20	2.3975	74.35	0.7624	13.42	11.05
1	1	2.4	3.44	10.00	5.86E+05	32.03	2.3975	74.35	0.7624	13.42	11.05
1	1	2.4	3.44	5.00	4.57E+05	35.15	2.3975	74.35	0.7624	13.42	11.05
1	1	2.4	3.44	2.00	3.20E+05	38.95	2.3975	74.35	0.7624	13.42	11.05
1	1	2.4	3.44	1.00	2.37E+05	41.95	2.3975	74.35	0.7624	13.42	11.05
1	1	2.4	3.44	0.50	1.77E+05	43.56	2.3975	74.35	0.7624	13.42	11.05
1	1	2.4	3.44	0.20	1.18E+05	45.18	2.3975	74.35	0.7624	13.42	11.05
1	1	2.4	3.44	0.10	8.47E+04	44.85	2.3975	74.35	0.7624	13.42	11.05
1	1	2.4	3.44	0.05	5.85E+04	46.22	2.3975	74.35	0.7624	13.42	11.05
1	1	2.4	3.44	0.02	4.32E+04	47.52	2.3975	74.35	0.7624	13.42	11.05
1	1	2.4	3.44	0.01	3.10E+04	44.70	2.3975	74.35	0.7624	13.42	11.05
1	1	2.6	7.07	15.00	4.36E+05	34.46	2.3075	57.60	0.6007	16.67	10.63
1	1	2.6	7.07	10.00	3.72E+05	36.34	2.3075	57.60	0.6007	16.67	10.63
1	1	2.6	7.07	5.00	2.80E+05	39.37	2.3075	57.60	0.6007	16.67	10.63
1	1	2.6	7.07	2.00	1.90E+05	44.22	2.3075	57.60	0.6007	16.67	10.63
1	1	2.6	7.07	1.00	1.38E+05	45.10	2.3075	57.60	0.6007	16.67	10.63
1	1	2.6	7.07	0.50	1.00E+05	46.53	2.3075	57.60	0.6007	16.67	10.63
1	1	2.6	7.07	0.20	6.52E+04	47.67	2.3075	57.60	0.6007	16.67	10.63
1	1	2.6	7.07	0.10	4.84E+04	48.01	2.3075	57.60	0.6007	16.67	10.63

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	1	2.6	7.07	0.05	3.25E+04	46.53	2.3075	57.60	0.6007	16.67	10.63
1	1	2.6	7.07	0.02	2.47E+04	49.35	2.3075	57.60	0.6007	16.67	10.63
1	1	2.6	7.07	0.01	1.91E+04	48.75	2.3075	57.60	0.6007	16.67	10.63
-1	1	-1	3.73	15.00	1.52E+06	16.95	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	3.73	10.00	1.41E+06	18.35	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	3.73	5.00	1.22E+06	21.11	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	3.73	2.00	9.77E+05	25.20	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	3.73	1.00	7.99E+05	28.97	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	3.73	0.50	6.07E+05	31.56	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	3.73	0.20	3.89E+05	32.33	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	3.73	0.10	2.84E+05	33.56	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	3.73	0.05	1.99E+05	34.46	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	3.73	0.02	1.55E+05	47.30	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	3.73	0.01	1.07E+05	49.70	2.3904	71.81	0.7253	13.22	9.84
-1	1	-1	7.45	15.00	1.04E+06	20.72	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.45	10.00	9.46E+05	22.38	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.45	5.00	7.94E+05	25.45	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.45	2.00	6.07E+05	29.97	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.45	1.00	4.78E+05	33.73	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.45	0.50	3.29E+05	30.44	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.45	0.20	2.19E+05	31.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.45	0.10	1.87E+05	45.03	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.45	0.05	8.16E+04	45.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.45	0.02	8.46E+04	47.03	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.45	0.01	6.54E+04	47.24	2.2982	55.08	0.5597	16.57	9.46
-1	1	-1	7.80	15.00	1.14E+06	18.29	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	7.80	10.00	1.05E+06	19.76	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	7.80	5.00	8.95E+05	22.62	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	7.80	2.00	7.09E+05	26.70	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	7.80	1.00	5.75E+05	30.21	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	7.80	0.50	4.57E+05	33.49	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	7.80	0.20	3.24E+05	37.44	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	7.80	0.10	2.46E+05	39.84	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	7.80	0.05	1.68E+05	40.92	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	7.80	0.02	1.23E+05	43.66	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	7.80	0.01	8.74E+04	40.54	2.2893	53.83	0.5472	16.89	9.43
-1	1	-1	9.27	15.00	8.50E+05	19.65	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.27	10.00	7.79E+05	21.05	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.27	5.00	6.62E+05	23.71	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.27	2.00	5.18E+05	27.78	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.27	1.00	4.17E+05	31.03	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.27	0.50	3.30E+05	34.01	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.27	0.20	2.35E+05	37.28	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.27	0.10	1.79E+05	38.73	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.27	0.05	1.29E+05	39.34	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.27	0.02	9.25E+04	40.85	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.27	0.01	6.76E+04	41.17	2.2499	49.44	0.5000	18.32	9.26
-1	1	-1	9.39	15.00	8.31E+05	20.27	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	10.00	7.58E+05	21.75	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	5.00	6.41E+05	24.65	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	2.00	4.96E+05	28.98	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	1.00	3.96E+05	32.24	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.50	3.11E+05	35.37	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.20	2.20E+05	38.71	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.10	1.66E+05	40.20	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.05	1.15E+05	40.33	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.02	8.49E+04	42.94	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.01	6.41E+04	40.34	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	15.00	7.93E+05	21.06	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	10.00	7.20E+05	22.66	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	5.00	6.04E+05	25.75	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	2.00	4.61E+05	30.27	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	1.00	3.65E+05	33.83	2.2530	48.46	0.4970	18.21	9.28

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	1	-1	9.39	0.50	2.83E+05	37.21	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.20	1.94E+05	41.51	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.10	1.42E+05	43.66	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.05	9.62E+04	46.31	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.02	6.52E+04	47.87	2.2530	48.46	0.4970	18.21	9.28
-1	1	-1	9.39	0.01	4.81E+04	49.63	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	3.73	15.00	1.16E+06	22.96	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.73	10.00	1.04E+06	24.92	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.73	5.00	8.58E+05	28.67	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.73	2.00	6.36E+05	33.94	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.73	1.00	4.89E+05	38.20	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.73	0.50	3.66E+05	42.04	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.73	0.20	2.41E+05	46.16	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.73	0.10	1.72E+05	48.66	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.73	0.05	1.11E+05	47.64	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.73	0.02	7.67E+04	48.54	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.73	0.01	5.62E+04	46.87	2.3904	71.81	0.7253	13.22	9.84
-1	1	0	3.86	15.00	1.29E+06	20.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	3.86	10.00	1.17E+06	22.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	3.86	5.00	9.91E+05	25.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	3.86	2.00	7.63E+05	29.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	3.86	1.00	6.05E+05	32.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	3.86	0.50	4.66E+05	35.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	3.86	0.20	3.30E+05	40.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	3.86	0.10	2.45E+05	42.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	3.86	0.05	1.73E+05	41.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	3.86	0.02	1.21E+05	43.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	3.86	0.01	9.13E+04	42.00	2.3872	71.07	0.7181	13.34	9.83
-1	1	0	7.45	15.00	8.47E+05	24.95	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	10.00	7.56E+05	26.82	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	5.00	6.11E+05	30.34	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	2.00	4.47E+05	35.21	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	1.00	3.38E+05	39.41	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.50	2.55E+05	41.66	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.20	1.70E+05	44.22	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.10	1.20E+05	45.05	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.05	8.28E+04	44.47	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.02	6.07E+04	43.52	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.01	4.47E+04	39.44	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	15.00	7.67E+05	26.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	10.00	6.83E+05	28.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	5.00	5.50E+05	31.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	2.00	4.01E+05	37.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	1.00	3.06E+05	40.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.50	2.25E+05	43.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.20	1.49E+05	46.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.10	1.08E+05	47.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.05	7.17E+04	46.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.02	5.32E+04	48.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	7.45	0.01	3.79E+04	44.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	0	9.39	15.00	6.84E+05	26.41	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	10.00	6.10E+05	28.40	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	5.00	4.90E+05	31.89	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	2.00	3.64E+05	36.47	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	1.00	2.92E+05	39.87	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.50	2.01E+05	42.29	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.20	1.34E+05	44.37	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.10	9.78E+04	44.46	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.05	6.73E+04	44.03	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.02	4.96E+04	42.81	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.01	3.75E+04	40.07	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	15.00	5.87E+05	26.99	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	10.00	5.16E+05	29.09	2.2530	48.46	0.4970	18.21	9.28

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	1	0	9.39	5.00	4.11E+05	32.52	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	2.00	2.94E+05	36.80	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	1.00	2.23E+05	39.84	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.50	1.69E+05	41.41	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.20	1.15E+05	42.68	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.10	8.55E+04	41.83	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.05	6.08E+04	40.48	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.02	4.70E+04	38.16	2.2530	48.46	0.4970	18.21	9.28
-1	1	0	9.39	0.01	3.48E+04	35.23	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	3.86	15.00	9.29E+05	26.90	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	3.86	10.00	8.20E+05	28.96	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	3.86	5.00	6.52E+05	32.68	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	3.86	2.00	4.64E+05	37.43	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	3.86	1.00	3.47E+05	41.03	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	3.86	0.50	2.56E+05	43.58	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	3.86	0.20	1.68E+05	45.64	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	3.86	0.10	1.22E+05	45.84	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	3.86	0.05	8.18E+04	44.88	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	3.86	0.02	5.83E+04	44.52	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	3.86	0.01	4.43E+04	40.60	2.3872	71.07	0.7181	13.34	9.83
-1	1	1	7.45	15.00	5.84E+05	30.89	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	7.45	10.00	5.05E+05	33.02	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	7.45	5.00	3.92E+05	36.66	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	7.45	2.00	2.70E+05	40.70	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	7.45	1.00	1.97E+05	42.19	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	7.45	0.50	1.45E+05	45.36	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	7.45	0.20	9.40E+04	45.93	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	7.45	0.10	6.88E+04	46.53	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	7.45	0.05	5.01E+04	43.00	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	7.45	0.02	3.57E+04	40.38	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	7.45	0.01	2.95E+04	41.06	2.2982	55.08	0.5597	16.57	9.46
-1	1	1	9.39	15.00	6.62E+05	31.88	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	10.00	5.78E+05	34.02	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	5.00	4.63E+05	37.73	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	2.00	3.52E+05	42.14	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	1.00	2.27E+05	44.55	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.50	1.65E+05	46.11	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.20	1.08E+05	46.96	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.10	7.77E+04	44.85	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.05	5.45E+04	42.16	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.02	4.11E+04	39.89	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.01	3.20E+04	40.83	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	15.00	4.06E+05	33.69	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	10.00	3.48E+05	35.76	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	5.00	2.62E+05	39.53	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	2.00	1.75E+05	44.44	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	1.00	1.26E+05	47.06	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.50	8.83E+04	49.47	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.20	5.52E+04	50.89	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.10	3.93E+04	50.63	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.05	2.58E+04	56.13	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.02	1.68E+04	50.32	2.2530	48.46	0.4970	18.21	9.28
-1	1	1	9.39	0.01	1.32E+04	47.90	2.2530	48.46	0.4970	18.21	9.28
-1	1	1.6	3.73	15.00	7.00E+05	33.18	2.3904	71.81	0.7253	13.22	9.84
-1	1	1.6	3.73	10.00	6.02E+05	35.48	2.3904	71.81	0.7253	13.22	9.84
-1	1	1.6	3.73	5.00	4.56E+05	39.39	2.3904	71.81	0.7253	13.22	9.84
-1	1	1.6	3.73	2.00	3.10E+05	41.61	2.3904	71.81	0.7253	13.22	9.84
-1	1	1.6	3.73	1.00	2.21E+05	45.69	2.3904	71.81	0.7253	13.22	9.84
-1	1	1.6	3.73	0.50	1.50E+05	49.54	2.3904	71.81	0.7253	13.22	9.84
-1	1	1.6	3.73	0.20	9.25E+04	50.25	2.3904	71.81	0.7253	13.22	9.84
-1	1	1.6	3.73	0.10	6.68E+04	47.48	2.3904	71.81	0.7253	13.22	9.84
-1	1	1.6	3.73	0.05	4.57E+04	42.35	2.3904	71.81	0.7253	13.22	9.84
-1	1	1.6	3.73	0.02	3.34E+04	32.19	2.3904	71.81	0.7253	13.22	9.84

AC	GR	Temp	Va	Freq	|E*|	phi	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	1	1.6	3.73	0.01	2.80E+04	37.20	2.3904	71.81	0.7253	13.22	9.84
-1	1	1.6	7.45	15.00	4.62E+05	35.85	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.45	10.00	3.91E+05	38.08	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.45	5.00	2.91E+05	41.50	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.45	2.00	1.94E+05	43.14	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.45	1.00	1.40E+05	46.30	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.45	0.50	9.50E+04	49.92	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.45	0.20	5.95E+04	49.45	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.45	0.10	4.34E+04	48.32	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.45	0.05	3.29E+04	43.27	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.45	0.02	2.03E+04	43.04	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.45	0.01	1.91E+04	38.68	2.2982	55.08	0.5597	16.57	9.46
-1	1	1.6	7.80	15.00	4.22E+05	37.60	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	7.80	10.00	3.55E+05	39.73	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	7.80	5.00	2.61E+05	43.11	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	7.80	2.00	1.70E+05	46.77	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	7.80	1.00	1.23E+05	47.71	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	7.80	0.50	8.82E+04	48.19	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	7.80	0.20	5.90E+04	46.42	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	7.80	0.10	4.72E+04	43.56	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	7.80	0.05	3.41E+04	41.79	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	7.80	0.02	2.73E+04	34.32	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	7.80	0.01	2.32E+04	29.66	2.2893	53.83	0.5472	16.89	9.43
-1	1	1.6	9.27	15.00	2.98E+05	38.13	2.2499	49.44	0.5000	18.32	9.26
-1	1	1.6	9.27	10.00	2.52E+05	39.79	2.2499	49.44	0.5000	18.32	9.26
-1	1	1.6	9.27	5.00	1.87E+05	42.16	2.2499	49.44	0.5000	18.32	9.26
-1	1	1.6	9.27	2.00	1.28E+05	42.13	2.2499	49.44	0.5000	18.32	9.26
-1	1	1.6	9.27	1.00	9.14E+04	45.34	2.2499	49.44	0.5000	18.32	9.26
-1	1	1.6	9.27	0.50	6.82E+04	44.61	2.2499	49.44	0.5000	18.32	9.26
-1	1	1.6	9.27	0.20	4.76E+04	42.24	2.2499	49.44	0.5000	18.32	9.26
-1	1	1.6	9.27	0.10	3.76E+04	37.82	2.2499	49.44	0.5000	18.32	9.26
-1	1	1.6	9.27	0.05	3.07E+04	34.11	2.2499	49.44	0.5000	18.32	9.26
-1	1	1.6	9.27	0.02	2.47E+04	30.04	2.2499	49.44	0.5000	18.32	9.26
-1	1	1.6	9.27	0.01	2.22E+04	25.86	2.2499	49.44	0.5000	18.32	9.26

Note: AC = Asphalt content. AC = -1 means optimum minus 0.5-percent asphalt content; AC=1 means optimum asphalt content.

GR = Gradation. GR =-1 means 12.5-mm mix; GR=1 means 19-mm mix.

Temp = Temperature. Temp = -1 means temperature is 15°C; and Temp = 0 means temperature is 20°C, and Temp = 1 means temperature is 25°C.

Appendix E. Shear frequency sweep test data

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	-1	3.61	15.00	7.65E+05	14.30	2.3818	74.55	0.7709	14.18	12.14
1	-1	-1	3.61	10.00	7.19E+05	14.46	2.3818	74.55	0.7709	14.18	12.14
1	-1	-1	3.61	5.00	6.51E+05	15.26	2.3818	74.55	0.7709	14.18	12.14
1	-1	-1	3.61	2.00	5.96E+05	21.99	2.3818	74.55	0.7709	14.18	12.14
1	-1	-1	3.61	1.00	5.40E+05	28.07	2.3818	74.55	0.7709	14.18	12.14
1	-1	-1	3.61	0.50	3.98E+05	34.62	2.3818	74.55	0.7709	14.18	12.14
1	-1	-1	3.61	0.20	1.60E+05	39.35	2.3818	74.55	0.7709	14.18	12.14
1	-1	-1	3.61	0.10	1.03E+05	43.03	2.3818	74.55	0.7709	14.18	12.14
1	-1	-1	3.61	0.05	6.42E+04	45.67	2.3818	74.55	0.7709	14.18	12.14
1	-1	-1	3.61	0.02	4.23E+04	49.37	2.3818	74.55	0.7709	14.18	12.14
1	-1	-1	3.61	0.01	2.96E+04	50.83	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	15.00	5.30E+05	16.34	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	10.00	4.80E+05	19.15	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	5.00	4.06E+05	25.38	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	2.00	3.02E+05	28.45	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	1.00	1.98E+05	36.46	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	0.50	1.19E+05	41.88	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	0.20	6.54E+04	46.23	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	0.10	4.38E+04	48.93	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	0.05	2.81E+04	50.61	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	0.02	1.81E+04	52.28	2.3818	74.55	0.7709	14.18	12.14
1	-1	0	3.61	0.01	1.24E+04	51.28	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	15.00	3.89E+05	28.85	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	10.00	3.34E+05	31.98	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	5.00	2.37E+05	38.20	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	2.00	1.24E+05	39.75	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	1.00	9.94E+04	46.55	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	0.50	6.24E+04	49.38	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	0.20	3.47E+04	52.49	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	0.10	2.30E+04	54.13	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	0.05	1.45E+04	54.29	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	0.02	9.19E+03	54.49	2.3818	74.55	0.7709	14.18	12.14
1	-1	1	3.61	0.01	6.38E+03	54.11	2.3818	74.55	0.7709	14.18	12.14
1	-1	-0.8	3.73	15.00	6.21E+05	6.28	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.73	10.00	5.90E+05	7.77	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.73	5.00	5.50E+05	11.26	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.73	2.00	4.75E+05	17.90	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.73	1.00	3.20E+05	7.44	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.73	0.50	2.35E+05	14.87	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.73	0.20	1.62E+05	29.26	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.73	0.10	1.03E+05	34.46	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.73	0.05	6.60E+04	37.60	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.73	0.02	4.71E+04	41.29	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.73	0.01	3.45E+04	42.17	2.3485	75.75	0.7625	15.38	11.97
1	-1	0	3.73	15.00	5.84E+05	11.86	2.3485	75.75	0.7625	15.38	11.97
1	-1	0	3.73	10.00	5.26E+05	15.80	2.3485	75.75	0.7625	15.38	11.97
1	-1	0	3.73	5.00	4.68E+05	20.82	2.3485	75.75	0.7625	15.38	11.97
1	-1	0	3.73	2.00	2.59E+05	25.66	2.3485	75.75	0.7625	15.38	11.97
1	-1	0	3.73	1.00	2.13E+05	30.53	2.3485	75.75	0.7625	15.38	11.97
1	-1	0	3.73	0.50	1.41E+05	38.41	2.3485	75.75	0.7625	15.38	11.97

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	0	3.73	0.20	7.39E+04	42.26	2.3485	75.75	0.7625	15.38	11.97
1	-1	0	3.73	0.10	5.05E+04	44.55	2.3485	75.75	0.7625	15.38	11.97
1	-1	0	3.73	0.05	3.33E+04	45.02	2.3485	75.75	0.7625	15.38	11.97
1	-1	0	3.73	0.02	2.28E+04	46.49	2.3485	75.75	0.7625	15.38	11.97
1	-1	0	3.73	0.01	1.62E+04	46.95	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	15.00	4.46E+05	20.75	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	10.00	3.83E+05	25.14	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	5.00	2.96E+05	31.29	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	2.00	1.34E+05	35.79	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	1.00	1.14E+05	39.73	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	0.50	6.98E+04	43.96	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	0.20	4.10E+04	47.00	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	0.10	2.87E+04	47.79	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	0.05	1.91E+04	47.14	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	0.02	1.32E+04	43.37	2.3485	75.75	0.7625	15.38	11.97
1	-1	1	3.73	0.01	9.60E+03	45.51	2.3485	75.75	0.7625	15.38	11.97
1	-1	-0.8	3.60	15.00	7.51E+05	0.97	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.60	10.00	6.61E+05	3.00	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.60	5.00	5.80E+05	6.00	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.60	2.00	4.80E+05	10.00	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.60	1.00	4.30E+05	14.50	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.60	0.50	3.16E+05	16.78	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.60	0.20	2.50E+05	20.00	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.60	0.10	2.00E+05	25.00	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.60	0.05	1.33E+05	31.21	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.60	0.02	9.15E+04	42.41	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.60	0.01	6.41E+04	42.36	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	15.00	5.42E+05	7.10	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	10.00	5.02E+05	9.15	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	5.00	4.42E+05	13.66	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	2.00	3.16E+05	16.78	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	1.00	2.62E+05	17.13	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	0.50	2.25E+05	24.32	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	0.20	1.33E+05	30.31	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	0.10	9.31E+04	33.54	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	0.05	6.18E+04	35.99	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	0.02	4.45E+04	39.32	2.3820	74.58	0.7712	14.17	12.14
1	-1	0	3.60	0.01	3.31E+04	40.38	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	15.00	4.18E+05	11.54	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	10.00	3.85E+05	13.46	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	5.00	3.27E+05	19.43	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	2.00	1.92E+05	24.64	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	1.00	1.71E+05	27.39	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	0.50	1.22E+05	33.09	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	0.20	7.12E+04	37.42	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	0.10	5.07E+04	39.93	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	0.05	3.45E+04	41.15	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	0.02	2.42E+04	43.83	2.3820	74.58	0.7712	14.17	12.14
1	-1	1	3.60	0.01	1.78E+04	43.66	2.3820	74.58	0.7712	14.17	12.14
1	-1	-0.8	3.91	15.00	9.81E+05	7.18	2.3743	72.94	0.7558	14.45	12.10
1	-1	-0.8	3.91	10.00	9.34E+05	8.41	2.3743	72.94	0.7558	14.45	12.10
1	-1	-0.8	3.91	5.00	8.96E+05	10.84	2.3743	72.94	0.7558	14.45	12.10
1	-1	-0.8	3.91	2.00	5.45E+05	16.63	2.3743	72.94	0.7558	14.45	12.10
1	-1	-0.8	3.91	1.00	1.38E+06	16.67	2.3743	72.94	0.7558	14.45	12.10
1	-1	-0.8	3.91	0.50	1.12E+06	22.09	2.3743	72.94	0.7558	14.45	12.10

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	-0.8	3.91	0.20	6.56E+05	24.67	2.3743	72.94	0.7558	14.45	12.10
1	-1	-0.8	3.91	0.10	4.40E+05	29.21	2.3743	72.94	0.7558	14.45	12.10
1	-1	-0.8	3.91	0.05	1.67E+05	26.12	2.3743	72.94	0.7558	14.45	12.10
1	-1	-0.8	3.91	0.02	1.00E+05	34.89	2.3743	72.94	0.7558	14.45	12.10
1	-1	-0.8	3.91	0.01	6.92E+04	37.75	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	15.00	5.37E+05	5.44	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	10.00	5.09E+05	6.52	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	5.00	4.69E+05	8.46	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	2.00	2.65E+05	14.10	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	1.00	4.55E+05	13.92	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	0.50	3.02E+05	20.39	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	0.20	1.32E+05	29.70	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	0.10	9.10E+04	33.14	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	0.05	5.96E+04	34.67	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	0.02	4.19E+04	39.20	2.3743	72.94	0.7558	14.45	12.10
1	-1	0	3.91	0.01	3.13E+04	40.93	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	15.00	5.66E+05	10.11	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	10.00	5.15E+05	12.50	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	5.00	4.40E+05	15.09	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	2.00	2.28E+05	18.28	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	1.00	2.91E+05	19.87	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	0.50	1.69E+05	30.83	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	0.20	8.85E+04	35.82	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	0.10	6.07E+04	38.22	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	0.05	3.96E+04	39.95	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	0.02	2.82E+04	42.82	2.3743	72.94	0.7558	14.45	12.10
1	-1	1	3.91	0.01	2.05E+04	42.71	2.3743	72.94	0.7558	14.45	12.10
1	-1	-1.2	6.00	15.00	9.18E+05	4.00	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1.2	6.00	10.00	9.01E+05	5.00	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1.2	6.00	5.00	7.99E+05	7.82	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1.2	6.00	2.00	5.50E+05	7.98	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1.2	6.00	1.00	4.70E+05	15.00	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1.2	6.00	0.50	3.40E+05	16.80	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1.2	6.00	0.20	2.07E+05	18.00	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1.2	6.00	0.10	1.41E+05	27.36	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1.2	6.00	0.05	9.06E+04	28.22	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1.2	6.00	0.02	6.59E+04	33.59	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1.2	6.00	0.01	5.01E+04	35.72	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	15.00	5.45E+05	6.49	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	10.00	5.04E+05	8.91	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	5.00	4.50E+05	9.43	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	2.00	3.66E+05	16.73	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	1.00	2.60E+05	18.00	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	0.50	2.07E+05	20.72	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	0.20	1.05E+05	30.38	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	0.10	7.42E+04	32.71	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	0.05	5.06E+04	34.26	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	0.02	3.68E+04	37.69	2.3226	63.22	0.6637	16.31	11.84
1	-1	0	6.00	0.01	2.83E+04	38.65	2.3226	63.22	0.6637	16.31	11.84
1	-1	1	6.00	15.00	3.96E+05	13.38	2.3226	63.22	0.6637	16.31	11.84
1	-1	1	6.00	10.00	3.50E+05	16.14	2.3226	63.22	0.6637	16.31	11.84
1	-1	1	6.00	5.00	2.81E+05	20.15	2.3226	63.22	0.6637	16.31	11.84
1	-1	1	6.00	2.00	2.14E+05	22.63	2.3226	63.22	0.6637	16.31	11.84
1	-1	1	6.00	1.00	1.48E+05	27.54	2.3226	63.22	0.6637	16.31	11.84
1	-1	1	6.00	0.50	9.88E+04	32.33	2.3226	63.22	0.6637	16.31	11.84

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	1	6.00	0.20	6.19E+04	35.22	2.3226	63.22	0.6637	16.31	11.84
1	-1	1	6.00	0.10	4.46E+04	37.04	2.3226	63.22	0.6637	16.31	11.84
1	-1	1	6.00	0.05	3.12E+04	38.09	2.3226	63.22	0.6637	16.31	11.84
1	-1	1	6.00	0.02	2.27E+04	39.65	2.3226	63.22	0.6637	16.31	11.84
1	-1	1	6.00	0.01	1.74E+04	39.61	2.3226	63.22	0.6637	16.31	11.84
1	-1	-1	5.42	15.00	5.24E+05	5.59	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	5.42	10.00	5.07E+05	6.73	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	5.42	5.00	4.74E+05	11.05	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	5.42	2.00	3.60E+05	14.92	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	5.42	1.00	3.00E+05	19.60	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	5.42	0.50	2.00E+05	29.67	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	5.42	0.20	1.54E+05	32.73	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	5.42	0.10	9.81E+04	36.14	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	5.42	0.05	6.30E+04	38.29	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	5.42	0.02	4.46E+04	41.65	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	5.42	0.01	3.28E+04	42.19	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	15.00	4.37E+05	10.57	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	10.00	4.10E+05	12.63	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	5.00	3.51E+05	17.85	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	2.00	2.86E+05	21.19	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	1.00	2.21E+05	25.92	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	0.50	1.52E+05	31.51	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	0.20	9.08E+04	36.29	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	0.10	6.32E+04	39.30	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	0.05	4.20E+04	40.99	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	0.02	2.94E+04	43.38	2.3369	65.69	0.6873	15.80	11.91
1	-1	0	5.42	0.01	2.11E+04	44.45	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	15.00	3.37E+05	18.58	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	10.00	2.98E+05	21.94	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	5.00	2.30E+05	28.76	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	2.00	1.20E+05	33.70	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	1.00	1.09E+05	36.62	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	0.50	7.05E+04	40.59	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	0.20	4.24E+04	44.39	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	0.10	3.00E+04	45.68	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	0.05	2.00E+04	46.42	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	0.02	1.37E+04	47.06	2.3369	65.69	0.6873	15.80	11.91
1	-1	1	5.42	0.01	9.72E+03	45.74	2.3369	65.69	0.6873	15.80	11.91
1	-1	-1	6.35	15.00	7.93E+05	4.45	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.35	10.00	7.35E+05	4.41	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.35	5.00	6.54E+05	7.20	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.35	2.00	4.50E+05	13.00	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.35	1.00	3.50E+05	15.00	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.35	0.50	2.67E+05	18.16	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.35	0.20	2.30E+05	28.48	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.35	0.10	1.60E+05	32.00	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.35	0.05	1.02E+05	31.32	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.35	0.02	7.07E+04	35.96	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.35	0.01	5.05E+04	37.49	2.3140	61.80	0.6501	16.62	11.80
1	-1	0	6.35	15.00	4.96E+05	11.15	2.3140	61.80	0.6501	16.62	11.80
1	-1	0	6.35	10.00	4.58E+05	12.41	2.3140	61.80	0.6501	16.62	11.80
1	-1	0	6.35	5.00	3.83E+05	14.68	2.3140	61.80	0.6501	16.62	11.80
1	-1	0	6.35	2.00	2.67E+05	16.70	2.3140	61.80	0.6501	16.62	11.80
1	-1	0	6.35	1.00	2.39E+05	16.97	2.3140	61.80	0.6501	16.62	11.80
1	-1	0	6.35	0.50	1.78E+05	26.02	2.3140	61.80	0.6501	16.62	11.80

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	0	6.35	0.20	1.13E+05	30.07	2.3140	61.80	0.6501	16.62	11.80
1	-1	0	6.35	0.10	8.17E+04	32.45	2.3140	61.80	0.6501	16.62	11.80
1	-1	0	6.35	0.05	5.54E+04	33.54	2.3140	61.80	0.6501	16.62	11.80
1	-1	0	6.35	0.02	3.92E+04	37.49	2.3140	61.80	0.6501	16.62	11.80
1	-1	0	6.35	0.01	2.90E+04	38.23	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	15.00	3.29E+05	14.03	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	10.00	2.94E+05	16.35	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	5.00	2.43E+05	20.38	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	2.00	1.88E+05	26.01	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	1.00	1.32E+05	29.26	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	0.50	9.01E+04	33.72	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	0.20	5.69E+04	37.01	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	0.10	4.09E+04	39.18	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	0.05	2.88E+04	40.18	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	0.02	2.04E+04	41.14	2.3140	61.80	0.6501	16.62	11.80
1	-1	1	6.35	0.01	1.52E+04	41.34	2.3140	61.80	0.6501	16.62	11.80
1	-1	-1	6.01	15.00	4.89E+05	31.91	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.01	10.00	4.29E+05	30.16	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.01	5.00	3.60E+05	28.87	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.01	2.00	2.60E+05	34.08	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.01	1.00	2.25E+05	29.69	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.01	0.50	1.52E+05	35.96	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.01	0.20	9.81E+04	42.19	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.01	0.10	6.93E+04	44.99	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.01	0.05	4.53E+04	42.27	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.01	0.02	3.05E+04	45.34	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.01	0.01	2.32E+04	46.52	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	15.00	2.59E+05	30.10	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	10.00	2.27E+05	30.63	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	5.00	1.82E+05	32.80	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	2.00	1.26E+05	38.06	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	1.00	9.46E+04	40.99	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	0.50	6.56E+04	45.20	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	0.20	4.08E+04	50.48	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	0.10	2.90E+04	53.55	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	0.05	1.75E+04	51.44	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	0.02	1.11E+04	53.62	2.3226	63.16	0.6633	16.31	11.84
1	-1	0	6.01	0.01	8.27E+03	54.15	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	15.00	1.95E+05	14.03	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	10.00	1.66E+05	16.35	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	5.00	1.23E+05	20.38	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	2.00	7.90E+04	26.01	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	1.00	5.55E+04	29.26	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	0.50	3.96E+04	33.72	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	0.20	1.24E+05	37.01	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	0.10	1.30E+04	39.18	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	0.05	1.98E+04	40.18	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	0.02	1.02E+04	41.14	2.3226	63.16	0.6633	16.31	11.84
1	-1	1	6.01	0.01	7.41E+03	41.34	2.3226	63.16	0.6633	16.31	11.84
1	-1	-1	6.23	15.00	4.89E+05	15.80	2.3170	62.27	0.6547	16.51	11.81
1	-1	-1	6.23	10.00	4.29E+05	17.88	2.3170	62.27	0.6547	16.51	11.81
1	-1	-1	6.23	5.00	3.60E+05	24.30	2.3170	62.27	0.6547	16.51	11.81
1	-1	-1	6.23	2.00	2.60E+05	26.13	2.3170	62.27	0.6547	16.51	11.81
1	-1	-1	6.23	1.00	2.25E+05	21.07	2.3170	62.27	0.6547	16.51	11.81
1	-1	-1	6.23	0.50	1.52E+05	24.25	2.3170	62.27	0.6547	16.51	11.81

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	-1	6.23	0.20	9.81E+04	31.73	2.3170	62.27	0.6547	16.51	11.81
1	-1	-1	6.23	0.10	6.93E+04	36.72	2.3170	62.27	0.6547	16.51	11.81
1	-1	-1	6.23	0.05	4.53E+04	38.48	2.3170	62.27	0.6547	16.51	11.81
1	-1	-1	6.23	0.02	3.05E+04	42.84	2.3170	62.27	0.6547	16.51	11.81
1	-1	-1	6.23	0.01	2.32E+04	44.47	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	15.00	4.34E+05	14.58	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	10.00	4.00E+05	16.15	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	5.00	3.42E+05	18.69	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	2.00	2.61E+05	23.17	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	1.00	2.04E+05	25.47	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	0.50	1.51E+05	30.86	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	0.20	8.75E+04	36.80	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	0.10	6.20E+04	39.50	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	0.05	4.14E+04	40.06	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	0.02	2.91E+04	43.04	2.3170	62.27	0.6547	16.51	11.81
1	-1	0	6.23	0.01	2.17E+04	43.87	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	15.00	3.14E+05	15.01	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	10.00	2.77E+05	17.70	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	5.00	2.19E+05	22.42	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	2.00	1.50E+05	27.09	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	1.00	1.11E+05	30.67	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	0.50	7.48E+04	35.09	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	0.20	7.12E+04	38.40	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	0.10	3.21E+04	40.27	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	0.05	2.50E+04	41.22	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	0.02	1.67E+04	42.25	2.3170	62.27	0.6547	16.51	11.81
1	-1	1	6.23	0.01	1.24E+04	42.00	2.3170	62.27	0.6547	16.51	11.81
1	-1	-1.3	7.69	15.00	6.20E+05	4.58	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1.3	7.69	10.00	5.99E+05	5.91	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1.3	7.69	5.00	5.86E+05	8.03	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1.3	7.69	2.00	3.52E+05	17.64	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1.3	7.69	1.00	2.81E+05	21.90	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1.3	7.69	0.50	2.08E+05	31.56	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1.3	7.69	0.20	1.28E+05	37.04	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1.3	7.69	0.10	7.96E+04	41.29	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1.3	7.69	0.05	5.04E+04	44.62	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1.3	7.69	0.02	3.45E+04	46.20	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1.3	7.69	0.01	2.40E+04	48.15	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	15.00	3.97E+05	17.69	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	10.00	3.52E+05	20.80	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	5.00	2.81E+05	27.27	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	2.00	2.06E+05	34.32	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	1.00	1.31E+05	38.15	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	0.50	8.03E+04	42.95	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	0.20	4.69E+04	47.17	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	0.10	3.26E+04	48.72	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	0.05	2.12E+04	49.35	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	0.02	1.49E+04	50.96	2.2811	56.84	0.6021	17.81	11.63
1	-1	0	7.69	0.01	1.01E+04	47.70	2.2811	56.84	0.6021	17.81	11.63
1	-1	1	7.69	15.00	2.23E+05	24.19	2.2811	56.84	0.6021	17.81	11.63
1	-1	1	7.69	10.00	1.89E+05	27.38	2.2811	56.84	0.6021	17.81	11.63
1	-1	1	7.69	5.00	1.35E+05	33.84	2.2811	56.84	0.6021	17.81	11.63
1	-1	1	7.69	2.00	8.23E+04	40.09	2.2811	56.84	0.6021	17.81	11.63
1	-1	1	7.69	1.00	6.11E+04	43.85	2.2811	56.84	0.6021	17.81	11.63
1	-1	1	7.69	0.50	4.13E+04	47.75	2.2811	56.84	0.6021	17.81	11.63

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	1	7.69	0.20	2.52E+04	50.89	2.2811	56.84	0.6021	17.81	11.63
1	-1	1	7.69	0.10	1.73E+04	52.19	2.2811	56.84	0.6021	17.81	11.63
1	-1	1	7.69	0.05	1.10E+04	51.97	2.2811	56.84	0.6021	17.81	11.63
1	-1	1	7.69	0.02	7.19E+03	50.77	2.2811	56.84	0.6021	17.81	11.63
1	-1	1	7.69	0.01	5.41E+03	51.10	2.2811	56.84	0.6021	17.81	11.63
1	-1	-1	7.07	15.00	4.55E+05	15.35	2.2962	59.04	0.6235	17.26	11.71
1	-1	-1	7.07	10.00	4.11E+05	16.97	2.2962	59.04	0.6235	17.26	11.71
1	-1	-1	7.07	5.00	3.55E+05	21.13	2.2962	59.04	0.6235	17.26	11.71
1	-1	-1	7.07	2.00	2.57E+05	26.38	2.2962	59.04	0.6235	17.26	11.71
1	-1	-1	7.07	1.00	2.43E+05	21.98	2.2962	59.04	0.6235	17.26	11.71
1	-1	-1	7.07	0.50	1.59E+05	34.60	2.2962	59.04	0.6235	17.26	11.71
1	-1	-1	7.07	0.20	1.07E+05	40.36	2.2962	59.04	0.6235	17.26	11.71
1	-1	-1	7.07	0.10	7.45E+04	52.81	2.2962	59.04	0.6235	17.26	11.71
1	-1	-1	7.07	0.05	5.06E+04	24.82	2.2962	59.04	0.6235	17.26	11.71
1	-1	-1	7.07	0.02	3.36E+04	39.11	2.2962	59.04	0.6235	17.26	11.71
1	-1	-1	7.07	0.01	2.48E+04	41.26	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	15.00	2.60E+05	21.31	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	10.00	2.29E+05	24.00	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	5.00	1.82E+05	30.21	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	2.00	1.23E+05	35.57	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	1.00	9.16E+04	39.65	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	0.50	6.28E+04	46.89	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	0.20	3.93E+04	50.45	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	0.10	2.83E+04	60.94	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	0.05	1.78E+04	30.45	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	0.02	1.23E+04	41.57	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.07	0.01	9.21E+03	42.79	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	15.00	1.76E+05	24.19	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	10.00	1.52E+05	27.38	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	5.00	1.16E+05	33.84	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	2.00	7.77E+04	40.09	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	1.00	5.51E+04	43.85	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	0.50	3.47E+04	47.75	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	0.20	2.40E+04	50.89	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	0.10	1.26E+04	52.19	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	0.05	2.08E+04	51.97	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	0.02	9.86E+03	50.77	2.2962	59.04	0.6235	17.26	11.71
1	-1	1	7.07	0.01	8.02E+03	51.10	2.2962	59.04	0.6235	17.26	11.71
1	-1	0	7.27	15.00	2.86E+05	25.64	2.2913	58.31	0.6164	17.44	11.68
1	-1	0	7.27	10.00	2.49E+05	27.95	2.2913	58.31	0.6164	17.44	11.68
1	-1	0	7.27	5.00	1.98E+05	33.30	2.2913	58.31	0.6164	17.44	11.68
1	-1	0	7.27	2.00	1.37E+05	40.38	2.2913	58.31	0.6164	17.44	11.68
1	-1	0	7.27	1.00	1.03E+05	43.05	2.2913	58.31	0.6164	17.44	11.68
1	-1	0	7.27	0.50	6.90E+04	54.59	2.2913	58.31	0.6164	17.44	11.68
1	-1	0	7.27	0.20	4.93E+04	53.45	2.2913	58.31	0.6164	17.44	11.68
1	-1	0	7.27	0.10	3.81E+04	57.82	2.2913	58.31	0.6164	17.44	11.68
1	-1	0	7.27	0.05	1.68E+04	49.29	2.2913	58.31	0.6164	17.44	11.68
1	-1	0	7.27	0.02	1.32E+04	51.19	2.2913	58.31	0.6164	17.44	11.68
1	-1	0	7.27	0.01	1.12E+04	59.10	2.2913	58.31	0.6164	17.44	11.68
1	-1	1	7.27	15.00	2.48E+05	24.19	2.2913	58.31	0.6164	17.44	11.68
1	-1	1	7.27	10.00	2.16E+05	27.38	2.2913	58.31	0.6164	17.44	11.68
1	-1	1	7.27	5.00	1.70E+05	33.84	2.2913	58.31	0.6164	17.44	11.68
1	-1	1	7.27	2.00	1.16E+05	40.09	2.2913	58.31	0.6164	17.44	11.68
1	-1	1	7.27	1.00	8.59E+04	43.85	2.2913	58.31	0.6164	17.44	11.68
1	-1	1	7.27	0.50	6.08E+04	47.75	2.2913	58.31	0.6164	17.44	11.68

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	-1	1	7.27	0.20	3.93E+04	50.89	2.2913	58.31	0.6164	17.44	11.68
1	-1	1	7.27	0.10	2.84E+04	52.19	2.2913	58.31	0.6164	17.44	11.68
1	-1	1	7.27	0.05	2.10E+04	51.97	2.2913	58.31	0.6164	17.44	11.68
1	-1	1	7.27	0.02	1.39E+04	50.77	2.2913	58.31	0.6164	17.44	11.68
1	-1	1	7.27	0.01	1.03E+04	51.10	2.2913	58.31	0.6164	17.44	11.68
-1	-1	1	3.27	15.00	5.42E+05	25.83	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	10.00	5.01E+05	27.97	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	5.00	3.91E+05	32.94	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	2.00	2.60E+05	37.14	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	1.00	1.43E+05	43.04	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	0.50	8.43E+04	44.71	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	0.20	4.52E+04	49.06	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	0.10	3.05E+04	50.37	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	0.05	1.87E+04	48.68	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	0.02	1.26E+04	40.85	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	0.01	9.17E+03	47.25	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	15.00	6.60E+05	15.28	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	10.00	6.21E+05	17.22	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	5.00	5.53E+05	21.14	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	2.00	4.00E+05	25.69	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	1.00	3.01E+05	30.21	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	0.50	1.68E+05	37.76	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	0.20	8.27E+04	41.96	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	0.10	5.30E+04	45.76	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	0.05	3.34E+04	33.89	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	0.02	2.17E+04	40.81	2.3903	75.65	0.7712	13.42	11.01
-1	-1	0	3.27	0.01	1.53E+04	43.42	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	15.00	7.50E+05	11.61	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	10.00	7.20E+05	12.57	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	5.00	6.80E+05	15.38	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	2.00	6.00E+05	18.51	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	1.00	5.00E+05	19.93	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	0.50	4.50E+05	23.07	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	0.20	2.80E+05	30.72	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	0.10	1.36E+05	34.59	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	0.05	7.40E+04	33.19	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	0.02	4.81E+04	36.68	2.3903	75.65	0.7712	13.42	11.01
-1	-1	-1	3.27	0.01	3.26E+04	39.04	2.3903	75.65	0.7712	13.42	11.01
-1	-1	1	3.27	15.00	5.42E+05	22.23	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	3.27	10.00	5.01E+05	25.69	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	3.27	5.00	3.91E+05	30.64	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	3.27	2.00	2.60E+05	36.29	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	3.27	1.00	1.43E+05	44.81	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	3.27	0.50	8.43E+04	49.75	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	3.27	0.20	4.52E+04	52.36	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	3.27	0.10	3.05E+04	53.92	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	3.27	0.05	1.87E+04	54.74	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	3.27	0.02	1.26E+04	54.58	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	3.27	0.01	9.17E+03	53.50	2.3901	75.64	0.7711	13.42	11.01
-1	-1	0	3.27	15.00	6.60E+05	15.47	2.3901	75.64	0.7711	13.42	11.01
-1	-1	0	3.27	10.00	6.21E+05	17.33	2.3901	75.64	0.7711	13.42	11.01
-1	-1	0	3.27	5.00	5.53E+05	21.68	2.3901	75.64	0.7711	13.42	11.01
-1	-1	0	3.27	2.00	4.20E+05	26.87	2.3901	75.64	0.7711	13.42	11.01
-1	-1	0	3.27	1.00	3.01E+05	37.13	2.3901	75.64	0.7711	13.42	11.01
-1	-1	0	3.27	0.50	1.68E+05	42.02	2.3901	75.64	0.7711	13.42	11.01

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	-1	0	3.27	0.20	8.27E+04	46.74	2.3901	75.64	0.7711	13.42	11.01
-1	-1	0	3.27	0.10	5.30E+04	48.98	2.3901	75.64	0.7711	13.42	11.01
-1	-1	0	3.27	0.05	3.34E+04	50.86	2.3901	75.64	0.7711	13.42	11.01
-1	-1	0	3.27	0.02	2.17E+04	52.29	2.3901	75.64	0.7711	13.42	11.01
-1	-1	0	3.27	0.01	1.53E+04	52.70	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	15.00	7.60E+05	10.00	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	10.00	7.30E+05	10.10	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	5.00	7.00E+05	10.28	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	2.00	6.30E+05	20.67	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	1.00	5.40E+05	27.96	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	0.50	4.50E+05	38.00	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	0.20	3.57E+05	46.01	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	0.10	1.36E+05	47.79	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	0.05	7.40E+04	48.42	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	0.02	4.81E+04	51.39	2.3901	75.64	0.7711	13.42	11.01
-1	-1	-1	3.27	0.01	3.26E+04	52.06	2.3901	75.64	0.7711	13.42	11.01
-1	-1	1	2.89	15.00	6.72E+05	21.95	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	2.89	10.00	6.18E+05	26.61	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	2.89	5.00	4.69E+05	36.52	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	2.89	2.00	3.00E+05	34.89	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	2.89	1.00	1.61E+05	46.80	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	2.89	0.50	9.43E+04	49.61	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	2.89	0.20	4.99E+04	51.18	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	2.89	0.10	3.30E+04	52.55	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	2.89	0.05	2.15E+04	53.65	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	2.89	0.02	1.37E+04	53.28	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	2.89	0.01	9.45E+03	52.36	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	15.00	6.94E+05	11.18	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	10.00	6.58E+05	11.68	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	5.00	5.79E+05	15.07	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	2.00	4.30E+05	19.79	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	1.00	3.50E+05	27.25	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	0.50	2.72E+05	32.52	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	0.20	1.34E+05	40.27	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	0.10	8.75E+04	43.08	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	0.05	5.38E+04	45.67	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	0.02	3.53E+04	48.57	2.3997	77.90	0.7928	13.08	11.06
-1	-1	0	2.89	0.01	2.45E+04	49.58	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	15.00	8.19E+05	6.14	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	10.00	8.06E+05	7.14	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	5.00	7.50E+05	9.94	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	2.00	6.36E+05	12.61	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	1.00	4.50E+05	20.24	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	0.50	3.50E+05	26.61	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	0.20	2.37E+05	31.51	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	0.10	1.48E+05	35.81	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	0.05	8.75E+04	39.11	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	0.02	5.92E+04	43.38	2.3997	77.90	0.7928	13.08	11.06
-1	-1	-1	2.89	0.01	4.18E+04	45.57	2.3997	77.90	0.7928	13.08	11.06
-1	-1	1	6.12	15.00	3.97E+05	28.69	2.3200	61.67	0.6359	15.97	10.69
-1	-1	1	6.12	10.00	3.61E+05	31.18	2.3200	61.67	0.6359	15.97	10.69
-1	-1	1	6.12	5.00	2.75E+05	36.20	2.3200	61.67	0.6359	15.97	10.69
-1	-1	1	6.12	2.00	1.18E+05	41.36	2.3200	61.67	0.6359	15.97	10.69
-1	-1	1	6.12	1.00	9.38E+04	46.80	2.3200	61.67	0.6359	15.97	10.69
-1	-1	1	6.12	0.50	5.60E+04	48.81	2.3200	61.67	0.6359	15.97	10.69

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	-1	1	6.12	0.20	3.01E+04	51.51	2.3200	61.67	0.6359	15.97	10.69
-1	-1	1	6.12	0.10	2.01E+04	51.86	2.3200	61.67	0.6359	15.97	10.69
-1	-1	1	6.12	0.05	1.25E+04	48.73	2.3200	61.67	0.6359	15.97	10.69
-1	-1	1	6.12	0.02	8.36E+03	49.37	2.3200	61.67	0.6359	15.97	10.69
-1	-1	1	6.12	0.01	6.07E+03	46.07	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	15.00	6.74E+05	19.35	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	10.00	6.27E+05	20.74	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	5.00	5.43E+05	25.28	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	2.00	2.61E+05	29.47	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	1.00	2.64E+05	34.65	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	0.50	1.46E+05	36.69	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	0.20	6.69E+04	44.03	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	0.10	4.08E+04	46.86	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	0.05	3.59E+04	44.43	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	0.02	2.06E+04	46.67	2.3200	61.67	0.6359	15.97	10.69
-1	-1	0	6.12	0.01	1.27E+04	49.66	2.3200	61.67	0.6359	15.97	10.69
-1	-1	1	5.89	15.00	3.47E+05	34.00	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	5.89	10.00	2.86E+05	37.61	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	5.89	5.00	1.91E+05	44.25	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	5.89	2.00	1.02E+05	44.87	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	5.89	1.00	7.44E+04	50.57	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	5.89	0.50	4.62E+04	53.02	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	5.89	0.20	2.59E+04	55.33	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	5.89	0.10	1.71E+04	55.69	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	5.89	0.05	1.11E+04	56.15	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	5.89	0.02	6.73E+03	53.17	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	5.89	0.01	4.85E+03	50.60	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	15.00	5.72E+05	21.72	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	10.00	5.06E+05	24.45	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	5.00	4.06E+05	29.88	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	2.00	1.98E+05	33.29	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	1.00	1.74E+05	41.08	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	0.50	1.09E+05	45.45	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	0.20	5.95E+04	49.42	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	0.10	3.93E+04	51.97	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	0.05	2.47E+04	53.74	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	0.02	1.54E+04	55.50	2.3255	62.64	0.6453	15.77	10.72
-1	-1	0	5.89	0.01	1.03E+04	54.75	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	15.00	6.90E+05	10.00	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	10.00	6.50E+05	10.28	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	5.00	5.50E+05	16.88	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	2.00	3.73E+05	22.63	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	1.00	2.25E+05	37.75	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	0.50	2.00E+05	45.24	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	0.20	1.24E+05	45.65	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	0.10	7.92E+04	48.36	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	0.05	4.87E+04	51.16	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	0.02	3.09E+04	53.29	2.3255	62.64	0.6453	15.77	10.72
-1	-1	-1	5.89	0.01	2.05E+04	54.56	2.3255	62.64	0.6453	15.77	10.72
-1	-1	1	7.70	15.00	1.99E+05	28.32	2.2808	55.72	0.5772	17.39	10.51
-1	-1	1	7.70	10.00	1.71E+05	31.31	2.2808	55.72	0.5772	17.39	10.51
-1	-1	1	7.70	5.00	1.27E+05	36.64	2.2808	55.72	0.5772	17.39	10.51
-1	-1	1	7.70	2.00	7.95E+04	40.52	2.2808	55.72	0.5772	17.39	10.51
-1	-1	1	7.70	1.00	6.06E+04	45.28	2.2808	55.72	0.5772	17.39	10.51
-1	-1	1	7.70	0.50	3.96E+04	51.49	2.2808	55.72	0.5772	17.39	10.51

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	-1	1	7.70	0.20	2.27E+04	55.40	2.2808	55.72	0.5772	17.39	10.51
-1	-1	1	7.70	0.10	1.48E+04	56.69	2.2808	55.72	0.5772	17.39	10.51
-1	-1	1	7.70	0.05	9.61E+03	59.04	2.2808	55.72	0.5772	17.39	10.51
-1	-1	1	7.70	0.02	5.68E+03	58.36	2.2808	55.72	0.5772	17.39	10.51
-1	-1	1	7.70	0.01	3.83E+03	56.95	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	15.00	3.24E+05	17.41	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	10.00	2.91E+05	19.67	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	5.00	2.30E+05	24.98	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	2.00	1.36E+05	29.00	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	1.00	1.24E+05	33.92	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	0.50	8.52E+04	39.08	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	0.20	5.14E+04	44.97	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	0.10	3.53E+04	47.71	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	0.05	2.26E+04	50.48	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	0.02	1.48E+04	52.14	2.2808	55.72	0.5772	17.39	10.51
-1	-1	0	7.70	0.01	1.01E+04	52.26	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	15.00	3.72E+05	10.49	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	10.00	3.49E+05	11.45	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	5.00	3.08E+05	14.22	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	2.00	1.95E+05	21.05	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	1.00	2.04E+05	17.90	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	0.50	1.55E+05	25.94	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	0.20	9.80E+04	34.14	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	0.10	6.88E+04	39.05	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	0.05	4.50E+04	42.11	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	0.02	3.06E+04	46.71	2.2808	55.72	0.5772	17.39	10.51
-1	-1	-1	7.70	0.01	2.16E+04	48.48	2.2808	55.72	0.5772	17.39	10.51
-1	-1	1	7.87	15.00	2.61E+05	39.76	2.2766	55.14	0.5715	17.54	10.49
-1	-1	1	7.87	10.00	2.05E+05	42.35	2.2766	55.14	0.5715	17.54	10.49
-1	-1	1	7.87	5.00	1.35E+05	47.13	2.2766	55.14	0.5715	17.54	10.49
-1	-1	1	7.87	2.00	7.47E+04	48.66	2.2766	55.14	0.5715	17.54	10.49
-1	-1	1	7.87	1.00	5.25E+04	51.71	2.2766	55.14	0.5715	17.54	10.49
-1	-1	1	7.87	0.50	3.32E+04	54.33	2.2766	55.14	0.5715	17.54	10.49
-1	-1	1	7.87	0.20	1.93E+04	55.72	2.2766	55.14	0.5715	17.54	10.49
-1	-1	1	7.87	0.10	1.28E+04	55.66	2.2766	55.14	0.5715	17.54	10.49
-1	-1	1	7.87	0.05	8.24E+03	55.62	2.2766	55.14	0.5715	17.54	10.49
-1	-1	1	7.87	0.02	5.23E+03	54.01	2.2766	55.14	0.5715	17.54	10.49
-1	-1	1	7.87	0.01	3.88E+03	51.68	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	15.00	4.71E+05	23.82	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	10.00	4.26E+05	26.89	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	5.00	3.18E+05	32.95	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	2.00	1.69E+05	35.70	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	1.00	1.39E+05	43.02	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	0.50	8.83E+04	46.70	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	0.20	4.94E+04	50.82	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	0.10	3.27E+04	52.99	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	0.05	2.04E+04	54.88	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	0.02	1.27E+04	56.49	2.2766	55.14	0.5715	17.54	10.49
-1	-1	0	7.87	0.01	8.55E+03	56.37	2.2766	55.14	0.5715	17.54	10.49
-1	-1	-1	7.87	15.00	5.03E+05	10.20	2.2766	55.14	0.5715	17.54	10.49
-1	-1	-1	7.87	10.00	4.75E+05	11.63	2.2766	55.14	0.5715	17.54	10.49
-1	-1	-1	7.87	5.00	4.17E+05	15.40	2.2766	55.14	0.5715	17.54	10.49
-1	-1	-1	7.87	2.00	3.20E+05	23.72	2.2766	55.14	0.5715	17.54	10.49
-1	-1	-1	7.87	1.00	2.61E+05	21.38	2.2766	55.14	0.5715	17.54	10.49
-1	-1	-1	7.87	0.50	1.62E+05	34.22	2.2766	55.14	0.5715	17.54	10.49

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	-1	-1	7.87	0.20	8.79E+04	42.31	2.2766	55.14	0.5715	17.54	10.49
-1	-1	-1	7.87	0.10	5.90E+04	46.23	2.2766	55.14	0.5715	17.54	10.49
-1	-1	-1	7.87	0.05	3.69E+04	48.37	2.2766	55.14	0.5715	17.54	10.49
-1	-1	-1	7.87	0.02	2.40E+04	52.91	2.2766	55.14	0.5715	17.54	10.49
-1	-1	-1	7.87	0.01	1.63E+04	53.91	2.2766	55.14	0.5715	17.54	10.49
1	1	1.2	3.75	15.00	4.92E+05	11.50	2.3899	72.62	0.7460	13.70	11.01
1	1	1.2	3.75	10.00	4.49E+05	13.69	2.3899	72.62	0.7460	13.70	11.01
1	1	1.2	3.75	5.00	3.72E+05	18.32	2.3899	72.62	0.7460	13.70	11.01
1	1	1.2	3.75	2.00	2.03E+05	22.23	2.3899	72.62	0.7460	13.70	11.01
1	1	1.2	3.75	1.00	2.45E+05	22.81	2.3899	72.62	0.7460	13.70	11.01
1	1	1.2	3.75	0.50	1.65E+05	29.52	2.3899	72.62	0.7460	13.70	11.01
1	1	1.2	3.75	0.20	9.52E+04	34.04	2.3899	72.62	0.7460	13.70	11.01
1	1	1.2	3.75	0.10	6.66E+04	36.52	2.3899	72.62	0.7460	13.70	11.01
1	1	1.2	3.75	0.05	4.59E+04	38.07	2.3899	72.62	0.7460	13.70	11.01
1	1	1.2	3.75	0.02	3.28E+04	38.53	2.3899	72.62	0.7460	13.70	11.01
1	1	1.2	3.75	0.01	2.50E+04	39.64	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	15.00	6.27E+05	5.46	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	10.00	6.14E+05	6.73	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	5.00	5.67E+05	10.03	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	2.00	5.50E+05	12.92	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	1.00	4.50E+05	16.00	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	0.50	3.35E+05	20.00	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	0.20	2.91E+05	25.48	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	0.10	1.29E+05	31.47	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	0.05	8.25E+04	33.40	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	0.02	5.92E+04	37.93	2.3899	72.62	0.7460	13.70	11.01
1	1	0	3.75	0.01	4.51E+04	38.91	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	15.00	1.46E+06	7.27	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	10.00	1.43E+06	8.97	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	5.00	1.33E+06	13.21	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	2.00	1.05E+06	19.39	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	1.00	9.17E+05	28.42	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	0.50	8.50E+05	37.04	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	0.20	8.00E+05	41.77	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	0.10	7.50E+05	44.82	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	0.05	4.57E+05	47.95	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	0.02	2.59E+05	51.82	2.3899	72.62	0.7460	13.70	11.01
1	1	-1	3.75	0.01	1.60E+05	52.20	2.3899	72.62	0.7460	13.70	11.01
1	1	1	4.18	15.00	3.63E+05	22.10	2.3793	70.31	0.7240	14.08	10.96
1	1	1	4.18	10.00	3.13E+05	26.80	2.3793	70.31	0.7240	14.08	10.96
1	1	1	4.18	5.00	2.31E+05	35.83	2.3793	70.31	0.7240	14.08	10.96
1	1	1	4.18	2.00	1.08E+05	41.69	2.3793	70.31	0.7240	14.08	10.96
1	1	1	4.18	1.00	8.74E+04	45.78	2.3793	70.31	0.7240	14.08	10.96
1	1	1	4.18	0.50	5.21E+04	50.48	2.3793	70.31	0.7240	14.08	10.96
1	1	1	4.18	0.20	2.99E+04	54.02	2.3793	70.31	0.7240	14.08	10.96
1	1	1	4.18	0.10	1.98E+04	55.06	2.3793	70.31	0.7240	14.08	10.96
1	1	1	4.18	0.05	1.27E+04	55.55	2.3793	70.31	0.7240	14.08	10.96
1	1	1	4.18	0.02	8.13E+03	54.61	2.3793	70.31	0.7240	14.08	10.96
1	1	1	4.18	0.01	5.60E+03	51.68	2.3793	70.31	0.7240	14.08	10.96
1	1	0	4.18	15.00	4.84E+05	16.07	2.3793	70.31	0.7240	14.08	10.96
1	1	0	4.18	10.00	4.45E+05	19.09	2.3793	70.31	0.7240	14.08	10.96
1	1	0	4.18	5.00	3.86E+05	24.76	2.3793	70.31	0.7240	14.08	10.96
1	1	0	4.18	2.00	1.77E+05	32.00	2.3793	70.31	0.7240	14.08	10.96
1	1	0	4.18	1.00	1.82E+05	38.23	2.3793	70.31	0.7240	14.08	10.96
1	1	0	4.18	0.50	1.03E+05	44.72	2.3793	70.31	0.7240	14.08	10.96

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	1	0	4.18	0.20	5.46E+04	49.15	2.3793	70.31	0.7240	14.08	10.96
1	1	0	4.18	0.10	3.69E+04	50.98	2.3793	70.31	0.7240	14.08	10.96
1	1	0	4.18	0.05	2.35E+04	52.18	2.3793	70.31	0.7240	14.08	10.96
1	1	0	4.18	0.02	1.54E+04	51.56	2.3793	70.31	0.7240	14.08	10.96
1	1	0	4.18	0.01	1.08E+04	49.62	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	15.00	7.27E+05	7.27	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	10.00	7.03E+05	8.97	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	5.00	6.50E+05	13.21	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	2.00	5.50E+05	19.39	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	1.00	4.60E+05	28.42	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	0.50	3.84E+05	37.04	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	0.20	1.28E+05	41.77	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	0.10	7.76E+04	44.82	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	0.05	4.78E+04	47.95	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	0.02	3.09E+04	51.82	2.3793	70.31	0.7240	14.08	10.96
1	1	-1	4.18	0.01	2.18E+04	52.20	2.3793	70.31	0.7240	14.08	10.96
1	1	1	5.55	15.00	3.00E+05	26.97	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.55	10.00	2.53E+05	30.17	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.55	5.00	1.79E+05	36.86	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.55	2.00	9.11E+04	42.24	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.55	1.00	7.29E+04	46.53	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.55	0.50	4.60E+04	50.18	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.55	0.20	2.63E+04	53.12	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.55	0.10	1.79E+04	53.57	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.55	0.05	1.13E+04	54.67	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.55	0.02	7.25E+03	49.40	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.55	0.01	5.27E+03	49.08	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	15.00	4.56E+05	16.90	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	10.00	4.06E+05	19.18	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	5.00	3.19E+05	25.15	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	2.00	2.25E+05	29.97	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	1.00	1.58E+05	38.46	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	0.50	9.93E+04	43.66	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	0.20	5.45E+04	48.32	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	0.10	3.60E+04	51.25	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	0.05	2.27E+04	53.49	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	0.02	1.42E+04	55.13	2.3451	63.76	0.6607	15.31	10.81
1	1	0	5.55	0.01	9.40E+03	53.77	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	15.00	4.92E+05	9.28	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	10.00	4.55E+05	10.66	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	5.00	4.23E+05	13.53	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	2.00	3.50E+05	21.22	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	1.00	2.89E+05	25.00	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	0.50	1.91E+05	29.40	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	0.20	1.00E+05	38.41	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	0.10	6.70E+04	43.36	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	0.05	4.37E+04	46.88	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	0.02	2.88E+04	49.71	2.3451	63.76	0.6607	15.31	10.81
1	1	-1	5.55	0.01	2.16E+04	48.59	2.3451	63.76	0.6607	15.31	10.81
1	1	1	5.70	15.00	3.80E+05	19.65	2.3416	63.08	0.6543	15.44	10.79
1	1	1	5.70	10.00	3.35E+05	21.71	2.3420	63.05	0.6544	15.43	10.79
1	1	1	5.70	5.00	2.64E+05	26.80	2.3416	63.08	0.6543	15.44	10.79
1	1	1	5.70	2.00	1.80E+05	31.81	2.3417	63.07	0.6543	15.44	10.79
1	1	1	5.70	1.00	1.29E+05	36.54	2.3417	63.07	0.6543	15.44	10.79
1	1	1	5.70	0.50	8.45E+04	41.29	2.3417	63.07	0.6543	15.44	10.79

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	1	1	5.70	0.20	5.00E+04	45.32	2.3417	63.07	0.6543	15.44	10.79
1	1	1	5.70	0.10	3.42E+04	47.32	2.3417	63.07	0.6543	15.44	10.79
1	1	1	5.70	0.05	2.23E+04	48.46	2.3417	63.07	0.6543	15.44	10.79
1	1	1	5.70	0.02	1.49E+04	51.51	2.3417	63.07	0.6543	15.44	10.79
1	1	1	5.70	0.01	1.10E+04	49.14	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	15.00	5.46E+05	10.26	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	10.00	5.03E+05	11.86	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	5.00	4.39E+05	14.00	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	2.00	3.70E+05	17.21	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	1.00	3.14E+05	19.00	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	0.50	2.07E+05	25.90	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	0.20	1.20E+05	34.59	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	0.10	8.01E+04	38.27	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	0.05	4.98E+04	41.43	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	0.02	3.41E+04	45.20	2.3417	63.07	0.6543	15.44	10.79
1	1	0	5.70	0.01	2.42E+04	46.64	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	15.00	6.23E+05	9.28	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	10.00	5.95E+05	10.66	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	5.00	5.70E+05	13.53	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	2.00	4.60E+05	18.00	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	1.00	4.30E+05	20.00	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	0.50	3.50E+05	22.00	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	0.20	2.04E+05	24.35	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	0.10	1.26E+05	31.07	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	0.05	7.77E+04	35.49	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	0.02	5.40E+04	40.38	2.3417	63.07	0.6543	15.44	10.79
1	1	-1	5.70	0.01	3.96E+04	43.27	2.3417	63.07	0.6543	15.44	10.79
1	1	1	5.36	15.00	5.79E+05	18.24	2.3498	64.60	0.6689	15.14	10.83
1	1	1	5.36	10.00	5.05E+05	21.45	2.3498	64.60	0.6689	15.14	10.83
1	1	1	5.36	5.00	4.01E+05	25.55	2.3498	64.60	0.6689	15.14	10.83
1	1	1	5.36	2.00	2.60E+05	29.88	2.3498	64.60	0.6689	15.14	10.83
1	1	1	5.36	1.00	1.80E+05	36.73	2.3498	64.60	0.6689	15.14	10.83
1	1	1	5.36	0.50	1.12E+05	40.94	2.3498	64.60	0.6689	15.14	10.83
1	1	1	5.36	0.20	6.37E+04	43.63	2.3498	64.60	0.6689	15.14	10.83
1	1	1	5.36	0.10	4.35E+04	44.95	2.3498	64.60	0.6689	15.14	10.83
1	1	1	5.36	0.05	2.82E+04	46.60	2.3498	64.60	0.6689	15.14	10.83
1	1	1	5.36	0.02	1.87E+04	46.54	2.3498	64.60	0.6689	15.14	10.83
1	1	1	5.36	0.01	1.38E+04	47.82	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	15.00	6.68E+05	5.72	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	10.00	6.16E+05	7.48	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	5.00	5.52E+05	11.55	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	2.00	4.80E+05	15.52	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	1.00	3.80E+05	17.18	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	0.50	2.60E+05	24.50	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	0.20	1.28E+05	31.74	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	0.10	8.52E+04	36.10	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	0.05	5.65E+04	38.66	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	0.02	4.15E+04	43.29	2.3498	64.60	0.6689	15.14	10.83
1	1	0	5.36	0.01	2.96E+04	42.21	2.3498	64.60	0.6689	15.14	10.83
1	1	-1	5.36	0.20	2.03E+05	23.21	2.3498	64.60	0.6689	15.14	10.83
1	1	-1	5.36	0.10	1.35E+05	28.65	2.3498	64.60	0.6689	15.14	10.83
1	1	-1	5.36	0.05	8.87E+04	30.92	2.3498	64.60	0.6689	15.14	10.83
1	1	-1	5.36	0.02	6.46E+04	35.82	2.3498	64.60	0.6689	15.14	10.83
1	1	-1	5.36	0.01	4.98E+04	38.23	2.3498	64.60	0.6689	15.14	10.83
1	1	1	6.33	15.00	2.90E+05	24.22	2.3258	60.47	0.6287	16.01	10.72

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	1	1	6.33	10.00	2.50E+05	26.31	2.3258	60.47	0.6287	16.01	10.72
1	1	1	6.33	5.00	1.86E+05	30.65	2.3258	60.47	0.6287	16.01	10.72
1	1	1	6.33	2.00	1.08E+05	35.94	2.3258	60.47	0.6287	16.01	10.72
1	1	1	6.33	1.00	9.06E+04	37.55	2.3258	60.47	0.6287	16.01	10.72
1	1	1	6.33	0.50	6.18E+04	41.11	2.3258	60.47	0.6287	16.01	10.72
1	1	1	6.33	0.20	3.83E+04	44.76	2.3258	60.47	0.6287	16.01	10.72
1	1	1	6.33	0.10	2.71E+04	46.80	2.3258	60.47	0.6287	16.01	10.72
1	1	1	6.33	0.05	1.81E+04	48.44	2.3258	60.47	0.6287	16.01	10.72
1	1	1	6.33	0.02	1.21E+04	47.27	2.3258	60.47	0.6287	16.01	10.72
1	1	1	6.33	0.01	7.75E+03	49.52	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	15.00	3.70E+05	13.37	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	10.00	3.31E+05	15.19	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	5.00	2.76E+05	18.41	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	2.00	1.62E+05	24.41	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	1.00	1.64E+05	25.18	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	0.50	1.14E+05	31.47	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	0.20	7.29E+04	36.23	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	0.10	5.29E+04	39.18	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	0.05	3.61E+04	40.74	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	0.02	2.54E+04	45.86	2.3258	60.47	0.6287	16.01	10.72
1	1	0	6.33	0.01	1.88E+04	45.08	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	15.00	4.25E+05	1.53	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	10.00	3.99E+05	2.50	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	5.00	3.80E+05	5.08	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	2.00	2.80E+05	11.97	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	1.00	2.36E+05	12.00	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	0.50	1.89E+05	13.17	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	0.20	1.30E+05	19.98	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	0.10	9.80E+04	24.97	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	0.05	6.91E+04	28.57	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	0.02	5.20E+04	34.20	2.3258	60.47	0.6287	16.01	10.72
1	1	-1	6.33	0.01	4.01E+04	38.49	2.3258	60.47	0.6287	16.01	10.72
1	1	1	7.73	15.00	4.34E+05	15.16	2.2911	55.22	0.5773	17.26	10.56
1	1	1	7.73	10.00	3.99E+05	17.22	2.2911	55.22	0.5773	17.26	10.56
1	1	1	7.73	5.00	3.40E+05	20.56	2.2911	55.22	0.5773	17.26	10.56
1	1	1	7.73	2.00	2.50E+05	26.93	2.2911	55.22	0.5773	17.26	10.56
1	1	1	7.73	1.00	1.84E+05	30.83	2.2911	55.22	0.5773	17.26	10.56
1	1	1	7.73	0.50	1.18E+05	36.52	2.2911	55.22	0.5773	17.26	10.56
1	1	1	7.73	0.20	7.06E+04	40.33	2.2911	55.22	0.5773	17.26	10.56
1	1	1	7.73	0.10	4.97E+04	42.02	2.2911	55.22	0.5773	17.26	10.56
1	1	1	7.73	0.05	3.27E+04	43.17	2.2911	55.22	0.5773	17.26	10.56
1	1	1	7.73	0.02	2.26E+04	45.77	2.2911	55.22	0.5773	17.26	10.56
1	1	1	7.73	0.01	1.64E+04	46.65	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	15.00	4.92E+05	8.95	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	10.00	4.58E+05	10.57	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	5.00	4.00E+05	13.51	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	2.00	3.00E+05	17.80	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	1.00	2.70E+05	19.05	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	0.50	1.86E+05	26.96	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	0.20	1.11E+05	32.72	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	0.10	7.89E+04	35.92	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	0.05	5.26E+04	38.00	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	0.02	3.78E+04	41.59	2.2911	55.22	0.5773	17.26	10.56
1	1	0	7.73	0.01	2.80E+04	43.11	2.2911	55.22	0.5773	17.26	10.56
1	1	-1	7.73	15.00	5.51E+05	2.41	2.2911	55.22	0.5773	17.26	10.56

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
1	1	-1	7.73	10.00	5.22E+05	3.53	2.2911	55.22	0.5773	17.26	10.56
1	1	-1	7.73	5.00	5.00E+05	5.66	2.2911	55.22	0.5773	17.26	10.56
1	1	-1	7.73	2.00	4.00E+05	11.38	2.2911	55.22	0.5773	17.26	10.56
1	1	-1	7.73	1.00	3.60E+05	13.00	2.2911	55.22	0.5773	17.26	10.56
1	1	-1	7.73	0.50	3.26E+05	14.00	2.2911	55.22	0.5773	17.26	10.56
1	1	-1	7.73	0.20	2.12E+05	20.07	2.2911	55.22	0.5773	17.26	10.56
1	1	-1	7.73	0.10	1.49E+05	25.26	2.2911	55.22	0.5773	17.26	10.56
1	1	-1	7.73	0.05	9.67E+04	28.31	2.2911	55.22	0.5773	17.26	10.56
1	1	-1	7.73	0.02	6.98E+04	34.14	2.2911	55.22	0.5773	17.26	10.56
1	1	-1	7.73	0.01	5.28E+04	36.63	2.2911	55.22	0.5773	17.26	10.56
-1	1	1	3.75	15.00	5.56E+05	17.87	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	3.75	10.00	5.18E+05	21.06	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	3.75	5.00	4.34E+05	25.78	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	3.75	2.00	3.00E+05	30.48	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	3.75	1.00	2.01E+05	38.92	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	3.75	0.50	1.13E+05	47.36	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	3.75	0.20	5.88E+04	49.94	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	3.75	0.10	3.84E+04	51.93	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	3.75	0.05	2.48E+04	52.87	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	3.75	0.02	1.63E+04	53.78	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	3.75	0.01	1.13E+04	53.58	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	15.00	7.09E+05	10.00	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	10.00	6.96E+05	11.46	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	5.00	6.26E+05	15.05	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	2.00	6.00E+05	19.79	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	1.00	5.48E+05	28.45	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	0.50	3.86E+05	36.46	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	0.20	1.53E+05	42.75	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	0.10	9.54E+04	45.13	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	0.05	5.76E+04	47.20	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	0.02	3.87E+04	49.63	2.3898	71.67	0.7240	13.25	9.84
-1	1	0	3.75	0.01	2.78E+04	50.12	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	15.00	1.02E+06	6.26	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	10.00	9.93E+05	7.00	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	5.00	9.10E+05	8.00	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	2.00	8.30E+05	16.88	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	1.00	7.90E+05	18.04	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	0.50	7.23E+05	34.76	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	0.20	4.80E+05	55.18	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	0.10	1.38E+05	49.15	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	0.05	7.68E+04	50.60	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	0.02	4.93E+04	53.20	2.3898	71.67	0.7240	13.25	9.84
-1	1	-1	3.75	0.01	3.31E+04	54.62	2.3898	71.67	0.7240	13.25	9.84
-1	1	1	4.19	15.00	4.98E+05	25.54	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	4.19	10.00	4.31E+05	29.40	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	4.19	5.00	3.19E+05	37.24	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	4.19	2.00	1.58E+05	38.95	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	4.19	1.00	1.22E+05	48.75	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	4.19	0.50	7.50E+04	51.08	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	4.19	0.20	4.05E+04	52.84	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	4.19	0.10	2.68E+04	53.77	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	4.19	0.05	1.74E+04	53.94	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	4.19	0.02	1.10E+04	53.20	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	4.19	0.01	7.69E+03	51.67	2.3790	69.29	0.7005	13.64	9.80
-1	1	0	4.19	15.00	8.52E+05	11.59	2.3790	69.29	0.7005	13.64	9.80

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	1	0	4.19	10.00	8.22E+05	12.40	2.3790	69.29	0.7005	13.64	9.80
-1	1	0	4.19	5.00	7.99E+05	15.75	2.3790	69.29	0.7005	13.64	9.80
-1	1	0	4.19	2.00	4.00E+05	25.41	2.3790	69.29	0.7005	13.64	9.80
-1	1	0	4.19	1.00	3.00E+05	40.60	2.3790	69.29	0.7005	13.64	9.80
-1	1	0	4.19	0.50	2.34E+05	43.08	2.3790	69.29	0.7005	13.64	9.80
-1	1	0	4.19	0.20	9.89E+04	46.98	2.3790	69.29	0.7005	13.64	9.80
-1	1	0	4.19	0.10	6.36E+04	49.04	2.3790	69.29	0.7005	13.64	9.80
-1	1	0	4.19	0.05	3.94E+04	50.94	2.3790	69.29	0.7005	13.64	9.80
-1	1	0	4.19	0.02	2.55E+04	52.59	2.3790	69.29	0.7005	13.64	9.80
-1	1	0	4.19	0.01	1.78E+04	52.37	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	15.00	1.11E+06	6.26	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	10.00	1.19E+06	7.00	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	5.00	9.50E+05	8.00	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	2.00	7.50E+05	10.76	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	1.00	6.00E+05	30.67	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	0.50	3.80E+05	44.54	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	0.20	2.50E+05	53.71	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	0.10	1.52E+05	46.33	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	0.05	8.61E+04	47.58	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	0.02	5.44E+04	50.20	2.3790	69.29	0.7005	13.64	9.80
-1	1	-1	4.19	0.01	3.74E+04	51.14	2.3790	69.29	0.7005	13.64	9.80
-1	1	1	5.56	15.00	2.64E+05	13.89	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.56	10.00	2.41E+05	16.40	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.56	5.00	1.95E+05	22.13	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.56	2.00	1.37E+05	26.44	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.56	1.00	1.10E+05	29.56	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.56	0.50	7.90E+04	34.69	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.56	0.20	4.85E+04	40.07	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.56	0.10	3.46E+04	42.61	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.56	0.05	2.35E+04	44.72	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.56	0.02	1.66E+04	45.84	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.56	0.01	1.23E+04	45.13	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	15.00	3.24E+05	8.22	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	10.00	3.05E+05	10.36	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	5.00	2.63E+05	14.40	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	2.00	2.20E+05	19.55	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	1.00	1.67E+05	21.00	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	0.50	1.25E+05	27.73	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	0.20	7.95E+04	34.93	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	0.10	5.62E+04	37.81	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	0.05	3.69E+04	41.67	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	0.02	2.67E+04	43.00	2.3450	62.63	0.6347	14.87	9.66
-1	1	0	5.56	0.01	1.96E+04	45.49	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	15.00	5.24E+05	5.51	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	10.00	5.04E+05	6.15	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	5.00	4.47E+05	9.09	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	2.00	4.00E+05	12.37	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	1.00	3.53E+05	13.00	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	0.50	2.98E+05	14.02	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	0.20	1.72E+05	27.02	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	0.10	1.20E+05	30.89	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	0.05	7.88E+04	31.72	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	0.02	5.61E+04	37.55	2.3450	62.63	0.6347	14.87	9.66
-1	1	-1	5.56	0.01	4.17E+04	38.98	2.3450	62.63	0.6347	14.87	9.66
-1	1	1	5.76	15.00	4.19E+05	23.01	2.3399	61.73	0.6257	15.06	9.63

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	1	1	5.76	10.00	3.63E+05	25.96	2.3399	61.73	0.6257	15.06	9.63
-1	1	1	5.76	5.00	2.69E+05	31.89	2.3399	61.73	0.6257	15.06	9.63
-1	1	1	5.76	2.00	1.67E+05	33.37	2.3399	61.73	0.6257	15.06	9.63
-1	1	1	5.76	1.00	1.22E+05	42.48	2.3399	61.73	0.6257	15.06	9.63
-1	1	1	5.76	0.50	7.94E+04	45.47	2.3399	61.73	0.6257	15.06	9.63
-1	1	1	5.76	0.20	4.47E+04	47.66	2.3399	61.73	0.6257	15.06	9.63
-1	1	1	5.76	0.10	3.02E+04	48.90	2.3399	61.73	0.6257	15.06	9.63
-1	1	1	5.76	0.05	1.97E+04	50.30	2.3399	61.73	0.6257	15.06	9.63
-1	1	1	5.76	0.02	1.32E+04	50.69	2.3399	61.73	0.6257	15.06	9.63
-1	1	1	5.76	0.01	9.15E+03	50.72	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	15.00	6.07E+05	12.23	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	10.00	5.53E+05	14.49	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	5.00	4.69E+05	18.82	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	2.00	3.67E+05	23.91	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	1.00	2.65E+05	29.09	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	0.50	1.59E+05	38.00	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	0.20	8.80E+04	42.34	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	0.10	5.86E+04	44.29	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	0.05	3.76E+04	45.91	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	0.02	2.49E+04	47.68	2.3399	61.73	0.6257	15.06	9.63
-1	1	0	5.76	0.01	1.79E+04	48.79	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	15.00	7.46E+05	2.03	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	10.00	7.20E+05	2.00	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	5.00	5.95E+05	3.66	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	2.00	4.95E+05	11.40	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	1.00	3.95E+05	18.20	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	0.50	2.95E+05	27.03	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	0.20	2.42E+05	30.50	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	0.10	1.41E+05	35.68	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	0.05	8.40E+04	38.11	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	0.02	5.69E+04	42.22	2.3399	61.73	0.6257	15.06	9.63
-1	1	-1	5.76	0.01	4.10E+04	43.43	2.3399	61.73	0.6257	15.06	9.63
-1	1	1	8.05	15.00	2.24E+05	24.79	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.05	10.00	1.94E+05	28.49	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.05	5.00	1.41E+05	35.18	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.05	2.00	8.58E+04	41.54	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.05	1.00	6.28E+04	44.98	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.05	0.50	4.18E+04	48.83	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.05	0.20	2.47E+04	51.75	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.05	0.10	1.67E+04	53.58	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.05	0.05	9.97E+03	58.40	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.05	0.02	6.97E+03	52.26	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.05	0.01	4.75E+03	51.57	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	15.00	3.11E+05	16.87	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	10.00	2.82E+05	19.22	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	5.00	2.27E+05	25.67	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	2.00	1.31E+05	30.71	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	1.00	1.19E+05	35.27	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	0.50	8.02E+04	39.52	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	0.20	4.76E+04	44.00	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	0.10	3.30E+04	46.68	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	0.05	2.15E+04	47.96	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	0.02	1.43E+04	49.27	2.2832	52.99	0.5388	17.12	9.40
-1	1	0	8.05	0.01	9.89E+03	49.84	2.2832	52.99	0.5388	17.12	9.40
-1	1	-1	8.05	15.00	4.25E+05	11.70	2.2832	52.99	0.5388	17.12	9.40

AC	GR	Temp	Va	Freq	|G*|	Phase angle	Gmb	VFA	$V_b/(V_a+V_b)$	VMA	V_b
		(°C)	(%)	(Hz)	(psi)	(Degree)		(%)		(%)	(%)
-1	1	-1	8.05	10.00	3.94E+05	13.46	2.2832	52.99	0.5388	17.12	9.40
-1	1	-1	8.05	5.00	3.29E+05	18.69	2.2832	52.99	0.5388	17.12	9.40
-1	1	-1	8.05	2.00	2.16E+05	20.67	2.2832	52.99	0.5388	17.12	9.40
-1	1	-1	8.05	1.00	2.01E+05	27.75	2.2832	52.99	0.5388	17.12	9.40
-1	1	-1	8.05	0.50	1.49E+05	32.70	2.2832	52.99	0.5388	17.12	9.40
-1	1	-1	8.05	0.20	9.38E+04	37.57	2.2832	52.99	0.5388	17.12	9.40
-1	1	-1	8.05	0.10	6.41E+04	40.74	2.2832	52.99	0.5388	17.12	9.40
-1	1	-1	8.05	0.05	4.17E+04	41.90	2.2832	52.99	0.5388	17.12	9.40
-1	1	-1	8.05	0.02	2.80E+04	46.33	2.2832	52.99	0.5388	17.12	9.40
-1	1	-1	8.05	0.01	1.94E+04	47.07	2.2832	52.99	0.5388	17.12	9.40
-1	1	1	8.07	15.00	2.52E+05	31.52	2.2827	52.92	0.5381	17.14	9.40
-1	1	1	8.07	10.00	2.06E+05	34.87	2.2827	52.92	0.5381	17.14	9.40
-1	1	1	8.07	5.00	1.39E+05	40.32	2.2827	52.92	0.5381	17.14	9.40
-1	1	1	8.07	2.00	7.75E+04	43.84	2.2827	52.92	0.5381	17.14	9.40
-1	1	1	8.07	1.00	5.66E+04	46.49	2.2827	52.92	0.5381	17.14	9.40
-1	1	1	8.07	0.50	3.70E+04	49.64	2.2827	52.92	0.5381	17.14	9.40
-1	1	1	8.07	0.20	2.21E+04	52.07	2.2827	52.92	0.5381	17.14	9.40
-1	1	1	8.07	0.10	1.51E+04	52.68	2.2827	52.92	0.5381	17.14	9.40
-1	1	1	8.07	0.05	9.70E+03	53.22	2.2827	52.92	0.5381	17.14	9.40
-1	1	1	8.07	0.02	6.35E+03	52.67	2.2827	52.92	0.5381	17.14	9.40
-1	1	1	8.07	0.01	4.30E+03	52.06	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	15.00	4.75E+05	16.72	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	10.00	4.33E+05	20.23	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	5.00	3.29E+05	26.81	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	2.00	2.30E+05	31.21	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	1.00	1.48E+05	39.62	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	0.50	9.39E+04	44.27	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	0.20	5.14E+04	47.50	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	0.10	3.39E+04	49.22	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	0.05	2.19E+04	51.29	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	0.02	1.40E+04	52.86	2.2827	52.92	0.5381	17.14	9.40
-1	1	0	8.07	0.01	9.62E+03	52.93	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	15.00	6.30E+05	7.12	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	10.00	6.02E+05	9.07	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	5.00	5.27E+05	12.30	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	2.00	3.80E+05	21.72	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	1.00	3.14E+05	27.67	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	0.50	1.98E+05	31.36	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	0.20	9.12E+04	40.43	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	0.10	5.84E+04	44.05	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	0.05	3.74E+04	46.20	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	0.02	2.48E+04	49.29	2.2827	52.92	0.5381	17.14	9.40
-1	1	-1	8.07	0.01	1.75E+04	50.36	2.2827	52.92	0.5381	17.14	9.40

Note: AC = Asphalt content. AC = -1 means optimum minus 0.5-percent asphalt content; AC=1 means optimum asphalt content.

GR = Gradation. GR =-1 means 12.5-mm mix; GR=1 means 19-mm mix.

Temp = Temperature. Temp = -1 means temperature is 15°C; and Temp = 0 means temperature is 20°C, and Temp = 1 means temperature is 25°C.

Appendix F. Shear frequency sweep test results, field cores

GR	Temp (°C)	V_a (%)	Freq (Hz)	$\|G^*\|$ (psi)	ϕ (degree)	GR	Temp (°C)	V_a (%)	Freq (Hz)	$\|G^*\|$ (psi)	ϕ (degree)
-1	-1	7.7	15	3.07E+05	20.15	-1	1	7.84	5	1.08E+05	31.37
-1	-1	7.7	10	2.81E+05	20.98	-1	1	7.84	2	7.38E+04	33.95
-1	-1	7.7	5	2.30E+05	23.54	-1	1	7.84	1	5.61E+04	37.73
-1	-1	7.7	2	1.76E+05	26.60	-1	1	7.84	0.5	3.95E+04	39.10
-1	-1	7.7	1	1.39E+05	31.34	-1	1	7.84	0.2	2.53E+04	42.56
-1	-1	7.7	0.5	1.04E+05	33.43	-1	1	7.84	0.1	1.83E+04	43.79
-1	-1	7.7	0.2	7.28E+04	34.82	-1	1	7.84	0.05	1.27E+04	42.54
-1	-1	7.7	0.1	5.62E+04	36.00	-1	1	7.84	0.02	9.08E+03	41.51
-1	-1	7.7	0.05	4.04E+04	36.32	-1	1	7.84	0.01	7.36E+03	39.36
-1	-1	7.7	0.02	2.95E+04	38.67	-1	-1	7.89	15	3.46E+05	16.04
-1	-1	7.7	0.01	2.23E+04	38.79	-1	-1	7.89	10	3.20E+05	16.68
-1	0	7.7	15	1.77E+05	24.07	-1	-1	7.89	5	2.69E+05	19.64
-1	0	7.7	10	1.58E+05	25.51	-1	-1	7.89	2	2.13E+05	21.66
-1	0	7.7	5	1.28E+05	28.51	-1	-1	7.89	1	1.75E+05	26.44
-1	0	7.7	2	9.40E+04	32.82	-1	-1	7.89	0.5	1.38E+05	29.31
-1	0	7.7	1	7.24E+04	35.91	-1	-1	7.89	0.2	9.97E+04	31.89
-1	0	7.7	0.5	5.43E+04	38.82	-1	-1	7.89	0.1	7.73E+04	33.85
-1	0	7.7	0.2	3.64E+04	40.87	-1	-1	7.89	0.05	5.55E+04	34.55
-1	0	7.7	0.1	2.69E+04	40.57	-1	-1	7.89	0.02	4.02E+04	37.35
-1	0	7.7	0.05	1.88E+04	40.14	-1	-1	7.89	0.01	2.99E+04	37.99
-1	0	7.7	0.02	1.38E+04	39.93	-1	0	7.89	15	1.92E+05	24.20
-1	0	7.7	0.01	1.05E+04	39.16	-1	0	7.89	10	1.72E+05	25.57
-1	1	7.7	15	1.81E+05	28.03	-1	0	7.89	5	1.38E+05	28.52
-1	1	7.7	10	1.57E+05	29.66	-1	0	7.89	2	1.02E+05	32.46
-1	1	7.7	5	1.18E+05	32.99	-1	0	7.89	1	7.78E+04	35.25
-1	1	7.7	2	8.43E+04	36.09	-1	0	7.89	0.5	5.87E+04	37.70
-1	1	7.7	1	6.01E+04	40.52	-1	0	7.89	0.2	3.99E+04	40.09
-1	1	7.7	0.5	4.36E+04	40.92	-1	0	7.89	0.1	2.95E+04	40.81
-1	1	7.7	0.2	2.78E+04	43.21	-1	0	7.89	0.05	2.09E+04	40.77
-1	1	7.7	0.1	1.97E+04	44.13	-1	0	7.89	0.02	1.51E+04	41.67
-1	1	7.7	0.05	1.31E+04	44.20	-1	0	7.89	0.01	1.16E+04	41.63
-1	1	7.7	0.02	9.44E+03	44.23	-1	1	7.89	15	2.17E+05	25.68
-1	1	7.7	0.01	6.10E+03	41.96	-1	1	7.89	10	1.89E+05	27.65
-1	-1	7.84	15	3.45E+05	17.48	-1	1	7.89	5	1.43E+05	31.92
-1	-1	7.84	10	3.17E+05	18.43	-1	1	7.89	2	9.38E+04	34.77
-1	-1	7.84	5	2.61E+05	21.05	-1	1	7.89	1	7.26E+04	38.48
-1	-1	7.84	2	2.01E+05	23.71	-1	1	7.89	0.5	5.15E+04	41.64
-1	-1	7.84	1	1.66E+05	28.31	-1	1	7.89	0.2	3.12E+04	44.45
-1	-1	7.84	0.5	1.26E+05	30.86	-1	1	7.89	0.1	2.16E+04	46.28
-1	-1	7.84	0.2	8.79E+04	33.80	-1	1	7.89	0.05	1.45E+04	46.64
-1	-1	7.84	0.1	6.71E+04	35.77	-1	1	7.89	0.02	9.89E+03	46.26
-1	-1	7.84	0.05	4.76E+04	36.99	-1	1	7.89	0.01	7.26E+03	43.55
-1	-1	7.84	0.02	3.40E+04	38.66	-1	-1	8.1	15	3.64E+05	15.59
-1	-1	7.84	0.01	2.53E+04	38.48	-1	-1	8.1	10	3.37E+05	16.03
-1	0	7.84	15	1.87E+05	26.84	-1	-1	8.1	5	2.85E+05	18.34
-1	0	7.84	10	1.65E+05	28.30	-1	-1	8.1	2	2.34E+05	21.46
-1	0	7.84	5	1.30E+05	31.14	-1	-1	8.1	1	1.88E+05	24.50
-1	0	7.84	2	9.54E+04	34.46	-1	-1	8.1	0.5	1.51E+05	27.30
-1	0	7.84	1	7.06E+04	37.22	-1	-1	8.1	0.2	1.12E+05	30.23
-1	0	7.84	0.5	5.32E+04	39.18	-1	-1	8.1	0.1	8.80E+04	32.62
-1	0	7.84	0.2	3.64E+04	41.18	-1	-1	8.1	0.05	6.43E+04	34.23
-1	0	7.84	0.1	2.71E+04	41.77	-1	-1	8.1	0.02	4.62E+04	37.84
-1	0	7.84	0.05	1.94E+04	41.29	-1	-1	8.1	0.01	3.34E+04	40.17
-1	0	7.84	0.02	1.39E+04	41.15	-1	0	8.1	15	1.98E+05	23.81
-1	0	7.84	0.01	1.09E+04	41.90	-1	0	8.1	10	1.79E+05	25.02
-1	1	7.84	15	1.60E+05	26.57	-1	0	8.1	5	1.46E+05	27.26
-1	1	7.84	10	1.40E+05	27.81	-1	0	8.1	2	1.09E+05	31.28

GR	Temp (°C)	V_a (%)	Freq (Hz)	$\|G^*\|$ (psi)	ϕ (degree)	GR	Temp (°C)	V_a (%)	Freq (Hz)	$\|G^*\|$ (psi)	ϕ (degree)
-1	0	8.1	1	8.54E+04	33.39	1	0	7.27	5	1.91E+05	25.91
-1	0	8.1	0.5	6.55E+04	36.02	1	0	7.27	2	1.45E+05	30.44
-1	0	8.1	0.2	4.49E+04	39.39	1	0	7.27	1	1.12E+05	34.60
-1	0	8.1	0.1	3.36E+04	40.20	1	0	7.27	0.5	8.43E+04	38.10
-1	0	8.1	0.05	2.37E+04	39.22	1	0	7.27	0.2	5.62E+04	41.81
-1	0	8.1	0.02	1.66E+04	44.54	1	0	7.27	0.1	4.04E+04	42.21
-1	0	8.1	0.01	1.23E+04	42.33	1	0	7.27	0.05	2.74E+04	44.70
-1	1	8.1	15	2.29E+05	23.45	1	0	7.27	0.02	1.89E+04	45.66
-1	1	8.1	10	2.03E+05	24.01	1	0	7.27	0.01	1.40E+04	45.18
-1	1	8.1	5	1.59E+05	28.39	1	1	7.27	15	2.42E+05	25.51
-1	1	8.1	2	1.12E+05	32.19	1	1	7.27	10	2.10E+05	27.48
-1	1	8.1	1	8.67E+04	36.32	1	1	7.27	5	1.59E+05	31.96
-1	1	8.1	0.5	6.27E+04	39.76	1	1	7.27	2	1.10E+05	36.89
-1	1	8.1	0.2	3.77E+04	43.55	1	1	7.27	1	8.09E+04	40.74
-1	1	8.1	0.1	2.53E+04	46.21	1	1	7.27	0.5	5.74E+04	44.63
-1	1	8.1	0.05	1.66E+04	46.69	1	1	7.27	0.2	3.45E+04	49.07
-1	1	8.1	0.02	1.15E+04	47.60	1	1	7.27	0.1	2.27E+04	50.33
-1	1	8.1	0.01	8.37E+03	46.16	1	1	7.27	0.05	1.46E+04	50.64
1	-1	7.92	15	4.04E+05	17.37	1	1	7.27	0.02	9.79E+03	48.14
1	-1	7.92	10	3.71E+05	18.06	1	1	7.27	0.01	7.29E+03	46.33
1	-1	7.92	5	3.16E+05	20.65	1	-1	7.42	15	4.80E+05	16.00
1	-1	7.92	2	2.51E+05	25.68	1	-1	7.42	10	4.60E+05	16.40
1	-1	7.92	1	2.09E+05	28.34	1	-1	7.42	5	4.29E+05	16.73
1	-1	7.92	0.5	1.56E+05	32.79	1	-1	7.42	2	3.16E+05	22.24
1	-1	7.92	0.2	1.07E+05	37.05	1	-1	7.42	1	4.10E+05	18.29
1	-1	7.92	0.1	8.02E+04	40.04	1	-1	7.42	0.5	3.17E+05	20.19
1	-1	7.92	0.05	5.40E+04	41.92	1	-1	7.42	0.2	1.57E+05	32.22
1	-1	7.92	0.02	3.71E+04	45.30	1	-1	7.42	0.1	1.18E+05	35.83
1	-1	7.92	0.01	2.62E+04	45.90	1	-1	7.42	0.05	8.31E+04	38.16
1	0	7.92	15	2.29E+05	24.47	1	-1	7.42	0.02	6.03E+04	41.68
1	0	7.92	10	2.07E+05	26.23	1	-1	7.42	0.01	3.70E+04	50.05
1	0	7.92	5	1.66E+05	29.87	1	0	7.42	15	2.98E+05	22.51
1	0	7.92	2	1.19E+05	35.19	1	0	7.42	10	2.71E+05	23.62
1	0	7.92	1	8.90E+04	39.13	1	0	7.42	5	2.25E+05	26.38
1	0	7.92	0.5	6.46E+04	42.36	1	0	7.42	2	1.68E+05	31.14
1	0	7.92	0.2	4.16E+04	45.66	1	0	7.42	1	1.31E+05	35.27
1	0	7.92	0.1	2.94E+04	44.55	1	0	7.42	0.5	9.75E+04	38.48
1	0	7.92	0.05	1.97E+04	47.72	1	0	7.42	0.2	6.50E+04	42.00
1	0	7.92	0.02	1.34E+04	47.41	1	0	7.42	0.1	4.72E+04	43.75
1	0	7.92	0.01	9.84E+03	45.98	1	0	7.42	0.05	3.21E+04	43.80
1	1	7.92	15	2.69E+05	28.49	1	0	7.42	0.02	2.28E+04	44.25
1	1	7.92	10	2.29E+05	30.39	1	0	7.42	0.01	1.72E+04	42.18
1	1	7.92	5	1.69E+05	34.88	1	1	7.42	15	2.91E+05	24
1	1	7.92	2	1.16E+05	38.75	1	1	7.42	10	2.55E+05	26
1	1	7.92	1	8.08E+04	43.62	1	1	7.42	5	1.95E+05	31
1	1	7.92	0.5	5.60E+04	46.73	1	1	7.42	2	1.38E+05	35
1	1	7.92	0.2	3.35E+04	50.02	1	1	7.42	1	9.89E+04	40
1	1	7.92	0.1	2.21E+04	51.22	1	1	7.42	0.5	7.03E+04	44
1	1	7.92	0.05	1.39E+04	50.37	1	1	7.42	0.2	4.28E+04	50
1	1	7.92	0.02	9.28E+03	49.23	1	1	7.42	0.1	2.83E+04	51
1	1	7.92	0.01	6.84E+03	45.82	1	1	7.42	0.05	1.73E+04	51
1	-1	7.27	15	4.61E+05	17.88	1	1	7.42	0.02	1.17E+04	49
1	-1	7.27	10	4.20E+05	18.62	1	1	7.42	0.01	8.53E+03	48
1	-1	7.27	5	3.59E+05	20.44	1	-1	7.51	15	4.43E+05	15.90
1	-1	7.27	2	2.97E+05	24.00	1	-1	7.51	10	4.05E+05	16.68
1	-1	7.27	1	2.49E+05	27.45	1	-1	7.51	5	3.46E+05	18.90
1	-1	7.27	0.5	1.90E+05	30.81	1	-1	7.51	2	2.81E+05	23.09
1	-1	7.27	0.2	1.32E+05	33.70	1	-1	7.51	1	2.32E+05	27.00
1	-1	7.27	0.1	1.02E+05	35.04	1	-1	7.51	0.5	1.77E+05	31.21
1	-1	7.27	0.05	7.36E+04	36.30	1	-1	7.51	0.2	1.22E+05	35.08
1	-1	7.27	0.02	5.44E+04	38.36	1	-1	7.51	0.1	9.33E+04	37.66

GR	Temp (°C)	V_a (%)	Freq (Hz)	$\|G^*\|$ (psi)	ϕ (degree)	GR	Temp (°C)	V_a (%)	Freq (Hz)	$\|G^*\|$ (psi)	ϕ (degree)
1	-1	7.27	0.01	4.14E+04	38.39	1	-1	7.51	0.05	6.54E+04	39.20
1	0	7.27	15	2.51E+05	21.67	1	-1	7.51	0.02	4.62E+04	42.27
1	0	7.27	10	2.29E+05	22.78	1	-1	7.51	0.01	3.33E+04	42.95
1	0	7.51	15	2.88E+05	19.50	1	-1	7.19	0.2	1.18E+05	42.15
1	0	7.51	10	2.64E+05	20.88	1	-1	7.19	0.1	8.51E+04	44.66
1	0	7.51	5	2.21E+05	24.16	1	-1	7.19	0.05	5.66E+04	46.90
1	0	7.51	2	1.68E+05	28.39	1	-1	7.19	0.02	3.78E+04	49.26
1	0	7.51	1	1.32E+05	33.22	1	-1	7.19	0.01	2.62E+04	49.72
1	0	7.51	0.5	1.01E+05	37.24	1	0	7.19	15	2.02E+05	21.95
1	0	7.51	0.2	6.66E+04	41.36	1	0	7.19	10	1.83E+05	23.59
1	0	7.51	0.1	4.81E+04	43.72	1	0	7.19	5	1.50E+05	26.94
1	0	7.51	0.05	3.20E+04	45.00	1	0	7.19	2	1.11E+05	31.65
1	0	7.51	0.02	2.20E+04	47.33	1	0	7.19	1	8.55E+04	35.86
1	0	7.51	0.01	1.60E+04	48.39	1	0	7.19	0.5	6.37E+04	39.06
1	1	7.51	15	2.87E+05	24	1	0	7.19	0.2	4.24E+04	42.21
1	1	7.51	10	2.49E+05	26	1	0	7.19	0.1	3.18E+04	43.28
1	1	7.51	5	1.93E+05	30	1	0	7.19	0.05	2.08E+04	46.37
1	1	7.51	2	1.37E+05	34	1	0	7.19	0.02	1.45E+04	45.88
1	1	7.51	1	1.01E+05	40	1	0	7.19	0.01	1.06E+04	46.71
1	1	7.51	0.5	7.13E+04	44	1	1	7.19	15	3.32E+05	32.63
1	1	7.51	0.2	4.37E+04	48	1	1	7.19	10	2.82E+05	34.53
1	1	7.51	0.1	2.93E+04	49	1	1	7.19	5	2.03E+05	38.99
1	1	7.51	0.05	1.85E+04	51	1	1	7.19	2	1.23E+05	44.57
1	1	7.51	0.02	1.21E+04	50	1	1	7.19	1	8.54E+04	48.75
1	1	7.51	0.01	8.77E+03	48	1	1	7.19	0.5	5.56E+04	51.46
1	-1	7.19	15	6.42E+05	23.22	1	1	7.19	0.2	3.22E+04	53.97
1	-1	7.19	10	5.79E+05	22.95	1	1	7.19	0.1	2.09E+04	53.89
1	-1	7.19	5	4.98E+05	25.35	1	1	7.19	0.05	1.32E+04	53.62
1	-1	7.19	2	3.34E+05	30.81	1	1	7.19	0.02	8.62E+03	51.75
1	-1	7.19	1	3.26E+05	33.32	1	1	7.19	0.01	6.21E+03	48.32
1	-1	7.19	0.5	2.12E+05	39.08						

Note:

GR = Gradation. GR =-1 means 12.5-mm mix;
GR=1 means 19-mm mix.

Temp = Temperature. Temp = -1 means temperature is 15°C; and
Temp = 0 means temperature is 20°C, and
Temp = 1 means temperature is 25°C.