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16. Abstract

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The objectives of this research study were to acquire a dynamic test system and to establish engineering materials properties in both static and dynamic modes for typical Louisiana hot mix.
A fully automated servo-hydraulic MTS test system was acquired. Software for data acquisition and equipment control was developed to perform engineering characterization tests (i.e., indirect tensile strength test, indirect tensile resilient modulus, dynamic modulus test, indirect tensile and axial creep test, axial repeated load test, and dynamic modulus test) on asphaltic concrete mixtures. The influence of two levels of mixture type (low and high stability), three levels of asphalt cement sources, and three levels of compaction effort on the engineering properties measured from the indirect tension strength, resilient modulus, creep compliance, and dynamic modulus are presented. In addition, both a maintenance program for the MTS and training program for Louisiana Department of Transportation and Development (LADOTD) laboratory technicians in the operation of the MTS have been established.

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A PARAMETRIC EVALUATION OF FUNDAMENTAL ENGINEERING PROPERTIES FOR LOUISIANA HOT MIX

FINAL REPORT

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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

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ABSTRACT

Historically, asphalt concrete has been designed and constructed using empirically developed criteria which has been based on static loading conditions. As loadings increase and stress distributions change due to increased tire pressures, such criteria become insufficient to provide durable pavements. Recognizing this design deficiency, in 1986 AASHTO incorporated an engineering materials property, resilient modulus, into its design procedure. This and other time dependent stress-strain relationships are becoming imperative design parameters to provide cost efficient and durable highway pavements for today's changing conditions. Engineering characterization of Louisiana's asphalt concrete mixtures using the indirect tensile test has been the focus of a recent comprehensive research program sponsored by the Louisiana Transportation Research Center (LTRC).

The objectives of this research study were to acquire a dynamic test system and to establish engineering materials properties in both static and dynamic modes for typical Louisiana hot mix.

A fully automated servo-hydraulic MTS test system was acquired. Software for data acquisition and equipment control was developed to perform engineering characterization tests (i.e., indirect tensile strength test, indirect tensile resilient modulus, dynamic modulus test, indirect tensile and axial creep test, axial repeated load test, and dynamic modulus test) on asphaltic concrete mixtures. The influence of two levels of mixture type (low and high stability), three levels of asphalt cement sources, and three levels of compaction effort on the engineering properties measured from the indirect tension strength, resilient modulus, creep compliance, and dynamic modulus are presented. In addition, both a maintenance program for the MTS and training program for Louisiana Department of Transportation and Development (LADOTD) laboratory technicians in the operation of the MTS have been established.

IMPLEMENTATION STATEMENT

The product of this research is to provide the first step in advancing Louisiana mixture design methods to include the use of engineering parameters. Currently, this dynamic capability is used as a research tool to fundamentally characterize transportation materials. A baseline of fundamental engineering properties for two Louisiana mix types in a parametric study has been established. This dynamic testing capability, among other things, provides the Louisiana Department of Transportation and Development with a tool to measure fundamental properties of hot mix asphaltic concrete. These properties are needed in performance evaluation, because of increased loading and frequency of traffic and for recommendations of special mixtures to be used in construction/rehabilitation projects. Also, these fundamental properties can be used to assess the capability of mechanistic flexible pavement design methods in predicting pavement behavior and performance. Additionally, as the use of lower quality and recycled materials becomes prevalent, engineering properties, as measured by this dynamic testing system, provide an effective and efficient means of judging alternate designs.

The fatigue and creep tests developed in this study have been used for mix design and to demonstrate the enhanced properties of an experimental mix for the Hale Boggs Bridge deck. Combining stone mastic asphalt technology and requiring a Strategic Highway Research Program PG 88-22 asphalt cement, these tests were capable of distinguishing between five possible asphalt binders to produce a superior performing mix.

In addition, the equipment and developed tests have been used to characterize asphalt rubber and polymer modified asphalt mixtures demonstrating enhanced mix properties.

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INTRODUCTION

Throughout their lives, pavements are subjected to a continuing state of stress and strain imposed by varying loads of different duration. Repetitive forces over time decrease pavement stiffness and increase deflection thus impacting the serviceability of the roadway. In Louisiana, the reduction in serviceability is generally attributed to such repetitive load cracking or fatigue and pavement distortion.

Historically, asphalt concrete has been designed and constructed using empirically developed criteria which were based on static loading conditions. As loadings increase and stress distributions change due to increased tire pressures static criteria become insufficient to provide durable pavements. Recognizing this design deficiency, AASHTO recently incorporated an engineering materials property, resilient modulus, into its pavement design procedure. Many agencies are beginning to examine pavement design procedures based on elastic or viscoelastic theory. These and other time dependent stress-strain relationships will become imperative design parameters to provide cost efficient and durable highway pavements for today's changing conditions.

Many studies (1, 2, 3) have shown that the repeated-load indirect tensile test can be used to evaluate the material properties related to the basic modes of pavement distress (i.e., thermal cracking, fatigue cracking, and permanent deformation).

One of the important inputs to these mechanistic evaluations is the response to the various materials when subjected to tensile stresses or strains, especially repeated tensile stresses or strains. Some of the basic material properties required as inputs for an elastic layer analysis of flexible pavement are:

(a) modulus of elasticity and Poisson's ratio, including variations with temperature and rate of loading,

(b) tensile strength, which is primarily required for thermal cracking analysis, and

(c) repeated-load characteristics of materials, which include the fatigue and permanent deformation characteristics.

In addition, a viscoelastic analysis may include other properties such as creep compliance or other material properties such as GNU and ALPHA used in the VESYS design system (4).

Hadley initiated work in materials characterization in Louisiana through his involvement with the Louisiana Experimental Base Study (5-10). The Louisiana Transportation Research Center recently completed a study (11) that evaluated the performance and repeatability of an indirect tension test device developed by Baladi at Michigan State University. A new modified indirect tension test device, the Louisiana Modified test device, was developed to reduce inconsistencies in the test results.

OBJECTIVES

The primary objectives of this study were to acquire a dynamic materials testing system, obtain initial familiarization with the equipment, develop necessary software for data acquisition and application, and develop and initiate a maintenance program. A secondary objective was to establish engineering materials properties in both static and dynamic modes for typical Louisiana hot mix.

SCOPE

The plan of this study was to acquire and set up a dynamic materials test system. Two different Louisiana mix types representing both low and high stability mixes (Type 1 and Type 8) were utilized. For each mix type, three air void levels and three asphalt cement sources were used. The indirect tension mode of testing was used to characterize these mixes. Specific tests developed included the indirect tensile strength test, diameteral resilient modulus test and creep test. In addition, Type 1 mixes were tested in the axial mode to determine the dynamic modulus.

METHODOLOGY

LOADING SYSTEM AND DATA ACQUISITION

A 22 kip servo-hydraulic MTS Model 810 material test system and accessories were acquired and installed. The system includes a load frame, control electronics, hydraulic power supply, and temperature chamber. The current control electronics include three DC transducer signal conditioners (load, extensometer, strain gage) and one AC transducer signal conditioner (LVDT). The digital controller operates under IBM OS/2 and MTS TestStar Materials Testing Workstation for data acquisition and equipment control. Specific application software was developed using MTS TestWare-SX to conduct the indirect tensile strength test, indirect tensile resilient modulus test, indirect tensile fatigue test, indirect tensile creep test, axial repeated-load test, and dynamic modulus test. A detailed manual for each test is provided in Appendix A. The temperature chamber can maintain a constant temperature to within ±1° F (±0.5°C) for an extended period. A thermostatically controlled probe was inserted in a drilled hole in a dummy specimen of the same size and shape as the test specimen to assure an equilibrium test temperature for the samples tested. The temperature was controlled by a microprocessor based controller for processing heat application. The operating temperature range of the chamber is between -100°F (-73°C) and 600°F (316°C).

INDIRECT TENSION TEST DEVICE

During the initial set up and calibration testing of the MTS test system, a modified shoe die, Figure 1, with the upper and lower platens constrained to remain parallel during testing, was used in the preliminary test program. Several problems were encountered during the initial testing that were attributed to the weight of the loading head and rocking of the sample during the application of dynamic loading. At about this period, LTRC was awarded a Federal Highway Administration contract to evaluate the repeatability and performance of an indirect tension device developed at Michigan State University. The details of the evaluation are provided in Reference 11. A new Louisiana Modified indirect tension test device was fabricated, Figure 2, and used in the indirect tension mode of the test program.

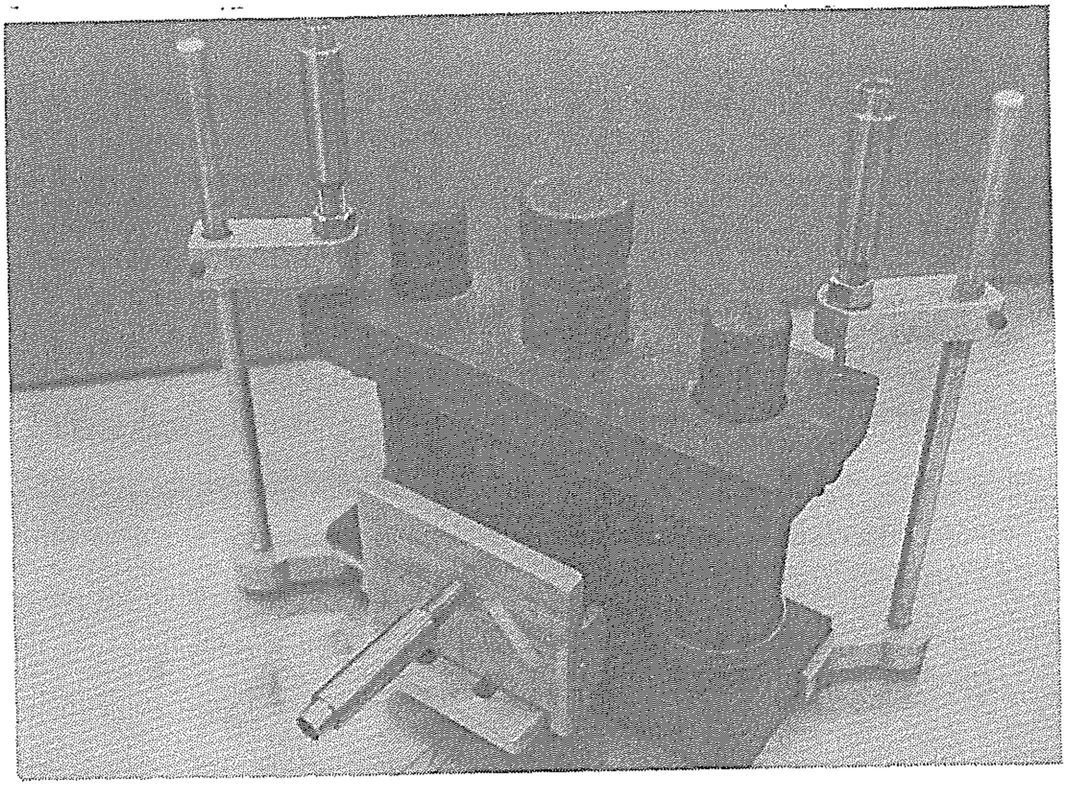

Figure 1. The LTRC Test Device

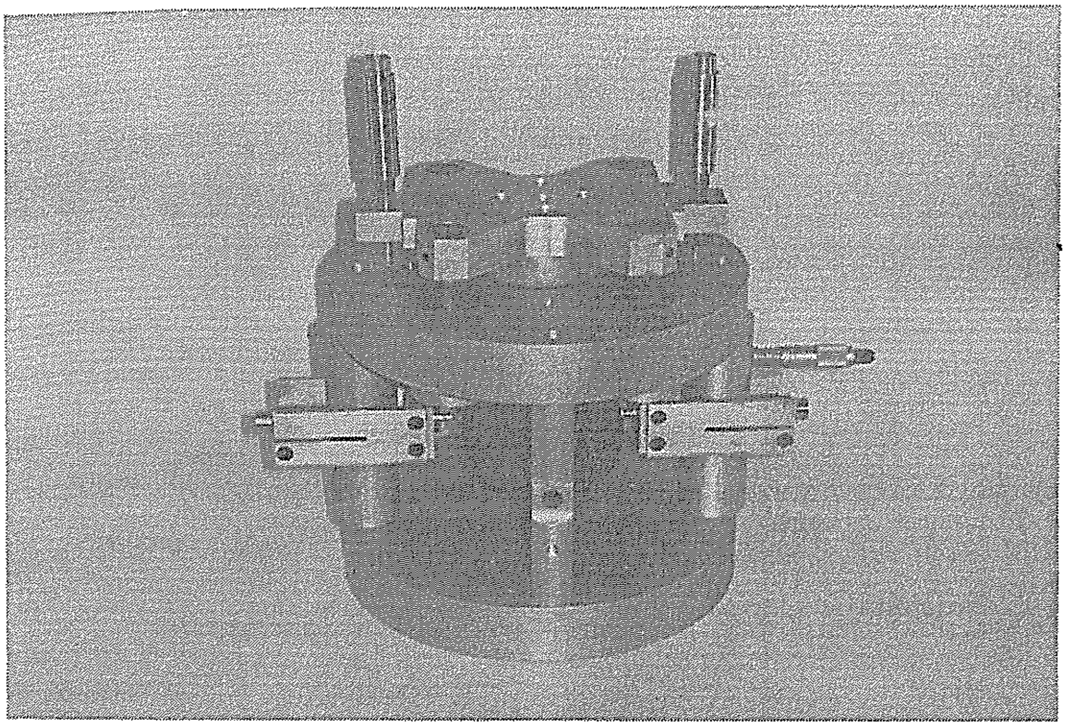

Figure 2. The Louisiana Modified Test Device

MEASUREMENT SYSTEM

Displacement measurement of the specimen due to dynamic loading is a critical factor in determining the resilient modulus. A typical range of the deformation along the horizontal diameter during the dynamic load application is 40 - 100 micro-inches (0.0010 - 0.0025 mm). Thus, the measurement device must have the sensitivity in this range so that it can respond and capture the change in sample deformation resulting from the application of dynamic loads.

Horizontal Deformation Measurement

Two linear variable differential transformers were used to measure the horizontal deformation with the outputs from each LVDT monitored independently and then summed for analysis. This was accomplished through software developed for data acquisition and control of the MTS test system. The LVDTs were made by Schaevitz model GCD.121-050. The maximum stroke for the LVDT was ± 0.05 in. (± 1.3 mm) full scale. This LVDT was selected because of the high resolution needed to capture the small amount of horizontal deformation during dynamic loadings.

Vertical Deformation Measurement

The vertical deformations were measured with two LVDTs, mounted 180 degrees apart on the piston guided plate. The output from each LVDT was monitored independently and simultaneously compared to the output of the other LVDT. If the difference between the peak value was not within 10 percent, further adjustment in seating the loading device was made. The LVDTs used in the loading devices were manufactured by Schaevitz model (GCD-121-050).

SPECIMEN PREPARATION

Test specimens were prepared using the U.S. Army Corps of Engineers Gyratory Test Machine at one degree gyration angle and 100 psi vertical pressure. Three sources of AC-30 asphalt cement, two mix types (Type 1 and Type 8) and three void levels were used per test device. Table 1 shows the properties of the binders. A typical Type 8 mixture with 35 percent coarse gravel, 31 percent sandstone, 25 percent course sand,

TABLE 1

ASPHALT CEMENT PROPERTIES

Original Properties			
Asphalt Cement Source	Southland	Exxon	Calumet
Asphalt Cement Grade	AC - 30	AC - 30	AC - 30
Penetration @ 25 °C	57	62	53
Specific Gravity 25/25 °C	1.03	1.03	1.03
Absolute Viscocity @ 25°C	3112	3054	2819
After T.F.O.			
Penetration @ 25 °C	39	45	36
Absolute Viscocity @ 60 °C	6287	6414	5912

9 percent fine sand, and Type 1 mixture with 65 percent by weight crushed gravel, 25 percent coarse sand and 10-percent fine sand were used. Samples were compacted at each of the three air void levels: at or near, below, and above the Marshall optimum air void content. This was achieved by compacting mixtures using 80, 40, and 15 gyrations to produce the three air void levels. Table 2 presents the target air void levels. The total number of samples fabricated for this phase was 216 for indirect mode testing. Each specimen was four inches in diameter by about 2.5 in. (63.5 mm) high. For each target air void level, 12 samples were compacted and statistically grouped in triplicate sets. Indirect tensile strength tests at two temperatures, diametral resilient modulus tests at three temperatures and indirect tensile creep tests were evaluated.

For the axial mode of testing, six specimens of Type 1 mixture (two for each asphalt cement source) were fabricated using the California Kneading Compactor (according to ASTM D3496-93) at a pressure of 500 psi (1.7 MPa). Table 3 shows the average air void levels. Each specimen was four in. (101.6 mm) in diameter by about 8 in. (203.2 mm) high.

MAINTENANCE PROGRAM

A detailed schedule of maintenance for the MTS test system was developed. The schedule of routine maintenance is described in Appendix B.

TABLE 2

TARGET AIR VOID LEVELS FOR INDIRECT MODE OF TESTING

	MIX TYPE					
	TYPE 1			TYPE 8		
	ASPHALT CEMENT SOURCE (±0.5)			ASPHALT CEMENT SOURCE (±0.2)		
NO. OF REV	CALUMET	EXXON	SOUTHLAND	CALUMET	EXXON	SOUTHLAND
80 REV	4.90	5.50	5.20	3.40	4.20	4.00
40 REV	6.40	6.10	6.60	4.60	5.10	4.90
15 REV	8.20	8.10	8.80	6.30	6.30	6.50

REV: Revolution

TABLE 3

AIR VOID LEVELS FOR AXIAL MODE OF TESTING, TYPE 1 MIXTURE

AC Source (% AC)	% Air Void
Calumet (5.8)	5.45
Exxon (5.8)	5.55
Southland (5.8)	5.40

EXPERIMENTAL DESIGN

TEST FACTORIAL

Figure 3 presents the test factorial used to establish the engineering materials properties for typical Louisiana hot mix in the indirect tension mode of testing. It incorporated two levels of mix type (low and high stability), three levels of asphalt cement source, and three levels of compaction effort. Three replicates were used for each test. Due to the lack of availability of materials, only two specimens per asphalt cement source of Type 1 mixture were used in the axial mode of testing. The test results were statistically analyzed using the analysis of variance (ANOVA) procedure as in the Statistical Analysis System (SAS) program, SAS Institute, Inc. (18). A multiple comparison procedure with a risk level of five percent was preformed on the means. A REGWF test was selected to control the experimentwise error. The REGWF test was selected because it can detect significant differences in the mean that might not be detected with other multiple comparison procedures. The independent variables (i.e., mix type, asphalt cement source, compaction effort, etc.) had populations with normal distributions.

MIX TYPE	LOW STABILITY			HIGH STABILITY		
ASPHALT CEMENT SOURCE	1	2	3	1	2	3
AIR VOID LEVEL 1	3	3	3	3	3	3
AIR VOID LEVEL 2	3	3	3	3	3	3
AIR VOID LEVEL 3	3	3	3	3	3	3

Figure 3. Test factorial for indirect mode of testing

TESTING PROCEDURES

INDIRECT TENSILE TEST

This test was conducted at 40° F (5°C) and 77°F (25°C) according to AASHTO T 245-82. Test specimens were loaded to failure at a deformation rate of two inches per minute. The load, vertical and horizontal deformations were continuously recorded to failure. Figure 4 shows a typical relationship between compressive load and deformation. The indirect tensile strength, S_T, was calculated as follows:

$$S_T = \frac{2\ P_{ult}}{\pi t D}$$

where,

P_{ult} = ultimate applied load required to fail specimen, lbf (or N),

t = thickness of specimen, in. (or mm), and

D = diameter of specimen, in. (or mm)

DIAMETRAL RESILIENT MODULUS TEST

The tests were conducted at 40°F (5°C), 77°F (25°C), and 104°F (40°C) according to ASTM D 4123 with the following modifications (12,13):

1. Test samples were seated with a sustained load of 20 pounds (89 N) and then a cyclic haversine load of 15 percent, 10 percent, and 5 percent of S_T at 77°F (25°C) for 40°F (5°C), 77°F (25°C), and 104°F (40°C) testing, respectively, was applied. The two vertical deformations were monitored independently. If the two measurements were not within ten percent, then further adjustment to the loading device was made in order to not exceed this tolerance. The average of the two measurements was used in the data analyses, Figure 5.

2. With the sustained load applied to the sample, the specimen was conditioned by monitoring the deformation continuously until the deformation rate of the specimen was essentially constant. The transducers were then rezeroed.

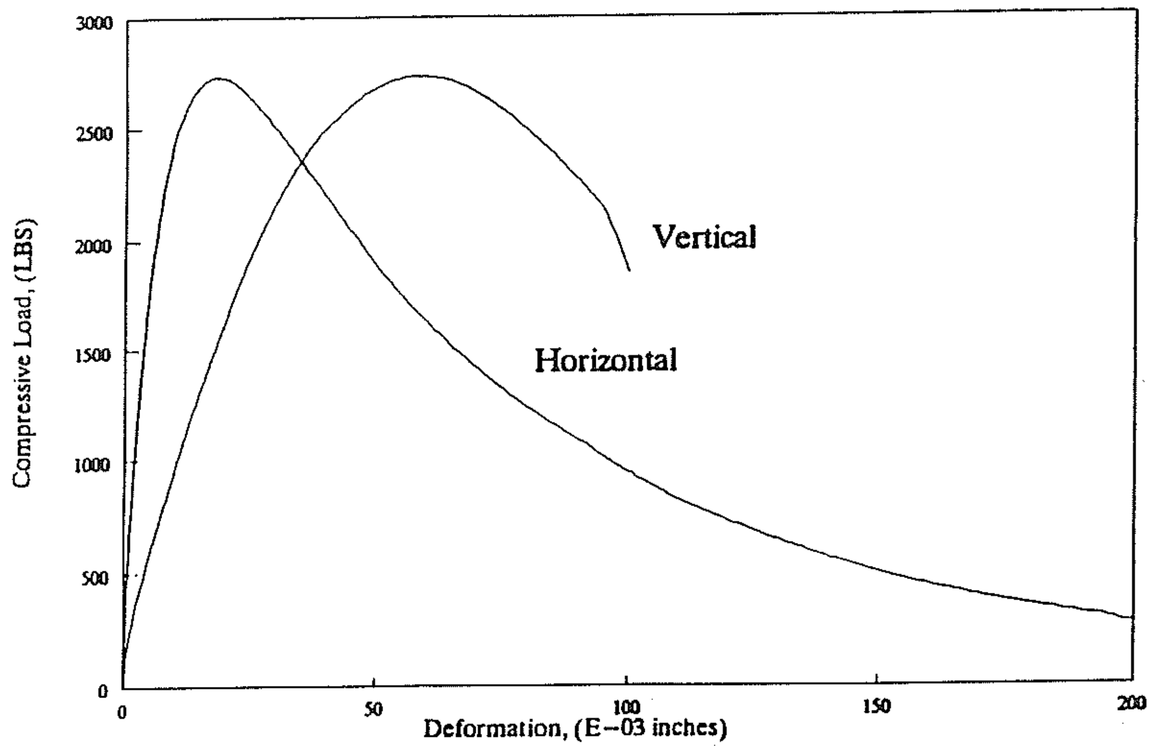

Figure 4. Typical Compressive Load vs. Deformation Relation at 77°F

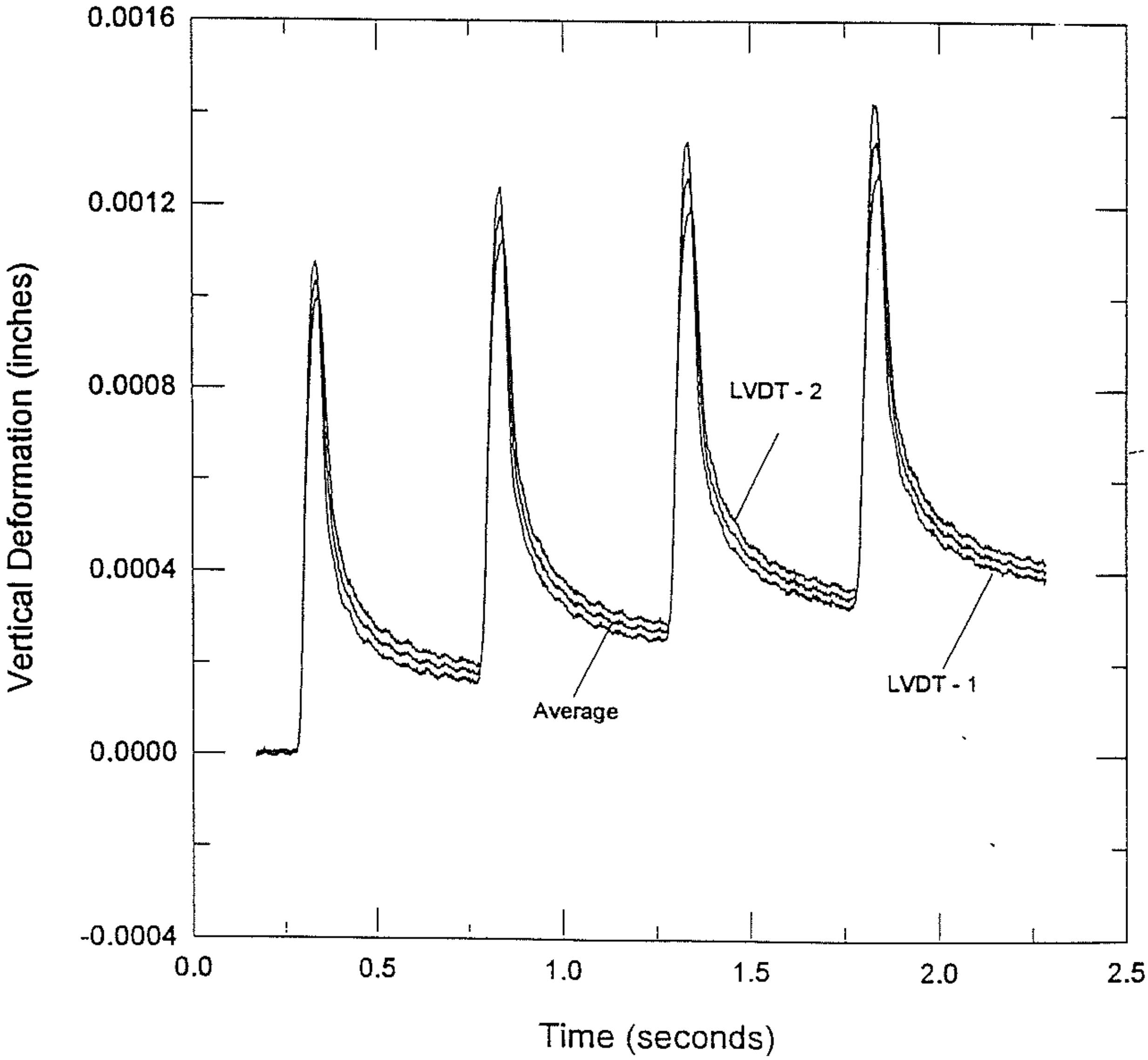

Figure 5. Typical Vertical Deformation vs. Time Diagram

3. A repetitive haversine wave form load with a peak value similar to the one described in step 1 was applied to the specimen. The load frequency was two cycles per second with a 0.1 second loading time and a 0.4 second relaxation period, Figure 6. All materials response parameters were measured at a rate of 500 Hz with the data acquisition system.

4. The instantaneous and total resilient moduli were computed as follows:

   a. The response curves (load, vertical deformation, and horizontal deformation) over the two cycles (step 3) were digitized. The data from these curves were then scanned to determine the instantaneous and total recoverable horizontal and vertical deformation. Data associated with the beginning of the relaxation period were used to compute instantaneous properties, while values associated with the end of the relaxation period were used to compute total properties as follow:

$$M_{RI}=\frac{P(\mu_I+0.27)}{t\ \delta H_I}$$

$$M_{RT}=\frac{P(\mu_T+0.27)}{t\ \delta H_T}$$

$$\mu_I=3.59\frac{\delta H_I}{\delta V_I}-0.27$$

$$\mu_T=3.59\frac{\delta H_T}{\delta V_T}-0.27$$

where

M_{RI} = instantaneous resilient modulus, psi (or MPa)
M_{RT} = total resilient modulus, psi (or MPa)
μ_I = instantaneous Poisson's ratio,
μ_T = total Poisson's ratio,
P = repeated load, lbf (or N)

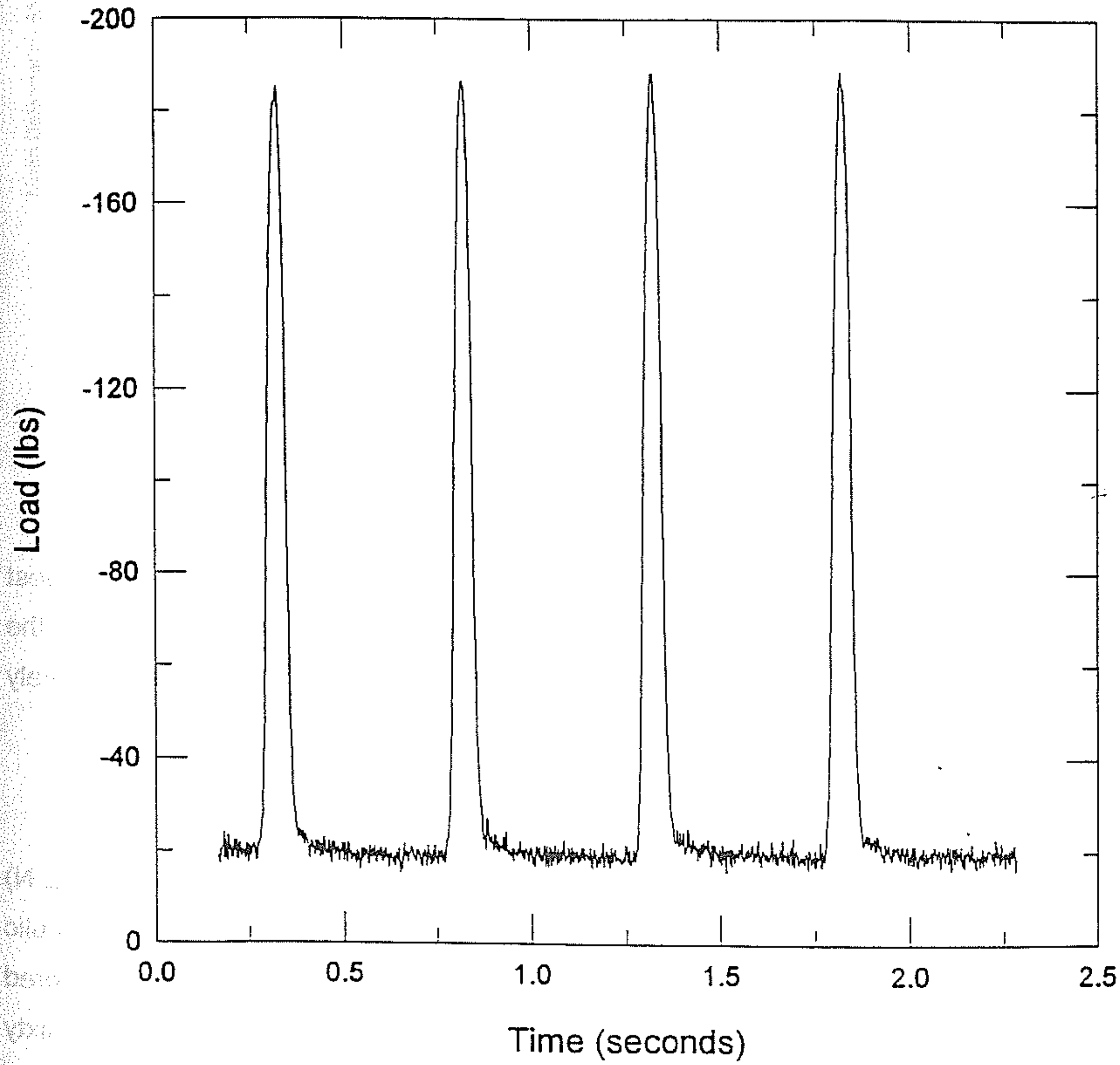

Figure 6. Typical Load vs. Time Diagram

t	= thickness of specimen, in. (or mm)
δH_I	= instantaneous recoverable horizontal deformation, in. (or mm),
δH_T	= total recoverable horizontal deformation, in. (or mm),
δV_I	= instantaneous recoverable vertical deformation, in. (or mm), and
δV_T	= total recoverable vertical deformation, in. (or mm)

b. The average resilient modulus, M_R was then calculated as:

$$M_R = \frac{\sum_{i=1}^{4} M_{R(i)}}{4}$$

c. The average Poisson's ratio was calculated as:

$$\mu = \frac{\sum_{i=1}^{4} \mu_i}{4}$$

Each specimen was tested at each of the three temperatures starting with the lowest temperature to minimize permanent damage to the sample. At each temperature, the sample was tested twice: following the first test, the sample was rotated approximately 45 degrees and the test (steps 1-4) was repeated.

INDIRECT TENSILE CREEP TEST

Creep tests were conducted at 77°F (25°C) using a ramp load of 250 pounds (1112 N) applied as quickly as possible using the stress-control mode of the MTS servo-hydraulic system. The load, vertical deformations and horizontal deformations were monitored continuously with the data acquisition system. The test was terminated either after sixty minutes of load duration or at failure. The mean horizontal deformations and mean vertical deformations were computed by summing the deformation at a particular time for each cell of the test factorial (described in Figure 3) and dividing the sum by the number of specimens. Figure 7 presents a typical creep deformation-time relationship. The creep

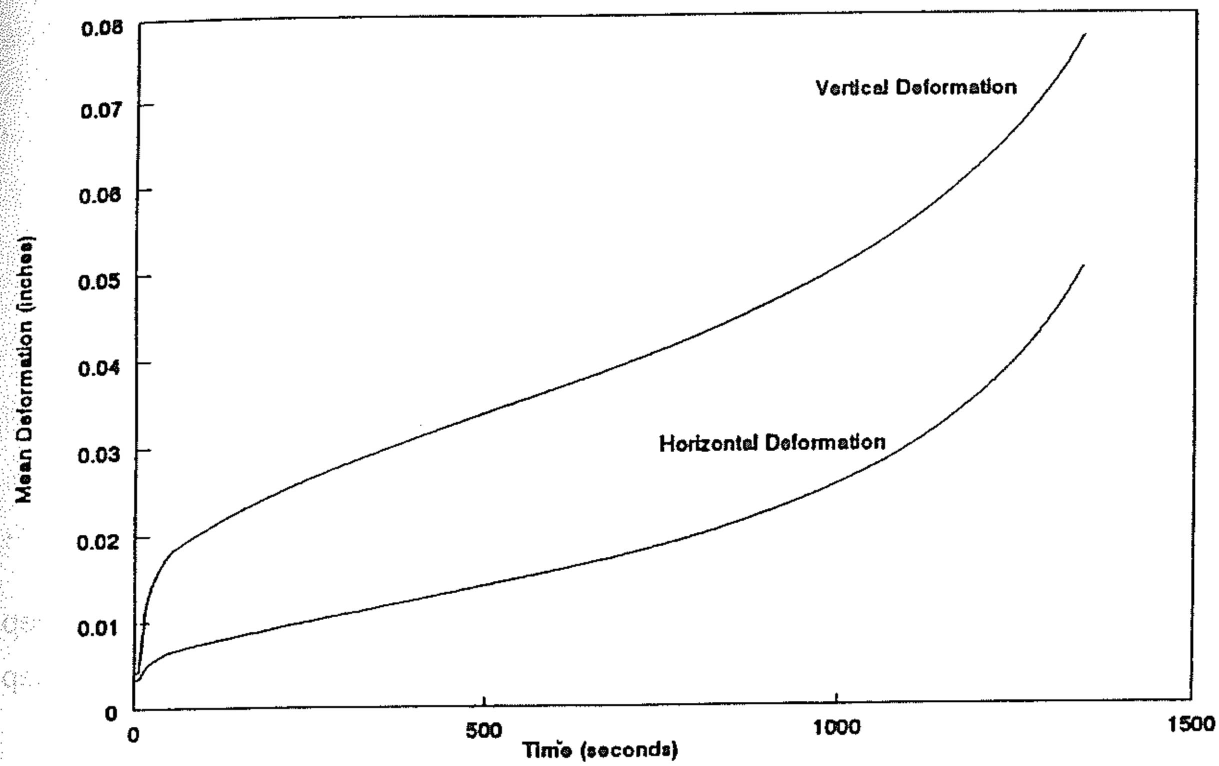

Figure 7. Typical Creep Deformation vs. Time Relation

modulus, S(t) is computed from the measured deformations as follows:

$$S(t) = \frac{P_o\ (\mu + 0.27)}{T\ \delta H(t)}$$

where

$S(t)$ = creep modulus at time t, psi (or MPa)

P_o = applied vertical load, lbf (or N)

μ = Poisson's ratio

T = sample thickness, in. (or mm), and

$\delta H(t)$= horizontal deformation at time t, in. (or mm)

The mean creep modulus was computed in a manner similar to the mean creep deformation. Mean values of vertical deformation, horizontal deformation, and creep modulus were used in the statistical analyses.

DYNAMIC MODULUS TEST

The tests were conducted at 40°F (5°C), 77°F (25°C), and 104°F (40°C) according to ASTM D 3497-93 with the following modifications:

1. Test samples were seated with a sustained load of 20 pounds (89 N) and then a cyclic haversine load of 15 percent, 10 percent, and 5 percent of S_T at 77°F (25°C) for 40°F (5°C), 77°F (25°C), and 104°F (40°C) testing, respectively, was applied. The axial deformation was measured with a clip on extensometer system.

2. With the sustained load applied to the sample, the specimen was conditioned by monitoring the deformation continuously until the deformation rate of the specimen was essentially constant. The extensometer system was then rezeroed.

3. A repetitive haversine wave form load with a peak value similar to the one described in step 1 was applied to the specimen. The load frequency was two cycles per second with a 0.1 second loading time and a 0.4 second relaxation period, Figure 6. All materials response parameters were measured at a rate of 500 Hz with the data acquisition system.

4. The dynamic modulus was computed as follows:

   a. The response curves (load, axial deformation over the four cycles) were scanned to determine the recoverable axial deformation. The recoverable axial strain, ϵ_0, and dynamic modulus, E_R^*, were then calculated as follows:

$$\epsilon_0 = \text{recoverable axial deformation} / L$$

$$E_R^* = (P \div A) \; / \; \epsilon_0$$

   where,

   L = gage length of the extensometer, in. (or mm)

   P = repeated load, lbf (or MPa), and

   A = cross sectional area of the specimen, $in.^2$ (or mm^2)

   b. The average dynamic modulus was then calculated as:

$$E_R^* = \frac{\sum_{i=1}^{4} E^*_{R(i)}}{4}$$

Each specimen was tested at each of the three temperatures starting with the lowest temperature to minimize permanent damage to the sample.

AXIAL REPEATED LOAD TEST

The test was conducted at 77°F (25°C). This test is similar to the dynamic modulus test described in the preceding section. The difference is in the testing duration; the dynamic modulus test requires four cycles of loading and unloading, whereas, the repeated load test was continued for a minimum of two to a maximum of six days. The axial deformations were measured with a clip on extensometer system. The computation procedure is similar to the one provided in the preceding section.

DISCUSSION OF RESULTS

INDIRECT TENSILE STRENGTH TEST

Table 4 presents the indirect tensile test results including the indirect tensile strength (ITS) and the corresponding vertical and horizontal deformations, along with means, standard deviations, and coefficients of variation.

Table 5 displays the influence of asphalt cement source, mix type, compaction effort, and temperature, respectively, on the means of the test results. Examination of the test results was conducted using the analysis of variance (ANOVA) and comparison of means procedures described in the Experimental Design section. It is summarized as follows:

The Effect on Indirect Tensile Strength

The mean indirect tensile strength for samples containing Exxon asphalt cement was significantly higher than that containing Calumet asphalt cement, which in turn was higher than that made with Southland asphalt cement. Furthermore, the ITS was not sensitive to the mix type. As expected, the denser mixes compacted by 80 gyrations had a higher strength than the 15 gyration mixes. Also as anticipated, samples tested at 40°F (5°C) were stiffer than those tested at 77°F (25°C).

The Effect on Vertical and Horizontal Deformation

Samples made with Calumet and Exxon asphalt cement presented significantly lower vertical deformation than those made with Southland asphalt cement, while no significant difference in the horizontal deformations were observed between the three asphalt cement sources. Physical properties of the binders indicated no apparent reason for any significant differences (Table 1). The horizontal deformations were more sensitive to the mix type than the vertical deformations. As for compaction effort, no significant differences were observed for the vertical deformations. However, denser mixes had lower horizontal deformations than mixes made with 15 gyrations. Both deformations did capture the temperature influence.

TABLE 4

INDIRECT TENSION TEST PROPERTIES

			MIX TYPE																	
			TYPE 1									TYPE 8								
			ASPHALT CEMENT SOURCE									ASPHALT CEMENT SOURCE								
			EXXON			CALUMET			SOUTHLAND			EXXON			CALUMET			SOUTHLAND		
		TEMP (°F)	MEAN	STD	(%)CV	MEAN	STD	(%)CV	MEAN	STD	(%)CV	MEAN	STD	(%)CV	MEAN	STD	(%)CV	MEAN	STD	(%)CV
80 REV	STRESS (PSI)	40	467.7	4.8	1	226.6	2.7	1	327.3	13.8	4	524.1	16.8	3	473.1	13.7	3	276.8	6.3	2
		77	152.8	10.5	7	127.1	2.1	2	139.5	5.6	4	140.8	5.6	4	167.8	3.4	2	90.9	4.0	4
	VER. DEF	40	26.8	2.2	8	59.1	1.1	2	46.0	2.3	5	44.7	3.6	8	34.5	1.7	5	51.1	3.0	6
		77	60.5	2.8	5	59.2	3.7	6	54.8	8.2	15	58.8	8.8	15	61.9	4.3	7	50.0	0.7	1
	HOR. DEF	40	4.6	0.4	9	13.8	0.2	2	10.8	0.5	8	8.8	0.9	10	5.5	1.6	29	14.9	1.3	8
		77	18.3	0.5	3	18.0	0.5	3	15.2	0.7	5	19.5	1.5	8	16.5	0.6	4	18.9	0.2	1
40 REV	STRESS (PSI)	40	456.4	15.6	3	199.0	7.9	4	300.3	7.6	3	471.2	22.6	5	375.1	9.3	2	265.8	17.3	7
		77	233.4	2.2	1	103.0	1.2	1	110.2	2.4	2	175.3	6.4	4	136.3	8.2	6	82.8	5.4	6
	VER. DEF	40	27.3	1.5	6	59.8	4.8	8	58.4	5.5	9	28.6	2.2	8	55.1	4.8	9	52.8	1.0	2
		77	72.1	4.4	6	60.6	2.5	4	64.2	3.1	5	57.9	0.6	1	61.2	1.6	3	56.1	3.2	6
	HOR. DEF	40	5.3	0.3	5	13.3	0.5	4	10.5	1.8	17	6.4	0.5	8	11.9	0.5	4	14.6	0.8	6
		77	14.9	1.4	9	6.6	0.5	7	16.6	0.4	2	17.9	2.9	16	17.7	2.0	11	20.5	0.7	3
15 REV	STRESS (PSI)	40	386.4	18.5	5	199.9	7.2	4	234.7	9.9	4	445.7	14.6	3	351.3	20.9	6	206.5	31.9	16
		77	154.1	3.7	2	95.7	6.4	7	68.0	3.5	5	103.6	2.3	2	97.4	7.5	8	84.0	19.5	23
	VER. DEF	40	34.8	3.4	10	64.2	4.0	6	61.0	3.7	6	43.2	1.4	3	58.2	11.4	21	60.1	2.8	5
		77	82.8	3.1	4	84.3	1.7	2	65.0	11.9	18	62.4	4.5	7	70.4	5.8	8	61.6	1.4	2
	HOR. DEF	40	5.6	1.1	20	11.1	0.6	5	11.8	0.4	3	7.2	0.9	13	10.0	2.4	24	13.4	0.9	7
		77	19.4	2.0	11	12.5	0.4	3	20.3	4.1	20	20.1	1.6	8	19.4	1.6	8	22.3	1.2	6

VER. DEF. : Vertical Deformation , E-03 inches

HOR. DEF. : Horizontal Deformation , E-03 inches

REV : Number of Revolutions

TABLE 5

EFFECT OF ASPHALT CEMENT SOURCE, MIX TYPE, COMPACTION EFFORT AND TEMPERATURE ON THE INDIRECT TENSION TEST PROPERTIES

Treatment	Asphalt Cement Source			Mix Type		Compaction Effort			Temperature	
Property	Calumet	Exxon	Southlan	1	8	15 Rev	40 Rev	80 Rev	40 °F	77 °F
ITS	B	A	C	A	A	B	B	A	A	B
Ver. Def.	B	B	A	A	A	A	A	A	B	A
Hor. Def.	A	A	A	A	B	A	B	B	B	A

Note : Rows with similar letter indicates no significant difference in the mean for each treatment

Rev : Revolutions

ITS : Indirect Tensile Strength

Ver. Def. : Vertical Deformation

Hor. Def. : Horizontal Deformation

DIAMETRAL RESILIENT MODULUS TEST

The instantaneous and total resilient modulus test results are presented in Table 6. Table 7 examines the influence of the asphalt cement source, mix type, compaction effort, and temperature on the resilient modulus and Poisson's ratio based on combined data for all variables except the indicated treatment. The comparison of means for asphalt cement sources shows that the instantaneous and total resilient modulus of samples made with Southland were significantly lower than those made with Calumet and Exxon, the instantaneous Poisson's ratio was significantly different for each source, and the total Poisson's ratios of Calumet and Southland were significantly higher than samples made with Exxon. Resilient modulus and Poisson's ratio were significantly different for samples of Type 1 mix than those containing a Type 8 mix except for the total moduli. For the total moduli, the results were not significantly different. The compaction effort effect indicated that the total moduli are not sensitive to the void level; furthermore, the instantaneous resilient moduli, instantaneous and total Poisson's ratio were not significantly different between samples compacted by 40 and 80 gyrations, whereas, those properties are significantly different at a compaction level of 15 gyrations. This insensitivity to the compaction effort can possibly be attributed to the overlap of the void contents at the three compaction levels, Table 2.

The influence of temperature on the mechanical properties shows, as expected, that the test results were significantly different for the three temperature levels.

Figure 8 presents a typical relationship between the instantaneous and total resilient modulus and temperature for each level of mixture type and asphalt cement source (graph shown for Type 8 -- Calumet mixtures).

INDIRECT TENSION CREEP TEST

The indirect tension creep test results for calculated and assumed Poisson's ratio at time intervals of 5, 10, 100, 200, and 500 seconds are presented in Tables 8 and 9. Several samples with compactions of 80 and 40 revolutions failed between 200 and 500 seconds, while most samples compacted at 15 revolutions failed between 200 and 500 seconds.

TABLE 6

DIAMETRAL RESILIENT MODULUS PROPERTIES

			MIX TYPE																	
			TYPE 1									TYPE 8								
			ASPHALT CEMENT SOURCE									ASPHALT CEMENT SOURCE								
			EXXON			CALUMET			SOUTHLAND			EXXON			CALUMET			SOUTHLAND		
		TEMP(°F)	MEAN	STD	(%)CV	MEAN	STD	(%)CV	MEAN	STD	(%)CV	MEAN	STD	(%)CV	MEAN	STD	(%)CV	MEAN	STD	(%)CV
8	MRI	40	753742	30128	4	882134	87707	10	720752	137424	19	642540	144945	23	837417	155407	19	502504	77520	15
0		77	739188	141504	19	621031	100917	16	556685	53119	10	730041	52156	7	815743	57335	7	451771	21802	5
		104	347772	56322	16	284784	44509	16	278396	55900	20	361198	31237	9	380823	54591	14	326855	57060	17
R	MRT	40	610830	31630	5	644210	55497	9	449040	62718	14	555106	112973	20	646238	112439	17	454587	116977	26
E		77	527822	78672	15	310858	32504	10	314625	7375	2	562778	69196	12	535258	58317	11	325531	17850	5
V		104	205227	23795	12	161544	18737	12	167416	15027	9	221300	20818	9	182185	6452	4	176814	7003	4
4	MRI	40	994081	204399	21	974934	136382	14	575374	119699	21	636796	85009	13	883693	80349	9	619760	49276	8
0		77	911521	139125	15	557171	35557	6	571670	93854	16	614795	74543	12	700309	102584	15	476378	59209	12
		104	361691	39507	11	1352385	191791	14	390745	63714	16	346406	64891	19	340173	50311	15	311297	65064	21
R	MRT	40	696242	93041	13	639083	83875	13	441880	92406	21	532794	53623	10	761250	97459	13	517928	24182	5
E		77	555894	56527	10	299092	28063	9	318502	24170	8	469734	43250	9	491289	66399	14	311707	36407	12
V		104	185976	23028	12	278554	21344	8	202786	32467	16	209744	23362	11	205541	27498	13	187312	38009	20
1	MRI	40	964999	170706	18	930719	168415	18	756920	72401	10	535372	113006	21	844969	200656	24	480437	129570	27
5		77	670162	136537	20	582107	149881	26	528910	61375	12	582119	54782	9	704138	71629	10	381315	42689	11
		104	**	**	**	368962	0 *	0 *	**	**	**	299446	48986	16	387954	111927	29	275071	24384	9
R	MRT	40	606173	115625	19	530310	79844	15	438708	66548	15	440893	76091	17	600201	82274	14	421756	91437	22
E		77	423557	35987	8	350585	80327	23	289960	11784	4	416821	25127	6	468963	12813	3	269144	8683	3
V		104	**	**	**	324317	89625	28	**	**	**	180693	11416	6	216413	43738	20	162122	16263	10

* : One data point was available, rest failed

** : Specimen failed

MRI : Instantaneous Resilient Modulus, psi

MRT : Total Resilient Modulus, psi

TABLE 7

EFFECT OF ASPHALT CEMENT SOURCE, MIX TYPE, COMPACTION EFFORT AND TEMPERATURE ON THE DIAMETRAL RESILIENT MODULUS PROPERTIES

Treatment	Asphalt Cement Source			Mix Type		Compaction Effort			Temperature		
Property	Calumet	Exxon	Southland	1	8	15 Rev	40 Rev	80 Rev	40 °F	77 °F	104 °F
MRI	A	A	B	A	B	A	B	B	A	B	C
MRT	A	A	B	A	A	A	A	A	A	B	C
MUI	A	B	C	A	B	A	B	A	A	B	C
MUT	A	B	A	A	B	A	B	B	A	B	C

Note : Rows with similar letters indicate no significant difference in the mean for each treatment

Rev : Revolutions

MRI : Instantaneous Resilient Modulus

MRT : Total Resilient Modulus

MUI : Instantaneous Poisson's Ratio

MUT : Total Poisson's Ratio

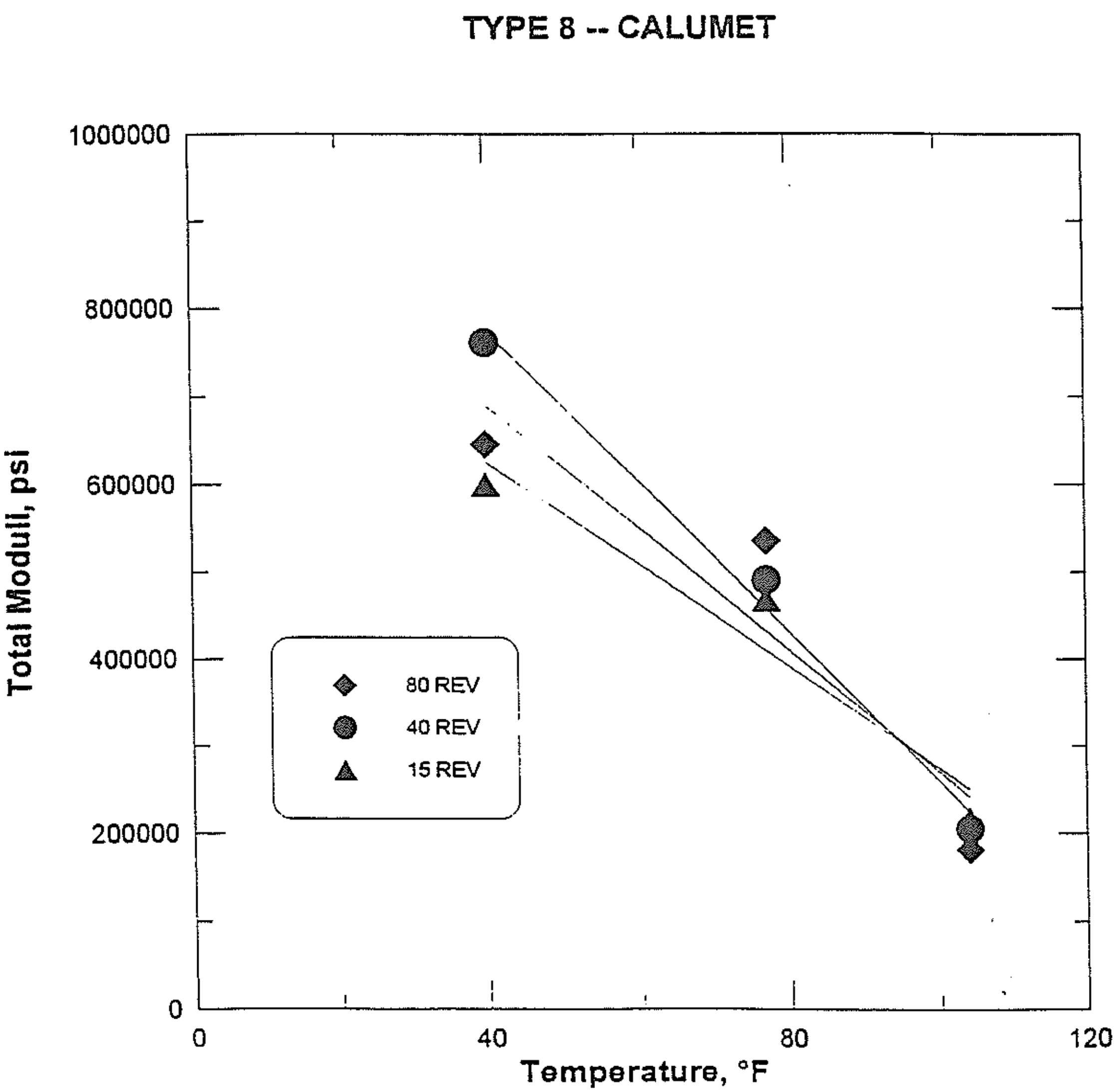

Figure 8. Total Resilient Modulus - Temperature Dependency

Therefore, discussion of the statistical analyses will be focused on test durations of up to 100 seconds. The analyses of the test data are presented in Tables 10 - 12. They are based on combined data for all variables except for the indicated one.

Table 10 presents the influence of the mix type on the creep modulus. No significant differences were observed between the mix types except for the first ten seconds of the modulus with computed Poisson's ratio. This could be due to the inherent variations of the test at small deformations coupled with the effect of the other treatments.

The effect of the various asphalt sources on the creep modulus is shown in Table 11. Samples made with Exxon had significantly higher modulus for the test duration than those made with Calumet and Southland. Once again, it is shown that the creep modulus was more sensitive to the horizontal deformation than the vertical deformation (i.e., creep modulus for assumed Poisson's ratio) during the first ten seconds of the test. Physical properties of the binders indicated no apparent reason for any significant differences, Table 1.

Table 12 examines the influence of the various levels of compaction effort on the creep modulus. It shows that denser mixtures yielded a higher creep modulus for test durations of up to 100 seconds.

Table 13 shows the slope and intercept of the log creep modulus versus log time along with means, standard deviations, and coefficients of variation. Table 14 examines the influence of the various asphalt sources, mix types, and compaction efforts on the means of the slopes and intercepts. These are based on combined data for all variables except the indicated treatment. Comparison of means for asphalt sources shows no significant differences in the slope, however, samples made with Exxon had a significantly higher intercept than those made with Southland and Calumet. Slopes and intercepts were not sensitive to the mixture types tested. The compaction effort effect indicated that the slopes of samples compacted by 80 gyrations were significantly higher than those compacted by 15 and 40 gyrations; furthermore, the intercepts for 80 gyrations were

TABLE 8
CREEP MODULUS WITH CALCULATED POISSON'S RATIO, PSI

	MIX TYPE 1														
Asphalt Cement Source	CALUMET					EXXON					SOUTHLAND				
Time (seconds)	5	10	100	200	500	5	10	100	200	500	5	10	100	200	500
80 Revolutions	32461	24918	10396	7337	(1)	43273	33150	15677	12739	8783	24970	19617	9417	7307	(1)
	26745	20743	7830	4807	(1)	36242	28093	13431	10873	7372	22221	17543	8421	6468	(1)
	29959	23171	8372	4655	(1)	44765	33978	15676	12652	8699	26898	21361	10757	8584	5042
Mean (psi)	29722	22944	8866	5600		41427	31740	14828	12088	8285	24696	19507	9532	7453	5042
STD	2340	1712	1104	1230		3716	2601	1059	860	646	1919	1581	957	870	
%CV	8	7	12	22		9	8	7	7	8	8	8	10	12	
40 Revolutions	23743	18521	7554	4897	(1)	38200	28051	12089	9543	6215	22643	17638	8252	6287	(1)
	20839	16057	6822	4663	(1)	37409	27652	12094	9556	6077	19900	15540	7059	4988	(1)
	17451	13577	6070	4294	(1)	29935	22118	9915	7939	5239	21553	16788	7305	5156	(1)
Mean (psi)	20678	16052	6815	4618		35181	25940	11366	9013	5844	21365	16655	7539	5477	
STD	2571	2018	606	248		3724	2706	1026	759	431	1128	862	514	577	
%CV	12	13	9	5		11	10	9	8	7	5	5	7	11	
15 Revolutions	20172	14908	6012	4271	(1)	24595	17788	7059	5274	(1)	15057	11533	3630	(1)	(1)
	17069	12517	4800	(1)	(1)	24686	17758	7291	5654	3379	15034	11255	3364	(1)	(1)
	20851	15185	5528	3581	(1)	19832	14779	6482	5052	(1)	11685	8712	(1)	(1)	(1)
Mean (psi)	19364	14203	5447	3926		23038	16775	6944	5327	3379	13925	10500	3497		
STD	1645	1198	498	345		2267	1411	340	249		1584	1269	133		
%CV	9	8	9	9		10	8	5	5		11	12	4		

	MIX TYPE 8														
Asphalt Cement Source	CALUMET					EXXON					SOUTHLAND				
Time (seconds)	5	10	100	200	500	5	10	100	200	500	5	10	100	200	500
80 Revolutions	29717	23252	11782	9650	6437	53030	43157	21275	16211	9347	33514	27435	13252	9853	(1)
	30797	24130	11911	9505	6056	37739	29669	13949	10692	5939	23144	19349	10527	8387	4541
	30083	23879	12195	9716	5968	36446	28436	13539	10769	6797	26273	21134	10521	8236	4346
Mean (psi)	30199	23754	11963	9624	6154	42405	33754	16288	12557	7361	27644	22639	11433	8825	4444
STD	448	369	173	88	204	7532	6658	3529	2584	1447	4343	3468	1286	729	98
%CV	1	2	1	1	3	18	20	22	21	20	16	15	11	8	2
40 Revolutions	21047	16229	6077	3576	(1)	30987	23800	10176	7381	(1)	21119	16968	8237	6161	(1)
	23756	17888	5386	(1)	(1)	31533	24068	10406	7664	(1)	24976	19798	9127	6720	(1)
	19206	14655	4623	(1)	(1)	26692	20622	9101	6660	(1)	17369	13746	6563	5013	(1)
Mean (psi)	21336	16257	5362	3576		29737	22830	9894	7235		21155	16837	7976	5965	
STD	1869	1320	594			2165	1565	569	423		3106	2472	1063	711	
%CV	9	8	11			7	7	6	6		15	15	13	12	
15 Revolutions	15039	11502	3524	(1)	(1)	24099	18599	7569	5143	(1)	16889	13087	5694	3943	(1)
	15534	11682	3401	(1)	(1)	18607	13974	4888	(1)	(1)	19867	15503	7221	5534	(1)
	17809	13635	4879	(1)	(1)	15499	11773	4406	(1)	(1)	16439	12933	6236	4823	(1)
Mean (psi)	16127	12273	3935			19402	14782	5621	5143		17732	13841	6384	4767	
STD	1206	966	670			3556	2845	1391			1521	1177	632	651	
%CV	7	8	17			18	19	25			9	9	10	14	

(1) : Sample failed

TABLE 9
CREEP MODULUS WITH ASSUMED POISSON'S RATIO OF 0.35, PSI

MIX TYPE 1

Asphalt Cement Source	CALUMET					EXXON					SOUTHLAND				
Time (seconds)	5	10	100	200	500	5	10	100	200	500	5	10	100	200	500
	19573	14369	4503	2607	(1)	31151	22577	8486	6262	3501	17592	12962	4858	3262	(1)
80 Revolutions	19098	13841	3347	1543	(1)	28105	20272	7705	5659	3049	19278	13863	4727	3024	(1)
	19285	13868	3278	1320	(1)	30229	21479	7950	5914	3424	22041	16030	6065	4134	1632
Mean (psi)	19319	14026	3709	1823		29828	21443	8047	5945	3325	19637	14285	5217	3473	1632
STD	195	243	562	562		1276	941	326	247	197	1834	1288	602	477	
%CV	1	2	15	31		4	4	4	4	6	9	9	12	14	
	19020	13678	3453	1698	(1)	37087	23997	6724	4618	2268	19149	13818	4319	2751	(1)
40 Revolutions	17482	12335	3351	1789	(1)	30491	21211	6969	4898	2417	16085	11267	3155	1759	(1)
	18148	12220	3264	1791	(1)	32750	21930	7078	5023	2474	15579	11323	3287	1929	(1)
Mean (psi)	18217	12744	3356	1759		33443	22379	6924	4846	2386	16938	12136	3587	2146	
STD	630	662	77	43		2737	1181	148	169	87	1577	1190	520	433	
%CV	3	5	2	2		8	5	2	3	4	9	10	15	20	
	11637	8581	2653	1625	(1)	20755	14516	4603	2925	(1)	10864	7389	1234	(1)	(1)
15 Revolutions	11533	7999	2237	(1)	(1)	24492	15995	4530	3003	1293	11147	7814	1196	(1)	(1)
	13053	9052	2339	1186	(1)	19889	13887	5135	3441	(1)	8919	5674	(1)	(1)	(1)
Mean (psi)	12074	8544	2410	1406		21712	14798	4756	3123	1293	10310	6959	1215		
STD	693	431	177	220		1997	884	270	227		990	925	19		
%CV	6	5	7	16		9	6	6	7		10	13	2		

MIX TYPE 8

Asphalt Cement Source	CALUMET					EXXON					SOUTHLAND				
Time (seconds)	5	10	100	200	500	5	10	100	200	500	5	10	100	200	500
	20878	15465	6507	4718	2375	29709	23767	10398	6990	2878	19444	14415	4594	2844	(1)
80 Revolutions	16774	11595	4138	2753	1593	24447	17317	5772	3848	1551	18041	13832	5030	3429	1186
	26560	19115	6710	4458	1890	25774	17909	5970	4058	1495	15695	11554	2888	2189	934
Mean (psi)	21404	15392	5785	3976	1953	26643	19664	7380	4965	1975	17727	13267	4171	2821	1060
STD	4012	3070	1168	872	322	2234	2911	2136	1434	639	1547	1234	924	506	126
%CV	19	20	20	22	17	8	15	29	29	32	9	9	22	18	12
	12188	8712	2217	941	(1)	9996	8116	3830	2277	(1)	16430	11928	3883	2404	(1)
40 Revolutions	14863	10480	1862	(1)	(1)	19877	13583	4015	2485	(1)	14792	10650	3413	2091	(1)
	13802	9543	1474	(1)	(1)	19183	13429	3819	2302	(1)	21244	14806	4549	2574	(1)
Mean (psi)	13618	9578	1851	941		16352	11709	3888	2355		17489	12461	3948	2356	
STD	1100	722	303			4503	2542	90	93		2738	1738	466	200	
%CV	8	8	16			28	22	2	4		16	14	12	8	
	12561	8675	1030	(1)	(1)	16753	12003	3217	1733	(1)	12464	9056	2711	1457	(1)
15 Revolutions	9978	6794	976	(1)	(1)	12084	8308	1838	(1)	(1)	18242	12877	3785	2513	(1)
	11827	8389	1687	(1)	(1)	13104	8882	1868	(1)	(1)	23537	15899	4707	2834	(1)
Mean (psi)	11455	7953	1231			13980	9731	2308	1733		18081	12611	3735	2268	
STD	1087	828	323			2004	1624	643			4522	2800	816	588	
%CV	9	10	26			14	17	28			25	22	22	26	

(1) : Specimen failed

TABLE 10

EFFECT OF MIX TYPE ON THE MEAN CREEP MODULUS

Mix Type	Creep Modulus									
	Calculated					Assumed MU = 0.35				
	Time (secs)					Time (secs)				
	5	10	100	200	500	5	10	100	200	500
1	A *	A	A	A	A	A	A	A	A	A
8	B	B	A	A	A	A	A	A	A	A

Note : Columns with similar letters indicate no significant difference in the mean.

TABLE 11

EFFECT OF ASPHALT CEMENT SOURCE ON THE MEAN CREEP MODULUS

Asphalt Cement Source	Creep Modulus									
	Calculated					Assumed MU = 0.35				
	Time (secs)					Time (secs)				
	5	10	100	200	500	5	10	100	200	500
Exxon	A *	A	A	A	A	A	A	A	A	A
Calumet	B	B	B	B	A / B	B	B	B	B	A / B
Southland	B	B	B	B	B	C	C	B	B	B

Note : Columns with similar letters indicate no significant difference in the mean.

TABLE 12

EFFECT OF COMPACTION EFFORT ON THE MEAN CREEP MODULUS

Compaction Effort	Creep Modulus							
	Calculated				Assumed MU = 0.35			
	Time (secs)				Time (secs)			
	5	10	100	200	5	10	100	200
80 Revolutions	A *	A	A	A	A	A	A	A
40 Revolutions	A	B	B	B	B	B	B	B
15 Revolutions	B	C	C	C	C	C	C	B

Note : Columns with similar letters indicate no significant difference in the mean.

TABLE 13

SLOPES AND INTERCEPTS OF LOG CREEP MODULUS (PSI) VS. LOG TIME (SECOND) -- CALCULATED POISSON'S RATIO

Mix Type	1						8					
Asphalt Cement Source	Calumet		Exxon		Southland		Calumet		Exxon		Southland	
	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept
80 Revolutions	-0.44	11.16	-0.39	11.39	-0.38	10.80	-0.22	10.40	-0.45	11.81	-0.40	11.18
	-0.46	11.02	-0.38	11.16	-0.37	10.66	-0.37	11.00	-0.42	11.31	-0.33	10.66
	-0.46	11.09	-0.40	11.42	-0.36	10.86	-0.38	11.12	-0.40	11.24	-0.36	10.83
Mean	-0.45	11.09	-0.39	11.32	-0.37	10.77	-0.32	10.84	-0.42	11.45	-0.36	10.89
STD	0.01	0.06	0.01	0.12	0.01	0.08	0.07	0.31	0.02	0.25	0.03	0.22
%CV	-2.08	0.52	-2.09	1.03	-2.21	0.78	-22.63	2.91	-4.85	2.22	-7.89	1.99
40 Revolutions	-0.47	10.98	-0.42	11.26	-0.38	10.70	-0.43	10.67	-0.43	11.10	-0.36	10.58
	-0.41	10.64	-0.42	11.24	-0.46	10.60	-0.50	10.94	-0.43	11.13	-0.39	10.82
	-0.42	10.57	-0.39	10.95	-0.41	10.69	-0.45	10.60	-0.41	10.90	-0.36	10.36
Mean	-0.43	10.73	-0.41	11.15	-0.42	10.66	-0.46	10.74	-0.42	11.04	-0.37	10.59
STD	0.03	0.18	0.01	0.14	0.03	0.04	0.03	0.15	0.01	0.10	0.01	0.19
%CV	-6.06	1.67	-3.45	1.27	-7.92	0.42	-6.40	1.37	-2.23	0.92	-3.82	1.77
15 Revolutions	-0.42	10.58	-0.44	10.82	-0.45	10.39	-0.44	10.33	-0.43	10.83	-0.39	10.37
	-0.43	10.43	-0.42	10.77	-0.48	10.42	-0.46	10.40	-0.45	10.58	-0.37	10.53
	-0.46	10.69	-0.39	10.52	-0.48	10.15	-0.44	10.54	-0.42	10.32	-0.34	10.26
Mean	-0.44	10.57	-0.42	10.70	-0.47	10.32	-0.45	10.42	-0.43	10.58	-0.37	10.39
STD	0.02	0.11	0.02	0.13	0.01	0.12	0.01	0.09	0.01	0.21	0.02	0.11
%CV	-3.89	1.01	-4.93	1.23	-3.01	1.17	-2.11	0.84	-2.88	1.97	-5.60	1.07

TABLE 14

EFFECT OF ASPHALT CEMENT SOURCE, MIX TYPE AND COMPACTION EFFORT ON THE SLOPE AND INTERCEPT OF THE DIAMETRAL CREEP MODULUS TEST

Treatment	Asphalt Cement Source			Mix Type		Compaction Effort		
Property	Calumet	Exxon	Southland	1	8	15 Rev	40 Rev	80 Rev
Slope	A	A	A	A	A	B	B	A
Intercept	B	A	B	B	A	C	B	A

Note : Rows with similar letters indicate no significant difference in the mean for each treatment

Rev : Revolutions

Slope : Slope of the creep modulus vs. time curve

Intercept : Intercept of the creep modulus vs. time curve significantly higher than the 40 gyrations, which in turn were higher than the 15 gyrations intercept.

DYNAMIC MODULUS TEST

Table 15 presents the dynamic modulus at 40°F (5°C), 77°F (25°C), and 104°F (40°C) along with means, standard deviations, and coefficients of variations. Figure 9 shows the mean dynamic modulus for Type 1 mixtures. Limited numbers of samples were tested in this mode due to the lack of availability of aggregates, thus, only Type 1 mixtures were tested. The mean dynamic modulus of samples made with Southland were higher than those made with Exxon which in turn were higher than those made with Calumet at 40°F (5°C). However, all samples had similar values at 104°F (40°C).

AXIAL REPEATED LOAD TEST

The axial repeated load test was conducted to compare the total deformation accumulated over 10,000 cycles for Type 1 mixtures with three asphalt cement sources (Calumet, Exxon, Southland). The loading in the axial repeated load test is similar to the dynamic modulus test. The difference is in the testing duration. The dynamic modulus test requires four cycles of loading and unloading, whereas, the repeated load test was continued for a minimum of two to a maximum of six days. The axial deformations were measured with a clip on extensometer.

The total deformations were computed with respect to each cycle and are presented in Figure 10. Figure 11 shows the deformations at 10,000 cycles. The three different types of asphalt cement sources provided similar results. This indicates that the asphalt cement source has no significant effect on the total deformation.

TABLE 15

DYNAMIC RESILIENT MODULUS TEST RESULTS, TYPE 1 MIXTURE

Temperature	Exxon			Calumet			Southland		
	Mean (ksi)	STD	%CV	Mean (ksi)	STD	%CV	Mean (ksi)	STD	%CV
40°F	1839	75	4.1	1597	128	8.0	2081	170	8.2
77°F	594	38	6.3	530	2	0.4	577	3	0.4
104°F	143	5	3.2	135	7	5.2	142	9	6.0

STD : Standard Deviation

%CV : Coefficient of Variation

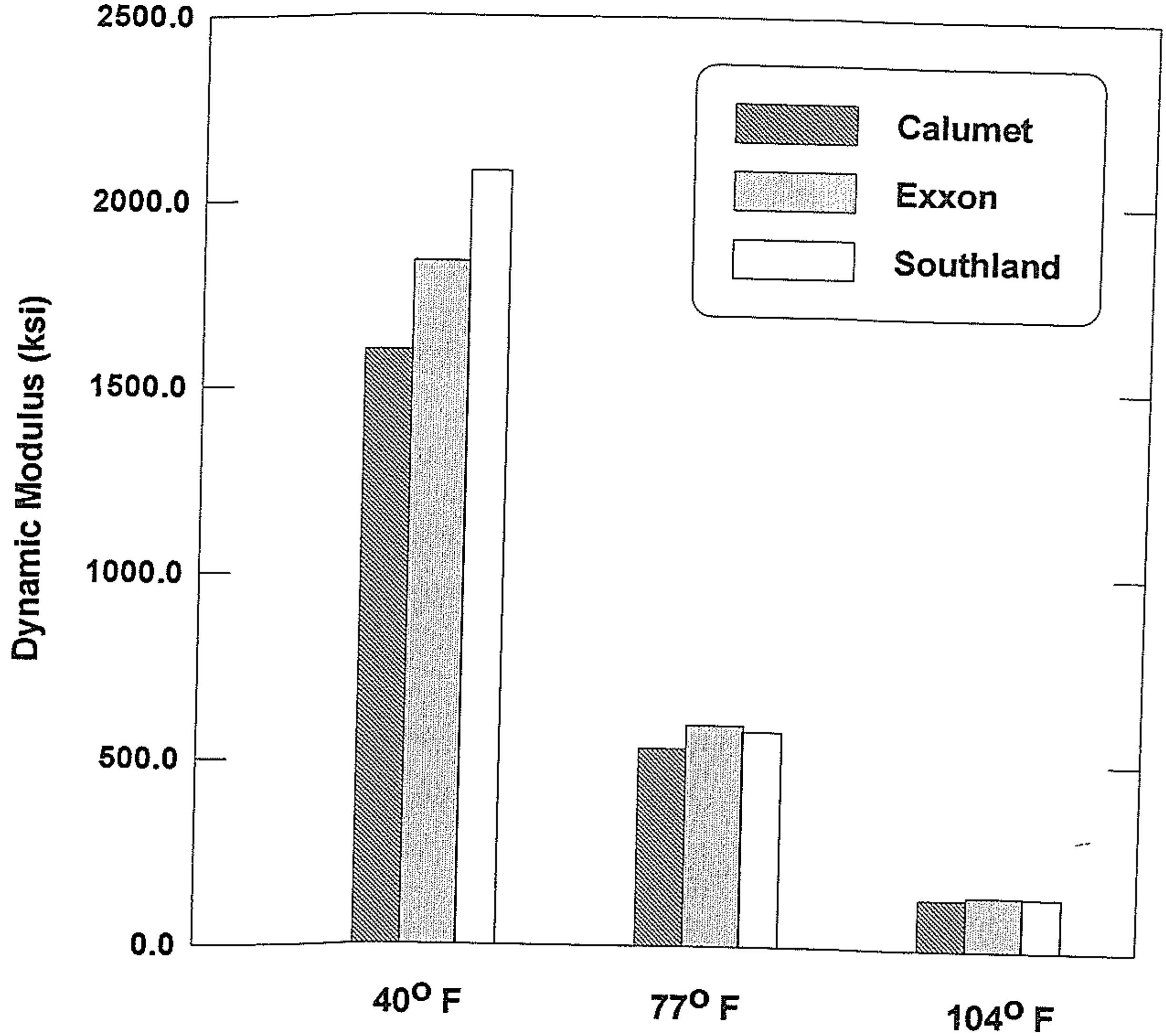

Figure 9. Mean Dynamic Modulus. Type 1 Mixture

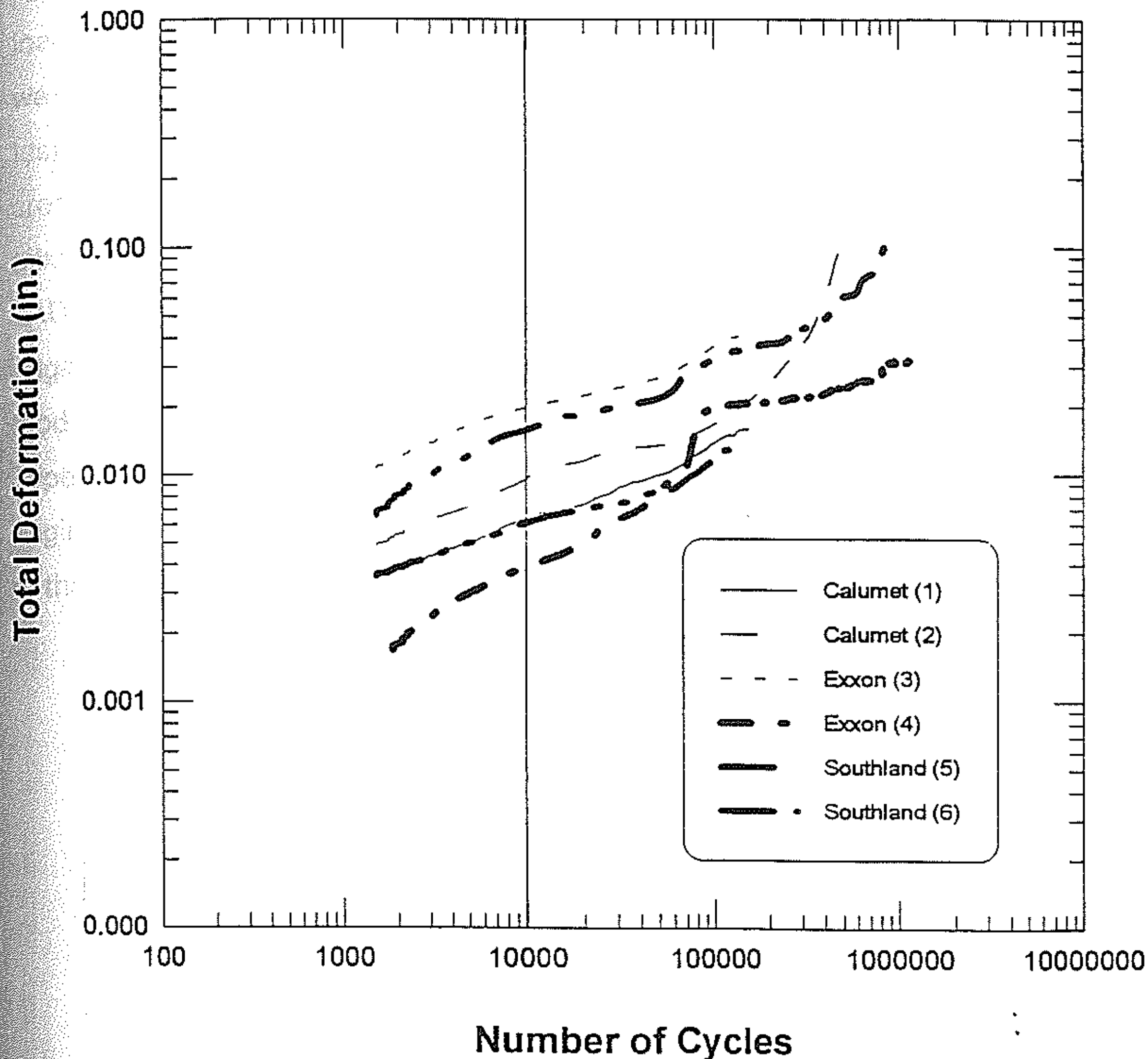

Figure 10. Axial Repeated Load Test Results, Type 1 Mixture

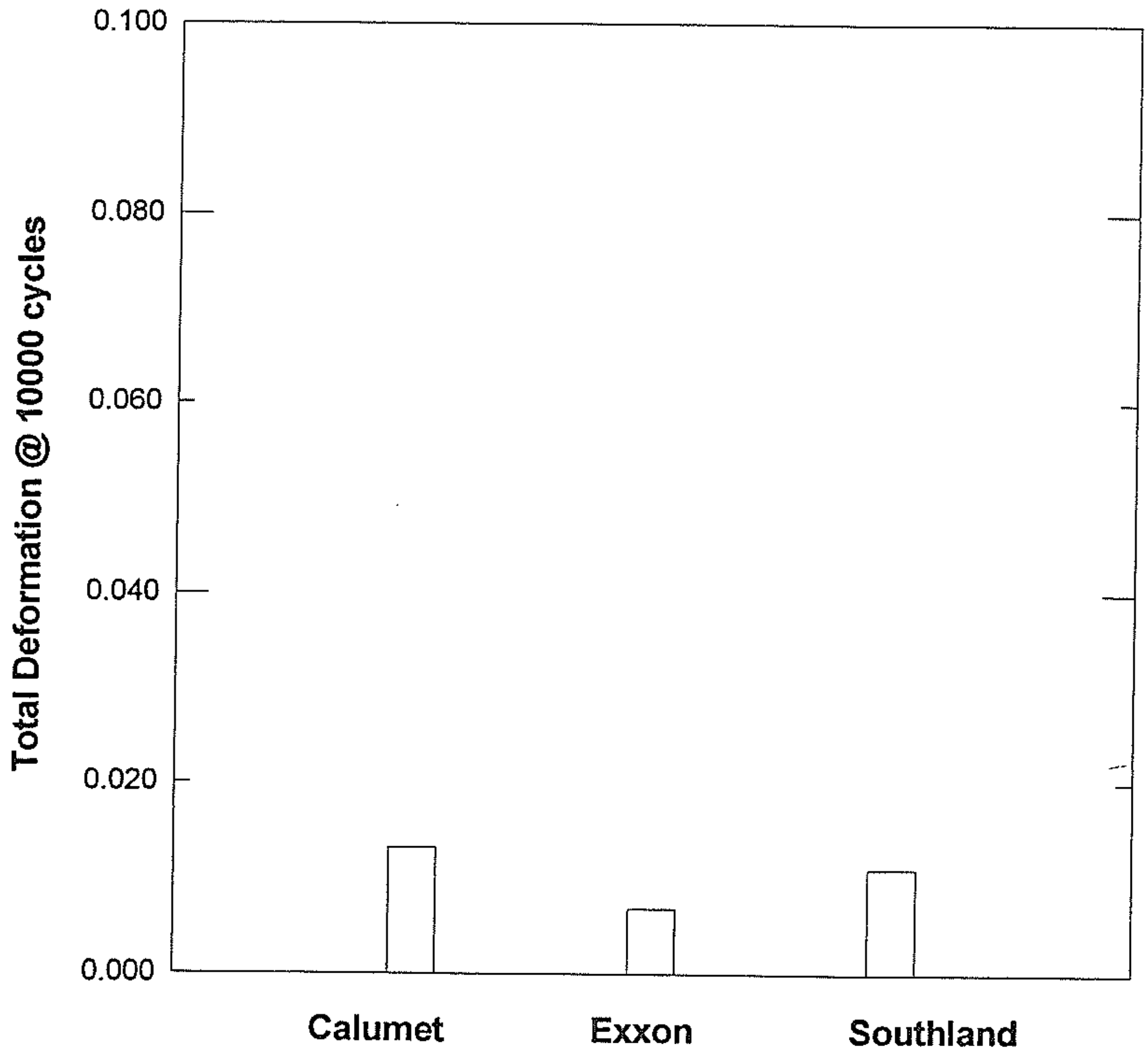

Figure 11. Total Deformation at the 10,000 Cycle. Type 1 Mixture

CONCLUSIONS

A servo-hydraulic MTS test system was acquired and initial familiarization with repetitive load testing has been conduced. Software for data acquisition and equipment control was developed to perform engineering characterization tests (i.e., indirect tensile strength test, indirect tensile resilient modulus, dynamic modulus test, indirect tensile and axial creep test, axial repeated load test, and dynamic modulus test) on asphalt concrete mixtures. In addition, a maintenance program for the MTS and a training program for LADOTD laboratory technicians in the operation of the MTS have been developed. The engineering materials properties, as defined by indirect tensile strength, diametral resilient modulus, and creep characteristics, in both static and dynamic modes for Type 1 and Type 8 mixtures tested have been documented. The range of variations in these engineering properties has been established. Other observations drawn from analysis of the data are as follows:

1. The indirect tensile strength (ITS) for samples containing Exxon asphalt cement had a significantly higher mean than those containing Calumet asphalt cement which in turn were higher than those made with Southland asphalt cement. Also, the ITS was not sensitive to the mixture type.
2. The resilient moduli for samples made with Southland were significantly different than those made with Calumet and Exxon.
3. The resilient modulus and Poisson's ratio were significantly different for samples of Type 1 mix than those containing a Type 8 mix except for the total moduli.
4. The creep moduli for samples made with Exxon were significantly higher for the test duration than those made with Calumet and Southland.
5. The creep moduli had no significant difference between the mix types except for the first ten seconds of the modulus with computed Poisson's ratio.
6. The total axial deformations at 10,000 cycles from the axial repeated load test were not significantly different among the three asphalt cement sources.

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APPENDIX A

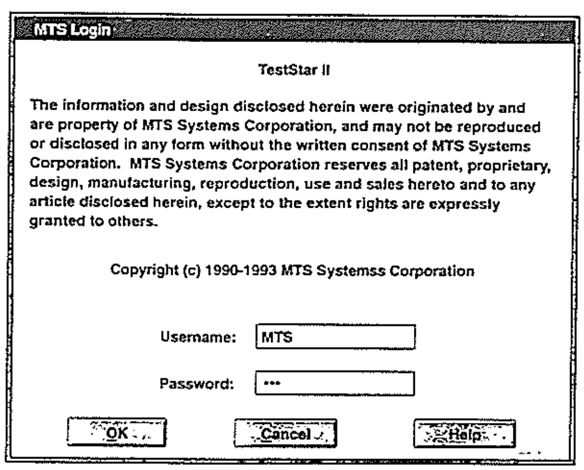
Procedure To Run The Axial Repeated Load Test (ASTM 3497) on the 810 MTS Material Test System

COMPUTER SETUP

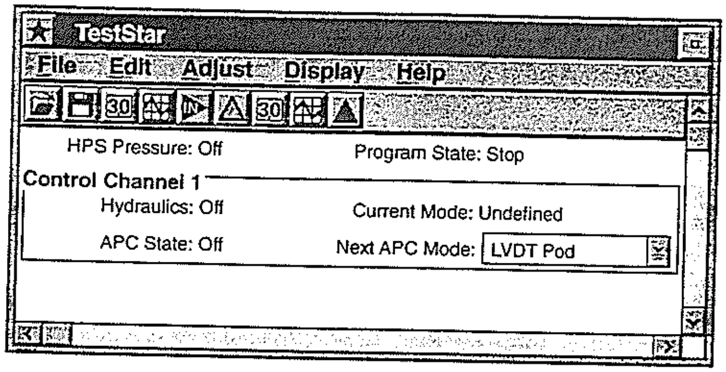
1. Turn on the power for the MTS System, Computer, Monitor, Line Printer, Oscilloscopes and LVDT conditioners.

2. If the computer is in DOS when switched on, type "OS2" at the "C:\" prompt to change to OS/2. Type "Y" at the question "You requested to start OS2 ..." and wait until the system changes to OS/2. If the computer is already in OS/2 when switched on, the above steps will not be necessary.

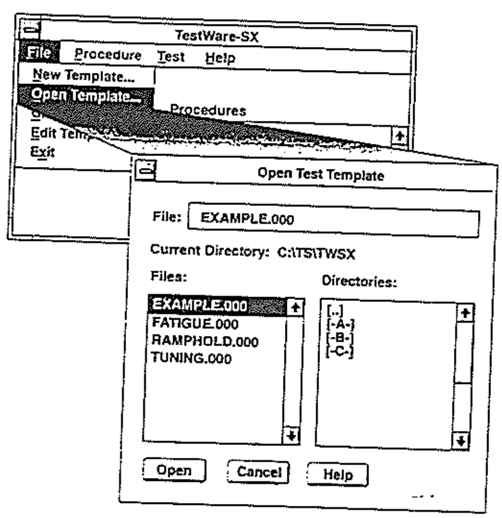
3. Once in OS/2, double click on the "MTS-TS II" icon. A "MTS-TS II - Icon View" window will open. Double click on "TestStar." A window for "MTS Login" for TestStar will open. At the "Username" prompt, type "MTS," press the "Tab" key, type "MTS" at the "Password" prompt and click "OK" in the window.



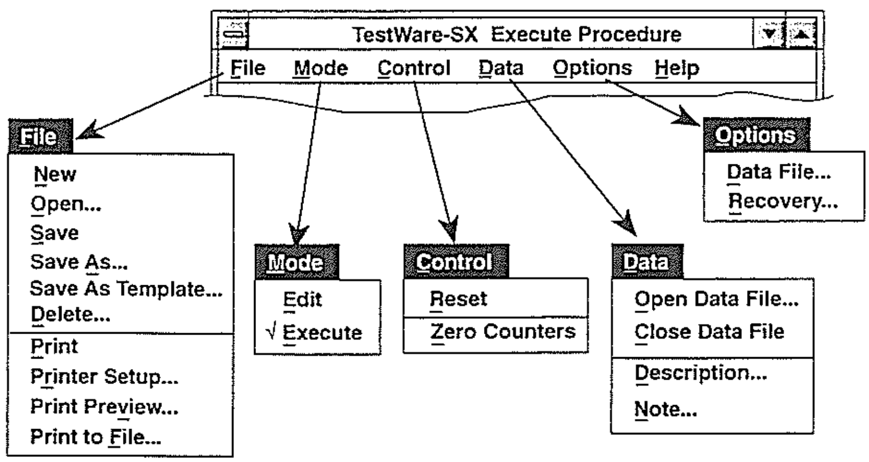
4. If your username and password are valid, the main TestStar window opens. In the "MTS-TS II Icon View" window double click the TWSX icon.



5. In the "TestWare-SX" window, click on "File" to display a pull down menu. Select "Open Template" which will open the "Open Test Template" window and display the templates in the current directory (the default directory is C:\TS2\TWSX). Highlight the file "ASTM3497.000" in the "C:\TS2\TWSX" directory and click "OK" to load the template. This will be the template used to conduct the Axial Repeated Load Test.

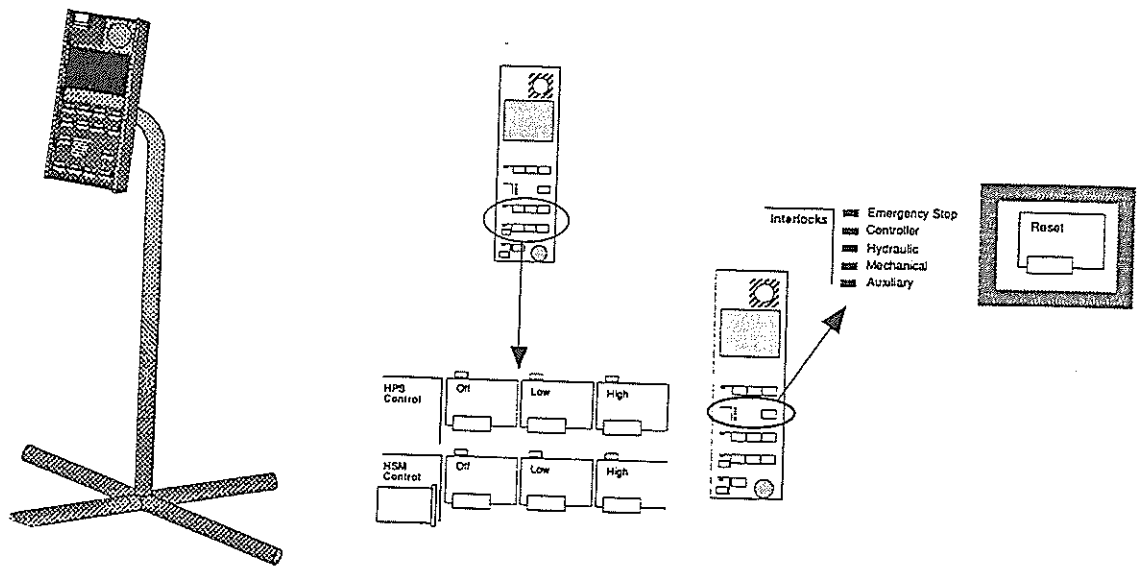


6. Click on "Procedure" in the "TestWare-SX" window to display a pull down menu. Select "Execute Procedure" which will open the "Test Data File" window and display the data files in the current directory (the default directory is C:\TS2\TWSX). Enter the name of the file to store the data of the test being conducted (change the directory if the test data is to be stored in another directory) and click "OK." An error message will be displayed when an attempt is made to run the test without having a data file open.



HYDRAULICS INITIALIZATION

7. Press the "Reset" button on the "MTS Load Unit Control" to reset the system. Start the hydraulic system of the MTS by switching the "HPS Control" to "Low" and after a few seconds to "High." After 2 or 3 minutes, switch the "HSM Control" to "Low," wait for a few seconds and switch to "High." Allow about 30 minutes for the hydraulic system to stabilize.



ZEROING THE FORCE SENSOR

8. Read the display on the "TestStar Controller" of the MTS "Load Unit Control." The "Force" sensor has to be zeroed.

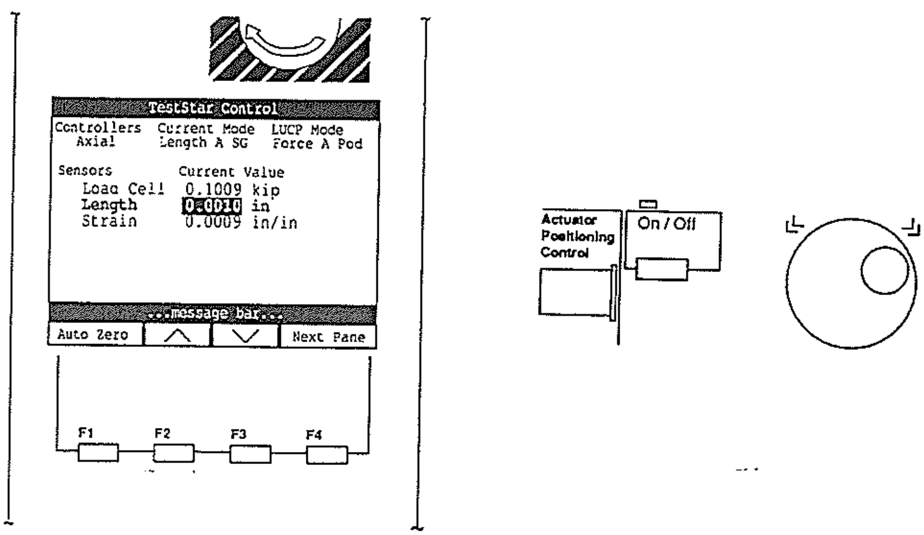
9. Using the "F2" or "F3" switches, highlight the text under "POD MODE." Click the "F1" switch until the text changes to "Length A Pod." Again, using the "F2" or "F3" switches, highlight the current value of the "Force" sensor. Press the "F1" switch to auto zero the "Force" sensor.

INSTALLING THE SPECIMEN

10. Samples used in this test are 4" in diameter and 8" in height. If the test is being conducted at a temperature other than room temperature (approximately 77°F), set the test temperature using the 409.80 MTS "Temperature Controller." First, seal all the openings in the chamber with insulator after inserting the thermocouple and the thermometer through the orifice provided. Close the door to the chamber and

switch on the power on the temperature controller. With the "Set Point" depressed on the controller, set the desired temperature using the up or down arrow to increase or decrease the temperature. After the temperature has been set to the desired level, turn on the chamber switch on the controller. After the temperature in the chamber has reached the desired level, switch off the "Chamber" switch. Mount the extensometer system on the previously heatd/cooled sample so that each extensometer is along its height. Place the sample in the chamber so that one of the caps of the sample rests on the bottom platen. Connect the extensometer electrical cable to the strain gage cable from the Digital Controller. Close the door to the chamber and wait until the chamber temperature reaches the preset level again. Caution: Read warning on the temperature controller prior to turning on the power. Switching on the "Chamber" switch on the "Temperature Controller," bring the temperature of the environmental chamber to the appropriate test temperature.

11. Apply an initial seating load of 50 lbs. on the specimen by switching on the "Actuator Positioning Control" and **slowly** turning the knob beside it in a **counterclockwise direction** until the "Current Value" of the "Force" sensor reads -50 lbs. Ensure that the "CURRENT MODE" of the "Axial Controller" reads "Force A Pod" while the initial seating load is being applied.

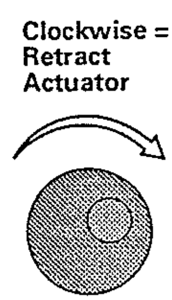


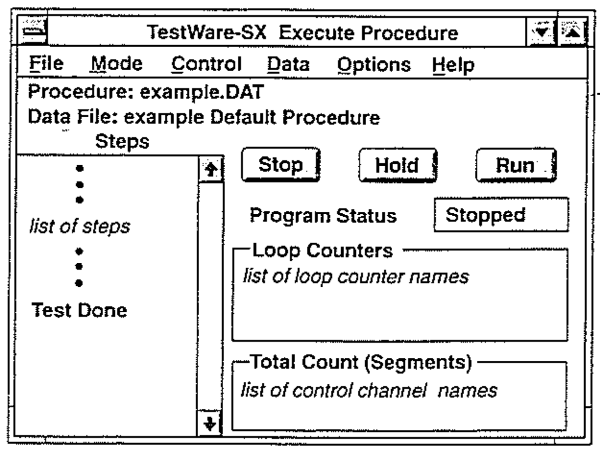
12. To make sure the sample is seated properly, wiggle the movable bottom platen slightly so that the top platen is seated properly on the top cap of the sample.

13. Remove the gage length locking pin of the extensometer. Using the "F2" or "F3" switches, highlight the current value of the "Extensometer." Press the "F1" switch to auto zero the "Extensometer."

RUNNING THE TEST

14. Click "Run" in the "TestStar-Execute Procedure" window to run the Axial Repeated Load test. The test is automatically stopped after the horizontal deformation reaches 0.1 inches (i.e. the specimen fails). The end of test is indicated by "Done" appearing beside "Test Status."

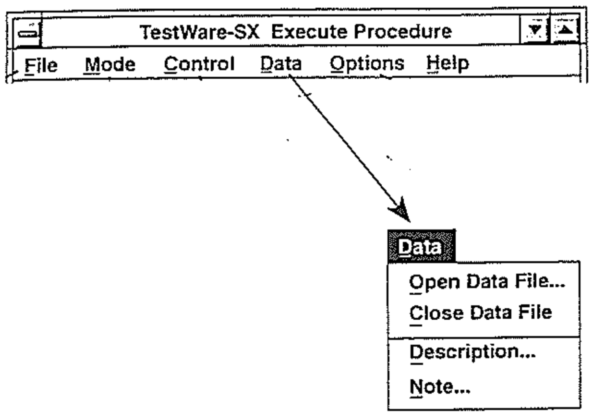


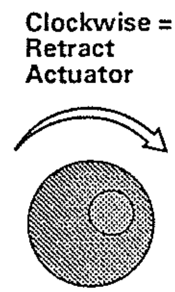


FINAL STEPS

15. Once the test is complete, the test data file has to be closed. Click on "Data" in the "TestWare-SX Execute Procedure" window to display a pull down menu. Click on "Close Data File" to close the data file. Click on "Control" to display a pull down menu. Click on "Reset" to reset the program. Now the program is ready to run again.

16. Click on the switch beside "Actuator Positioning Control" and **slowly** rotate the knob beside it in a **clockwise direction** until the applied load on the specimen is removed.





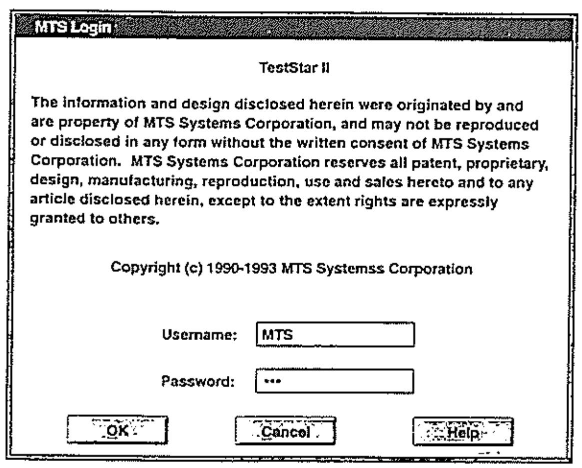
Procedure To Run The Indirect Fatigue Test on the 810 MTS Material Test System

COMPUTER SETUP

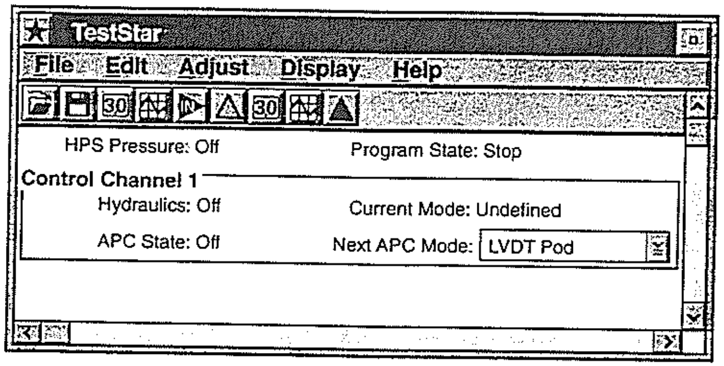
1. Turn on the power for the MTS System, Computer, Monitor, Line Printer, Oscilloscopes and LVDT conditioners.

2. If the computer is in DOS when switched on, type "OS2" at the "C:\" prompt to change to OS/2. Type "Y" at the question "You requested to start OS2 ..." and wait until the system changes to OS/2. If the computer is already in OS/2 when switched on, the above steps will not be necessary.

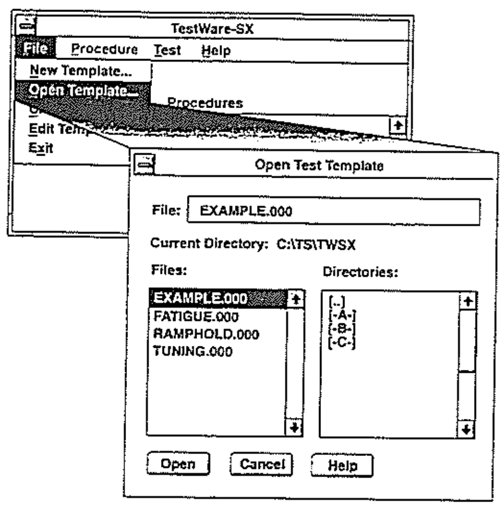
3. Once in OS/2, double click on the "MTS-TS II" icon. A "MTS-TS II - Icon View" window will open. Double click on "TestStar." A window for "MTS Login" for TestStar will open. At the "Username" prompt, type "MTS," press the "Tab" key, type "MTS" at the "Password" prompt and click "OK" in the window.



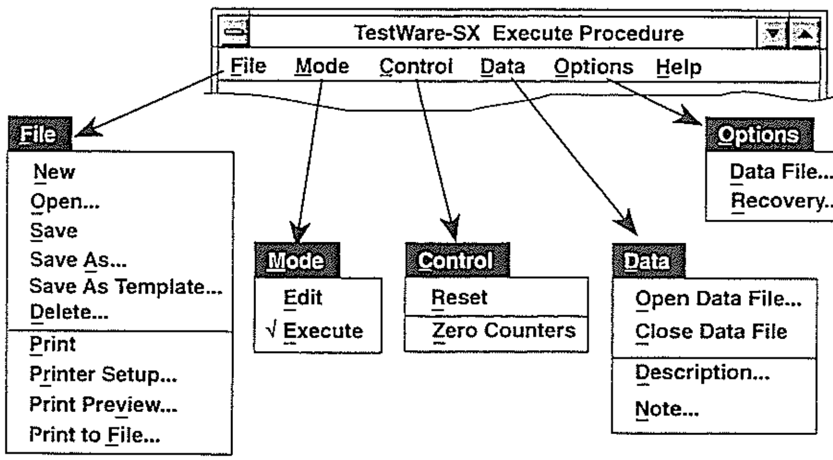
4. If your username and password are valid, the main TestStar window opens. In the "MTS-TS II Icon View" window double click the TWSX icon.



5. In the "TestWare-SX" window, click on "File" to display a pull down menu. Select "Open Template" which will open the "Open Test Template" window and display the templates in the current directory (the default directory is C:\TS2\TWSX). Highlight the file "FATIGUE.000" in the "C:\TS2\TWSX" directory and click "OK" to load the template. This will be the template used to conduct the Fatigue Test.

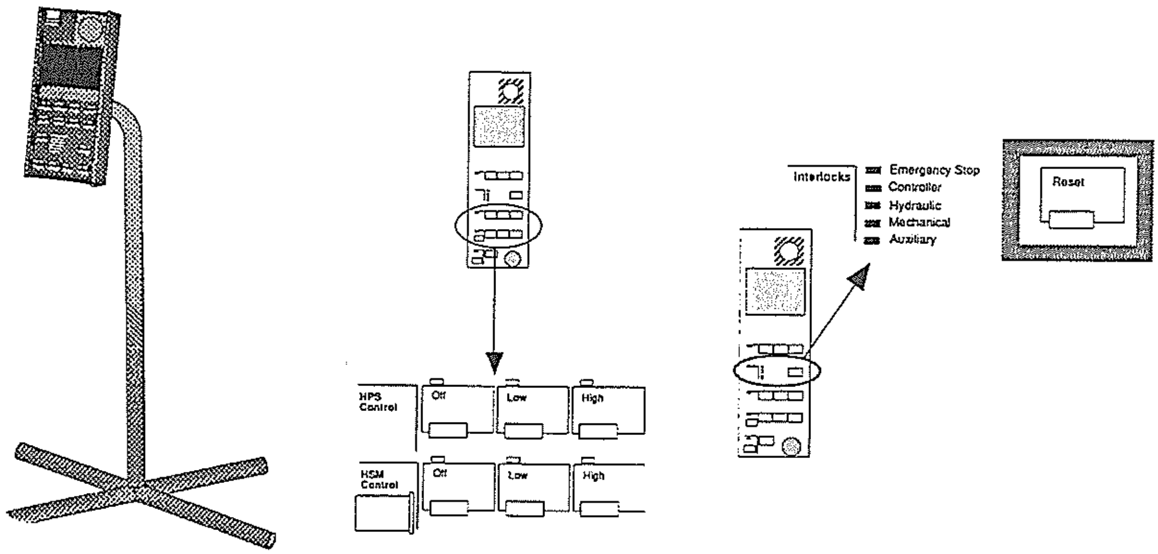


6. Click on "Procedure" in the "TestWare-SX" window to display a pull down menu. Select "Execute Procedure" which will open the "Test Data File" window and display the data files in the current directory (the default directory is C:\TS2\TWSX). Enter the name of the file to store the data of the test being conducted (change the directory if the test data is to be stored in another directory) and click "OK." An error message will be displayed when an attempt is made to run the test without having a data file open.



HYDRAULICS INITIALIZATION

7. Press the "Reset" button on the "MTS Load Unit Control" to reset the system. Start the hydraulic system of the MTS by switching the "HPS Control" to "Low" and after a few seconds to "High." After 2 or 3 minutes, switch the "HSM Control" to "Low," wait for a few seconds and switch to "High." Allow about 30 minutes for the hydraulic system to stabilize.



ZEROING THE FORCE SENSOR

8. Read the display on the "TestStar Controller" of the MTS "Load Unit Control". The "Force" sensor has to be zeroed.

9. Using the "F2" or "F3" switches highlight the text under "POD MODE." Click the "F1" switch until the text changes to "Length A Pod." Again, using the "F2" or "F3" switches, highlight the current value of the "Force" sensor. Press the "F1" switch to auto zero the "Force" sensor.

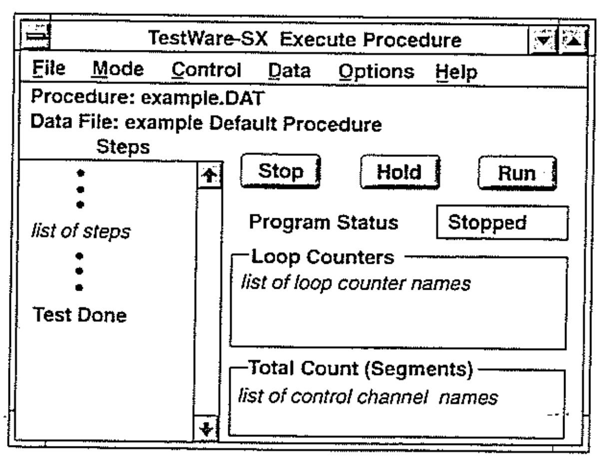
INSTALLING SPECIMEN

10. Samples tested in this test are 4" in diameter and 2.5" thick. If extensometers are being used to measure horizontal deformation:

    Use a square to draw a diametral line on each side of the specimen. Mount

13. If the signal is at the top of the screen of the Oscilloscope it means that the LVDT is very much outside and has to be moved in to come into the visible range. Conversely, if the signal is at the bottom of the screen of the Oscilloscope it means that the LVDT is very much inside and it has to be moved out to come into the visible range. Move the LVDTs appropriately such that signals from the LVDTs are visible.

14. To test if the specimen is seated properly, click "Run" in the "TestWare-SX Execute Procedure" and monitor the signals from the LVDTs on the Oscilloscopes. If the signals for both the vertical LVDTs and both the horizontal LVDTs (in case LVDTs are being used to measure horizontal deformation) are identical and in the same direction, it means that the specimen is seated properly. If the signals are not in the same direction, press "Hold" on the "TestWare-SX Execute Procedure," wiggle the specimen slightly, and press "Run" on the "TestWare-SX Execute Procedure" again to run the program again. Repeat this process until the signals are identical for both the vertical LVDTs (and both the horizontal LVDTs in case they are being used). If after a few repeated tries to wiggle the specimen into proper seating position does not result in the specimen being seated properly, remove the load, reseat the specimen and run the program again until the specimen is seated properly.



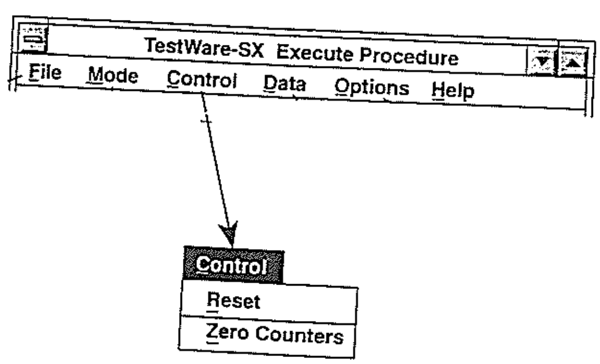
15. After the specimen is seated satisfactorily, click "Control" on the "TestWare-SX Execute Procedure" and choose "Reset" in the pull down menu.

16. Bring all four potentiometers to the null position by turning the knobs of the potentiometer box in the clockwise direction. Read the "Current Value" readings of the LVDT sensors. The values for the LVDTs measuring vertical deformation, (marked LVDTVL and LVDTVR) should read just below -0.04500 inches. In case LVDTs are being used to measure horizontal deformation:

    The two LVDTs measuring horizontal deformation, marked LVDTHL and LVDTHR, should read close to 0.00000 inches. If not, move the LVDTs inside or outside as appropriate, until the "Current Value" of the LVDTHL and LVDTHR LVDTs read about 0.00100 inches (i.e., just above zero).

To get the vertical LVDTs close to zero, move the LVDTs up or down as appropriate, until the "Current Value" of the LVDTVL and LVDTVR LVDTs read the desired values.

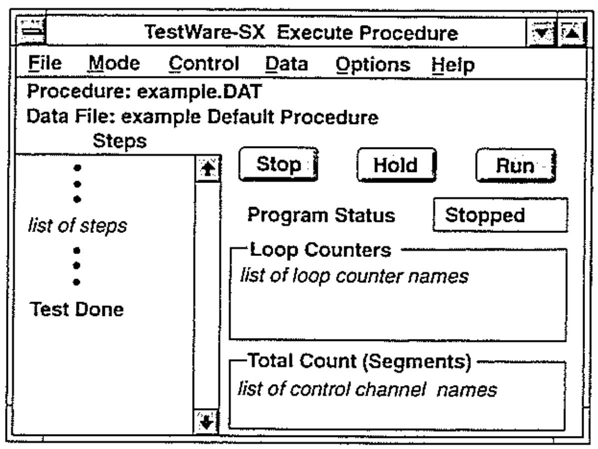
17. Slowly rotate the potentiometer knobs for each of the LVDTs in the counterclockwise direction to fine tune the "Current Value" readings of the sensors to the desired values. If extensometers are being used, remove the gage length

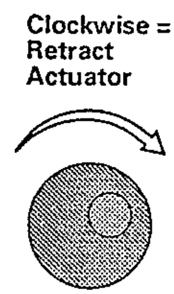


locking pin of the extensometer. Using the "F2" or "F3" switches, highlight the current value of the "Extensometer." Press the "F1" switch to auto zero the "Extensometer."

RUNNING THE TEST

18. Click "Run" in the "TestStar-Execute Procedure" window to run the Fatigue test. The test is automatically stopped after the horizontal deformation reaches 0.1 inches (i.e. the specimen fails). The end of the test is indicated by "Done" appearing beside "Test Status".





FINAL STEPS

19. Once the test is complete, the test data file has to be closed. Click on "Data" in the "TestWare-SX Execute Procedure" window to display a pull down menu. Click on "Close Data File" to close the data file. Click on "Control" to display a pull down menu. Click on "Reset" to reset the program. Now the program is ready to run again.

22. Click on the switch beside "Actuator Positioning Control" and **slowly** rotate the

knob beside it in a **clockwise direction** until the applied load on the specimen is removed.

DATA ANALYSIS

21. To analyze the data, run the program "fatigue.exe." To do this, change to the root directory by typing CD\ at the DOS prompt. The type FATIGUE. The program will prompt you to enter the name of the data file. Enter the name of the data file to be analyzed. The program then processes the data and writes the permanent, recoverable, and total deformations to the files "perm.out", "recv.out," and "tot.out" respectively.

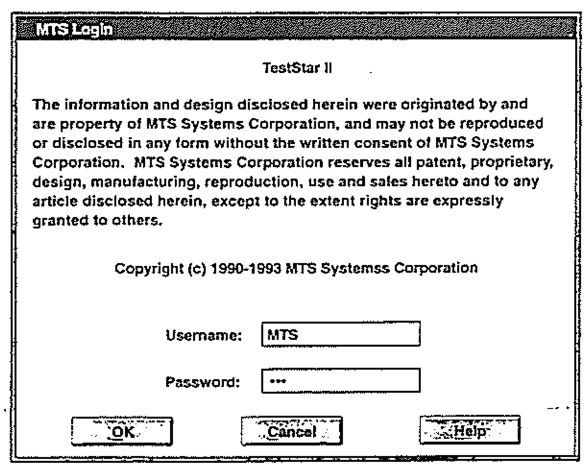
Procedure To Run The Axial Repeated Load Test on the 810 MTS Material Test System

COMPUTER SETUP

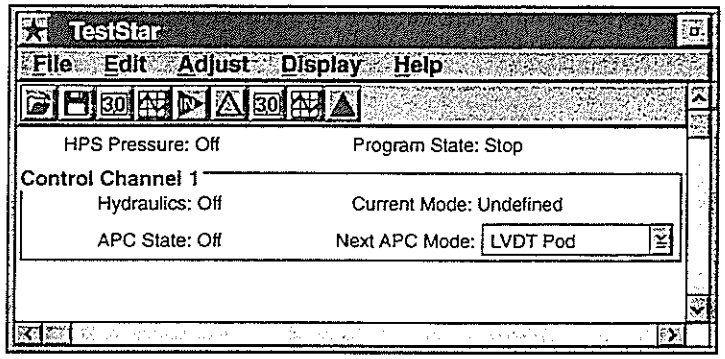
1. Turn on the power for the MTS System, Computer, Monitor, Line Printer, Oscilloscopes and LVDT conditioners.

2. If the computer is in DOS when switched on, type "OS2" at the "C:\" prompt to change to OS/2. Type "Y" at the question "You requested to start OS2 ..." and wait until the system changes to OS/2. If the computer is already in OS/2 when switched on, the above steps will not be necessary.

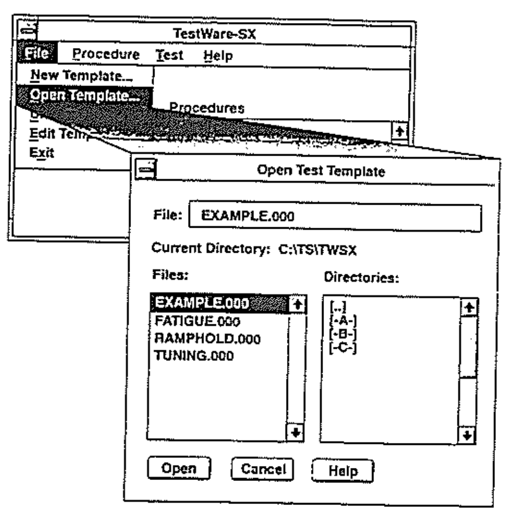
3. Once in OS/2, double click on the "MTS-TS II" icon. A "MTS-TS II - Icon View" window will open. Double click on "TestStar." A window for "MTS Login" for TestStar will open. At the "Username" prompt, type "MTS," press the "Tab" key, type "MTS" at the "Password" prompt and click "OK" in the window.



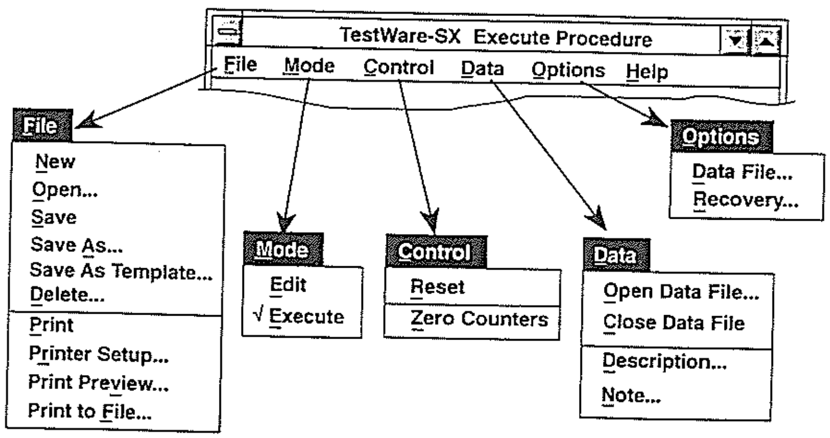
4. If your username and password are valid, the main TestStar window opens. In the "MTS-TS II Icon View" window double click the TWSX icon.



5. In the "TestWare-SX" window, click on "File" to display a pull down menu. Select "Open Template" which will open the "Open Test Template" window and display the templates in the current directory (the default directory is C:\TS2\TWSX). Highlight the file "DYN_CRP.000" in the "C:\TS2\TWSX" directory and click "OK" to load the template. This will be the template used to conduct the Axial Repeated Load Test.



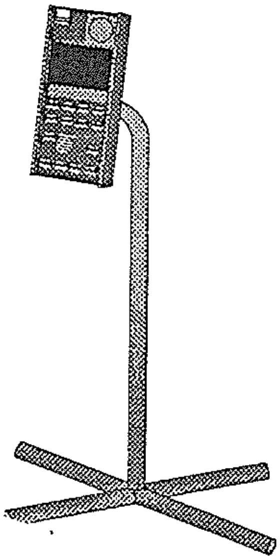
6. Click on "Procedure" in the "TestWare-SX" window to display a pull down menu. Select "Execute Procedure" which will open the "Test Data File" window and display the data files in the current directory (the default directory is C:\TS2\TWSX). Enter the name of the file to store the data of the test being conducted (change the directory if the test data is to be stored in another directory) and click "OK." An error message will be displayed when an attempt is made to run the test without having a data file open.

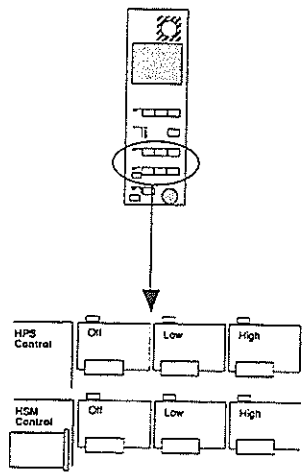


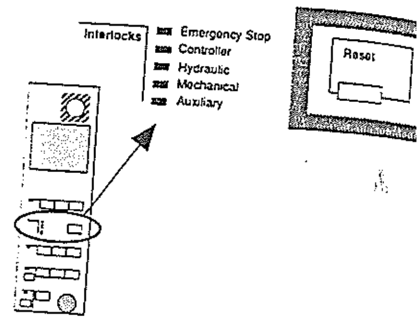
HYDRAULICS INITIALIZATION

7. Press the "Reset" button on the "MTS Load Unit Control" to reset the system. Start the hydraulic system of the MTS by switching the "HPS Control" to "Low" and after a few seconds to "High." After 2 or 3 minutes, switch the "HSM Control" to "Low", wait for a few seconds and switch to "High". Allow about 30 minutes for the

hydraulic system to stabilize.







ZEROING THE FORCE SENSOR

8. Read the display on the "TestStar Controller" of the MTS "Load Unit Control." The "Force" sensor has to be zeroed.

9. Using the "F2" or "F3" switches, highlight the text under "POD MODE." Click the "F1" switch until the text changes to "Length A Pod." Again, using the "F2" or "F3" switches, highlight the current value of the "Force" sensor. Press the "F1" switch to auto zero the "Force" sensor.

INSTALLING THE SPECIMEN

10. Samples used in this test are 4" in diameter and 8" in height. Mount the extensometer system on the sample so that each extensometer is along its height. Place the sample in the chamber so that one of the caps of the sample rests on

the bottom platen. Connect the extensometer electrical cable to the strain gage cable from the Digital Controller.

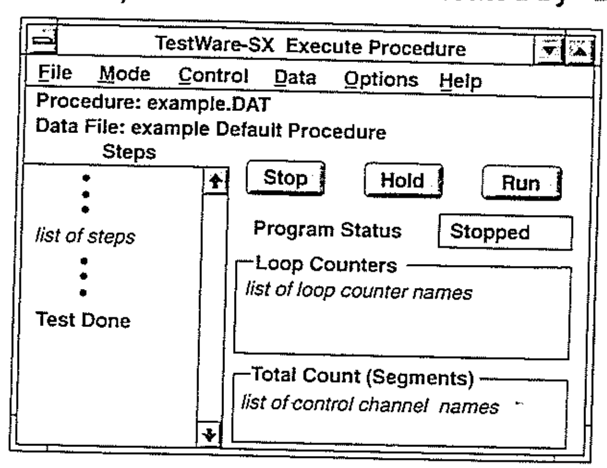
11. Apply an initial seating load of 50 lbs. on the specimen by switching on the "Actuator Positioning Control" and **slowly** turning the knob beside it in a **counterclockwise direction** until the "Current Value" of the "Force" sensor reads -50 lbs. Ensure that the "CURRENT MODE" of the "Axial Controller" reads "Force A Pod" while the initial seating load is being applied.

12. To make sure the sample is seated properly, wiggle the movable bottom platen slightly so that the top platen is seated properly on the top cap of the sample.

13. Remove the gage length locking pin of the extensometer. Using the "F2" or "F3" switches, highlight the current value of the "Extensometer." Press the "F1" switch to auto zero the "Extensometer".

RUNNING THE TEST

14. Click "Run" in the "TestStar-Execute Procedure" window to run the Axial Repeated Load test. The test is automatically stopped after the horizontal deformation reaches 0.1 inches (i.e. the specimen fails). The end of test is indicated by "Done" appearing beside "Test Status."



FINAL STEPS

15. Once the test is complete, the test data file has to be closed. Click on "Data" in the "TestWare-SX Execute Procedure" window to display a pull down menu. Click on "Close Data File" to close the data file. Click on "Control" to display a pull down menu. Click on "Reset" to reset the program. Now the program is ready to run again.

16. Click on the switch beside "Actuator Positioning Control" and **slowly** rotate the knob beside it in a **clockwise direction** until the applied load on the specimen is removed.

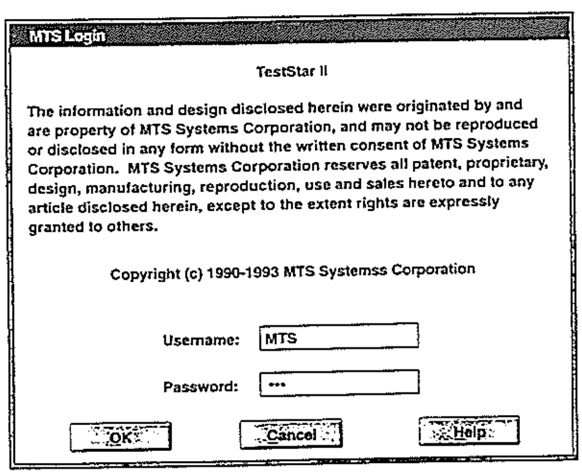
Procedure To Run The Indirect Resilient Modulus Test on the 810 MTS Material Test System

COMPUTER SETUP

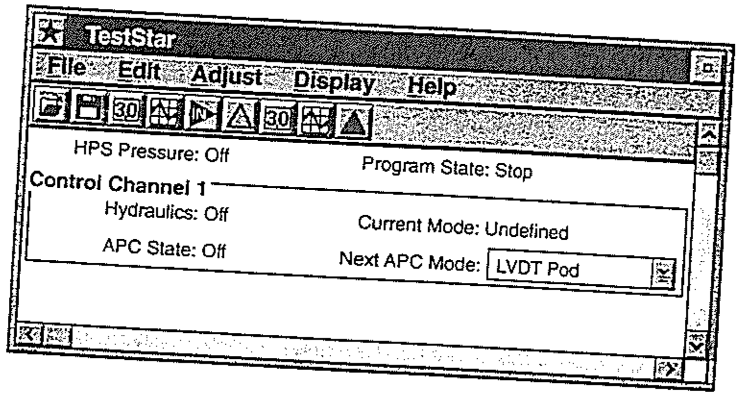
1. Turn on the power for the MTS System, Computer, Monitor, Line Printer, Oscilloscopes and LVDT conditioners.

2. If the computer is in DOS when switched on, type "OS2" at the "C:\" prompt to change to OS/2. Type "Y" at the question "You requested to start OS2 ..." and wait until the system changes to OS/2. If the computer is already in OS/2 when switched on, the above steps will not be necessary.

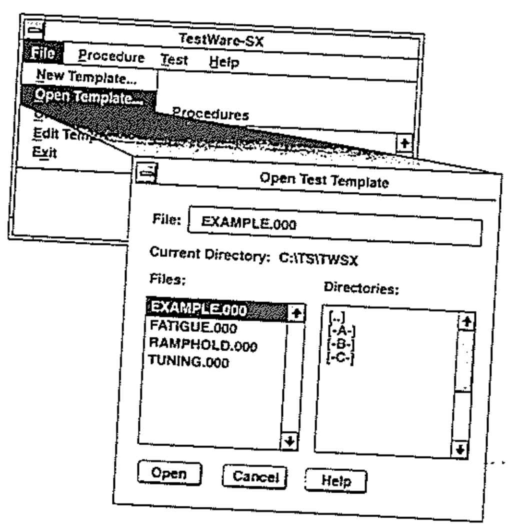
3. Once in OS/2, double click on the "MTS-TS II" icon. A "MTS-TS II - Icon View" window will open. Double click on "TestStar." A window for "MTS Login" for TestStar will open. At the "Username" prompt, type "MTS," press the "Tab" key, type "MTS" at the "Password" prompt and click "OK" in the window.



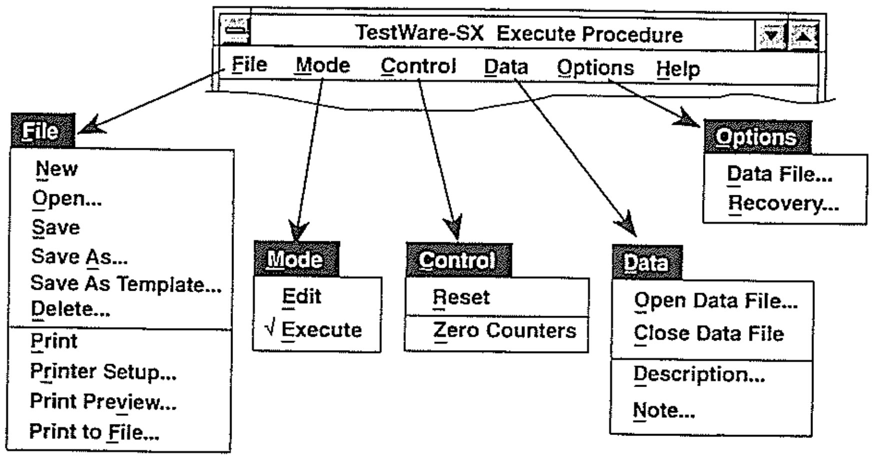
4. If your username and password are valid, the main TestStar window opens. In the "MTS-TS II Icon View" window double click the TWSX icon.



5. Before the resilient modulus test is conducted, the specimen has to be conditioned. In the "TestWare-SX" window, click on "File" to display a pull down menu. Select "Open Template" to open the "Open Test Template" window and display the templates in the current directory (the default directory is C:\TS2\TWSX). Highlight the file "MRL_COND.000" in the "C:\TS2\TWSX" directory and click "OK" to load the template. This will be the template used to condition the specimen before conducting the resilient modulus test.

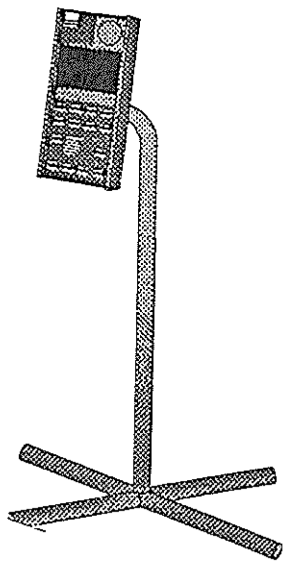


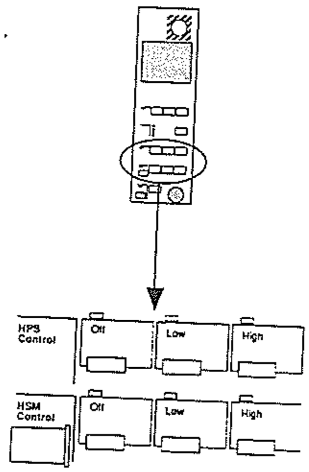
6. Click on "Procedure" in the "TestWare-SX" window to display a pull down menu. Select "Execute Procedure" which will open the "Test Data File" window and display the data files in the current directory (the default directory is C:\TS2\TWSX). Enter the name of the file to store the data of the test being conducted (change the directory if the test data is to be stored in another directory) and click "OK." An error message will be displayed when an attempt is made to run the test without having a data file open.

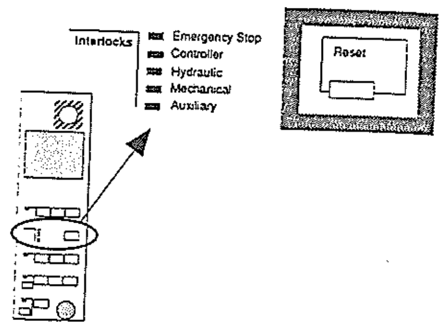


HYDRAULICS INITIALIZATION

7. Press the "Reset" button on the "MTS Load Unit Control" to reset the system. Start the hydraulic system of the MTS by switching the "HPS Control" to "Low" and after a few seconds to "High." After 2 or 3 minutes, switch the "HSM Control" to "Low," wait for a few seconds and switch to "High." Allow about 30 minutes for the hydraulic system to stabilize.







ZEROING THE FORCE SENSOR

8. Read the display on the "TestStar Controller" of the MTS "Load Unit Control." The "Force" sensor has to be zeroed.

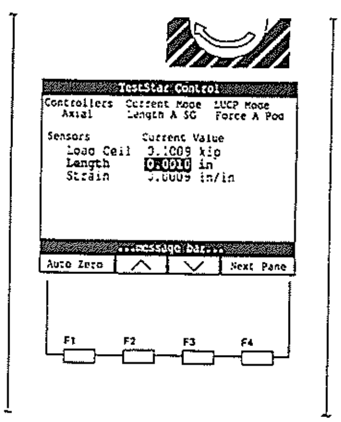
9. Using the "F2" or "F3" switches, highlight the text under "POD MODE." Click the "F1" switch until the text changes to "Length A Pod." Again, using the "F2" or "F3" switches, highlight the current value of the "Force" sensor. Press the "F1" switch to auto zero the "Force" sensor.

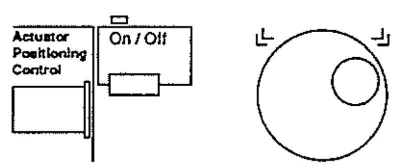
INSTALLING THE SPECIMEN

10. Samples tested in this test are 4" in diameter and 2.5" thick. If extensometers are being used to measure horizontal deformation:

    Use a square to draw a diametral line on each side of the specimen. Mount the extensometer system on the sample so that each extensometer is on a drawn line.

If the test is being conducted at a temperature other than room temperature (approximately 77°F), set the test temperature using the 409.80 MTS "Temperature Controller." First, seal all the openings in the chamber with insulator after inserting the thermocouple and the thermometer through the orifice provided. Close the door to the chamber and switch on the power on the temperature controller. With the "Set Point" depressed on the controller, set the desired temperature using the up or down arrow to increase or decrease the temperature. After the temperature has been set to the desired level, turn on the chamber switch on the controller. After the temperature in the chamber has reached the desired level, switch off the "Chamber" switch. Place the preheated / pre-cooled Asphalt Briquette Specimen in the Test Device by inserting it between the loading strips such that the two horizontally placed micrometers are on either side of the specimen circumference. Ensure that the specimen is placed on the loading strips so that the applied load will be distributed evenly on the specimen. For this, holding down the head of the test device (on which the vertically placed LVDTs are mounted), wiggle the





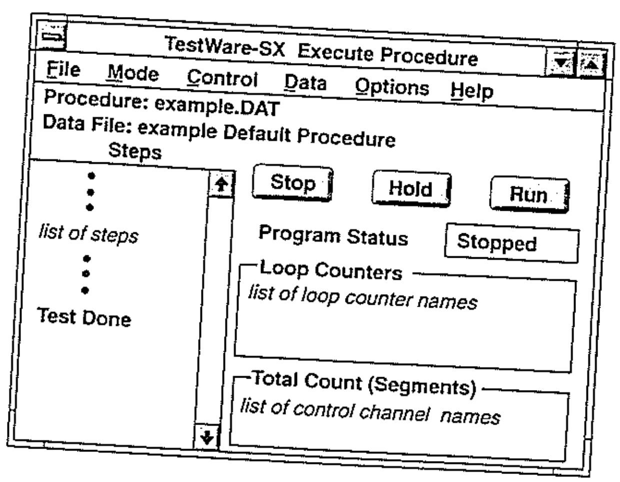
specimen and make sure that the specimen does not rock. Connect the extensometer electrical cable to the strain gage cable from the Digital Controller. Close the door to the chamber and wait until the chamber temperature reaches the preset level again. Caution: Read warning on the temperature controller prior to turning on the power. Switching on the "Chamber" switch on the "Temperature

Controller," bring the temperature of the environmental chamber to the appropriate test temperature.

11. Apply an initial seating load of 50 lbs. on the specimen by switching on the "Actuator Positioning Control" and **slowly** turning the knob beside it in a **counterclockwise direction** till the "Current Value" of the "Force" sensor reads -50 lbs. Ensure that the "CURRENT MODE" of the "Axial Controller" reads "Force A Pod" while the initial seating load is being applied.

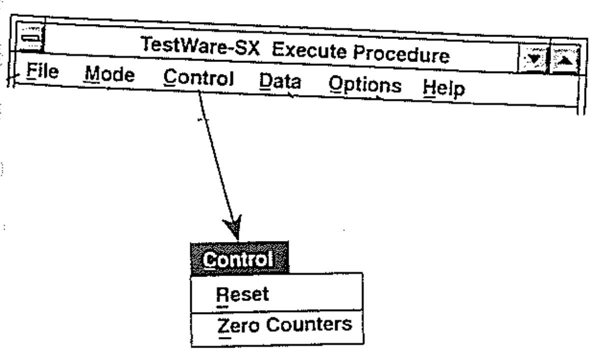
12. Look for signals from the LVDTs on the Oscilloscopes. If the signals are not visible this means the signals are out of the Oscilloscope's range and the LVDTs have to be moved in or out to get the signals in the visible range.

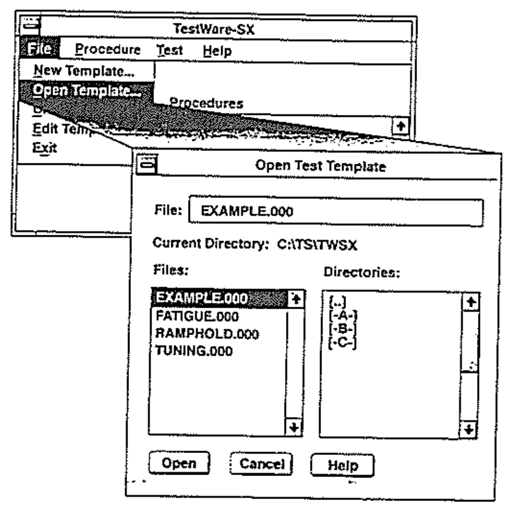
13. If the signal is at the top of the screen of the Oscilloscope it means that the LVDT is very much outside and has to be moved in to come into the visible range. Conversely, if the signal is at the bottom of the screen of the Oscilloscope it means that the LVDT is very much inside and it has to be moved out to come into the visible range. Move the LVDTs appropriately such that signals from the LVDTs are visible.



14. To test if the specimen is seated properly, click "Run" in the "TestWare-SX Execute Procedure" and monitor the signals from the LVDTs on the Oscilloscopes. If the signals for both the vertical LVDTs and both the horizontal LVDTs (in case LVDTs are being used to measure horizontal deformation) are identical and in the same direction, it means that the specimen is seated properly. If the signals are not in the same direction, press "Hold" on the "TestWare-SX Execute Procedure," wiggle the specimen slightly, and press "Run" on the "TestWare-SX Execute Procedure" again to run the program again. Repeat this process until the signals are identical for both the vertical LVDTs (and both the horizontal LVDTs in case they are being used). If a few repeated tries to wiggle the specimen into proper seating position does not result in the specimen being seated properly, remove the load, reseat the specimen and run the program again until the specimen is seated properly.

15. After the specimen is seated satisfactorily, click "Control" on the "TestWare-SX Execute Procedure," choose "Zero Counters" in the pull down menu and run the entire program again until "Done" appears beside "Program Status." Now the specimen is preconditioned and ready for the test. Double click on the "sine wave symbol" beside "TestWare-SX Execute Procedure" to exit the conditioning program.





16. In the "TestWare-SX" window which opens after closing the conditioning program, click on "File" and in the pull down menu click on "Open Template." This will open the "Open Test Template" window and display the templates in the current directory (the default directory is C:\TS2\TWSX). Highlight the file "MRL_TEST.000" in the "C:\TS2\TWSX" directory and click "OK" to load the template. This will be the template used to conduct the Resilient Modulus Test.

17. Bring all the four potentiometers to the null position by turning the knobs of the potentiometer box in the clockwise direction. Read the "Current Value" readings of the LVDT sensors. The values for the LVDTs measuring vertical deformation, (marked LVDTVL and LVDTVR) should read just below -0.04500 inches. If LVDTs are being used to measure horizontal deformation:

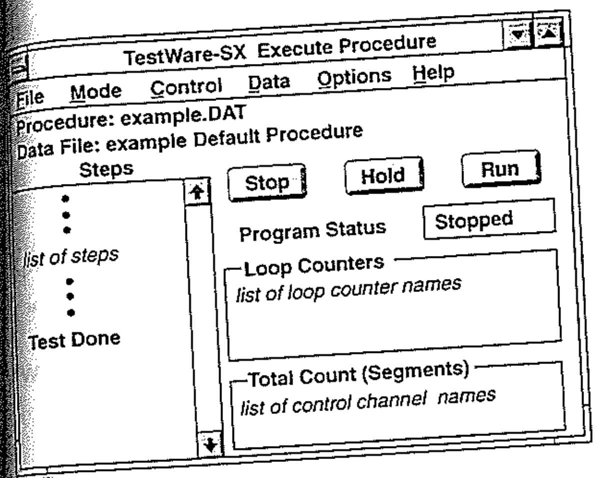
    The two LVDTs measuring horizontal deformation, marked LVDTHL and LVDTHR, should read close to 0.00000 inches. If not, move the LVDTs inside or outside as appropriate, until the "Current Value" of the LVDTHL and LVDTHR LVDTs read about 0.00100 inches (i.e., just above zero).

    To get the vertical LVDTs close to zero, move the LVDTs up or down as appropriate until the "Current Value" of the LVDTVL and LVDTVR LVDTs read the desired values.

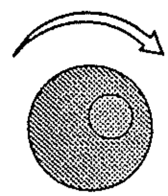
18. Once the temperature in the environmental chamber is stabilized at the test temperature, slowly rotate the potentiometer knobs for each of the LVDTs in the counterclockwise direction to fine tune the "Current Value" readings of the sensors to the desired values. Remove the gage length locking pin of the extensometer. Using the "F2" or "F3" switches, highlight the current value of the "Extensometer." Press the "F1" switch to auto zero the "Extensometer."

NNING THE TEST

Click "Run" in the "TestStar-Execute Procedure" window to run the Resilient Modulus test. The test is for a period of two seconds and the end of the test is indicated by "Done" appearing beside "Test Status."



Clockwise =
Retract
Actuator



INAL STEPS

20. Once the test is complete, the test data file has to be closed. Click on "Data" in the "TestWare-SX Execute Procedure" window to display a pull down menu. Click on "Close Data File" to close the data file. Click on "Control" to display a pull down menu. Click on "Reset" to reset the program. Now the program is ready to run again.

21. Click on the switch beside "Actuator Positioning Control" and **slowly** rotate the knob beside it in a **clockwise direction** until the applied load on the specimen is removed.

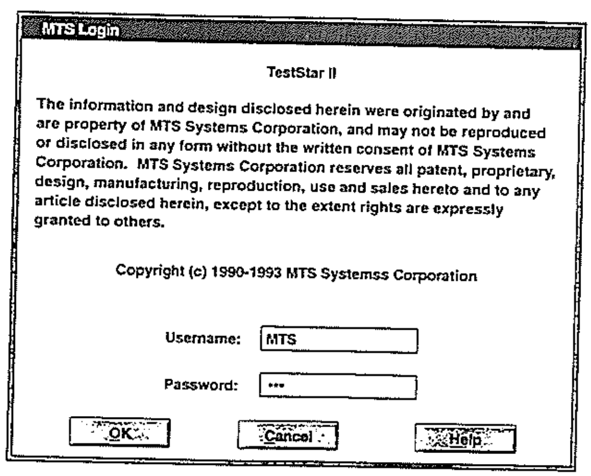
Procedure To Run The Indirect Creep Test on the 810 MTS Material Test System

COMPUTER SETUP

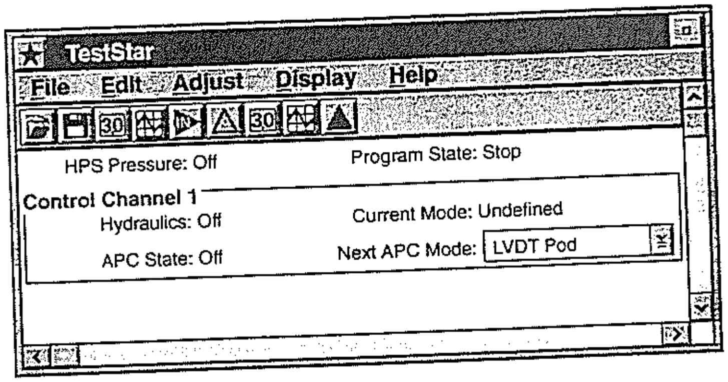
1. Turn on the power for the MTS system, Computer, Monitor, Line Printer, Oscilloscope and LVDT conditioners.

2. If the computer is in DOS when switched on, type "OS2" at the "C:\" prompt to change to OS/2. Type "Y" at the question "You requested to start OS/2 ..." and wait until the system changes to OS/2. If the computer is already in OS/2 when switched on, the above steps will not be necessary.

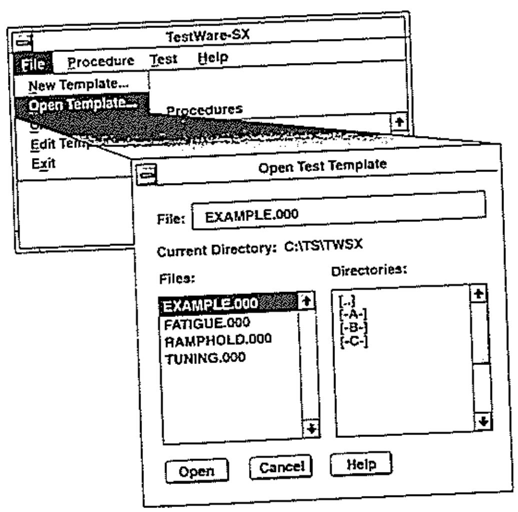
3. Once in OS/2, double click on the "MTS-TS II" icon. A "MTS-TS II - Icon View" window will open. Double click on "TestStar." A window for "MTS Login" for TestStar will open. Type "MTS" at the "Username" prompt, press the "Tab" key, type "MTS" at the "Password" prompt and click "OK" in the window.



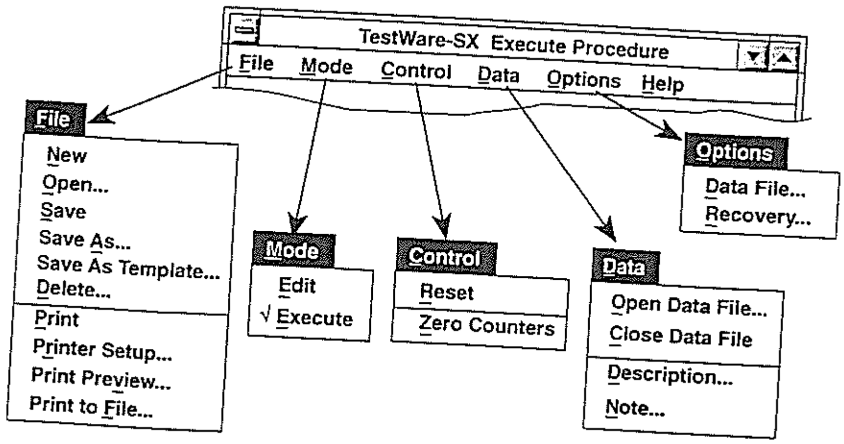
If your username and password are valid, the main TestStar window opens. In the "MTS-TS II Icon View" window double click the TWSX icon.



6. In the "TestWare-SX" window, click on "File" to display a pull down menu. Select "Open Template" which will open the "Open Test Template" window and display the templates in the current directory (the default directory is C:\TS2\TWSX). Highlight the file "CRP_TEST.000" in the "C:\TS2\TWSX" directory and click "OK" to load the template. This will be the template used to conduct the Creep Test.



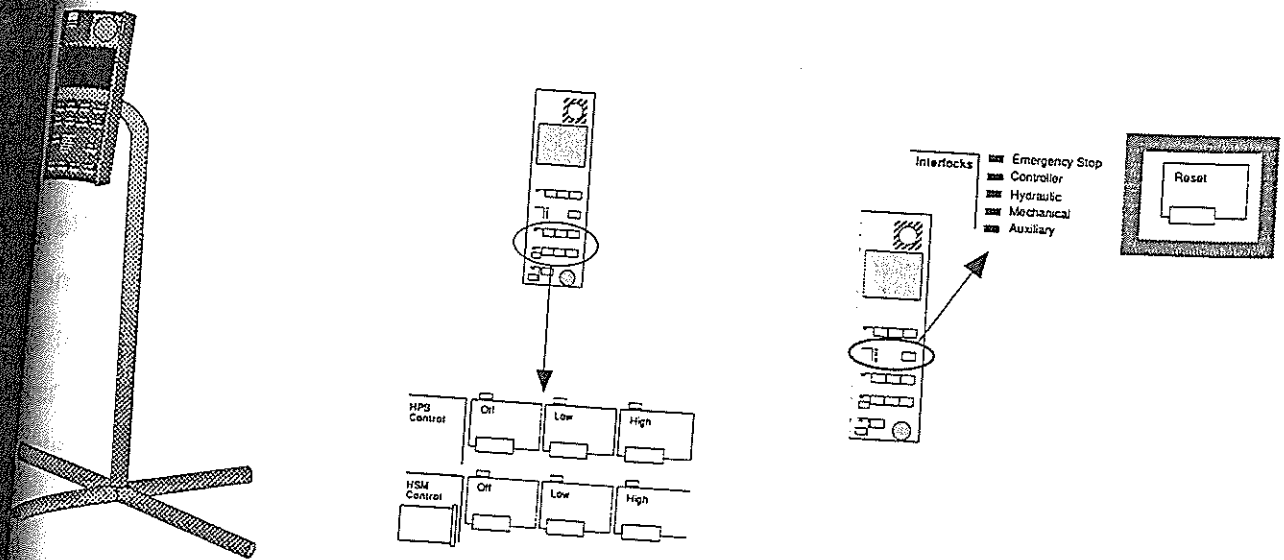
6. Click on "Procedure" in the "TestWare-SX" window to display a pull down menu. Select "Execute Procedure" which will open the "Test Data File" window and display the data files in the current directory (the default directory is C:\TS2\TWSX). Enter the name of the file to store the data of the test being conducted (change the directory if the test data is to be stored in another directory) and click "OK." An error message will be displayed when an attempt is made to run the test without having a data file open.



7. The "TestWare-SX Execute Procedure" window displays the name of the procedure being used to conduct the test in "Procedure" and the name of the file being used to store the test data in "Data File."

HYDRAULICS INITIALIZATION

8. Press the "Reset" button on the "MTS Load Unit Control" to reset the system. Start the hydraulic system of the MTS by switching the "HPS Control" to "Low" and after a few seconds to "High". After 2 or 3 minutes switch the "HSM Control" to "Low," wait for a few seconds and switch to "High." Allow about 30 minutes for the hydraulic system to stabilize.



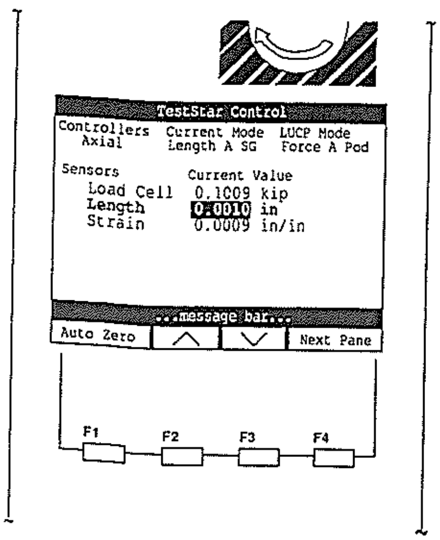
STALLING THE SPECIMEN - PART I

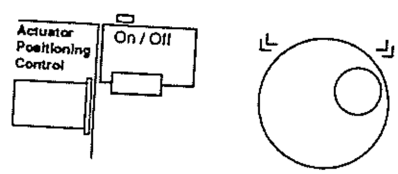
Samples tested in this test are 4" in diameter and 2.5" thick. If extensometers are being used to measure horizontal deformation:

Use a square to draw a diametral line on each side of the specimen. Mount the extensometer system on the sample so that each extensometer is on a drawn line.

If the test is being conducted at a temperature other than room temperature (approximately 77°F), set the test temperature using the 409.80 MTS "Temperature Controller." First, seal all the openings in the chamber with insulator after inserting the thermocouple and the thermometer through the orifice provided. Close the door to the chamber and switch on the power on the temperature controller. With the "Set Point" depressed on the controller, set the desired temperature using the up or down arrow to increase or decrease the temperature. After the temperature has been set to the desired level, turn on the chamber switch on the controller. After the temperature in the chamber has reached the desired level, switch off the "Chamber" switch. Place the preheated/pre-cooled Asphalt Briquette Specimen in the test device by inserting it between the loading strips such that the two horizontally placed micrometers are on either side of the specimen circumference.

Ensure that the specimen is placed on the loading strips so that the applied load will be distributed evenly on the specimen. For this, holding down the head of the test device (on which the vertically placed LVDTs are mounted), wiggle the specimen and make sure that the specimen does not rock. In case the extensometer is being used, connect the extensometer electrical cable to the strain gage cable from the Digital Controller. Close the door to the chamber and wait until the chamber temperature reaches the preset level again. Caution: Read warning on the temperature controller prior to turning on the power. Switching on the "Chamber" switch on the "Temperature Controller," bring the temperature of the environmental chamber to the appropriate test temperature.





ZEROING THE FORCE SENSOR

10. After the hydraulic system has stabilized for about 30 minutes, read the display on the "TestStar Controller" of the "MTS Load Unit Control." The "Force" sensor has to be zeroed.

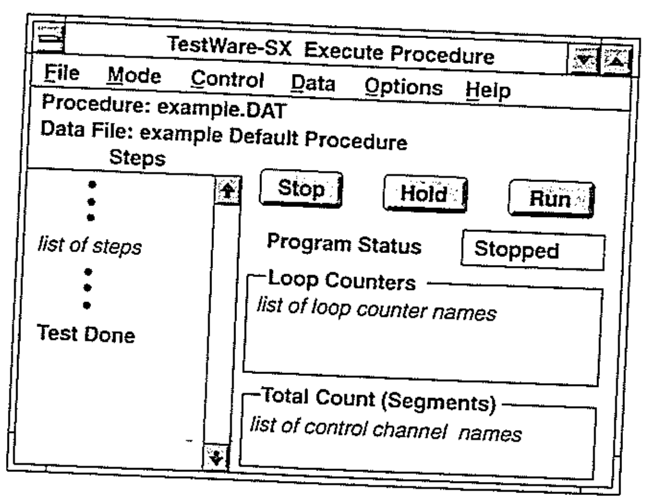
11. Using the "F2" or "F3" switches, highlight the text under "POD MODE." Click the "F1" switch until the text changes to "Length A Pod." Again, using the "F2" or "F3"

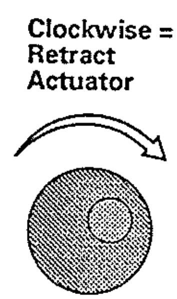
switches, highlight the current value of the "Force" sensor. Press the "F1" switch to auto zero the "Force" sensor.

INSTALLING THE SPECIMEN - PART II

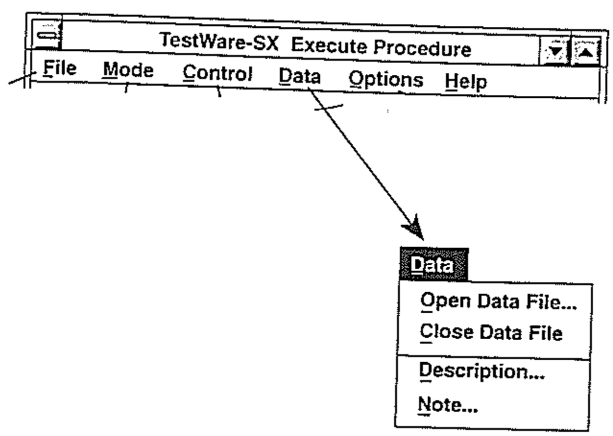
12. Apply an initial seating load of 50 lbs. on the specimen by switching on the "Actuator Positioning Control" and **slowly** turning the knob beside it in a **counterclockwise direction**, until the "Current Value" of the "Force" sensor reads -50 lbs. Ensure that the "CURRENT MODE" of the "Axial Controller" reads "Force A Pod" while the initial seating load is being applied.

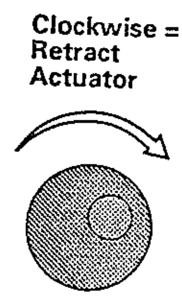
13. Bring all the four potentiometers to the null position by turning the knobs of the potentiometer box in the clockwise direction. Read the "Current Value" readings of the LVDT sensors. The values for the LVDTs measuring the vertical deformation, (marked LVDTVL and LVDTVR), should read just below -0.04500 inches. When LVDTs are being used to measure horizontal deformation, the two LVDTs measuring the horizontal deformation, (marked LVDTHL and LVDTHR), should read close to 0.00000 inches. To adjust the LVDTs to read these values, using the micrometer move the LVDTs on the test device inside or outside as appropriate, until the "Current Value" readings have the desired values.





14. Rotate the potentiometer knobs in the counterclockwise direction for each of the LVDTs to fine tune the "Current Value" reading of the sensors to the desired values. Remove the gage length locking pin of the extensometer. Using the "F2" or "F3" switches, highlight the current value of the "Extensometer." Press the "F1" switch to auto zero the "Extensometer".





RUNNING THE TEST

15. Click "Run" in the "TestStar-Execute Procedure" window to run the test. Monitor the "Current Value" readings for the vertical and horizontal (if applicable) LVDT sensors on the "MTS Load Unit Control" during the test. Stop the test by clicking "Stop" in the "TestStar Execute Procedure" window or by pressing the "Stop" button beside "Test Control" on the "MTS Load Unit Control" when the "Current Value" for the vertical LVDT sensors readings cross 0.04500 inches or the specimen fails. The test is automatically stopped after 3600 seconds if the vertical deformation has not yet crossed 0.04500 inches.

6. Once the test is complete, the data file has to be closed. Click on "Data" in the "TestWare-SX Execute Procedure" window to display a pull down menu. Click on "Close Data File" to close the test data file.

7. Click on the switch beside "Actuator Positioning Control" and **slowly** rotate the knob beside it in a clockwise direction until the applied load on the specimen is removed.

8. Click on "Control" in the "TestWare-SX Execute Procedure" window to display a pull down menu. Click on "Reset" to reset "Program Status".

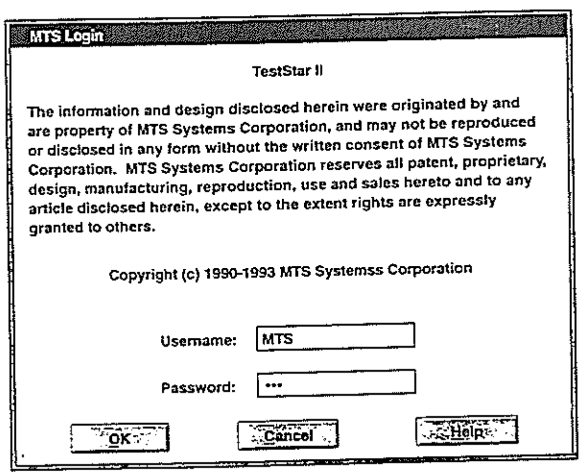
Procedure To Run The Indirect Tensile Strength Test on the 810 MTS Material Test System

COMPUTER SETUP

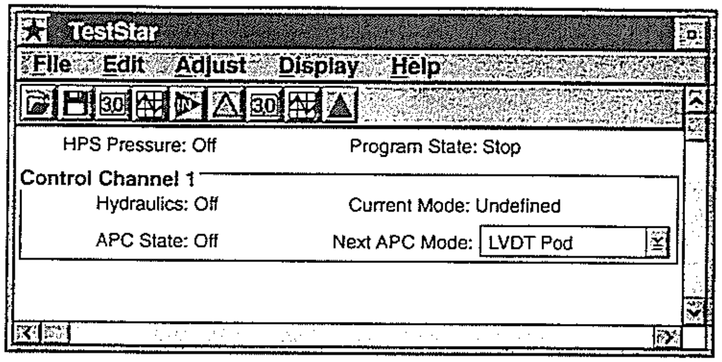
1. Turn on the power for the MTS system, Computer, Monitor, Line Printer, Oscilloscope and LVDT conditioners.

2. If the computer is in DOS when switched on, type "OS2" at the "C:\" prompt to change to OS/2. Type "Y" at the question "You requested to start OS/2 ..." and wait till the system changes to OS/2. If the computer is already in OS/2 when switched on, the above steps will not be necessary.

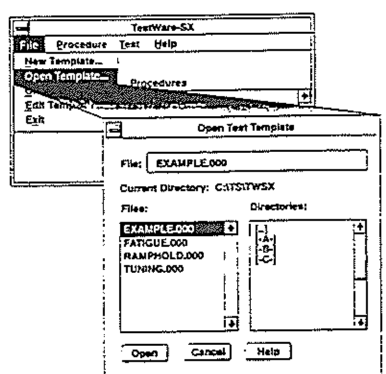
3. Once in OS/2, double click on the "MTS-TS II" icon. A "MTS-TS II - Icon View" window will open. Double click on "TestStar." A window for "MTS Login" for TestStar will open. At the "Username" prompt, type "MTS," press the "Tab" key, type "MTS" at the "Password" prompt and click "OK" in the window.



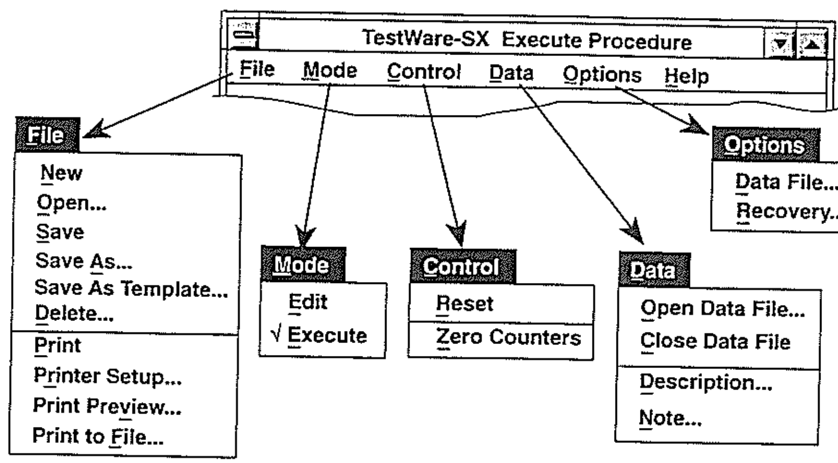
If the username and password are valid, the main TestStar window opens. In the "MTS-TS II Icon View" window double click the TWSX icon.



5. In the "TestWare-SX" window, click on "File" to display a pull down menu. Select "Open Template" which will open the "Open Test Template" window and display the templates in the current directory (the default directory is C:\TS2\TWSX). Highlight the file "ITS_TEST.000" in the "C:\TS2\TWSX" directory and click "OK" to load the template. This will be the template used to conduct the ITS Test.



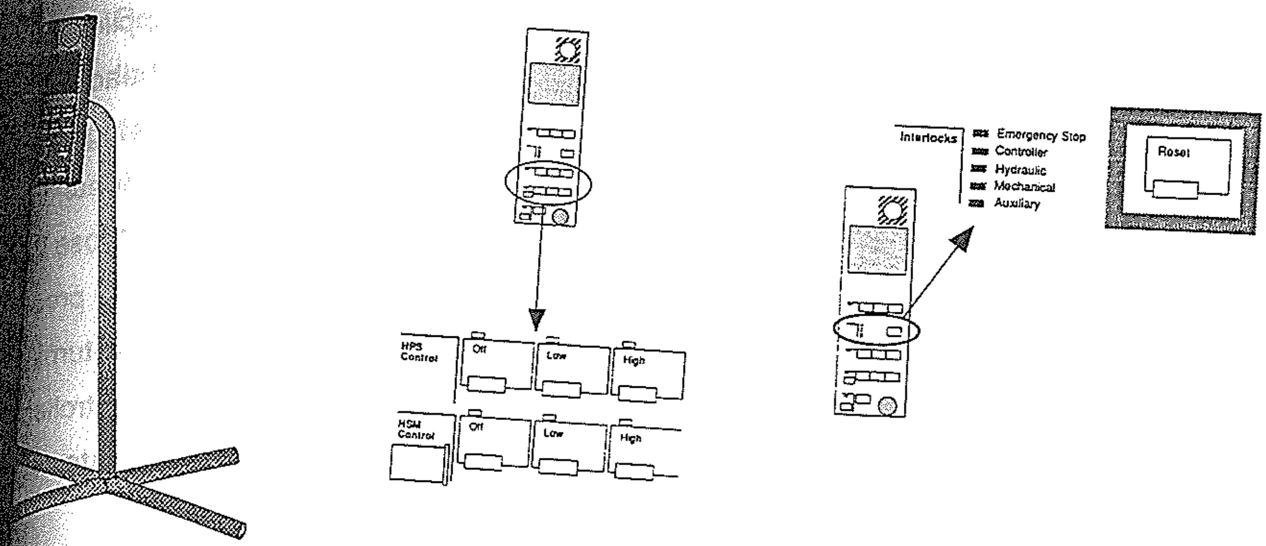
6. Click on "Procedure" in the "TestWare-SX" window to display a pull down menu. Select "Execute Procedure" which will open the "Test Data File" window and display the data files in the current directory (the default directory is C:\TS2\TWSX). Enter the name of the file to store the data of the test being conducted (change the directory if the test data is to be stored in another directory) and click "OK." An error message will be displayed when an attempt is made to run the test without having a data file open.



7. The "TestWare-SX Execute Procedure" window displays the name of the procedure being used to conduct the test in "Procedure" and the name of the file being used to store the test data in "Data File."

HYDRAULICS INITIALIZATION

8. Press the "Reset" button on the "MTS Load Unit Control" to reset the system. Start the hydraulic system of the MTS by switching the "HPS Control" to "Low" and after a few seconds to "High." After 2 or 3 minutes switch the "HSM Control" to "Low," wait for a few seconds and switch to "High." Allow about 30 minutes for the hydraulic system to stabilize.



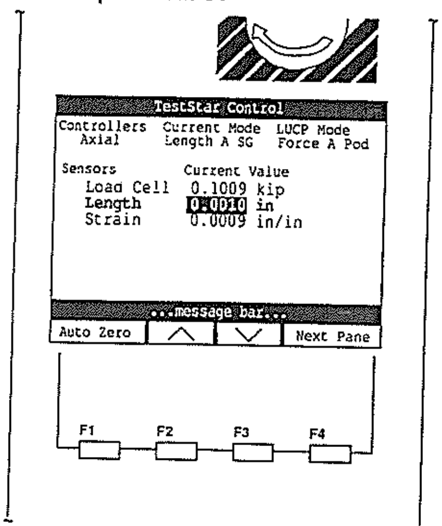
INSTALLING THE SPECIMEN - PART I

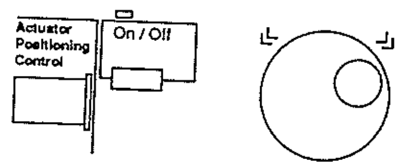
9. Samples tested in this test are 4" in diameter and 2.5" thick. If extensometers are being used to measure horizontal deformation:

    Use a square to draw a diametral line on each side of the specimen. Mount the extensometer system on the sample so that each extensometer is on a drawn line.

If the test is being conducted at a temperature other than room temperature (approximately 77°F), set the test temperature using the 409.80 MTS "Temperature Controller." First, seal all the openings in the chamber with insulator after inserting the thermocouple and the thermometer through the orifice provided. Close the door to the chamber and switch on the power on the temperature controller. With the "Set Point" depressed on the controller, set the desired temperature using the up or down arrow to increase or decrease the temperature. After the temperature has been set to the desired level, turn on the chamber switch on the controller. After the temperature in the chamber has reached the desired level, switch off the "Chamber" switch. Place the preheated/pre-cooled Asphalt Briquette Specimen in the test device by inserting it between the loading strips such that the two horizontally placed micrometers are on either side of the specimen circumference.

Ensure that the specimen is placed on the loading strips so that the applied load will be distributed evenly on the specimen. For this, holding down the head of the test device (on which the vertically placed LVDTs are mounted), wiggle the specimen and make sure that the specimen does not rock. Connect the extensometer cable to the strain gage cable from the Digital Controller. Close the door to the chamber and wait until the chamber temperature reaches the preset level again. Caution: Read warning on the temperature controller prior to turning on the power. Switching on the "Chamber" switch on the "Temperature Controller," bring the temperature of the environmental chamber to the appropriate test temperature.



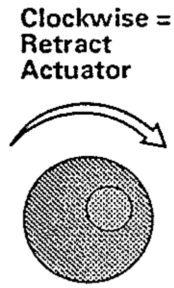


ZEROING THE FORCE SENSOR AND DISPLACEMENT SENSORS

10. After the hydraulic system has been stabilized for about 30 minutes, read the display on the "TestStar Controller" of the "MTS Load Unit Control." The "Force" sensor and the "Displacement" sensors have to be zeroed.

11. The "force" sensor shall be zeroed first. Using the "F2" or "F3" switches, highlight the text under "POD MODE." Click the "F1" switch till the text changes to "Length A Pod." Again, using the "F2" or "F3" switches, highlight the current value of the "Force" sensor. Press the "F1" switch to auto zero the "Force" sensor.

12. Before the displacement sensor is zeroed, ensure that the surface of the actuator that will come in contact with the test device when the load is applied is about 2 or 3 inches away from the test device. To zero the "Displacement" sensor use the "F2" or "F3" switches to highlight the text under "POD MODE." Click the "F1" switch until the text changes to "Force A Pod." Again, using the "F2" or "F3" switches, highlight the current value of the "Displacement" sensor. Press the "F1" switch to auto zero the "Displacement" sensor.



INSTALLING THE SPECIMEN - PART II

13. Apply an initial seating load of 50 lbs. on the specimen by switching on the "Actuator Positioning Control" and **slowly** turning the knob beside it in a **counterclockwise direction** till the "Current Value" of the "Force" sensor reads -50 lbs. Ensure that the "CURRENT MODE" of the "Axial Controller" reads "Force A Pod" while the initial seating is being applied.

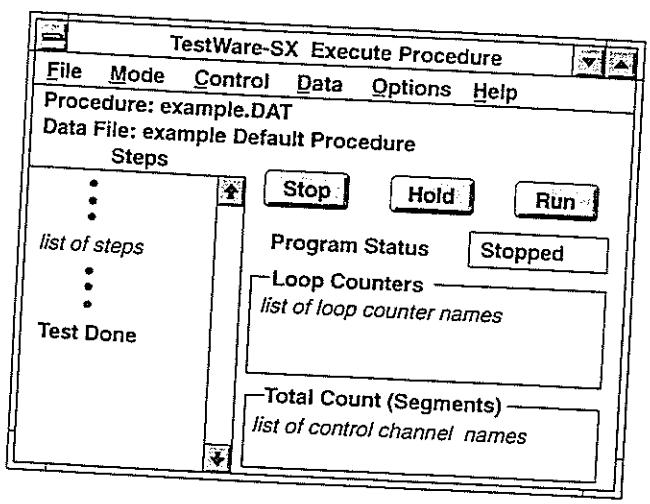
14. Bring all the four potentiometers to the null position by turning the knobs of the potentiometer box in the clockwise direction. Read the "Current Value" readings of the four LVDT sensors. The values for the LVDTs measuring the vertical deformation, (marked LVDTVL and LVDTVR) should read just below -0.04500 inches. When LVDTs are being used to measure the horizontal deformation, the two LVDT's measuring horizontal deformation, (marked LVDTHL and LVDTHR), should read close to 0.00000 inches. To adjust the LVDTs to read these values, move the LVDTs on the test device inside or outside as appropriate, until the

"Current Value" readings read the desired values.

15. Once the temperature in the environmental chamber is stabilized at the test temperature, rotate the potentiometer knobs in the counterclockwise direction for each of the LVDTs to fine tune the "Current Value" reading of the sensors to the desired values. Remove the gage length locking pin of the extensometer. Using the "F2" or "F3" switches, highlight the current value of the "Extensometer." Press the "F1" switch to auto zero the "Extensometer."

RUNNING THE TEST

16. Click "Run" in the "TestStar-Execute Procedure" window to run the test. Monitor the "Current Value" readings for the vertical and horizontal LVDT sensors (if applicable) on the "MTS Load Unit Control" during the test. Stop the test by clicking "Stop" in the "TestStar Execute Procedure" window or by pressing the "Stop" button beside "Test Control" on the "MTS Load Unit Control" when the "Current Value" for the vertical LVDT sensors readings cross 0.04500 inches or the specimen fails.

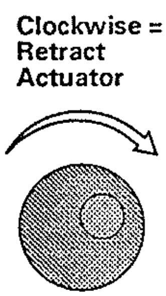


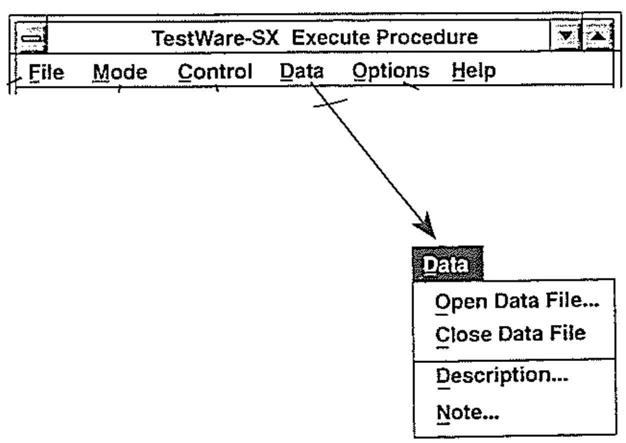
FINAL STEPS

17. Once the test is complete, the data file has to be closed. Click on "Data" in the "TestWare-SX Execute Procedure" to display a pull down menu. Click on "Close Data File" to close the test data file.

18. Click on the switch beside "Actuator Positioning Control" and **slowly** rotate the knob beside it in a clockwise direction until the applied load on the specimen is removed.

19. Click on "Control" in the "TestWare-SX Execute Procedure" window to display a pull down menu. Click on "Reset" to reset "Program Status".





APPENDIX B

MAINTENANCE

This section provides a maintenance schedule and example log sheet for the MTS Testing System. General maintenance procedures should be fully studied before begining any repair. Also, the "Safety Practices" described in Section 2 of the MTS Product Information Manual should be read concerning any maintenance procedure.

Interval	**Procedure**
Every 100 Operating Hours	Check Servovalve balance. Balance the Servovalve if necessary. (Reference: AC or DC Controller Product Manual)
Every 100 Lock and release cycles	Apply anti-seizing compound to the edges of the wedge. Material required: Malykote G-n lubricant. (Reference: Product Information Manual, Hydraulic Wedge Grips Section)
Every 500 Hours (Max. 6 months)	Replace the HPS filter element whenever the dirty-filter indicator extends from the filter manifold or when the hydraulic fluid is changed (Reference: Product Information Manual, Hydraulic Power Supply Section)
Monthly[1]	Check the hydraulic power supply (HPS) accumulator for a nitrogen precharge of 1000 psi (6.89 MPa). Renew the precharge if necessary. (Reference: Product Information Manual, Accumulator Series 111 Section)
	Check the 294.12 HSM slow-turn-on accumulator for a precharge of 100 psi (0.69 MPa). Renew precharge if necessary. (Reference: Product Information Manual, Accumulator Series 111 section)
	Check the HSM return-line accumulator for a nitrogen precharge of 50 psi (0.34 MPa). renew the precharge if necessary. (Reference: Product Information Manual, Accumulator Series 111 Section)
	Check the HSM pressure-line accumulator for a nitrogen precharge of 1000 psi (6.89 MPa). renew the precharge if necessary. (Reference: Product Information Manual, Accumulator Series 111 Section)

Monthly (cont'd)	Drain the hydraulic grips pressure supply air filter moisture trap. (Reference: Product Information Manual, Hydraulic Grips Section)
	Clean the air filter element in the control console. Replace if required. (Reference: Product Information Manual, Service Section, Appendix C)
As Required[2]	Flush the hydraulic system after making any replacement or modification of system hoses or hard plumbing. (Reference: Product Information Manual, Service Section, Appendix A)
	Replace the Actuator pressure seals when leakage past the seals becomes excessive. (Reference: Product Information Manual, Series 318 Load Unit Control Section)
	Replace the hydraulic lift seals when fluid leakage is evident during or following use. (Reference: Product Information Manual, Series 318 Load Unit Control Section)
	Align load cell whenever a major component of the Load Unit/Load Frame is removed and replaced. (Reference: Product Information Manual, Series 318 Load Unit or Load Frame Control Section)
	Bleed the Hydraulic Lift cylinders after Hydraulic System maintenance or when the Hydraulic lift cylinders do not operate smoothly. (Reference: Product Information Manual, Series 318 Load Unit or Load Frame Control Section)

[1] Use accumulator charger kit, either bought from MTS or locally fabricated
[2] Performed by MTS Service Engineers

CALIBRATION INFORMATION

TestStar provides two utilities that indicate when to calibrate and two programs that calibrate the electronic components of the system.
(Reference: Installation Manual)

MAINTENANCE LOG FOR MTS

System:
Page__ of __

NAME	PROCEDURE (OIL,FILTER CHANGE ETC)	RECOMMENDED INTERVAL	OPERATING HOURS/ DATE OF MAINTENANCE			

HYDRAULIC POWER SUPPLY
MODEL 510.10B
OIL FILTER REPLACEMENT

Check the dirty filter pop-up button first. If the red section is popped out, it is time to change the filter.

Filter Kit:

MTS: (800) 328-2255
Level 1 Kit (includes filter, o-rings)
MTS Part No.: 38750601
When calling MTS, operator will ask for a site number.
Our site no.: C49662-M02

Filter replacement:

MTS: (800) 328-2255
MTS Part No.: 100883-23
Filter replacement for the HPS Model 5510.10B
**Allow 3-4 days for delivery of filter.

O-ring replacement:

MTS: (800) 328-2255
MTS Part No.: 100115-06
O-ring replacement for the HPS Model 510.10B
**Allow 3-4 days for delivery of O-ring

Items needed:

Filter replacement or filter kit
O-ring replacement(s)
Log sheet
Lint-free cloth
Drain pan for oil

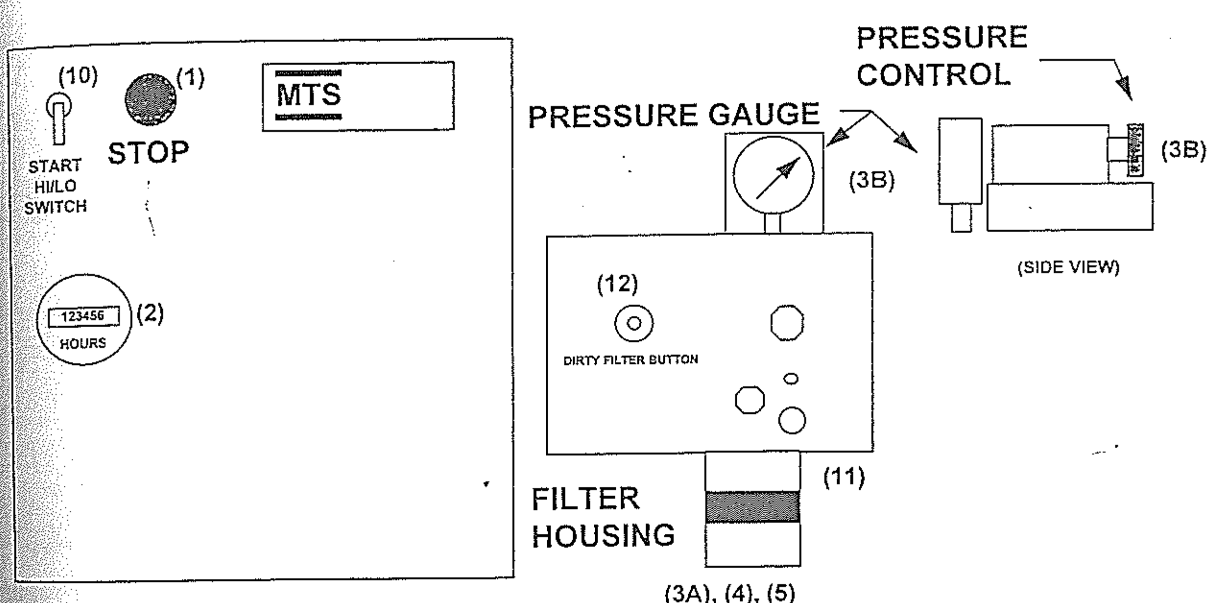
Procedure:

1. Turn off HPS (Stop button of control console).
2. Log hours from hours meter.
3. **Before loosening filter:**
   A. Put drain pan under filter.
   B. Make sure pressure is at zero.
4. Unscrew plug located at bottom of filter housing and allow to drain.
5. Once drained, unscrew filter housing carefully.
6. Throw away disposable part of filter and any excess oil.
7. Wipe out filter housing with a lint-free cloth.
8. Inspect O-rings for any deterioration. If any deterioration, replace them.
9. Insert new filter into housing and screw back onto manifold.
10. Turn on HPS, switch to high-pressure mode.
11. Check top of filter for leaks or oil. If there are any leaks, repeat steps 1-5

and 8-11.

12. If no leaks, reset dirty indicator by pressing in the pop-up button.

CONTROLS FOR HPS MODEL 510.10B



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