Appendix B

Data Analysis Algorithms

B1. INTRODUCTION

This appendix contains the algorithms used to determine the resilient modulus, creep compliance and indirect tensile strength for specimens tested using the P07 testing protocol. The algorithms presented herein are based upon the data format, data sampling rates and file structures used for LTPP P07 testing purposes. If formats, sampling rates or file structures used are different than outlined herein, the algorithms should be modified appropriately.

These algorithms are based upon the methods developed by Dr. Reynaldo Roque *et. al.* and documented in the report referenced in Section 4.4 of this protocol. Dr. Roque and his colleagues developed two programs, MRFHWA to reduce and analyze resilient modulus data, and ITLTFHWA to reduce and analyze creep compliance and indirect tensile strength data. The user's guide for the software is available as a separate document. The data analysis methods used in MRFHWA and ITLTFHWA are documented in this appendix. Appendix C of this document contains a step-by-step example of the calculations presented herein.

This appendix is divided into four sections as follows:

B1. Introduction
B2. Resilient Modulus Data Analysis Algorithm
B3. Creep Compliance Data Analysis Algorithm
B4. Indirect Tensile Strength Analysis Algorithm

B2. RESILIENT MODULUS DATA ANALYSIS ALGORITHM

An outline of the resilient modulus data analysis algorithm that is used in the "MRFHWA" software, and described in the report by Roque *et. al.* is presented in section B2.2. The algorithm is described graphically in section B2.3

B2.1 Subscript Convention

For the purpose of clarity, a subscript convention has been developed. The subscript 'i' represents the specimen number (i = 1, 2, or 3), the subscript 'j' represents the cycle number (j = 1, 2, or 3), and the subscript 'k' represents the specimen face (k = 1 or 2). Thus a variable may have up to three subscripts of the following form: $X_{i,j,k}$.

B2.2 Analysis

<u>A separate analysis must be performed for each of the three temperatures</u>.

B2.2.1 Select Cycles

For each of the three specimens, determine which three cycles of the five recorded in the data file shall be used for analysis. Find the maximum load (Pmax) of the first recorded cycle in the data file. If the maximum occurs at or after 150 points from the start of the file, then the first three cycles recorded in the data file shall be used for subsequent analysis. If the maximum occurs less than 150 points from the start of the file, then the second, third and fourth cycles recorded in the test shall be used. From now on, regardless of which cycles have been selected for analysis, they shall be referred to as cycles 1, 2 and 3, respectively.

B2.2.2 Calculate Contact Load ($Pcontact_i$)

For each of the three specimens calculate the contact load. Only one contact load shall be calculated for each specimen as follows:

(1) Determine the point at which the maximum load (Pmax) occurs for cycle 1.
(2) Select the range of cells from 80 points before Pmax to 30 points before Pmax (50 points total)

(3) Average the load values in the selected range as follows:

Eq. B1 :
$$Pcontact_i = \frac{\sum_{y=x-80}^{x-30} P_y}{50}$$

where: $Pcontact_i$ = the contact load for specimen i, lbs.
P_y = the load at point y, lbs.
x = the point at which $Pmax_{i,1}$ occurs

B2.2.3 Determine Cycle Start and End Points

For each cycle **j** on each specimen **i**, determine the start and end points as follows. Determine Pmax for cycle **j**

(1) Starting at Pmax, and moving to the left, the start of cycle **j** is defined as the last data point for which the load is greater than $Pcontact_i$ + 6 lbs. This value shall be referred to as $sp_{i,j}$.

(2) Starting at Pmax and moving to the right, the end point for cycle j is defined as the last data point for which the load is less than $Pcontact_i$ + 6 lbs. This value shall be referred to as $ep_{i,j}$.

B2.2.4 Determine the Cyclic Load

For each cycle **j** on each specimen **i**, determine the cyclic load ($Pcyclic_{i,j}$) as follows:

Eq. B2 :
$$Pcyclic_{i,j} = P\max_{i,j} - Pcontact_i$$

where: $Pcyclic_{i,j}$ = the cyclic load for cycle j of specimen i, lbs.
$Pmax_{i,j}$ = the maximum load for cycle j of specimen i, lbs.
$Pcontact_i$ = the contact load of specimen i, lbs

B2.2.5 Calculate the maximum deformations :

On each of the two sawn faces of the sample, deformations are measured in the horizontal and vertical axes. Thus for each sample there will be a total of four deformation vs. time traces. From each of these traces, pick off the maximum deformation for each of the three cycles, within the cycle start and end points defined in section B2.2.3. These deformations will be referred to in the following format:

$$\{\mathbf{H,V}\}\mathrm{max}_{\mathbf{i,j,k}}, \text{ inches}$$

where {H,V} refers to the axis in which the deformation was measured (horizontal or vertical) and subscripts i, j and k refer to the specimen, cycle and face, as defined in section B2.1.

B2.2.6 Determine minimum deformations :

For $\{\mathbf{H,V}\}\mathrm{max}_{\mathbf{i,j,k}}$ calculated in section 4.2.5 there will be two corresponding minimum deformations: Total and Instantaneous, as shown in Figure 3 of the main body of this procedure. To calculate these minimum deformations two regression lines must be developed. These minimum deformations shall be referred to in the following format:

$$\{\mathbf{H,V}\}\mathrm{min}\{\mathbf{I,T}\}_{\mathbf{i,j,k}}, \text{ inches}$$

where {H,V} refers to the axis in which the deformation was measured (horizontal or vertical), {I,T} refers to the type of deformation (instantaneous or total) and subscripts i, j and k refer to the specimen, cycle and face, as defined in section B2.1.

To calculate $\{\mathbf{H,V}\}\mathrm{min}\{\mathbf{I,T}\}_{\mathbf{i,j,k}}$, two regression lines must be developed from the deformation vs. time trace.

B2.2.6.1 Regression Line 1

(1) Starting at $\{\mathbf{H,V}\}\mathrm{max}_{\mathbf{i,j,k}}$ and moving to the right, select the 5^{th} through 17^{th} data points (13 data points total).

(2) Perform a least squares linear regression on deformation vs. time for the selected data points. The resulting equation shall be as follows:

Eq. B3 $$Deformation = m_1 \times (Time) + b_1$$

Where: m_1 = the slope of regression line 1, and

$b_1 =$ the Y-intercept of regression line 1

B2.2.6.2 Regression Line 2

(1) Starting at the start point of cycle **j+1** and moving to the left, select first 300 data points (300 data points total).

(2) Perform a least squares linear regression on deformation versus time for the selected data points. The resulting equation shall be as follows:

Eq. B4 $$Deformation = m_2 \times (Time) + b_2$$

Where: $m_2 =$ the slope of regression line 2, and
$b_2 =$ the Y-intercept of regression line 2

B2.2.6.3 Calculate $\{\mathbf{H,V}\}\mathrm{minI}_{\mathbf{i,j,k}}$

$\{\mathbf{H,V}\}\mathrm{minI}_{\mathbf{i,j,k}}$ is the deformation at the intersection of regression lines 1 and 2.

Eq. B5 $$\{H,V\}\min T_{i,j,k} = m_2 \times \left(\frac{b_2 - b_1}{m_1 - m_2}\right) + b_1$$

B2.2.6.4 Calculate $\{\mathbf{H,V}\}\mathrm{minT}_{\mathbf{i,j,k}}$
$\{\mathbf{H,V}\}\mathrm{minT}_{\mathbf{i,j,k}}$ is the deformation calculated from regression line 1 and the first point of cycle **j+1**

Eq.B6 $$\{H,V\}\min T_{i,j,k} = m_2 \times (sp_{i,j+1}) + b_2$$

B2.2.7 Calculate the total and instantaneous recoverable deformations

The total and instantaneous recoverable deformations shall be referred to as $\Delta\{H,V\}T_{i,j,k}$ and $)\{H,V\}I_{i,j,k}$ respectively.

Eq. B7 $$\Delta\{H,V\}\{I,T\}_{i,j,k} = \{H,V\}\max_{i,j,k} - \{H,V\}\min\{I,T\}_{i,j,k}$$

B2.2.8 Calculate average thickness and diameter

Eq. B8 $$tavg = \frac{\sum_{i=1}^{3} t_i}{3}$$

Eq. B9 $$davg = \frac{\sum_{i=1}^{3} d_i}{3}$$

Where: tavg = the average thickness for all the specimens, inches
t_i = the thickness of specimen i, in
davg = the average thickness for all the specimens, inches
d_i = the diameter of specimen i, in

B2.2.9 Calculate the average cyclic load

Eq. B10 $$Pavg_j = \frac{\sum_{i=1}^{3} Pcyclic_{i,j}}{3}$$

Where: $Pavg_j$ = the average cyclic load for cycle j, lbs.
$Pcyclic_{i,j}$ = the cyclic load for cycle j of specimen i, lbs.

B2.2.10 Calculate the deformation normalization factors

Eq. B11 $$Cnorm_{i,j} = \left(\frac{t_i}{tavg}\right) \times \left(\frac{d_i}{davg}\right) \times \left(\frac{Pcyclic_{i,j}}{Pavg_j}\right)$$

Where $Cnorm_{i,j}$ = the deformation correction factor for cycle j of specimen i,
t_i = the thickness of specimen i, in.
tavg = the average thickness of the specimens, in.

d_i = the diameter of specimen i,in.
davg = the average diameter of the specimens, in.
$Pcyclic_{i,j}$ = the cyclic load for cycle j of specimen i,lb.
$Pavg_j$ = the average cyclic load for cycle j lb.

B2.2.11 Calculate the normalized deformations

Eq. B12
$$\Delta\{H,V\}\{I,T\}n_{i,j,k} = \left(Cnorm_{i,j,k}\right)\times\left(\Delta\{H,V\}\{I,T\}_{i,j,k}\right)$$

Where: $\Delta\{H,V\}\{I,T\}n_{i,j,k}$ = the normalized deformation for face k and cycle j of specimen i, in.
$Cnorm_{i,j}$ = the deformation correction factor for cycle j of specimen i,
$\in\{H,V\}\{I,T\}_{i,j,k}$ = the deformation for face k and cycle j of specimen i, in.

B2.2.12 Average deformation data sets

There are 12 deformation data sets. A deformation data set consists of all the recoverable deformations calculated for a given axis {H,V}, measurement point {I,T} and cycle **j**. Average the deformation data sets by <u>one</u> of the following methods:

B2.2.12.1 Method 1: Normal Analysis

For each deformation data set, remove the highest and lowest deformation and average the remaining four. This average shall be referred to as $\Delta\{H,V\}\{I,T\}navg_j$

B2.2.12.2 Method 2: Variation of Normal Analysis

For each deformation data set, remove the tow highest and the two lowest deformations and average the remaining two. This average shall be referred to as $\Delta\{H,V\}\{I,T\}navg_j$

B2.2.12.3 Method 3: Individual Analysis

For each deformation data set, remove any deformations and average the remaining deformations. This average shall be referred to as $\Delta\{H,V\}\{I,T\}navg_j$

B2.2.13 Calculate Poisson's ratios

Eq. B13

$$\nu\{I,T\}_j = -0.1 + 1.480 \times \left(\frac{\Delta H\{I,T\}navg_j}{\Delta V\{I,T\}navg_j} \right) - 0.778 \times \left(\frac{\Delta HInavg_j}{\Delta VInavg_j} \right)$$

B2.2.14 Calculate the cycle averaged deformations

Eq. B14

$$\Delta\{H,V\}\{I,T\}ncycleavg = \frac{\sum_{j=1}^{3} \Delta\{H,V\}\{I,T\}navg_j}{3}$$

B2.2.15 Calculate the resilient modulus correction factors

Eq. B15

$$Cmr\{I,T\} = 0.6345 \times \left(\frac{\Delta V\{I,T\}ncycleavg}{\Delta H\{I,T\}ncycleavg} \right) - 0.332$$

B2.2.16 Calculate resilient modulus

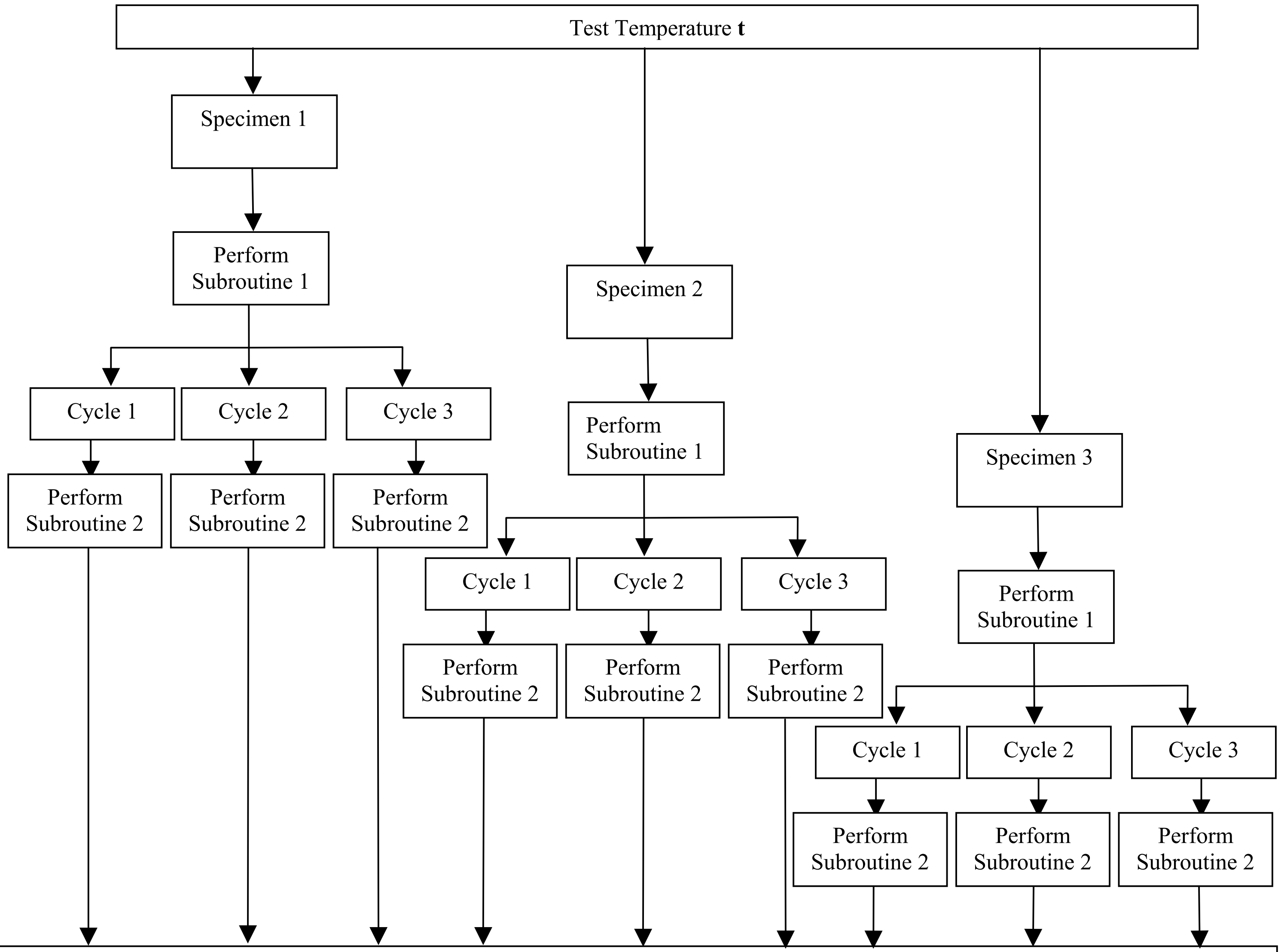
Eq. B16

$$M_r\{I,T\}_j = \frac{l \times Pavg_j}{\Delta H\{I,T\}navg_j \times davg \times tavg \times Cmr\{I,T\}}$$

B2.2.18 Repeat sections B2.2.1 through B2.2.17 for each temperature

B2.3 Resilient Modulus Data Analysis Algorithm Flowchart

B2.3.1 Main Procedure



Here's what you have calculated so far:

Specimen	Cycle	P_{cyclic}	Face 1 Deformations				Face 2 Deformations			
			Total		Instant.		Total		Instant.	
			Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.
1	1	$Pcyclic_{1,1}$	$\Delta HT_{1,1,1}$	$\Delta VT_{1,1,1}$	$\Delta HI_{1,1,1}$	$\Delta VI_{1,1,1}$	$\Delta HT_{1,1,2}$	$\Delta VT_{1,1,2}$	$\Delta HI_{1,1,2}$	$\Delta VI_{1,1,2}$
	2	$Pcyclic_{1,2}$	$\Delta HT_{1,2,1}$	$\Delta VT_{1,2,1}$	$\Delta HI_{1,2,1}$	$\Delta VI_{1,2,1}$	$\Delta HT_{1,2,2}$	$\Delta VT_{1,2,2}$	$\Delta HI_{1,2,2}$	$\Delta VI_{1,2,2}$
	3	$Pcyclic_{1,3}$	$\Delta HT_{1,3,1}$	$\Delta VT_{1,3,1}$	$\Delta HI_{1,3,1}$	$\Delta VI_{1,3,1}$	$\Delta HT_{1,3,2}$	$\Delta VT_{1,3,2}$	$\Delta HI_{1,3,2}$	$\Delta VI_{1,3,2}$
2	1	$Pcyclic_{2,1}$	$\Delta HT_{2,1,1}$	$\Delta VT_{2,1,1}$	$\Delta HI_{2,1,1}$	$\Delta VI_{2,1,1}$	$\Delta HT_{2,1,2}$	$\Delta VT_{2,1,2}$	$\Delta HI_{2,1,2}$	$\Delta VI_{2,1,2}$
	2	$Pcyclic_{2,2}$	$\Delta HT_{2,2,1}$	$\Delta VT_{2,2,1}$	$\Delta HI_{2,2,1}$	$\Delta VI_{2,2,1}$	$\Delta HT_{2,2,2}$	$\Delta VT_{2,2,2}$	$\Delta HI_{2,2,2}$	$\Delta VI_{2,2,2}$
	3	$Pcyclic_{2,3}$	$\Delta HT_{2,3,1}$	$\Delta VT_{2,3,1}$	$\Delta HI_{2,3,1}$	$\Delta VI_{2,3,1}$	$\Delta HT_{2,3,2}$	$\Delta VT_{2,3,2}$	$\Delta HI_{2,3,2}$	$\Delta VI_{2,3,2}$
3	1	$Pcyclic_{3,1}$	$\Delta HT_{21,1}$	$\Delta VT_{3,1,1}$	$\Delta HI_{3,1,1}$	$\Delta VI_{3,1,1}$	$\Delta HT_{3,1,2}$	$\Delta VT_{3,1,2}$	$\Delta HI_{3,1,2}$	$\Delta VI_{3,1,2}$
	2	$Pcyclic_{3,2}$	$\Delta HT_{2,2,1}$	$\Delta VT_{3,2,1}$	$\Delta HI_{3,2,1}$	$\Delta VI_{3,2,1}$	$\Delta HT_{3, 2,2}$	$\Delta VT_{3,2,2}$	$\Delta HI_{3,2,2}$	$\Delta VI_{3,2,2}$
	3	$Pcyclic_{3,3}$	$\Delta HT_{2,3,1}$	$\Delta VT_{3,3,1}$	$\Delta HI_{3,3,1}$	$\Delta VI_{3,3,1}$	$\Delta HT_{3,3,2}$	$\Delta VT_{3,3,2}$	$\Delta HI_{3,3,2}$	$\Delta VI_{3,3,2}$

1

1

Calculate average thickness (tavg)and diameter (davg)for each specimen:

$tavg = (t_1 + t_2 + t_3)/3$
$davg = (d_1 + d_2 + d_3)/3$

Calculate average cyclic load ($Pavg_j$) for each cycle:

$Pavg_j = Pcyclic_{1,j} + Pcyclic_{2,j} + Pcyclic_{3,j}$

Calculate $Cnorm_{i,j}$ for each specimen and cycle:

$Cnorm_{i,j} = (t_i / tavg) * (d_i / davg) * (Pcyclic_{i,j} / Pavg_j)$

Calculate normalized deformations ($\Delta\{H,V\}\{I,T\}norm_{i,j,k}$):

$\Delta\{H,V\}\{I,T\}n_{i,j,k} = Cnorm_{i,j} * \Delta\{H,V\}\{I,T\}_{i,j,k}$

Here's what you have calculated so far:

Spec-imen	Cycle	Pcyclic	Cnorm	Face 1 Normal.Deformations				Face 2 Normal. Deformations			
				Total		Instant.		Total		Instant.	
				Hor.	Vert.	Hor.	Vert.	Hor.	Vert.	Hor.	Vert.
1	1	$Pcyclic_{1,1}$	$Cnorm_{1,1}$	$\Delta HTn_{1,1,1}$	$\Delta VTn_{1,1,1}$	$\Delta HIn_{1,1,1}$	$\Delta VIn_{1,1,1}$	$\Delta HTn_{1,1,2}$	$\Delta VTn_{1,1,2}$	$\Delta HIn_{1,1,2}$	$\Delta VIn_{1,1,2}$
	2	$Pcyclic_{1,2}$	$Cnorm_{1,2}$	$\Delta HTn_{1,2,1}$	$\Delta VTn_{1,2,1}$	$\Delta HIn_{1,2,1}$	$\Delta VIn_{1,2,1}$	$\Delta HTn_{1,2,2}$	$\Delta VTn_{1,2,2}$	$\Delta HIn_{1,2,2}$	$\Delta VIn_{1,2,2}$
	3	$Pcyclic_{1,3}$	$Cnorm_{1,3}$	$\Delta HTn_{1,3,1}$	$\Delta VTn_{1,3,1}$	$\Delta HIn_{1,3,1}$	$\Delta VIn_{1,3,1}$	$\Delta HTn_{1,3,2}$	$\Delta VTn_{1,3,2}$	$\Delta HIn_{1,3,2}$	$\Delta VIn_{1,3,2}$
2	1	$Pcyclic_{2,1}$	$Cnorm_{2,1}$	$\Delta HTn_{2,1,1}$	$\Delta VTn_{2,1,1}$	$\Delta HIn_{2,1,1}$	$\Delta VIn_{2,1,1}$	$\Delta HTn_{2,1,2}$	$\Delta VTn_{2,1,2}$	$\Delta HIn_{2,1,2}$	$\Delta VIn_{2,1,2}$
	2	$Pcyclic_{2,2}$	$Cnorm_{2,2}$	$\Delta HTn_{2,2,1}$	$\Delta VTn_{2,2,1}$	$\Delta HIn_{2,2,1}$	$\Delta VIn_{2,2,1}$	$\Delta HTn_{2,2,2}$	$\Delta VTn_{2,2,2}$	$\Delta HIn_{2,2,2}$	$\Delta VIn_{2,2,2}$
	3	$Pcyclic_{2,3}$	$Cnorm_{2,3}$	$\Delta HTn_{2,3,1}$	$\Delta VTn_{2,3,1}$	$\Delta HIn_{2,3,1}$	$\Delta VIn_{2,3,1}$	$\Delta HTn_{2,3,2}$	$\Delta VTn_{2,3,2}$	$\Delta HIn_{2,3,2}$	$\Delta VIn_{2,3,2}$
3	1	$Pcyclic_{3,1}$	$Cnorm_{3,1}$	$\Delta HTn_{21,1}$	$\Delta VTn_{3,1,1}$	$\Delta HIn_{3,1,1}$	$\Delta VIn_{3,1,1}$	$\Delta HTn_{3,1,2}$	$\Delta VTn_{3,1,2}$	$\Delta HIn_{3,1,2}$	$\Delta VIn_{3,1,2}$
	2	$Pcyclic_{3,2}$	$Cnorm_{3,2}$	$\Delta HTn_{2,2,1}$	$\Delta VTn_{3,2,1}$	$\Delta HIn_{3,2,1}$	$\Delta VIn_{3,2,1}$	$\Delta HTn_{3, 2,2}$	$\Delta VTn_{3,2,2}$	$\Delta HIn_{3,2,2}$	$\Delta VIn_{3,2,2}$
	3	$Pcyclic_{3,3}$	$Cnorm_{3,3}$	$\Delta HT_{2,3,1}$	$\Delta VTn_{3,3,1}$	$\Delta HIn_{3,3,1}$	$\Delta VIn_{3,3,1}$	$\Delta HTn_{3,3,2}$	$\Delta VTn_{3,3,2}$	$\Delta HIn_{3,3,2}$	$\Delta VIn_{3,3,2}$

2

2

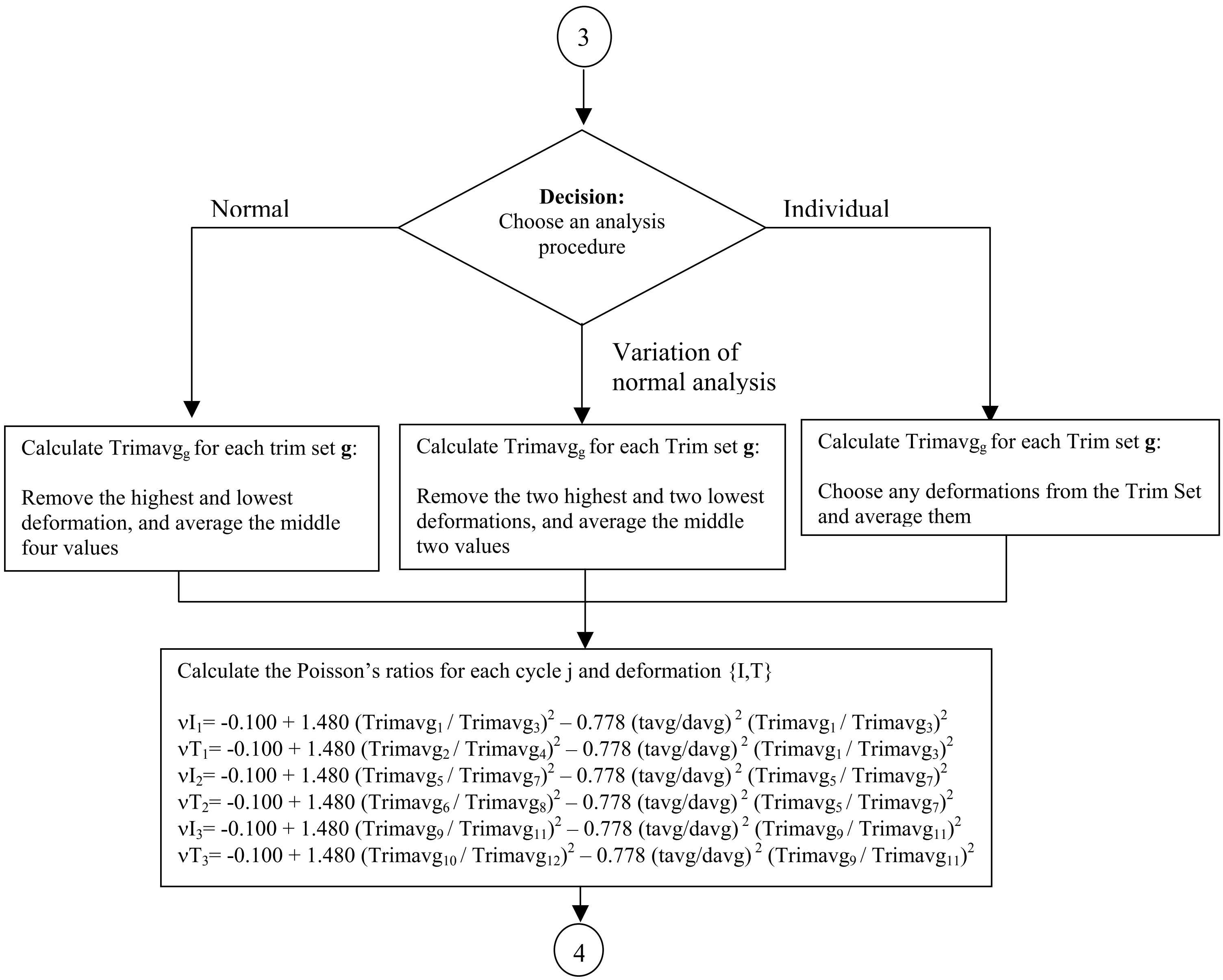
Develop Trim Data Sets ($Trim_{g,h}$)

Trim Data Sets

Set 1: Cycle1, Total Horizontal Deformation	Set 2: Cycle1, Instant Horizontal Deformation	Set 3: Cycle1, Total Vertical Deformation	Set 4: Cycle1, Instant Vertical Deformation	Set 5: Cycle 2, Total Horizontal Deformation	Set 6: Cycle 2, Instant Horizontal Deformation
$Trim_{1,1} = \Delta HTn_{1,1,1}$	$Trim_{2,1} = \Delta HIn_{1,1,1}$	$Trim_{3,1} = \Delta VTn_{1,1,1}$	$Trim_{4,1} = \Delta VIn_{1,1,1}$	$Trim_{5,1} = \Delta HTn_{1,2,1}$	$Trim_{6,1} = \Delta HIn_{1,2,1}$
$Trim_{1,2} = \Delta HTn_{2,1,1}$	$Trim_{2,2} = \Delta HIn_{2,1,1}$	$Trim_{3,2} = \Delta VTn_{2,1,1}$	$Trim_{4,2} = \Delta VIn_{2,1,1}$	$Trim_{5,2} = \Delta HTn_{2,2,1}$	$Trim_{6,2} = \Delta HIn_{2,2,1}$
$Trim_{1,3} = \Delta HTn_{3,1,1}$	$Trim_{2,3} = \Delta HIn_{3,1,1}$	$Trim_{3,3} = \Delta VTn_{3,1,1}$	$Trim_{4,3} = \Delta VIn_{3,1,1}$	$Trim_{5,3} = \Delta HTn_{3,2,1}$	$Trim_{6,3} = \Delta HIn_{3,2,1}$
$Trim_{1,4} = \Delta HTn_{1,1,2}$	$Trim_{2,4} = \Delta HIn_{1,1,2}$	$Trim_{3,4} = \Delta VTn_{1,1,2}$	$Trim_{4,4} = \Delta VIn_{1,1,2}$	$Trim_{5,4} = \Delta HTn_{1,2,2}$	$Trim_{6,4} = \Delta HIn_{1,2,2}$
$Trim_{1,5} = \Delta HTn_{2,1,2}$	$Trim_{2,5} = \Delta HIn_{2,1,2}$	$Trim_{3,5} = \Delta VTn_{2,1,2}$	$Trim_{4,5} = \Delta VIn_{2,1,2}$	$Trim_{5,5} = \Delta HTn_{2,2,2}$	$Trim_{6,5} = \Delta HIn_{2,2,2}$
$Trim_{1,6} = \Delta HTn_{3,1,2}$	$Trim_{2,6} = \Delta HIn_{3,1,2}$	$Trim_{3,6} = \Delta VTn_{3,1,2}$	$Trim_{4,6} = \Delta VIn_{3,1,2}$	$Trim_{5,6} = \Delta HTn_{3,2,2}$	$Trim_{6,6} = \Delta HIn_{3,2,2}$

Set 7: Cycle 2, Total Vertical Deformation	Set 8: Cycle 2, Instant. Vertical Deformation	Set 9: Cycle 3, Total Horizontal Deformation	Set 10: Cycle 3, Instant Horizontal Deformation	Set 11: Cycle 3, Total Vertical Deformation	Set 12: Cycle 3, Instant. Vertical Deformation
$Trim_{7,1} = \Delta VTn_{1,2,1}$	$Trim_{8,1} = \Delta VIn_{1,2,1}$	$Trim_{9,1} = \Delta HTn_{1,3,1}$	$Trim_{10,1} = \Delta HIn_{1,3,1}$	$Trim_{11,1} = \Delta VTn_{1,3,1}$	$Trim_{12,1} = \Delta VIn_{1,3,1}$
$Trim_{7,2} = \Delta VTn_{2,2,1}$	$Trim_{8,2} = \Delta VIn_{2,2,1}$	$Trim_{9,2} = \Delta HTn_{2,3,1}$	$Trim_{10,2} = \Delta HIn_{2,3,1}$	$Trim_{11,2} = \Delta VTn_{2,3,1}$	$Trim_{12,2} = \Delta VIn_{2,3,1}$
$Trim_{7,3} = \Delta VTn_{3,2,1}$	$Trim_{8,3} = \Delta VIn_{3,2,1}$	$Trim_{9,3} = \Delta HTn_{3,3,1}$	$Trim_{10,3} = \Delta HIn_{3,3,1}$	$Trim_{11,3} = \Delta VTn_{3,3,1}$	$Trim_{12,3} = \Delta VIn_{3,3,1}$
$Trim_{7,4} = \Delta VTn_{1,2,2}$	$Trim_{8,4} = \Delta VIn_{1,2,2}$	$Trim_{9,4} = \Delta HTn_{1,3,2}$	$Trim_{10,4} = \Delta HIn_{1,3,2}$	$Trim_{11,4} = \Delta VTn_{1,3,2}$	$Trim_{12,4} = \Delta VIn_{1,3,2}$
$Trim_{7,5} = \Delta VTn_{2,2,2}$	$Trim_{8,5} = \Delta VIn_{2,2,2}$	$Trim_{9,5} = \Delta HTn_{2,3,2}$	$Trim_{10,5} = \Delta HIn_{2,3,2}$	$Trim_{11,5} = \Delta VTn_{2,3,2}$	$Trim_{12,5} = \Delta VIn_{2,3,2}$
$Trim_{7,6} = \Delta VTn_{3,2,2}$	$Trim_{8,6} = \Delta VIn_{3,2,2}$	$Trim_{9,6} = \Delta HTn_{3,3,2}$	$Trim_{10,6} = \Delta HIn_{3,3,2}$	$Trim_{11,6} = \Delta VTn_{3,3,2}$	$Trim_{12,6} = \Delta VIn_{3,3,2}$

3


3
Decision:
Choose an analysis procedure
Normal
Variation of normal analysis
Individual
Calculate $Trimavg_g$ for each trim set **g**:
Remove the highest and lowest deformation, and average the middle four values
Calculate $Trimavg_g$ for each Trim set **g**:
Remove the two highest and two lowest deformations, and average the middle two values
Calculate $Trimavg_g$ for each Trim set **g**:
Choose any deformations from the Trim Set and average them
Calculate the Poisson's ratios for each cycle j and deformation {I,T}
$\nu I_1 = -0.100 + 1.480\,(Trimavg_1 / Trimavg_3)^2 - 0.778\,(tavg/davg)^2\,(Trimavg_1 / Trimavg_3)^2$
$\nu T_1 = -0.100 + 1.480\,(Trimavg_2 / Trimavg_4)^2 - 0.778\,(tavg/davg)^2\,(Trimavg_1 / Trimavg_3)^2$
$\nu I_2 = -0.100 + 1.480\,(Trimavg_5 / Trimavg_7)^2 - 0.778\,(tavg/davg)^2\,(Trimavg_5 / Trimavg_7)^2$
$\nu T_2 = -0.100 + 1.480\,(Trimavg_6 / Trimavg_8)^2 - 0.778\,(tavg/davg)^2\,(Trimavg_5 / Trimavg_7)^2$
$\nu I_3 = -0.100 + 1.480\,(Trimavg_9 / Trimavg_{11})^2 - 0.778\,(tavg/davg)^2\,(Trimavg_9 / Trimavg_{11})^2$
$\nu T_3 = -0.100 + 1.480\,(Trimavg_{10} / Trimavg_{12})^2 - 0.778\,(tavg/davg)^2\,(Trimavg_9 / Trimavg_{11})^2$
4

4

Calculate the cycle averaged trim deformation ($\Delta\{H,V\}\{I,T\}$trimavg) for each orientation {H,V} and deformation {I,T}:

ΔHTtrimavg = (Trimavg_1 + Trimavg_5 + Trimavg_9) / 3
ΔHItrimavg = (Trimavg_2 + Trimavg_6 + Trimavg_{10}) / 3
ΔVTtrimavg = (Trimavg_3 + Trimavg_7 + Trimavg_{11}) / 3
ΔVItrimavg = (Trimavg_4 + Trimavg_8 + Trimavg_{12}) / 3

Calculate resilient modulus correction factors (Cmr{I,T}):

CmrI = 0.6345 * (ΔHItrimavg/ΔVItrimavg)$^{-1}$ – 0.332
CmrlT = 0.6345 * (ΔHTtrimavg/ΔVTtrimavg)$^{-1}$ – 0.332

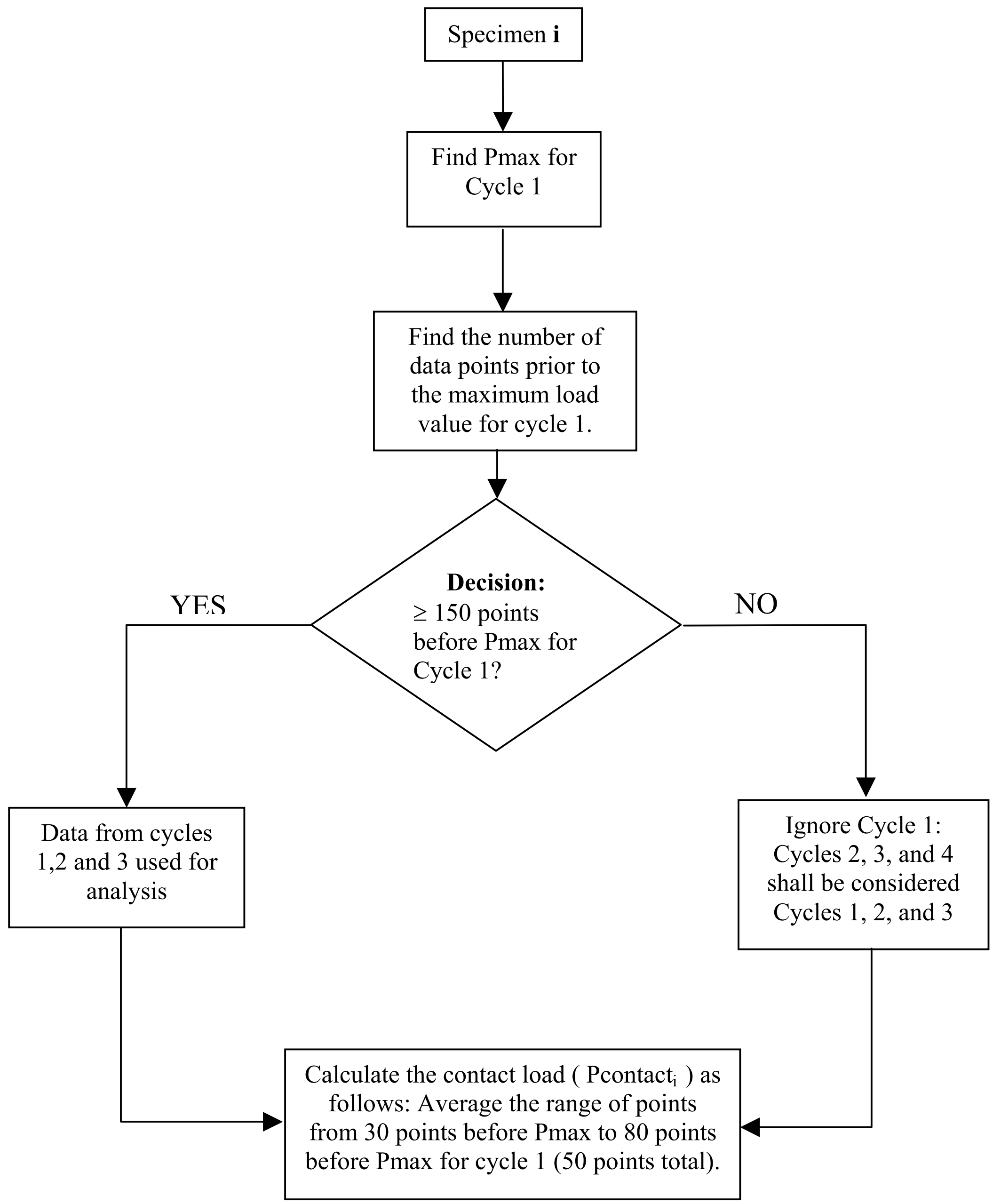
Calculate instantaneous and total resilient modulus ($\text{MR}\{I,T\}_j$) for each Cycle **j**

MRT_1 = (gauge length * Pavg_1) / (Trimavg_1 * davg * tavg * CcmplT)
MRI_1 = (gauge length * Pavg_1) / (Trimavg_2 * davg * tavg * CcmplI)
MRT_2 = (gauge length * Pavg_2) / (Trimavg_5 * davg * tavg * CcmplT)
MRI_2 = (gauge length * Pavg_2) / (Trimavg_6 * davg * tavg * CcmplI)
MRT_3 = (gauge length * Pavg_3) / (Trimavg_9 * davg * tavg * CcmplT)
MRI_3 = (gauge length * Pavg_3) / (Trimavg_{10} * davg * tavg * CcmplI)

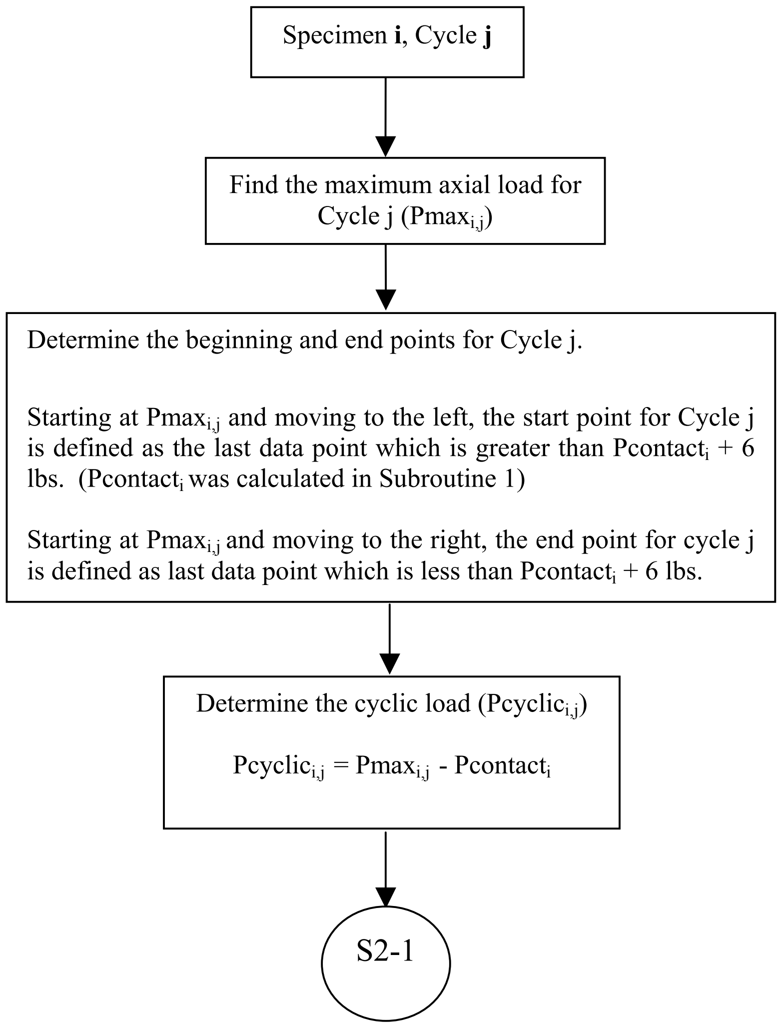
Report the following:

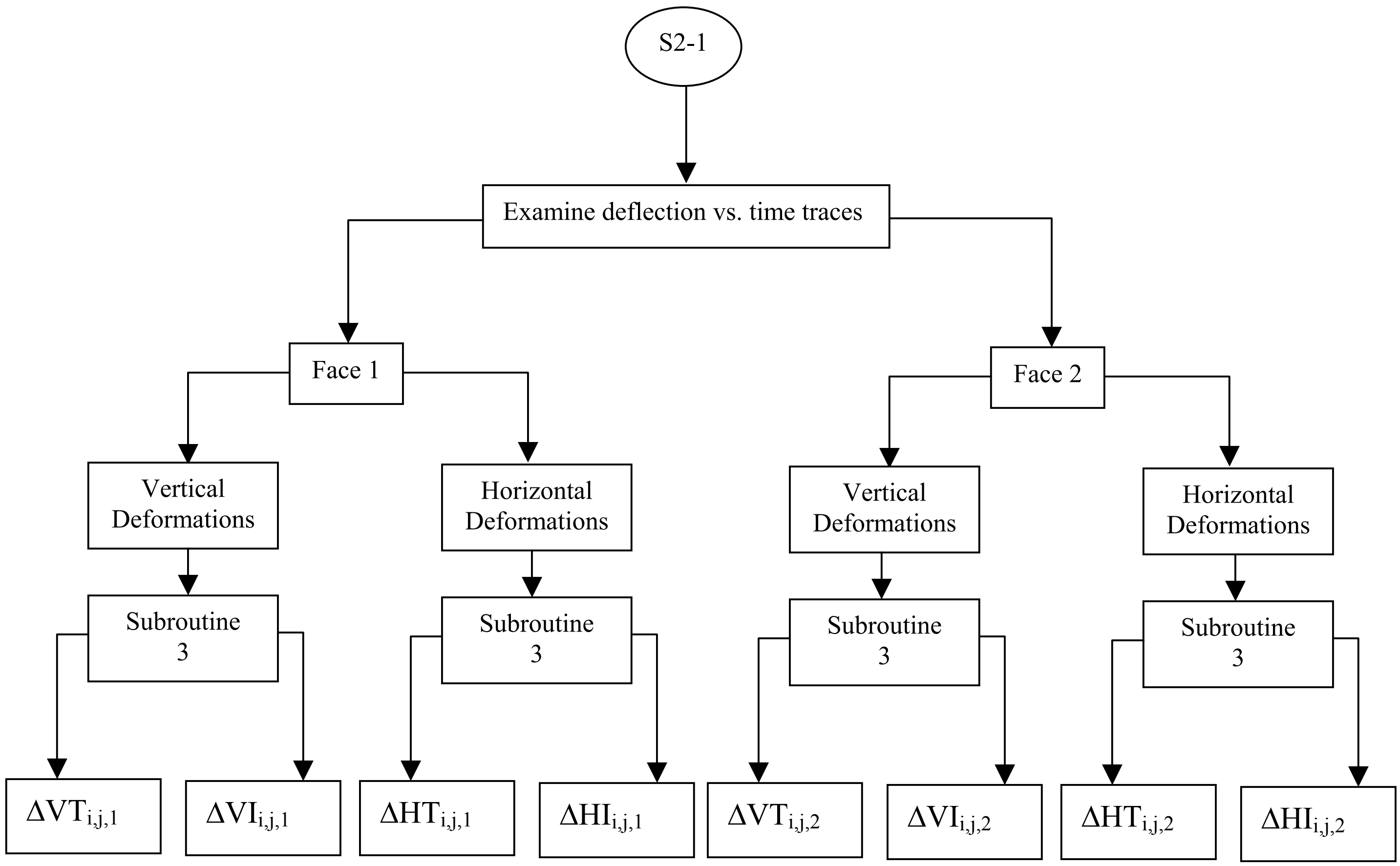
Cycle	νI_j	νT_j	MRI_j	MRT_j
1	νI_1	νT_1	MRI_1	MRT_1
2	νI_2	νT_2	MRI_2	MRT_2
3	νI_3	νT_3	MRI_3	MRT_3

B2.3.2 Subroutine 1

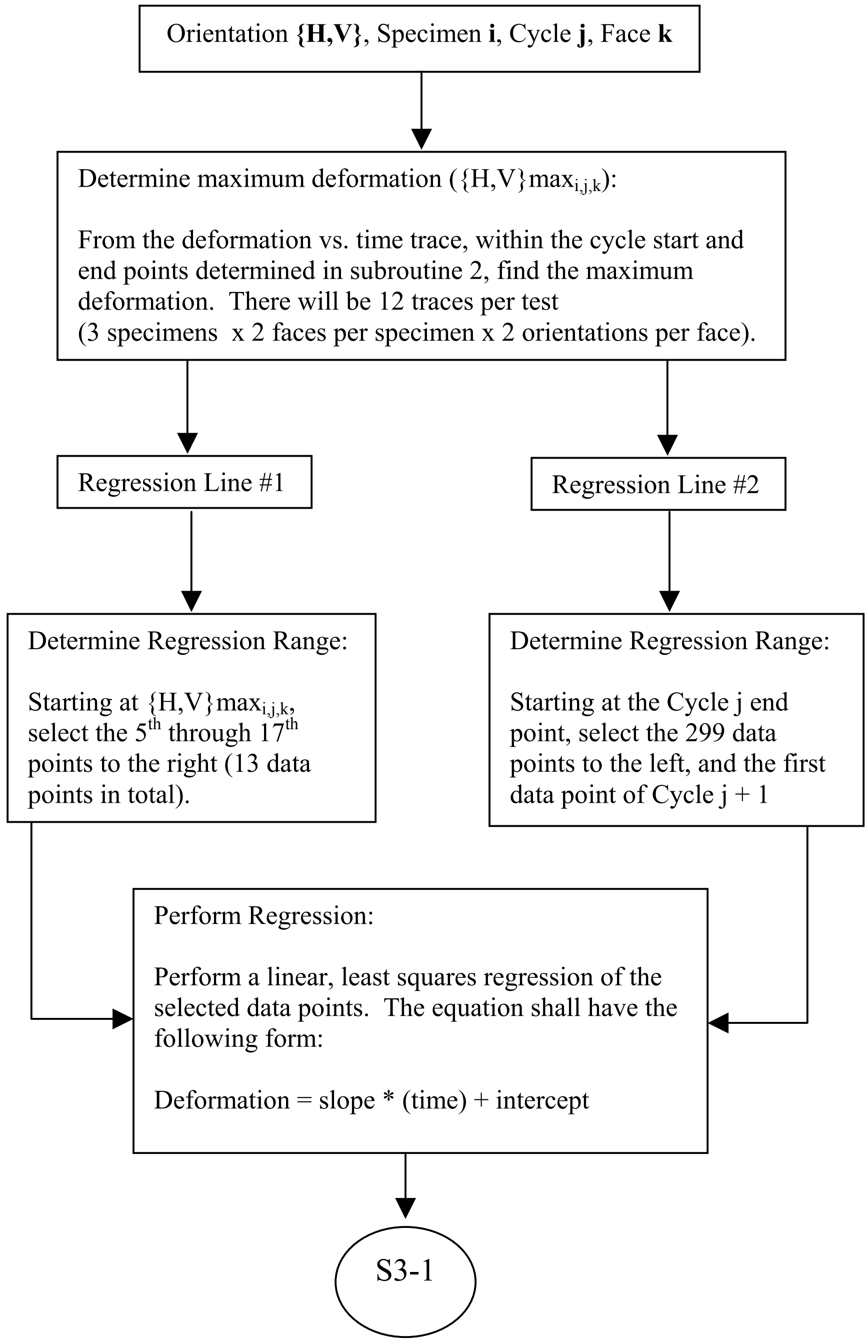


B2.3.3 Subroutine 2




S2-1
Examine deflection vs. time traces
Face 1
Face 2
Vertical Deformations
Horizontal Deformations
Vertical Deformations
Horizontal Deformations
Subroutine 3
Subroutine 3
Subroutine 3
Subroutine 3
$\Delta VT_{i,j,1}$
$\Delta VI_{i,j,1}$
$\Delta HT_{i,j,1}$
$\Delta HI_{i,j,1}$
$\Delta VT_{i,j,2}$
$\Delta VI_{i,j,2}$
$\Delta HT_{i,j,2}$
$\Delta HI_{i,j,2}$

B2.3.4 Subroutine 3



S3-1

Instantaneous Resilient Deformation ($\Delta\{H,V\}I_{i,j,k}$):

Find the intersection of regression lines 1 and 2. The deformation at this point is $\{H,V\}Imin_{i,j,k}$.

$\Delta\{H,V\}I_{i,j,k} = \{H,V\}max_{i,j,k} - \{H,V\}Imin_{i,j,k}$

Total Resilient Deformation ($\Delta\{H,V\}T_{i,j,k}$):

Find the deformation given by regression line 2 at the first point of Cycle J +1. This deformation is $\{H,V\}Tmin_{i,j,k}$.

$\Delta\{H,V\}T_{i,j,k} = \{H,V\}max_{i,j,k} - \{H,V\}Tmin_{i,j,k}$

B3. Creep Compliance Data Analysis Algorithm

An outline of the creep compliance data analysis algorithm that is used in the "ITLTFHWA" software, and described in the report by Roque *et. al.* is presented in section B3.2. The algorithm is described graphically in section B3.3.

B3.1 Subscript Convention

For the purpose of clarity, a subscript convention has been developed. The subscript 'i' represents the specimen number (i = 1, 2, or 3), the subscript 'j' represents the creep time (j = 1, 2, 5, 10, 20, 50, or 100), and the subscript 'k' represents the specimen face (k = 1 or 2). Thus a variable may have up to three subscripts of the following form: $X_{i,j,k}$.

B3.2 Analysis

A separate analysis must be performed for each of the three temperatures at which creep compliance data is collected.

B3.2.1 Determine the creep test start point

The 10th data point in the file is always assumed to be the starting point of the test. **It is essential that when the test is performed that exactly 10 data points are collected prior to the initial application of the creep load otherwise this analysis algorithm will produce erroneous results. Since the data sampling rate should be constant at 10 Hz, the creep load should be applied exactly 1 second after the data acquisition is initiated.**

B3.2.2 Determine initial extensometer readings

Determine the extensometer reading ($\{H,V\}min_{i,k}$) at the starting point of the creep test for each specimen **i** and face **k**. The starting point was defined in Section B3.2.1.

B3.2.3 Determine the extensometer reading for each creep time **j**

The Table B2 indicates the data point that corresponds to a certain creep time **j** for each face **k** of each specimen **i**.

Table B 2. Extensometer reading data points

Extensometer reading at time **j**	Data Point
$\{H,V\}_{i,1,k}$	20th point in data file
$\{H,V\}_{i,2,k}$	30th point in data file
$\{H,V\}_{i,5,k}$	60th point in data file
$\{H,V\}_{i,10,k}$	110th point in data file
$\{H,V\}_{i,20,k}$	210th point in data file
$\{H,V\}_{i,50,k}$	Average 505th point through 515th point (11 points total)
$\{H,V\}_{i,100,k}$	1010th point in data file

For a 100-second creep test, the deformations at 50 seconds are used to calculate the Poisson's ratio for the experiment. To prevent a spike in the data from influencing the Poisson ratio value, the average of the 505th point through the 515th point (11 points total) is taken as the deformation at 50 seconds.

B3.2.4 Calculate deformations for each creep time **j**, face **k**, and orientation {**H,V**} of each specimen **i**.

Eq. B20

$$\Delta\{H,V\}_{i,j,k} = \{H,V\}_{i,j,k} - \{H,V\}\min_{i,k}$$

Where: $\Delta\{H,V\}_{i,j,k}$ = the deformation for creep time **j** of face **k** of each specimen **i**, in.

$\{H,V\}_{i,j,k}$ = the extensometer reading for creep time **i** of face **k** of each specimen **i**, in.

$\{H,V\}\min_{i,k}$ = the extensometer reading at the start of the creep test for each face **k** of each specimen **i**, in.

B3.2.5 Determine the axial load ($P_{i,j}$) for each creep time **j** of each specimen **i**.

Table B 3. Axial load data points

Axial load at time **j**	Data Point
$P_{i,1}$	20th point in data file
$P_{i,2}$	30th point in data file
$P_{i,5}$	60th point in data file
$P_{i,10}$	110th point in data file
$P_{i,20}$	210th point in data file
$P_{i,50}$	510th point in data file
$P_{i,100}$	1010th point in data file

B3.2.6 Determine the average axial load (P_i) on specimen **i** .

Eq. B21

$$P_i = \frac{\sum_{t=1,2,5,10,20,50,100} P_{i,t}}{7}$$

where: P_i = the average axial load for specimen **i**, lbs.

$P_{i,t}$ = the axial load for specimen **i** at time = t, lbs.

B3.2.7 Calculate the average specimen thickness (tavg), the average specimen diameter (davg), and the average axial load (Pavg).

Eq. B22

$$tavg = \frac{\sum_{i=1}^{3} t_i}{3} \qquad davg = \frac{\sum_{i=1}^{3} d_i}{3} \qquad Pavg = \frac{\sum_{i=1}^{3} P_i}{3}$$

where: tavg = the average specimen thickness, in.

davg = the average specimen diameter, in.

Pavg = the average axial load, lbs.

t_i = the thickness of specimen **i**, in.

d_i = the diameter of specimen **i**, in.

P_i = the axial load for specimen **i**, lbs.

B3.2.8 Calculate the deformation normalization factor ($Cnorm_i$)for each specimen **i**.

Eq. B23

$$Cnorm_i = \left(\frac{t_i}{tavg}\right) \times \left(\frac{d_i}{davg}\right) \times \left(\frac{Pavg}{P_i}\right)$$

Where: $Cnorm_i$ = the deformation normalization factor for specimen **i**.
tavg = the average specimen thickness, inches.
davg = the average specimen diameter, inches.
Pavg = the average axial load, lbs.
t_i = the thickness of specimen **i**, inches.
d_i = the diameter of specimen **i**, inches.
P_i = the axial load for specimen **i**, lbs.

B3.2.9 Calculate the normalized deformations (♠{H,V}$norm_{i,j,k}$) for time **j** and face **k** of each specimen **i**.

Eq. B24

$$\Delta\{H,V\}norm_{i,j,k} = (Cnorm_i) \times \left(\Delta\{H,V\}_{i,j,k}\right)$$

where: $\Delta\{H,V\}norm_{i,j,k}$ = the normalized deformations for time **j** and face **k** of specimen **i**, inches.
$\Delta\{H,V\}_{i,j,k}$ = the deformation for creep time **j** of face **k** of each specimen **i**, inches.
$Cnorm_i$ = the deformation normalization factor for specimen **i**.

B3.2.10 Average deformation data sets

There are 14 "trim" data sets. A deformation data set consists of all the recoverable deformations calculated for a given orientation {H,V}, and time **j**. Average the deformation data sets by <u>one</u> of the following methods:

B3.2.10.1 Method 1: Normal Analysis

For each trim data set, remove the highest and lowest deformation and average the remaining four. This average shall be referred to as $\Delta\{H,V\}trimavg_j$ for time **j**.

B3.2.10.2 Method 2: Variation of Normal Analysis

For each trim data set, remove the two highest and the two lowest deformations and average the remaining two. This average shall be referred to as $\Delta\{H,V\}trimavg_j$ for time **j**.

B3.2.10.3 Method 3: Individual Analysis

For each trim data set, remove any deformations and average the remaining deformations. This average shall be referred to as $\Delta\{H,V\}trimavg_j$ for time **j**.

B3.2.11 Calculate the Poisson's Ratio at time = 50.

Eq. B25

$$\nu = -0.10 + 1.45\left(\frac{\Delta Htrimavg_{50}}{\Delta Vtrimavg_{50}}\right)^2 - 0.778\left(\frac{\Delta Htrimavg_{50}}{\Delta Vtrimavg_{50}}\right)^2\left(\frac{tavg}{davg}\right)^2$$

Where: ν = the Poisson's Ratio

$\Delta Htrimavg_{50}$ = the average horizontal trimmed deformation at time = 50, in.

$\Delta Vtrimavg_{50}$ = the average vertical trimmed deformation at time = 50, in.

tavg = the average specimen thickness, in.

davg = the average specimen diameter, in.

B3.2.12 Calculate the creep compliance correction factor ($Compl_y$) for each time **j**.

Eq. B26

$$Ccmpli = 0.6354\left(\frac{\Delta Htrimavg_j}{\Delta Vtrimavg_j}\right)^{-1} - 0.332$$

Where: $Ccmpl_j$ = the creep compliance correction factor at time **j**.

$\Delta Htrimavg_j$ = the average horizontal trimmed deformation at time **j**, in.

ΔVtrimavgj = the average vertical trimmed deformation at time **j**, in.

B3.2.13 Calculate the creep compliance for each time **j** .

Eq. B27

$$D_j = \left(\frac{\Delta Htrimavg_j \times davg \times tavg \times Ccmpl_j}{Pavg \times GL}\right)$$

where: D_j = the creep compliance at time **j**, 1/psi

$\Delta Htrimavg_j$ = the average horizontal trimmed deformation at time **j**, in.

davg = the average specimen diameter, in.

tavg = the average specimen thickness, in.

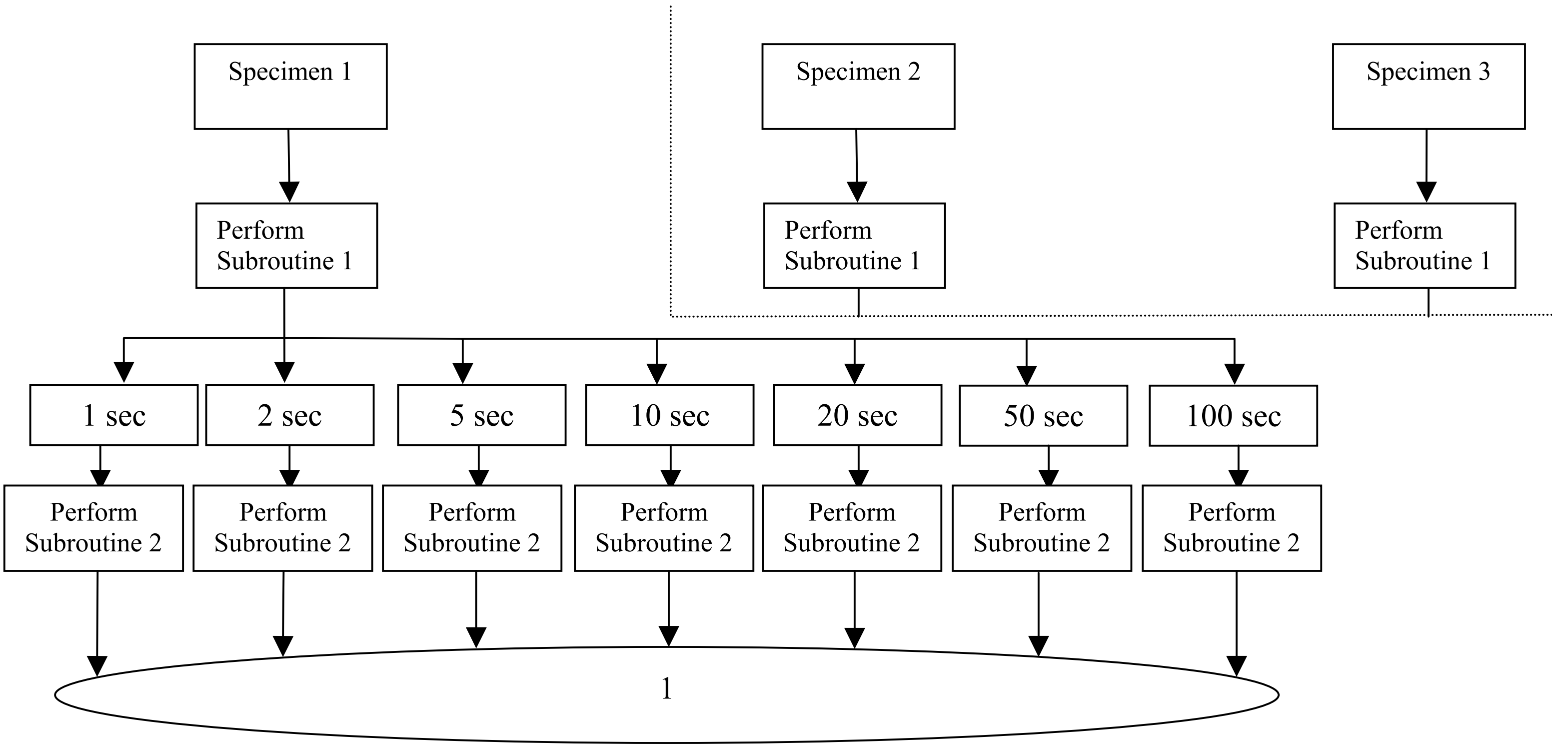
$Ccmpl_j$ = the creep compliance correction factor at time **j**.

Pavg = the average axial load, lbs.

GL = the extensometer gage length (1 inch for a nominal 4 inch specimen diameter, 1.5 inches for a nominal 6 inch specimen diameter).

B3.3 Creep Compliance Data Analysis Flow Charts

B3.3.1 Main Procedure



1

Here’s what you have calculated so far:

Specimen	P	Time (sec)	Face 1		Face 2	
			Horiz.	Vertical	Horiz.	Vertical
1	P_1	1	$\Delta H_{1,1,1}$	$\Delta V_{1,1,1}$	$\Delta H_{1,1,2}$	$\Delta V_{1,1,2}$
		2	$\Delta H_{1,2,1}$	$\Delta V_{1,2,1}$	$\Delta H_{1,2,2}$	$\Delta V_{1,2,2}$
		5	$\Delta H_{1,5,1}$	$\Delta V_{1,5,1}$	$\Delta H_{1,5,2}$	$\Delta V_{1,5,2}$
		10	$\Delta H_{1,10,1}$	$\Delta V_{1,10,1}$	$\Delta H_{1,10,2}$	$\Delta V_{1,10,2}$
		20	$\Delta H_{1,20,1}$	$\Delta V_{1,20,1}$	$\Delta H_{1,20,2}$	$\Delta V_{1,20,2}$
		50	$\Delta H_{1,50,1}$	$\Delta V_{1,50,1}$	$\Delta H_{1,50,2}$	$\Delta V_{1,50,2}$
		100	$\Delta H_{1,100,1}$	$\Delta V_{1,100,1}$	$\Delta H_{1,100,2}$	$\Delta V_{1,100,2}$
2	P_2	1	$\Delta H_{2,1,1}$	$\Delta V_{2,1,1}$	$\Delta H_{2,1,2}$	$\Delta V_{2,1,2}$
		2	$\Delta H_{2,2,1}$	$\Delta V_{2,2,1}$	$\Delta H_{2,2,2}$	$\Delta V_{2,2,2}$
		5	$\Delta H_{2,5,1}$	$\Delta V_{2,5,1}$	$\Delta H_{2,5,2}$	$\Delta V_{2,5,2}$
		10	$\Delta H_{2,10,1}$	$\Delta V_{2,10,1}$	$\Delta H_{2,10,2}$	$\Delta V_{2,10,2}$
		20	$\Delta H_{2,20,1}$	$\Delta V_{2,20,1}$	$\Delta H_{2,20,2}$	$\Delta V_{2,20,2}$
		50	$\Delta H_{2,50,1}$	$\Delta V_{2,50,1}$	$\Delta H_{2,50,2}$	$\Delta V_{2,50,2}$
		100	$\Delta H_{2,100,1}$	$\Delta V_{2,100,1}$	$\Delta H_{2,100,2}$	$\Delta V_{2,100,2}$
3	P_3	1	$\Delta H_{3,1,1}$	$\Delta V_{3,1,1}$	$\Delta H_{3,1,2}$	$\Delta V_{3,1,2}$
		2	$\Delta H_{3,2,1}$	$\Delta V_{3,2,1}$	$\Delta H_{3,2,2}$	$\Delta V_{3,2,2}$
		5	$\Delta H_{3,5,1}$	$\Delta V_{3,5,1}$	$\Delta H_{3,5,2}$	$\Delta V_{3,5,2}$
		10	$\Delta H_{3,10,1}$	$\Delta V_{3,10,1}$	$\Delta H_{3,10,2}$	$\Delta V_{3,10,2}$
		20	$\Delta H_{3,20,1}$	$\Delta V_{3,20,1}$	$\Delta H_{3,20,2}$	$\Delta V_{3,20,2}$
		50	$\Delta H_{3,50,1}$	$\Delta V_{3,50,1}$	$\Delta H_{3,50,2}$	$\Delta V_{3,50,2}$
		100	$\Delta H_{3,100,1}$	$\Delta V_{3,100,1}$	$\Delta H_{3,100,2}$	$\Delta V_{3,100,2}$

Calculate average specimen thickness (Tavg), diameter (Davg) and axial load (Pavg):

Tavg = $(T_1 + T_2 + T_3) / 3$
Davg = $(D_1 + D_2 + D_3) / 3$
Pavg = $(P_1 + P_2 + P_3) / 3$

2

2

Calculate the deformation normalization factors for each specimen **i** ($Cnorm_i$)

$Cnorm_i = (T_i / Tavg) * (D_i / Davg) * (Pavg / P_i)$

Calculate the normalized deformations for each orientation {H,V}specimen **i**, time **j** and face **k** ($\Delta\{H,V\}norm_{i,j,k}$):

$\Delta\{H,V\}norm_{i,j,k} = Cnorm_i * \Delta\{H,V\}_{i,j,k}$

Here's what you have calculated so far

Specimen	P	Cnorm	Time (sec)	Face 1		Face 2	
				Horiz.	Vertical	Horiz.	Vertical
1	P_1	$Cnorm_1$	1	$\Delta Hnorm_{1,1,1}$	$\Delta Vnorm_{1,1,1}$	$\Delta Hnorm_{1,1,2}$	$\Delta Vnorm_{1,1,2}$
			2	$\Delta Hnorm_{1,2,1}$	$\Delta Vnorm_{1,2,1}$	$\Delta Hnorm_{1,2,2}$	$\Delta Vnorm_{1,2,2}$
			5	$\Delta Hnorm_{1,5,1}$	$\Delta Vnorm_{1,5,1}$	$\Delta Hnorm_{1,5,2}$	$\Delta Vnorm_{1,5,2}$
			10	$\Delta Hnorm_{1,10,1}$	$\Delta Vnorm_{1,10,1}$	$\Delta Hnorm_{1,10,2}$	$\Delta Vnorm_{1,10,2}$
			20	$\Delta Hnorm_{1,20,1}$	$\Delta Vnorm_{1,20,1}$	$\Delta Hnorm_{1,20,2}$	$\Delta Vnorm_{1,20,2}$
			50	$\Delta Hnorm_{1,50,1}$	$\Delta Vnorm_{1,50,1}$	$\Delta Hnorm_{1,50,2}$	$\Delta Vnorm_{1,50,2}$
			100	$\Delta Hnorm_{1,100,1}$	$\Delta Vnorm_{1,100,1}$	$\Delta Hnorm_{1,100,2}$	$\Delta Vnorm_{1,100,2}$
2	P_2	$Cnorm_2$	1	$\Delta Hnorm_{2,1,1}$	$\Delta Vnorm_{2,1,1}$	$\Delta Hnorm_{2,1,2}$	$\Delta Vnorm_{2,1,2}$
			2	$\Delta Hnorm_{2,2,1}$	$\Delta Vnorm_{2,2,1}$	$\Delta Hnorm_{2,2,2}$	$\Delta Vnorm_{2,2,2}$
			5	$\Delta Hnorm_{2,5,1}$	$\Delta Vnorm_{2,5,1}$	$\Delta Hnorm_{2,5,2}$	$\Delta Vnorm_{2,5,2}$
			10	$\Delta Hnorm_{2,10,1}$	$\Delta Vnorm_{2,10,1}$	$\Delta Hnorm_{2,10,2}$	$\Delta Vnorm_{2,10,2}$
			20	$\Delta Hnorm_{2,20,1}$	$\Delta Vnorm_{2,20,1}$	$\Delta Hnorm_{2,20,2}$	$\Delta Vnorm_{2,20,2}$
			50	$\Delta Hnorm_{2,50,1}$	$\Delta Vnorm_{2,50,1}$	$\Delta Hnorm_{2,50,2}$	$\Delta Vnorm_{2,50,2}$
			100	$\Delta Hnorm_{2,100,1}$	$\Delta Vnorm_{2,100,1}$	$\Delta Hnorm_{2,100,2}$	$\Delta Vnorm_{2,100,2}$
3	P_3	$Cnorm_3$	1	$\Delta Hnorm_{3,1,1}$	$\Delta Vnorm_{3,1,1}$	$\Delta Hnorm_{3,1,2}$	$\Delta Vnorm_{3,1,2}$
			2	$\Delta Hnorm_{3,2,1}$	$\Delta Vnorm_{3,2,1}$	$\Delta Hnorm_{3,2,2}$	$\Delta Vnorm_{3,2,2}$
			5	$\Delta Hnorm_{3,5,1}$	$\Delta Vnorm_{3,5,1}$	$\Delta Hnorm_{3,5,2}$	$\Delta Vnorm_{3,5,2}$
			10	$\Delta Hnorm_{3,10,1}$	$\Delta Vnorm_{3,10,1}$	$\Delta Hnorm_{3,10,2}$	$\Delta Vnorm_{3,10,2}$
			20	$\Delta Hnorm_{3,20,1}$	$\Delta Vnorm_{3,20,1}$	$\Delta Hnorm_{3,20,2}$	$\Delta Vnorm_{3,20,2}$
			50	$\Delta Hnorm_{3,50,1}$	$\Delta Vnorm_{3,50,1}$	$\Delta Hnorm_{3,50,2}$	$\Delta Vnorm_{3,50,2}$
			100	$\Delta Hnorm_{3,100,1}$	$\Delta Vnorm_{3,100,1}$	$\Delta Hnorm_{3,100,2}$	$\Delta Vnorm_{3,100,2}$

3

3

Develop the trim data sets ($\Delta\{H,V\}trim_j$)

A trim data set consists of all the normalized deformations for a given time **j** and specimen orientation {**H,V**}

$\Delta Htrim_j = \{\Delta Hnorm_{1,j,1}, \Delta Hnorm_{1,j,2}, \Delta Hnorm_{2,j,1}, \Delta Hnorm_{2,j,2}, \Delta Hnorm_{3,j,1}, \Delta Hnorm_{3,j,2}\}$
$\Delta Vtrim_j = \{\Delta Vnorm_{1,j,1}, \Delta Vnorm_{1,j,2}, \Delta Vnorm_{2,j,1}, \Delta Vnorm_{2,j,2}, \Delta Vnorm_{3,j,1}, \Delta Vnorm_{3,j,2}\}$

Decision:
Choose an analysis procedure

Normal

Variation of normal analysis

Individual

Calculate $\Delta\{H,V\}trimavg_j$ for each orientation {H,V} and time **j** :

Remove the highest and lowest deformation, and average the middle four values

Calculate $\Delta\{H,V\}trimavg_j$ for each orientation {H,V} and time **j** :

Remove the two highest and two lowest deformations, and average the middle two values

Calculate $\Delta\{H,V\}trimavg_j$ for each orientation {H,V} and time **j** :

Choose any deformations from the Trim Set and average them

4

4

Calculate Poisson's Ratios at time **50** (ν_{50}):

$$\nu_{50} = -0.10 + (1.48 - 0.778 * (Tavg / Davg)^2) * (\Delta Htrimavg_{50} / \Delta Vtrimavg_{50})^2$$

Calculate the creep compliance correction factors for each time **j** ($Ccmpl_j$):

$$Ccmpl_j = 0.634 * (\Delta Vtrimavg_j / \Delta Htrimavg_j)$$

Calculate creep compliance at each time **j** (D_j):

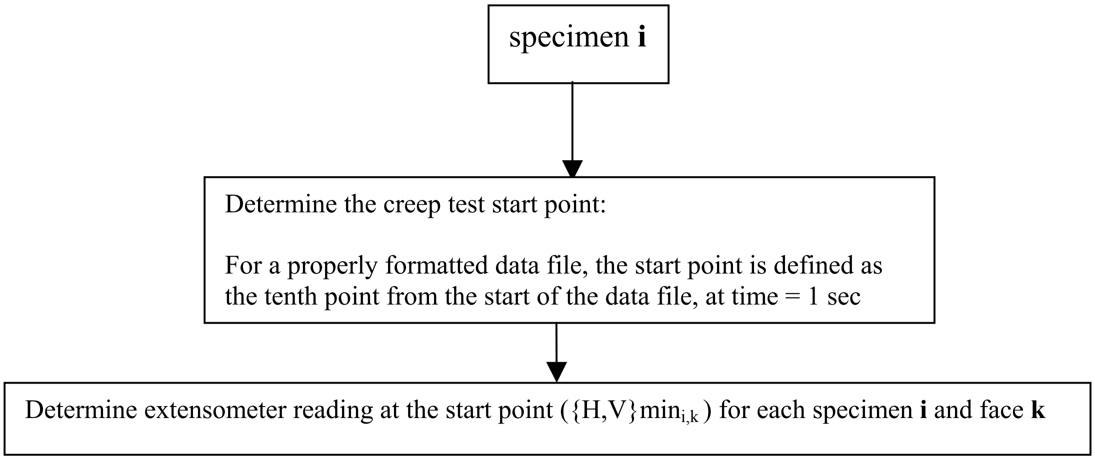
$$D_j = (\Delta Htrimavg_j) * (Davg) * (Tavg) * (Ccmpl_j) / ((Pavg) * (gauge\ length)$$

Report the following:

Time (sec)	D_j
1	D_1
2	D_2
5	D_5
10	D_{10}
20	D_{20}
50	D_{50}
100	D_{100}

ν_{50}

B3.3.2 Subroutine 1



B3.3.3 Subroutine 2

specimen **i**,

Determine the extensometer reading of specimen **i**, orientation {**H,V**} face **k** at time **j** ($\{H,V\}_{i,j,k}$):
<u>EXCEPT for time **50**</u>

From the deformation vs. time trace select the point at (start point + (j * 10))

Determine the extensometer reading of specimen **i**, orientation {**H,V**} face **k** at time **50** ($\{H,V\}_{i,j,50}$):

From the deformation vs. time trace select the points at (start point + 495) to (start point + 505), and average them

Calculate the deformation of specimen **i**, orientation {**H,V**} face **k** at time **j** ($\Delta\{H,V\}_{i,j,k}$):

$\Delta\{H,V\}_{i,j,k} = \{H,V\}_{i,j,k} - \{H,V\}min_{i,k}$

Determine the axial load on specimen **i**, at time **j** ($P_{i,j}$)

From the load vs. time trace select the point at (start point + (j * 10))

Calculate the average axial load on specimen **i**, ($P_{i,}$)

$P_i = (P_{i,1} + P_{i,2} + P_{i,5} + P_{i,10} + P_{i,20} + P_{i,50} + P_{i,100}) / 7$

B4. INDIRECT TENSILE STRENGTH DATA ANALYSIS ALGORITHIM

An outline of the indirect tensile strength algorithm that is used in the “ITLTFHWA” software, and described in the report by Roque et. al. is presented in section B4.2. The algorithm is described graphically in section B4.3

B4.1 Subscript Convention

For the purpose of clarity, a subscript convention has been developed. the subscript ‘i’ represents the specimen number (i = 1,2 or 3), the subscript ‘j’ represents the specimen face (j =1 or 2) and the subscript ‘t’ represents the time at which a value was measured. Thus a variable may have up to three subscripts of the following form: $X_{i,j,t}$.

B4.2 Analysis

B.4.2.1 Invert Load Values

For each of the three specimens, multiply all load values by –1, so that compression values are positive.

B.4.2.2 Determine Cycle Start Time (ts_i):

For specimen **i**, determine the time at which the load cycle starts. The load cycle start time is defined as the first time **t** that satisfies the following two requirements:

1) The load must continuously increase over the three data points subsequent to ts_i, as shown below:

Eq. B28:

$$P_{i,ts_i+1.5} \rangle P_{i,ts_i+1.0} \rangle P_{i,ts_i+0.5} \rangle P_{i,ts_i}$$

2) The load must increase by at least 40 lbs over the three data points subsequent to ts_i, as shown below:

Eq. B29:

$$P_{t+1.5} - P_t \rangle 40 lbs.$$

B4.2.3 Zero the Time Values

For each specimen **i**, subtract ts_i from each time value, so that the load cycle starts at t = 0.

B4.2.4 Zero the Load Values

For each specimen **i**, subtract the initial load value, $P_{i,0}$ from each load value, so that the load at the time the cycle starts is 0.

B4.2.5 Calculate the Deformation Zero Value ($\{H,V\}s_{i,j}$)

For each specimen **i**, face **j**, and orientation **{H,V}**, the deformation zero value is equal to the average of the 10 deformation values <u>prior</u> to the load cycle start, as shown below:

Eq. B30:

$$\{H,V\}s_{i,j} = \frac{\sum_{t=1}^{10} \{H,V\}_{i,j,\frac{-t}{2}}}{10}$$

B4.2.6 Zero the Deformation Values

For each specimen **i**, face **j**, and orientation **{H,V}**, subtract $\{H,V\}s_{i,j}$ from the respective deformation value.

B4.2.7 Determine the Failure Load ($P_{i,tfi}$)

B4.2.7.1 Determine $tf_{i,j}$

For each specimen **i**, and face **j**, determine the time where $V_{i,j,t} - H_{i,j,t}$ is at a maximum ($tf_{i,j}$).

B4.2.7.2 Determine Time of Specimen Failure (tf_i)

For each specimen **i**, the time of specimen failure (tf_i) is the minimum of $tf_{i,1}$ and $tf_{i,2}$.

B4.2.7.3 Determine the Failure Load ($P_{i,tfi}$)

For each specimen **i**, the failure load is the load **P** corresponding to time tf_i.

B4.2.9 Determine the Deformations at Half the Failure Load $\Delta\{H,V\}_{i,j}$)

B4.2.9.1 Determine the Time of Half Failure Load (th_i)

For each specimen **i,** th_i is the time that satisfies the following equation:

Eq. B31
$$P_{i,th_i} = \frac{P_{i,tf_i}}{2}$$

B4.2.9.2 Determine Deformations at Time th_i

For each specimen i, face j and orientation {H,V}, select the deformations at time th_i. This value shall be referred to as $\Delta\{H,V\}_{i,j}$.

B4.2.10 Calculate the Average Specimen Thickness and Diameter

Calculate the average specimen thickness (Tavg) and diameter (Davg) as shown below:

Eq. B32
$$Tavg = \frac{T_1 + T_2 + T_3}{3}$$

Eq. B33
$$Davg = \frac{D_1 + D_2 + D_3}{3}$$

B4.2.11 Calculate the Deformation Normalization Factors ($Cnorm_i$)

For each specimen i, calculate the deformation normalization factors as shown below:

Eq. B34
$$Cnorm_i = \frac{T_i}{Tavg} + \frac{D_i}{Davg}$$

B4.2.12 Calculate the Normalized Deformations (){H,V}$norm_{i,j}$)

Eq. B35
$$\Delta\{H,V\}norm_{i,j} = Cnorm_i \times \Delta\{H,V\}norm_{i,j}$$

B4.2.13 Average deformation data sets

There are 2 “trim” data sets. A deformation data set consists of all the normalized deformations calculated for a given orientation {H,V}. Average the deformation data sets by <u>one</u> of the following methods:

B4.2.13.1 Method 1: Normal Analysis

For each trim data set, remove the highest and lowest deformation and average the remaining four. This average shall be referred to as Δ{H,V}trimavg.

B4.2.13.2 Method 2: Variation of Normal Analysis

For each trim data set, remove the two highest and the two lowest deformations and average the remaining two. This average shall be referred to asΔ{H,V}trimavg.

B4.2.13.3 Method 3: Individual Analysis

For each trim data set, remove any deformations and average the remaining deformations. This average shall be referred to as Δ{H,V}trimavg.

B4.2.14 Calculate Poisson's Ratio (ν)

Eq. B36

$$\nu = -0.10 + 1.48\left(\frac{\Delta Htrimavg}{\Delta Vtrimavg}\right)^2 - 0.778\left(\frac{\Delta Htrimavg}{\Delta Vtrimavg}\right)^2 * \left(\frac{Tavg}{Davg}\right)^2$$

B4.2.15 Calculate "Used" Poisson's Ratio (υ_{used})

B4.2.15.1 Case 1: ν > 0.5

If the < calculated in step B4.2.14 is greater than 0.5, then $\nu_{used} = 0.5$.

B4.2.15.2 Case 2: ν < 0.05

If the < calculated in step B4.2.14 is less than 0.05, then $\nu_{used} = 0.05$.

B4.2.15.3 Case 3: 0.05 < ν < 0.5

If the ν calculated in step B4.2.14 is between 0.05 and 0.5, then $\nu_{used} = \nu$.

B4.2.16 Calculate the Stress Correction Factors

For each specimen **i**, calculate the stress correction factors as follows:

Eq. B37 $$CSX_i = 0.948 - 0.1114\left(\frac{T_i}{D_i}\right) - 0.2963 v_{used} + 1.463\left(\frac{T_i}{D_i}\right) v_{used}$$

B4.2.17 Calculate the Indirect Tensile Strength

For each specimen **i**, calculate the indirect tensile strength as follows:

Eq. B38 $$ITS_i = \frac{2 P_{i,tf_i} CSX_i}{\pi T_i D_i}$$

B4.2.18 Calculate the Average Indirect Tensile Strength

Eq. B39 $$ITSavg = \frac{ITS_1 + ITS_2 + ITS_3}{3}$$

B4.3 Indirect Tensile Strength Analysis Flowcharts

B4.3.1 Main Procedure

Specimen 1

Perform Subroutine 1

Specimen 2

Perform Subroutine 1

Specimen 3

Perform Subroutine 1

Here's what you have calculated so far:

Specimen	Load	Face 1 deformations		Face 2 Deformations	
		Horiz.	Vertical	Horiz.	Vertical
1	$P_{1,f}$	$\Delta H_{1,1,f/2}$	$\Delta V_{1,1,f/2}$	$\Delta H_{1,2,f/2}$	$\Delta V_{1,2,f/2}$
2	$P_{2,f}$	$\Delta H_{2,1,f/2}$	$\Delta V_{2,1,f/2}$	$\Delta H_{2,2,f/2}$	$\Delta V_{2,2,f/2}$
3	$P_{3,f}$	$\Delta H_{3,1,f/2}$	$\Delta V_{3,1,f/2}$	$\Delta H_{3,2,f/2}$	$\Delta V_{3,2,f/2}$

Calculate average specimen thickness (Tavg) and diameter (Davg):

$Tavg = (T_1 + T_2 + T_3) / 3$
$Davg = (D_1 + D_2 + D_3) / 3$

Calculate the deformation normalization factors for each specimen **i** ($Cnorm_i$)

$Cnorm_i = (T_i / Tavg) * (D_i / Davg)$

Calculate the normalized deformations for each orientation **{H,V}**, specimen **i** and face **j** ($\Delta\{H,V\}norm_{i,j,f/2}$):

$\Delta\{H,V\}norm_{i,j,f/2} = Cnorm_i * \Delta\{H,V\}_{i,j,f/2}$

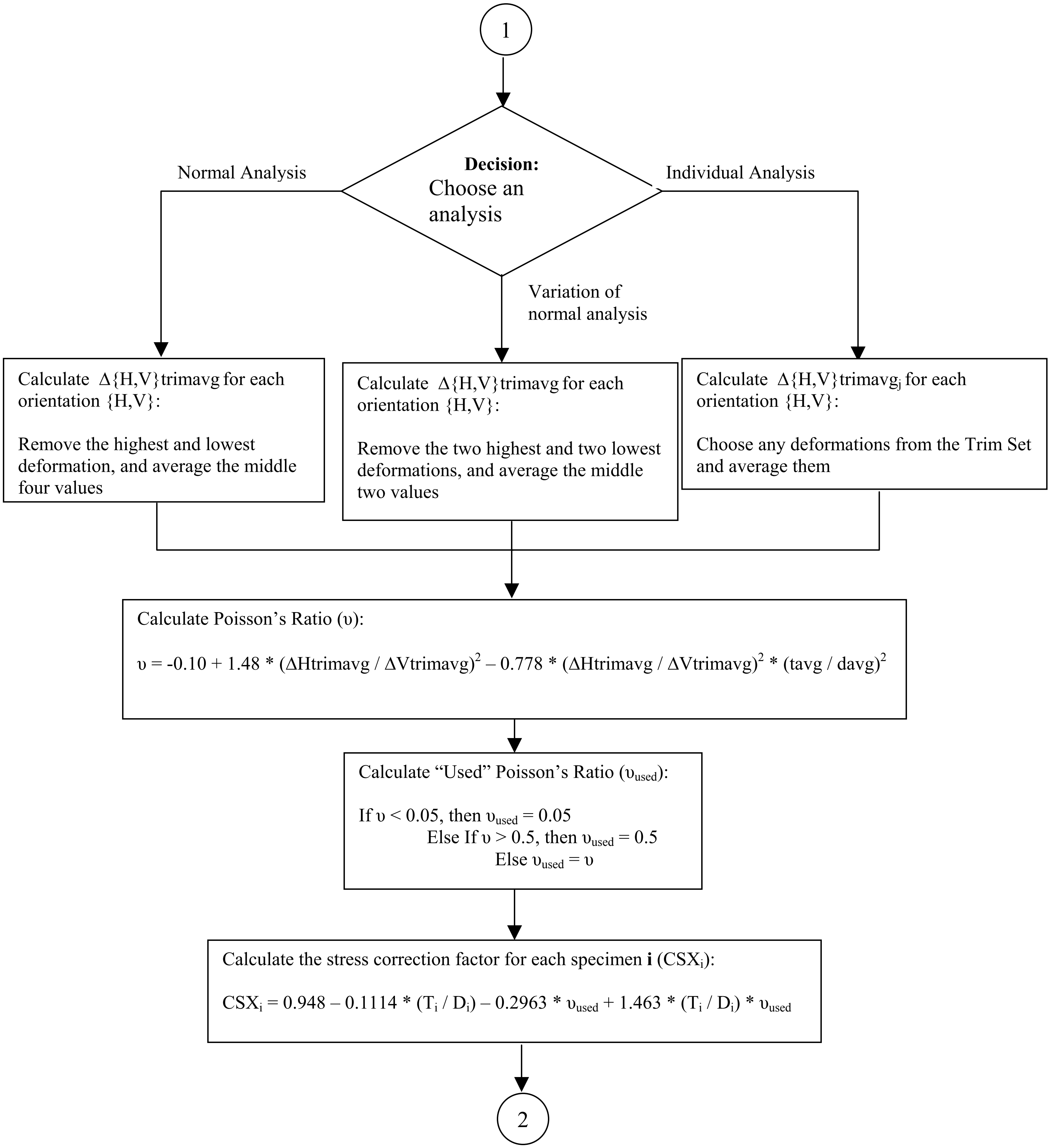
Develop the trim data sets (**Δ{H,V}trim**):

A trim data set contains all of the normalized deformations for a given specimen orientation {H,V}:

$\Delta Htrim = (\Delta Hnorm_{1,1,f/2}, \Delta Hnorm_{1,2,f/2}, \Delta Hnorm_{2,1,f/2}, \Delta Hnorm_{2,2,f/2}, \Delta Hnorm_{3,1,f/2}, \Delta Hnorm_{3,2,f/2})$

$\Delta Vtrim = (\Delta Vnorm_{1,1,f/2}, \Delta Vnorm_{1,2,f/2}, \Delta Vnorm_{2,1,f/2}, \Delta Vnorm_{2,2,f/2}, \Delta Vnorm_{3,1,f/2}, \Delta Vnorm_{3,2,f/2})$

1


1
Decision:
Choose an analysis
Normal Analysis
Variation of normal analysis
Individual Analysis
Calculate Δ{H,V}trimavg for each orientation {H,V}:
Remove the highest and lowest deformation, and average the middle four values
Calculate Δ{H,V}trimavg for each orientation {H,V}:
Remove the two highest and two lowest deformations, and average the middle two values
Calculate $\Delta\{H,V\}trimavg_j$ for each orientation {H,V}:
Choose any deformations from the Trim Set and average them
Calculate Poisson's Ratio (υ):
$\upsilon = -0.10 + 1.48 * (\Delta Htrimavg / \Delta Vtrimavg)^2 - 0.778 * (\Delta Htrimavg / \Delta Vtrimavg)^2 * (tavg / davg)^2$
Calculate "Used" Poisson's Ratio (υ_{used}):
If $\upsilon < 0.05$, then $\upsilon_{used} = 0.05$
Else If $\upsilon > 0.5$, then $\upsilon_{used} = 0.5$
Else $\upsilon_{used} = \upsilon$
Calculate the stress correction factor for each specimen **i** (CSX_i):
$CSX_i = 0.948 - 0.1114 * (T_i / D_i) - 0.2963 * \upsilon_{used} + 1.463 * (T_i / D_i) * \upsilon_{used}$
2

2

Calculate the indirect tensile strength for each specimen **i** (ITS_i):

$ITS_i = (2 * P_{i,f} * CSX_i) / (\pi * T_i * D_i)$

Calculate the average indirect tensile strength (ITSavg):

$ITSavg = (ITS_1 + ITS_2 + ITS_3) / 3$

Report the following:

ITS_1
ITS_2
ITS_3
ITSavg
υ
υ_{used}

B.4.3.2 Subroutine 1

Specimen i

↓

Multiply all load values by –1 so that compression values are positive.

↓

Determine the time at which the load cycle starts (s):

s is the earliest time **t** (in seconds) that satisfies the following two equations:

$P_{t+1.5} - P_t > 40$ lbs.

$P_{t+1.5} > P_{t+1.0} > P_{t+0.5} > P_t$

↓

Zero the time values for each time **t**:

SET $t = t - s$

↓

Normalize the load values, **P**, for each time **t** (P_t):

SET $P_t = P_t - P_s$

↓

Normalize the deformation values for each orientation **{H,V},** face **j** and time **t** ($\{H,V\}_{j,t}$):

SET $\{H,V\}_{j,t} = \{H,V\}_{j,t} - (\{H,V\}_{j,s-5.0} + \{H,V\}_{j,s-4.5} + \{H,V\}_{j,s-4.0} + \{H,V\}_{j,s-3.5} + \{H,V\}_{j,s-3.0} + \{H,V\}_{j,s-2.5} + \{H,V\}_{j,s-2.0} + \{H,V\}_{j,s-1.5} + \{H,V\}_{j,s-1.0} + \{H,V\}_{j,s-0.5}) / 10$

↓

S-1

S-1

Find the time at which maximum difference between the vertical and horizontal deformations occurs for each face **j** (f_j):

f_j is the time t where $(V\}_{j,t}$ - $\{H\}_{j,t}$ is at a maximum

Select the minimum of f_1 and f_2 (f). This is the time of the specimen failure.

Select the load **P** at time **f** (P_f). This is the specimen failure load

Find the time at which the load is one-half the failure load (f/2):

f/2 is the time t that satisfies the following equation:

$P_{f/2} = (P_f) / 2$

Select the deformations for each orientation {H,V} and face j ($\Delta\{HV\}_{j,f/2}$)

LTPP LABORATORY MATERIAL HANDLING AND TESTING
LABORATORY MATERIAL TEST DATA
CREEP COMPLIANCE, RESILIENT MODULUS AND INDIRECT TENSILE STRENGTH
***LAB DATA SHEET T07* - SAMPLE SUMMARY INFORMATION**

ASPHALT CONCRETE LAYER (ASPHALTIC CONCRETE PROPERTIES)
LTPP TEST DESIGNATION AC07/LTPP PROTOCOL P07

LABORATORY PERFORMING TEST:____

LABORATORY IDENTIFICATION CODE: ___ ___ ___ ___

1. STATE CODE: ___ ___ 2. SHRP ID: ___ ___ ___ ___

3. LAYER NO: ___ 4. FIELD SET: ___

DATA ITEM	SPECIMEN 1	SPECIMEN 2	SPECIMEN 3
5. TEST NO	___	___	___
6. SAMPLE AREA (SA-)	___ ___	___ ___	___ ___
7. LOCATION NO	___ ___ ___ ___ ___ ___	___ ___ ___ ___ ___ ___	___ ___ ___ ___ ___ ___
8. LTPP SAMPLE NO	___ ___ ___ ___ ___ ___ ___	___ ___ ___ ___ ___ ___ ___	___ ___ ___ ___ ___ ___ ___
9. AVG. THICKNESS (mm)	___ ___ . ___	___ ___ . ___	___ ___ . ___
10. AVG. DIAMETER (mm)	___ ___ ___ . ___	___ ___ ___ . ___	___ ___ ___ . ___
11. BULK SPECIFIC GRAVITY	___ . ___ ___ ___	___ . ___ ___ ___	___ . ___ ___ ___
12. COMMENT 1	___ ___	___ ___	___ ___
13. COMMENT 2	___ ___	___ ___	___ ___
14. COMMENT 3	___ ___	___ ___	___ ___
15. Other Comments			

1. STATE CODE: ___ ___ 2. SHRP ID: ___ ___ ___ ___

3. LAYER NO: ___ 4. FIELD SET: ___

DATA ITEM	SPECIMEN 1	SPECIMEN 2	SPECIMEN 3
RESILIENT MODULUS TEST			
16. DATA FILENAME, TEST 1	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT
17. TEST 1 TEMP. (°C)	___ ___ . ___	___ ___ . ___	___ ___ . ___
18. DATA FILENAME, TEST 2	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT
19. TEST 2 TEMP. (°C)	___ ___ . ___	___ ___ . ___	___ ___ . ___
20. DATA FILENAME, TEST 3	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT
21. TEST 3 TEMP. (°C)	___ ___ . ___	___ ___ . ___	___ ___ . ___
22. ANALYSIS FILENAME	_ _ _ _ _ _ _ _ . MRO		
CREEP COMPLIANCE TEST			
23. DATA FILENAME, TEST 1	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT
24. TEST 1 TEMP. (°C)	___ ___ . ___	___ ___ . ___	___ ___ . ___
25. DATA FILENAME, TEST 2	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT
26. TEST 2 TEMP. (°C)	___ ___ . ___	___ ___ . ___	___ ___ . ___
27. DATA FILENAME, TEST 3	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT
28. TEST 3 TEMP. (°C)	___ ___ . ___	___ ___ . ___	___ ___ . ___
29. ANALYSIS FILENAME	_ _ _ _ _ _ _ _ . OUT		
INDIRECT TENSILE STRENGTH TEST			
30. DATA FILENAME	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT	_ _ _ _ _ _ _ _ _ . DAT
31. TEST TEMP. (°C)	___ ___ . ___	___ ___ . ___	___ ___ . ___
32. ".OUT" FILENAME	_ _ _ _ _ _ _ _ . OUT		
33. ".STR" FILENAME	_ _ _ _ _ _ _ _ . STR		
34. ".FAM" FILENAME	_ _ _ _ _ _ _ _ . FAM		

GENERAL REMARKS: ____

SUBMITTED BY, DATE CHECKED AND APPROVED, DATE

______________________________ ______________________________

LABORATORY CHIEF

Affiliation: ______________________ Affiliation: ______________________