

# **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

A separate analysis must be performed for each of the three temperatures.

#### 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 ( $P_{max}$ ) 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 ( $P_{contact_i}$ )

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 ( $P_{max}$ ) occurs for cycle 1.
- (2) Select the range of cells from 80 points before  $P_{max}$  to 30 points before  $P_{max}$  (50 points total)

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

$$\text{Eq. B1 : } P_{\text{contact } i} = \frac{\sum_{y=x-80}^{x-30} P_y}{50}$$

where:  $P_{\text{contact } i}$  = the contact load for specimen  $i$ , lbs.

$P_y$  = the load at point  $y$ , lbs.

$x$  = the point at which  $P_{\text{max},i,1}$  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  $P_{\text{max}}$  for cycle  $j$

- (1) Starting at  $P_{\text{max}}$ , and moving to the left, the start of cycle  $j$  is defined as the last data point for which the load is greater than  $P_{\text{contact } i} + 6$  lbs. This value shall be referred to as  $sp_{i,j}$ .
- (2) Starting at  $P_{\text{max}}$  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  $P_{\text{contact } i} + 6$  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 ( $P_{\text{cyclic},i,j}$ ) as follows:

$$\text{Eq. B2 : } P_{\text{cyclic},i,j} = P_{\text{max},i,j} - P_{\text{contact } i}$$

where:  $P_{\text{cyclic},i,j}$  = the cyclic load for cycle  $j$  of specimen  $i$ , lbs.

$P_{\text{max},i,j}$  = the maximum load for cycle  $j$  of specimen  $i$ , lbs.

$P_{\text{contact } i}$  = 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:

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

where  $\{\mathbf{H}, \mathbf{V}\}$  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  $\{\mathbf{H}, \mathbf{V}\}_{\max_{i,j,k}}$  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:

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

where  $\{\mathbf{H}, \mathbf{V}\}$  refers to the axis in which the deformation was measured (horizontal or vertical),  $\{\mathbf{I}, \mathbf{T}\}$  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  $\{\mathbf{H}, \mathbf{V}\}_{\min \{\mathbf{I}, \mathbf{T}\}_{i,j,k}}$ , two regression lines must be developed from the deformation vs. time trace.

##### B2.2.6.1 Regression Line 1

- (1) Starting at  $\{\mathbf{H}, \mathbf{V}\}_{\max_{i,j,k}}$  and moving to the right, select the 5<sup>th</sup> through 17<sup>th</sup> 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

$$\text{Deformation} = m_1 \times (\text{Time}) + b_1$$

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 $\{\mathbf{H}, \mathbf{V}\}_{\min I_{i,j,k}}$

$\{\mathbf{H}, \mathbf{V}\}_{\min I_{i,j,k}}$  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 $\{\mathbf{H}, \mathbf{V}\}_{\min T_{i,j,k}}$ $\{\mathbf{H}, \mathbf{V}\}_{\min T_{i,j,k}}$ 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  $\Delta\{\mathbf{H}, \mathbf{V}\}_{T_{i,j,k}}$  and  $\{\mathbf{H}, \mathbf{V}\}_{I_{i,j,k}}$  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 
$$t_{avg} = \frac{\sum_{i=1}^3 t_i}{3}$$

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

Where:  $t_{avg}$  = the average thickness for all the specimens, inches  
 $t_i$  = the thickness of specimen i, in  
 $d_{avg}$  = 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 
$$P_{avg_j} = \frac{\sum_{i=1}^3 P_{cyclic_{i,j}}}{3}$$

Where:  $P_{avg_j}$  = the average cyclic load for cycle j, lbs.  
 $P_{cyclic_{i,j}}$  = the cyclic load for cycle j of specimen i, lbs.

#### B2.2.10 Calculate the deformation normalization factors

Eq. B11 
$$C_{norm_{i,j}} = \left( \frac{t_i}{t_{avg}} \right) \times \left( \frac{d_i}{d_{avg}} \right) \times \left( \frac{P_{cyclic_{i,j}}}{P_{avg_j}} \right)$$

Where  $C_{norm_{i,j}}$  = the deformation correction factor for cycle j of specimen i,  
 $t_i$  = the thickness of specimen i, in.  
 $t_{avg}$  = the average thickness of the specimens, in.

$d_i$  = the diameter of specimen i, in.  
 $d_{avg}$  = the average diameter of the specimens, in.  
 $P_{cyclic_{ij}}$  = the cyclic load for cycle j of specimen i, lb.  
 $P_{avg_j}$  = the average cyclic load for cycle j lb.

#### B2.2.11 Calculate the normalized deformations

Eq. B12

$$\Delta\{H,V\}\{I,T\}n_{i,j,k} = (C_{norm_{i,j,k}}) \times (\Delta\{H,V\}\{I,T\}_{i,j,k})$$

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

$C_{norm_{i,j}}$  = 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 one 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

$$\Delta\{H,V\}\{I,T\}_{avg_j}$$

##### 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  $\Delta\{H,V\}\{I,T\}_{avg_j}$

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

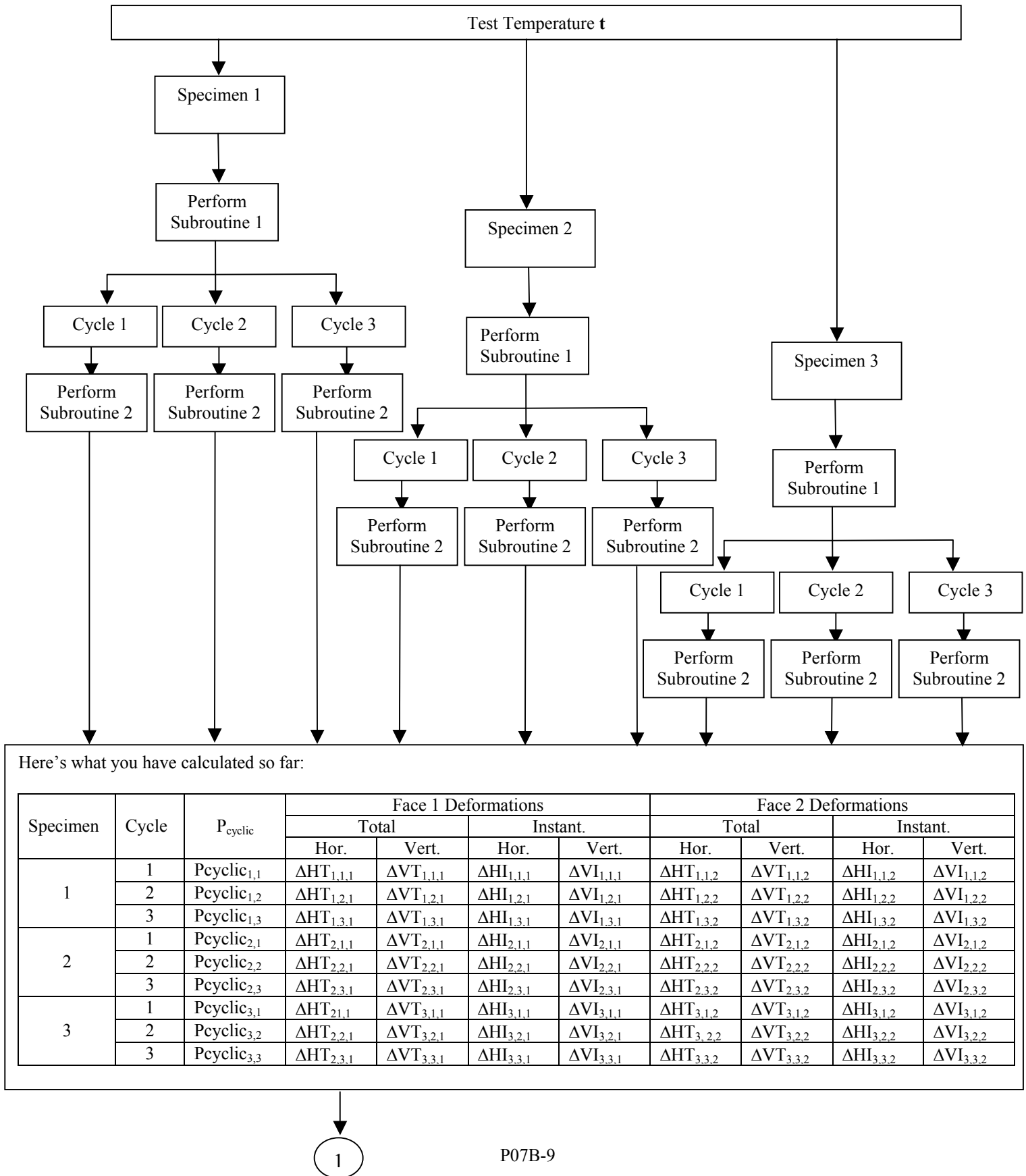
B2.2.16 Calculate resilient modulus

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



1

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

$$t_{avg} = (t_1 + t_2 + t_3)/3$$

$$d_{avg} = (d_1 + d_2 + d_3)/3$$

Calculate average cyclic load (Pavg<sub>j</sub>) for each cycle:

$$P_{avg_j} = P_{cyclic_{1,j}} + P_{cyclic_{2,j}} + P_{cyclic_{3,j}}$$

Calculate Cnorm<sub>i,j</sub> for each specimen and cycle:

$$C_{norm_{i,j}} = (t_i / t_{avg}) * (d_i / d_{avg}) * (P_{cyclic_{i,j}} / P_{avg_j})$$

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

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

Here's what you have calculated so far:

| Specimen | 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 <sub>1,1</sub> | Cnorm <sub>1,1</sub> | $\Delta HTn_{1,1,1}$        | $\Delta VTn_{1,1,1}$ | $\Delta HIn_{1,1,1}$ | $\Delta VIn_{1,1,1}$ | $\Delta HTn_{1,1,2}$        | $\Delta VTn_{1,1,2}$ | $\Delta HIn_{1,1,2}$ | $\Delta VIn_{1,1,2}$ |
|          | 2     | Pcyclic <sub>1,2</sub> | Cnorm <sub>1,2</sub> | $\Delta HTn_{1,2,1}$        | $\Delta VTn_{1,2,1}$ | $\Delta HIn_{1,2,1}$ | $\Delta VIn_{1,2,1}$ | $\Delta HTn_{1,2,2}$        | $\Delta VTn_{1,2,2}$ | $\Delta HIn_{1,2,2}$ | $\Delta VIn_{1,2,2}$ |
|          | 3     | Pcyclic <sub>1,3</sub> | Cnorm <sub>1,3</sub> | $\Delta HTn_{1,3,1}$        | $\Delta VTn_{1,3,1}$ | $\Delta HIn_{1,3,1}$ | $\Delta VIn_{1,3,1}$ | $\Delta HTn_{1,3,2}$        | $\Delta VTn_{1,3,2}$ | $\Delta HIn_{1,3,2}$ | $\Delta VIn_{1,3,2}$ |
| 2        | 1     | Pcyclic <sub>2,1</sub> | Cnorm <sub>2,1</sub> | $\Delta HTn_{2,1,1}$        | $\Delta VTn_{2,1,1}$ | $\Delta HIn_{2,1,1}$ | $\Delta VIn_{2,1,1}$ | $\Delta HTn_{2,1,2}$        | $\Delta VTn_{2,1,2}$ | $\Delta HIn_{2,1,2}$ | $\Delta VIn_{2,1,2}$ |
|          | 2     | Pcyclic <sub>2,2</sub> | Cnorm <sub>2,2</sub> | $\Delta HTn_{2,2,1}$        | $\Delta VTn_{2,2,1}$ | $\Delta HIn_{2,2,1}$ | $\Delta VIn_{2,2,1}$ | $\Delta HTn_{2,2,2}$        | $\Delta VTn_{2,2,2}$ | $\Delta HIn_{2,2,2}$ | $\Delta VIn_{2,2,2}$ |
|          | 3     | Pcyclic <sub>2,3</sub> | Cnorm <sub>2,3</sub> | $\Delta HTn_{2,3,1}$        | $\Delta VTn_{2,3,1}$ | $\Delta HIn_{2,3,1}$ | $\Delta VIn_{2,3,1}$ | $\Delta HTn_{2,3,2}$        | $\Delta VTn_{2,3,2}$ | $\Delta HIn_{2,3,2}$ | $\Delta VIn_{2,3,2}$ |
| 3        | 1     | Pcyclic <sub>3,1</sub> | Cnorm <sub>3,1</sub> | $\Delta HTn_{3,1,1}$        | $\Delta VTn_{3,1,1}$ | $\Delta HIn_{3,1,1}$ | $\Delta VIn_{3,1,1}$ | $\Delta HTn_{3,1,2}$        | $\Delta VTn_{3,1,2}$ | $\Delta HIn_{3,1,2}$ | $\Delta VIn_{3,1,2}$ |
|          | 2     | Pcyclic <sub>3,2</sub> | Cnorm <sub>3,2</sub> | $\Delta HTn_{3,2,1}$        | $\Delta VTn_{3,2,1}$ | $\Delta HIn_{3,2,1}$ | $\Delta VIn_{3,2,1}$ | $\Delta HTn_{3,2,2}$        | $\Delta VTn_{3,2,2}$ | $\Delta HIn_{3,2,2}$ | $\Delta VIn_{3,2,2}$ |
|          | 3     | Pcyclic <sub>3,3</sub> | Cnorm <sub>3,3</sub> | $\Delta HTn_{3,3,1}$        | $\Delta VTn_{3,3,1}$ | $\Delta HIn_{3,3,1}$ | $\Delta VIn_{3,3,1}$ | $\Delta HTn_{3,3,2}$        | $\Delta VTn_{3,3,2}$ | $\Delta HIn_{3,3,2}$ | $\Delta VIn_{3,3,2}$ |

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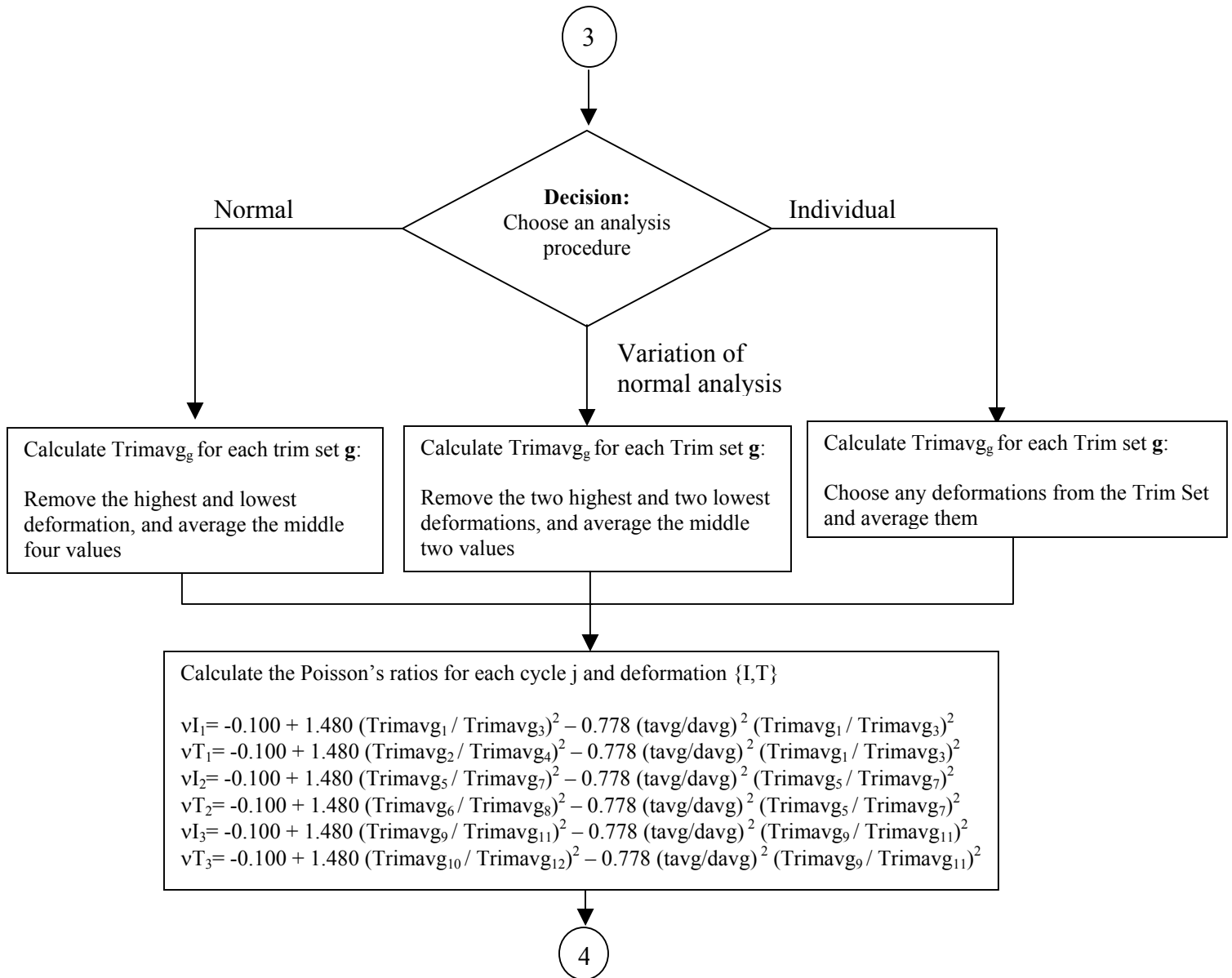
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Develop Trim Data Sets ( $\text{Trim}_{g,h}$ )

## Trim Data Sets

| Set 1: Cycle1,<br>Total Horizontal<br>Deformation                                                                                                                                                                                                                                                              | Set 2: Cycle1,<br>Instant Horizontal<br>Deformation                                                                                                                                                                                                                                                            | Set 3: Cycle1,<br>Total Vertical<br>Deformation                                                                                                                                                                                                                                                                | Set 4: Cycle1,<br>Instant Vertical<br>Deformation                                                                                                                                                                                                                                                                    | Set 5: Cycle 2,<br>Total Horizontal<br>Deformation                                                                                                                                                                                                                                                                   | Set 6: Cycle 2,<br>Instant Horizontal<br>Deformation                                                                                                                                                                                                                                                                 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\text{Trim}_{1,1} = \Delta \text{HTn}_{1,1,1}$<br>$\text{Trim}_{1,2} = \Delta \text{HTn}_{2,1,1}$<br>$\text{Trim}_{1,3} = \Delta \text{HTn}_{3,1,1}$<br>$\text{Trim}_{1,4} = \Delta \text{HTn}_{1,1,2}$<br>$\text{Trim}_{1,5} = \Delta \text{HTn}_{2,1,2}$<br>$\text{Trim}_{1,6} = \Delta \text{HTn}_{3,1,2}$ | $\text{Trim}_{2,1} = \Delta \text{HIn}_{1,1,1}$<br>$\text{Trim}_{2,2} = \Delta \text{HIn}_{2,1,1}$<br>$\text{Trim}_{2,3} = \Delta \text{HIn}_{3,1,1}$<br>$\text{Trim}_{2,4} = \Delta \text{HIn}_{1,1,2}$<br>$\text{Trim}_{2,5} = \Delta \text{HIn}_{2,1,2}$<br>$\text{Trim}_{2,6} = \Delta \text{HIn}_{3,1,2}$ | $\text{Trim}_{3,1} = \Delta \text{VTn}_{1,1,1}$<br>$\text{Trim}_{3,2} = \Delta \text{VTn}_{2,1,1}$<br>$\text{Trim}_{3,3} = \Delta \text{VTn}_{3,1,1}$<br>$\text{Trim}_{3,4} = \Delta \text{VTn}_{1,1,2}$<br>$\text{Trim}_{3,5} = \Delta \text{VTn}_{2,1,2}$<br>$\text{Trim}_{3,6} = \Delta \text{VTn}_{3,1,2}$ | $\text{Trim}_{4,1} = \Delta \text{VIn}_{1,1,1}$<br>$\text{Trim}_{4,2} = \Delta \text{VIn}_{2,1,1}$<br>$\text{Trim}_{4,3} = \Delta \text{VIn}_{3,1,1}$<br>$\text{Trim}_{4,4} = \Delta \text{VIn}_{1,1,2}$<br>$\text{Trim}_{4,5} = \Delta \text{VIn}_{2,1,2}$<br>$\text{Trim}_{4,6} = \Delta \text{VIn}_{3,1,2}$       | $\text{Trim}_{5,1} = \Delta \text{HTn}_{1,2,1}$<br>$\text{Trim}_{5,2} = \Delta \text{HTn}_{2,2,1}$<br>$\text{Trim}_{5,3} = \Delta \text{HTn}_{3,2,1}$<br>$\text{Trim}_{5,4} = \Delta \text{HTn}_{1,2,2}$<br>$\text{Trim}_{5,5} = \Delta \text{HTn}_{2,2,2}$<br>$\text{Trim}_{5,6} = \Delta \text{HTn}_{3,2,2}$       | $\text{Trim}_{6,1} = \Delta \text{HIn}_{1,2,1}$<br>$\text{Trim}_{6,2} = \Delta \text{HIn}_{2,2,1}$<br>$\text{Trim}_{6,3} = \Delta \text{HIn}_{3,2,1}$<br>$\text{Trim}_{6,4} = \Delta \text{HIn}_{1,2,2}$<br>$\text{Trim}_{6,5} = \Delta \text{HIn}_{2,2,2}$<br>$\text{Trim}_{6,6} = \Delta \text{HIn}_{3,2,2}$       |
| Set 7: Cycle 2,<br>Total Vertical<br>Deformation                                                                                                                                                                                                                                                               | Set 8: Cycle 2,<br>Instant. Vertical<br>Deformation                                                                                                                                                                                                                                                            | Set 9: Cycle 3,<br>Total Horizontal<br>Deformation                                                                                                                                                                                                                                                             | Set 10: Cycle 3,<br>Instant Horizontal<br>Deformation                                                                                                                                                                                                                                                                | Set 11: Cycle 3,<br>Total Vertical<br>Deformation                                                                                                                                                                                                                                                                    | Set 12: Cycle 3,<br>Instant. Vertical<br>Deformation                                                                                                                                                                                                                                                                 |
| $\text{Trim}_{7,1} = \Delta \text{VTn}_{1,2,1}$<br>$\text{Trim}_{7,2} = \Delta \text{VTn}_{2,2,1}$<br>$\text{Trim}_{7,3} = \Delta \text{VTn}_{3,2,1}$<br>$\text{Trim}_{7,4} = \Delta \text{VTn}_{1,2,2}$<br>$\text{Trim}_{7,5} = \Delta \text{VTn}_{2,2,2}$<br>$\text{Trim}_{7,6} = \Delta \text{VTn}_{3,2,2}$ | $\text{Trim}_{8,1} = \Delta \text{VIn}_{1,2,1}$<br>$\text{Trim}_{8,2} = \Delta \text{VIn}_{2,2,1}$<br>$\text{Trim}_{8,3} = \Delta \text{VIn}_{3,2,1}$<br>$\text{Trim}_{8,4} = \Delta \text{VIn}_{1,2,2}$<br>$\text{Trim}_{8,5} = \Delta \text{VIn}_{2,2,2}$<br>$\text{Trim}_{8,6} = \Delta \text{VIn}_{3,2,2}$ | $\text{Trim}_{9,1} = \Delta \text{HTn}_{1,3,1}$<br>$\text{Trim}_{9,2} = \Delta \text{HTn}_{2,3,1}$<br>$\text{Trim}_{9,3} = \Delta \text{HTn}_{3,3,1}$<br>$\text{Trim}_{9,4} = \Delta \text{HTn}_{1,3,2}$<br>$\text{Trim}_{9,5} = \Delta \text{HTn}_{2,3,2}$<br>$\text{Trim}_{9,6} = \Delta \text{HTn}_{3,3,2}$ | $\text{Trim}_{10,1} = \Delta \text{HIn}_{1,3,1}$<br>$\text{Trim}_{10,2} = \Delta \text{HIn}_{2,3,1}$<br>$\text{Trim}_{10,3} = \Delta \text{HIn}_{3,3,1}$<br>$\text{Trim}_{10,4} = \Delta \text{HIn}_{1,3,2}$<br>$\text{Trim}_{10,5} = \Delta \text{HIn}_{2,3,2}$<br>$\text{Trim}_{10,6} = \Delta \text{HIn}_{3,3,2}$ | $\text{Trim}_{11,1} = \Delta \text{VTn}_{1,3,1}$<br>$\text{Trim}_{11,2} = \Delta \text{VTn}_{2,3,1}$<br>$\text{Trim}_{11,3} = \Delta \text{VTn}_{3,3,1}$<br>$\text{Trim}_{11,4} = \Delta \text{VTn}_{1,3,2}$<br>$\text{Trim}_{11,5} = \Delta \text{VTn}_{2,3,2}$<br>$\text{Trim}_{11,6} = \Delta \text{VTn}_{3,3,2}$ | $\text{Trim}_{12,1} = \Delta \text{VIn}_{1,3,1}$<br>$\text{Trim}_{12,2} = \Delta \text{VIn}_{2,3,1}$<br>$\text{Trim}_{12,3} = \Delta \text{VIn}_{3,3,1}$<br>$\text{Trim}_{12,4} = \Delta \text{VIn}_{1,3,2}$<br>$\text{Trim}_{12,5} = \Delta \text{VIn}_{2,3,2}$<br>$\text{Trim}_{12,6} = \Delta \text{VIn}_{3,3,2}$ |

3



4

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

$$\begin{aligned}\Delta H T \text{trimavg} &= (\text{Trimavg}_1 + \text{Trimavg}_5 + \text{Trimavg}_9) / 3 \\ \Delta H I \text{trimavg} &= (\text{Trimavg}_2 + \text{Trimavg}_6 + \text{Trimavg}_{10}) / 3 \\ \Delta V T \text{trimavg} &= (\text{Trimavg}_3 + \text{Trimavg}_7 + \text{Trimavg}_{11}) / 3 \\ \Delta V I \text{trimavg} &= (\text{Trimavg}_4 + \text{Trimavg}_8 + \text{Trimavg}_{12}) / 3\end{aligned}$$

Calculate resilient modulus correction factors ( $C_{mr}\{I,T\}$ ):

$$\begin{aligned}C_{mrI} &= 0.6345 * (\Delta H I \text{trimavg} / \Delta V I \text{trimavg})^{-1} - 0.332 \\ C_{mrT} &= 0.6345 * (\Delta H T \text{trimavg} / \Delta V T \text{trimavg})^{-1} - 0.332\end{aligned}$$

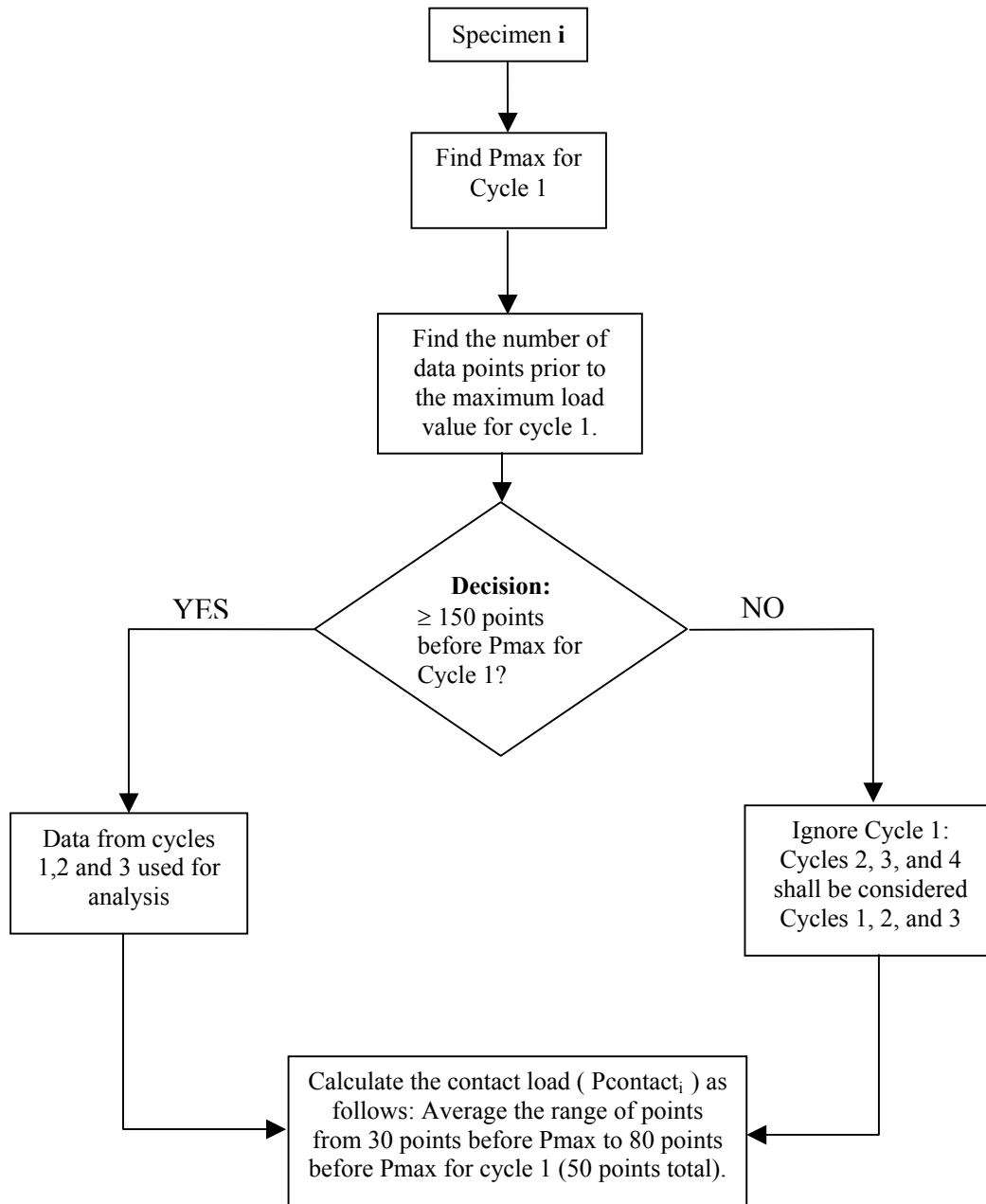
Calculate instantaneous and total resilient modulus ( $MR\{I,T\}_j$ ) for each Cycle  $j$

$$\begin{aligned}MRT_1 &= (\text{gauge length} * P_{avg_1}) / (\text{Trimavg}_1 * \text{davg} * \text{tavg} * C_{cmplT}) \\ MRI_1 &= (\text{gauge length} * P_{avg_1}) / (\text{Trimavg}_2 * \text{davg} * \text{tavg} * C_{cmplI}) \\ MRT_2 &= (\text{gauge length} * P_{avg_2}) / (\text{Trimavg}_5 * \text{davg} * \text{tavg} * C_{cmplT}) \\ MRI_2 &= (\text{gauge length} * P_{avg_2}) / (\text{Trimavg}_6 * \text{davg} * \text{tavg} * C_{cmplI}) \\ MRT_3 &= (\text{gauge length} * P_{avg_3}) / (\text{Trimavg}_9 * \text{davg} * \text{tavg} * C_{cmplT}) \\ MRI_3 &= (\text{gauge length} * P_{avg_3}) / (\text{Trimavg}_{10} * \text{davg} * \text{tavg} * C_{cmplI})\end{aligned}$$

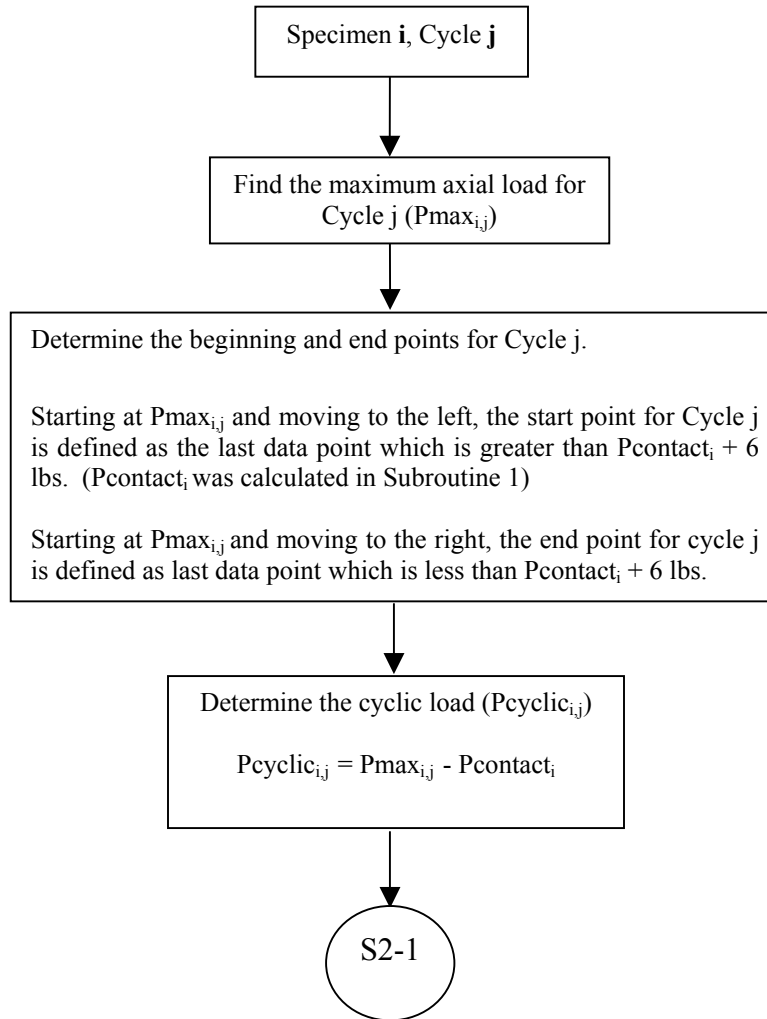
Report the following:

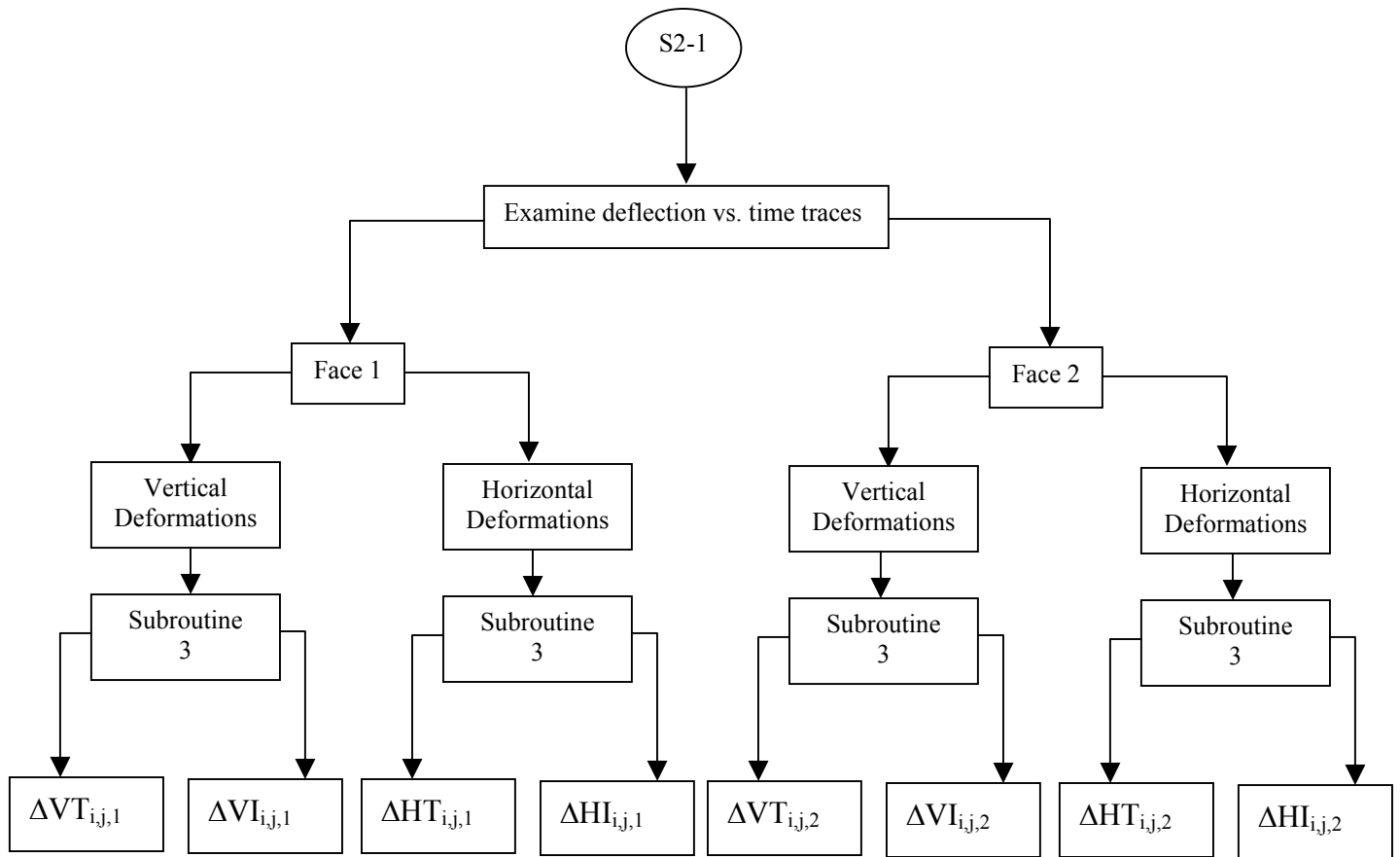
| Cycle | $vI_j$ | $vT_j$ | $MRI_j$ | $MRT_j$ |
|-------|--------|--------|---------|---------|
| 1     | $vI_1$ | $vT_1$ | $MRI_1$ | $MRT_1$ |
| 2     | $vI_2$ | $vT_2$ | $MRI_2$ | $MRT_2$ |
| 3     | $vI_3$ | $vT_3$ | $MRI_3$ | $MRT_3$ |

## B2.3.2 Subroutine 1

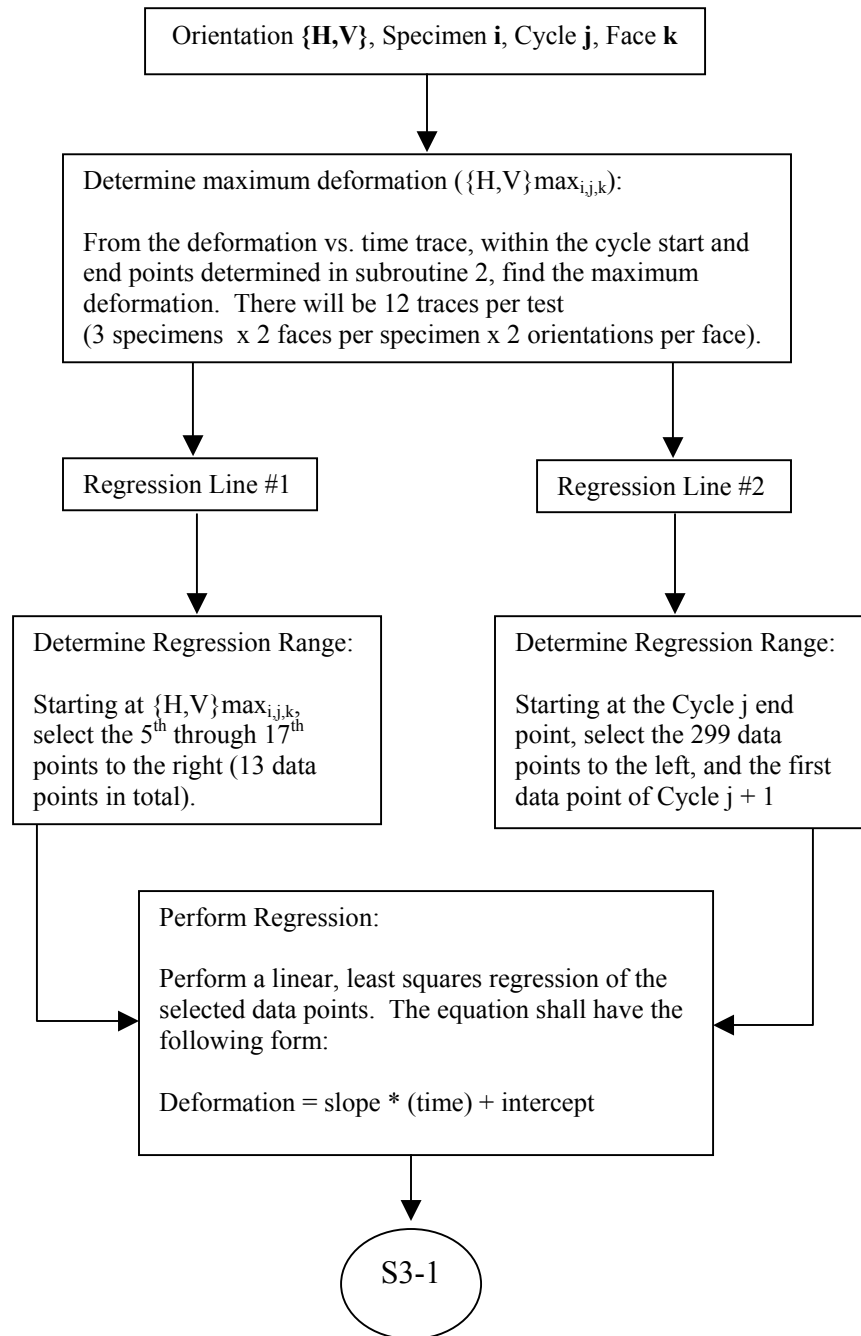


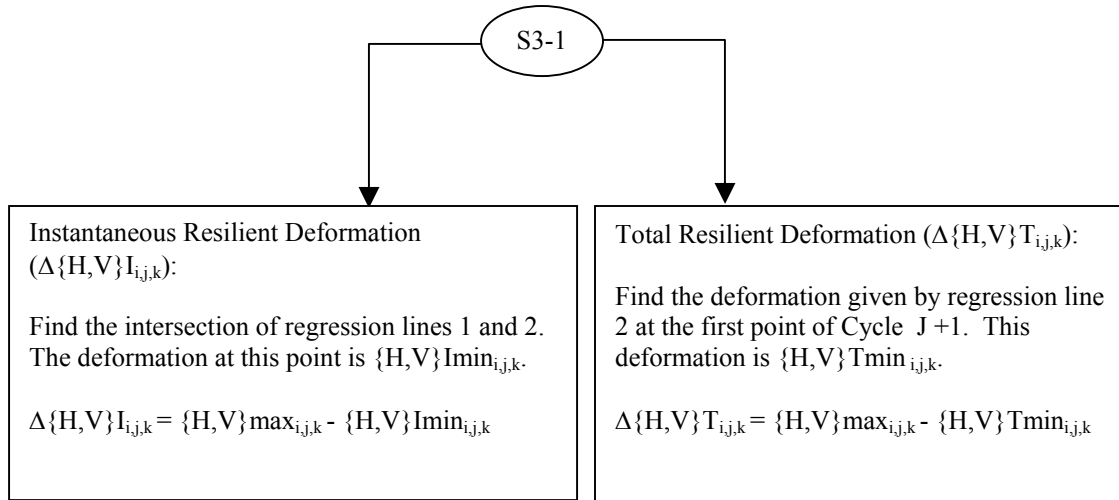
## B2.3.3 Subroutine 2





## B2.3.4 Subroutine 3





### 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 ( $i = 1, 2, \text{ or } 3$ ), the subscript ‘j’ represents the creep time ( $j = 1, 2, 5, 10, 20, 50, \text{ or } 100$ ), and the subscript ‘k’ represents the specimen face ( $k = 1 \text{ or } 2$ ). 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 10<sup>th</sup> 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 <b>j</b> | Data Point                                                                        |
|---------------------------------------|-----------------------------------------------------------------------------------|
| $\{H,V\}_{i,1,k}$                     | 20 <sup>th</sup> point in data file                                               |
| $\{H,V\}_{i,2,k}$                     | 30 <sup>th</sup> point in data file                                               |
| $\{H,V\}_{i,5,k}$                     | 60 <sup>th</sup> point in data file                                               |
| $\{H,V\}_{i,10,k}$                    | 110 <sup>th</sup> point in data file                                              |
| $\{H,V\}_{i,20,k}$                    | 210 <sup>th</sup> point in data file                                              |
| $\{H,V\}_{i,50,k}$                    | Average 505 <sup>th</sup> point through 515 <sup>th</sup> point (11 points total) |
| $\{H,V\}_{i,100,k}$                   | 1010 <sup>th</sup> 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 505<sup>th</sup> point through the 515<sup>th</sup> 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 <b>j</b> | Data Point                            |
|-----------------------------|---------------------------------------|
| $P_{i,1}$                   | 20 <sup>th</sup> point in data file   |
| $P_{i,2}$                   | 30 <sup>th</sup> point in data file   |
| $P_{i,5}$                   | 60 <sup>th</sup> point in data file   |
| $P_{i,10}$                  | 110 <sup>th</sup> point in data file  |
| $P_{i,20}$                  | 210 <sup>th</sup> point in data file  |
| $P_{i,50}$                  | 510 <sup>th</sup> point in data file  |
| $P_{i,100}$                 | 1010 <sup>th</sup> 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 ( $t_{avg}$ ), the average specimen diameter ( $d_{avg}$ ), and the average axial load ( $P_{avg}$ ).

Eq. B22

$$t_{avg} = \frac{\sum_{i=1}^3 t_i}{3} \quad d_{avg} = \frac{\sum_{i=1}^3 d_i}{3} \quad P_{avg} = \frac{\sum_{i=1}^3 P_i}{3}$$

where:  $t_{avg}$  = the average specimen thickness, in.

$d_{avg}$  = the average specimen diameter, in.

$P_{avg}$  = 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 ( $\Delta\{H,V\}norm_{i,j,k}$ ) for time **j** and face **k** of each specimen **i**.

Eq. B24

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

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 one 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

$$\nu = -0.10 + 1.45 \left( \frac{\Delta H_{trimavg_{50}}}{\Delta V_{trimavg_{50}}} \right)^2 - 0.778 \left( \frac{\Delta H_{trimavg_{50}}}{\Delta V_{trimavg_{50}}} \right)^2 \left( \frac{t_{avg}}{d_{avg}} \right)^2$$

Where:  $\nu$  = the Poisson's Ratio

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

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

$t_{avg}$  = the average specimen thickness, in.

$d_{avg}$  = the average specimen diameter, in.

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

Eq. B26

$$C_{cmpli} = 0.6354 \left( \frac{\Delta H_{trimavg_j}}{\Delta V_{trimavg_j}} \right)^{-1} - 0.332$$

Where:  $C_{cmpli_j}$  = the creep compliance correction factor at time  $j$ .

$\Delta H_{trimavg_j}$  = the average horizontal trimmed deformation at time  $j$ , in.

$\Delta V_{trimavg_j}$  = the average vertical trimmed deformation at time  $j$ , in.

B3.2.13

Calculate the creep compliance for each time  $j$ .

Eq. B27

$$D_j = \left( \frac{\Delta H_{trimavg_j} \times d_{avg} \times t_{avg} \times C_{cmpli_j}}{P_{avg} \times GL} \right)$$

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

$\Delta H_{trimavg_j}$  = the average horizontal trimmed deformation at time  $j$ , in.

$d_{avg}$  = the average specimen diameter, in.

$t_{avg}$  = the average specimen thickness, in.

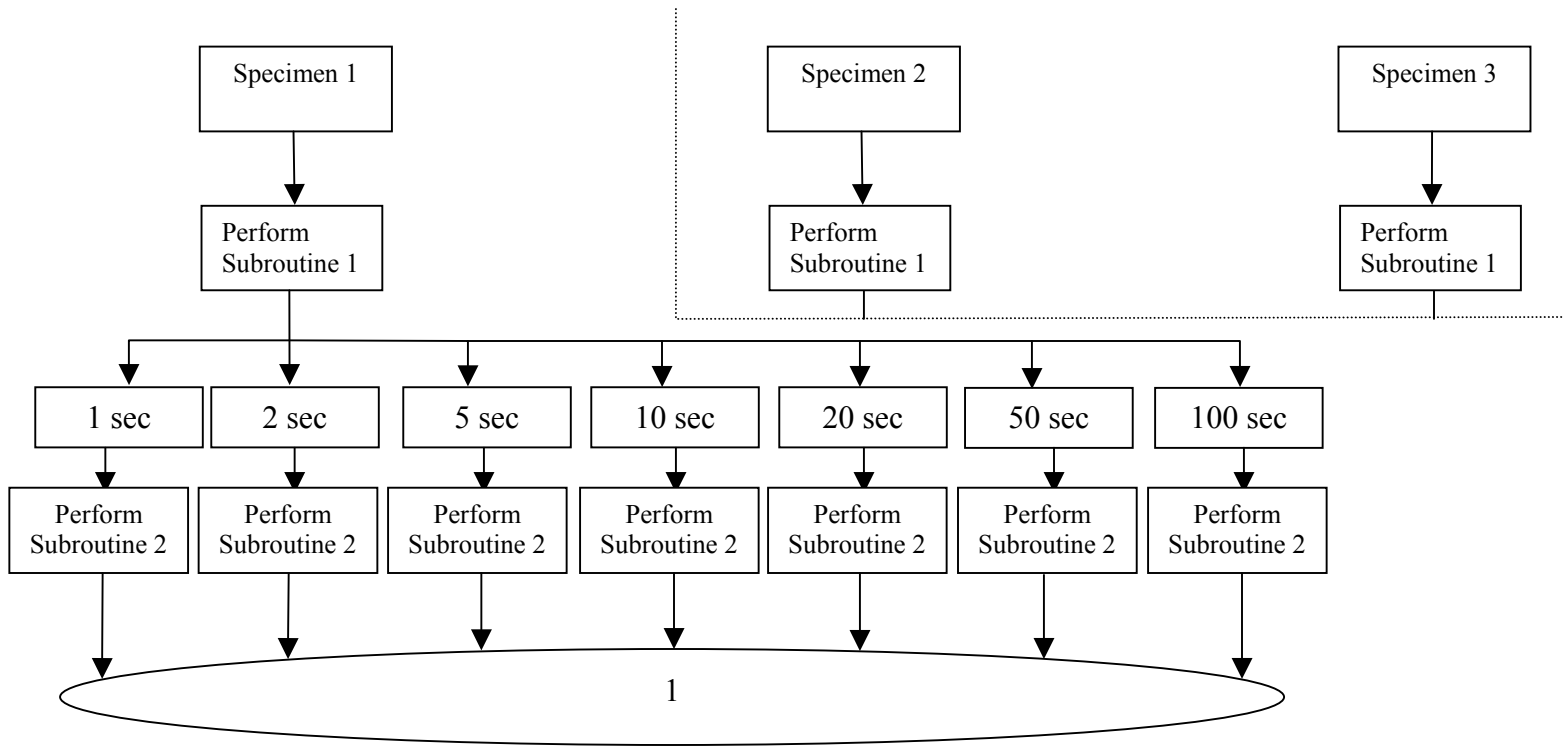
$C_{cmpli_j}$  = the creep compliance correction factor at time  $j$ .

$P_{avg}$  = 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<br>(sec) | Face 1               |                      | Face 2               |                      |
|----------|----------------|---------------|----------------------|----------------------|----------------------|----------------------|
|          |                |               | Horiz.               | Vertical             | Horiz.               | Vertical             |
| 1        | P <sub>1</sub> | 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 <sub>2</sub> | 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 <sub>3</sub> | 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 (T<sub>avg</sub>), diameter (D<sub>avg</sub>) and axial load (P<sub>avg</sub>):

$$T_{avg} = (T_1 + T_2 + T_3) / 3$$

$$D_{avg} = (D_1 + D_2 + D_3) / 3$$

$$P_{avg} = (P_1 + P_2 + P_3) / 3$$

2

2

Calculate the deformation normalization factors for each specimen  $i$  ( $C_{norm_i}$ )

$$C_{norm_i} = (T_i / T_{avg}) * (D_i / D_{avg}) * (P_{avg} / P_i)$$

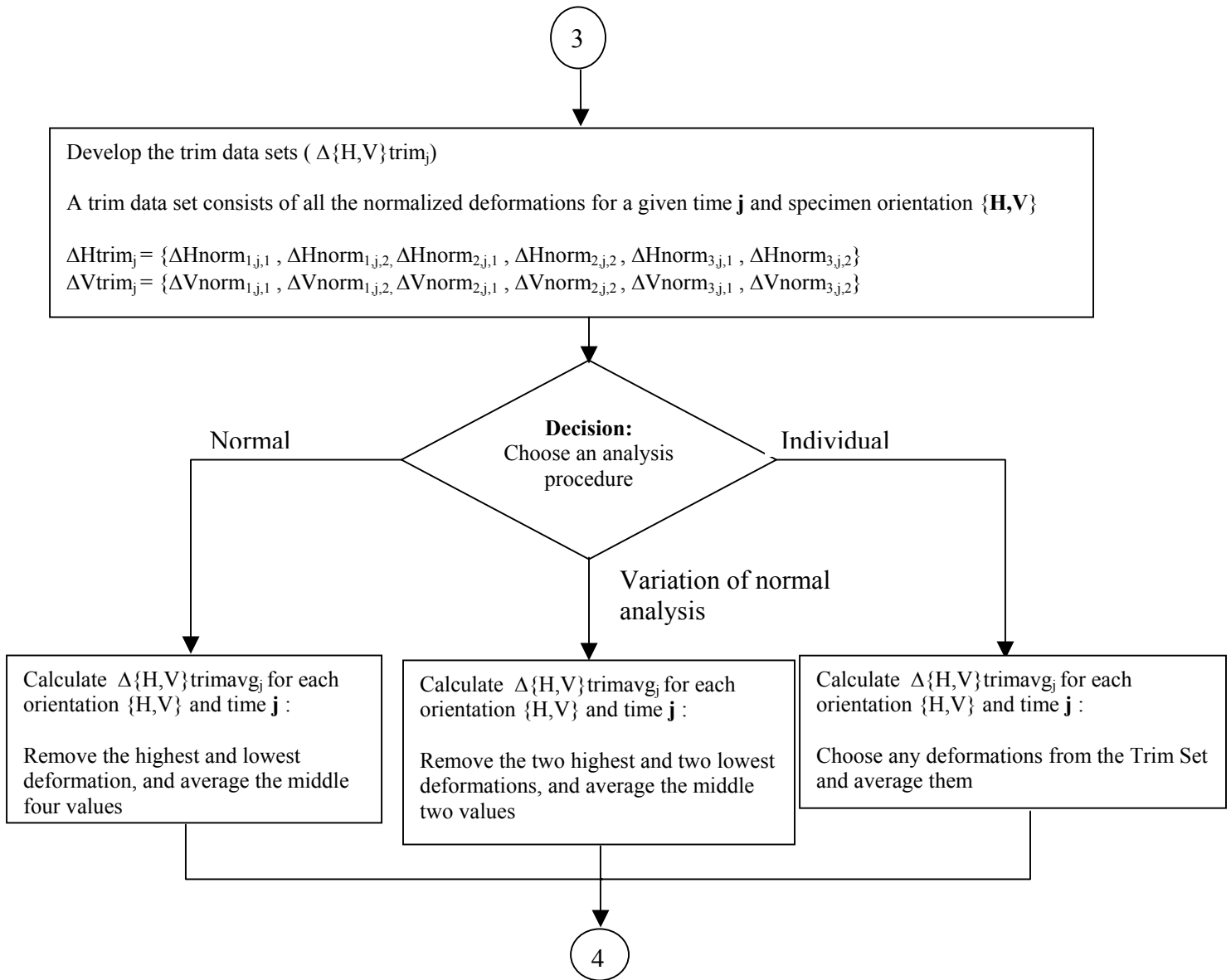
Calculate the normalized deformations for each orientation  $\{H,V\}$  specimen  $i$ , time  $j$  and face  $k$  ( $\Delta\{H,V\}_{norm_{i,j,k}}$ ):

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

Here's what you have calculated so far

| Specimen | P              | Cnorm              | Time (sec) | Face 1                      |                             | Face 2                      |                             |
|----------|----------------|--------------------|------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
|          |                |                    |            | Horiz.                      | Vertical                    | Horiz.                      | Vertical                    |
| 1        | P <sub>1</sub> | Cnorm <sub>1</sub> | 1          | $\Delta H_{norm_{1,1,1}}$   | $\Delta V_{norm_{1,1,1}}$   | $\Delta H_{norm_{1,1,2}}$   | $\Delta V_{norm_{1,1,2}}$   |
|          |                |                    | 2          | $\Delta H_{norm_{1,2,1}}$   | $\Delta V_{norm_{1,2,1}}$   | $\Delta H_{norm_{1,2,2}}$   | $\Delta V_{norm_{1,2,2}}$   |
|          |                |                    | 5          | $\Delta H_{norm_{1,5,1}}$   | $\Delta V_{norm_{1,5,1}}$   | $\Delta H_{norm_{1,5,2}}$   | $\Delta V_{norm_{1,5,2}}$   |
|          |                |                    | 10         | $\Delta H_{norm_{1,10,1}}$  | $\Delta V_{norm_{1,10,1}}$  | $\Delta H_{norm_{1,10,2}}$  | $\Delta V_{norm_{1,10,2}}$  |
|          |                |                    | 20         | $\Delta H_{norm_{1,20,1}}$  | $\Delta V_{norm_{1,20,1}}$  | $\Delta H_{norm_{1,20,2}}$  | $\Delta V_{norm_{1,20,2}}$  |
|          |                |                    | 50         | $\Delta H_{norm_{1,50,1}}$  | $\Delta V_{norm_{1,50,1}}$  | $\Delta H_{norm_{1,50,2}}$  | $\Delta V_{norm_{1,50,2}}$  |
|          |                |                    | 100        | $\Delta H_{norm_{1,100,1}}$ | $\Delta V_{norm_{1,100,1}}$ | $\Delta H_{norm_{1,100,2}}$ | $\Delta V_{norm_{1,100,2}}$ |
| 2        | P <sub>2</sub> | Cnorm <sub>2</sub> | 1          | $\Delta H_{norm_{2,1,1}}$   | $\Delta V_{norm_{2,1,1}}$   | $\Delta H_{norm_{2,1,2}}$   | $\Delta V_{norm_{2,1,2}}$   |
|          |                |                    | 2          | $\Delta H_{norm_{2,2,1}}$   | $\Delta V_{norm_{2,2,1}}$   | $\Delta H_{norm_{2,2,2}}$   | $\Delta V_{norm_{2,2,2}}$   |
|          |                |                    | 5          | $\Delta H_{norm_{2,5,1}}$   | $\Delta V_{norm_{2,5,1}}$   | $\Delta H_{norm_{2,5,2}}$   | $\Delta V_{norm_{2,5,2}}$   |
|          |                |                    | 10         | $\Delta H_{norm_{2,10,1}}$  | $\Delta V_{norm_{2,10,1}}$  | $\Delta H_{norm_{2,10,2}}$  | $\Delta V_{norm_{2,10,2}}$  |
|          |                |                    | 20         | $\Delta H_{norm_{2,20,1}}$  | $\Delta V_{norm_{2,20,1}}$  | $\Delta H_{norm_{2,20,2}}$  | $\Delta V_{norm_{2,20,2}}$  |
|          |                |                    | 50         | $\Delta H_{norm_{2,50,1}}$  | $\Delta V_{norm_{2,50,1}}$  | $\Delta H_{norm_{2,50,2}}$  | $\Delta V_{norm_{2,50,2}}$  |
|          |                |                    | 100        | $\Delta H_{norm_{2,100,1}}$ | $\Delta V_{norm_{2,100,1}}$ | $\Delta H_{norm_{2,100,2}}$ | $\Delta V_{norm_{2,100,2}}$ |
| 3        | P <sub>3</sub> | Cnorm <sub>3</sub> | 1          | $\Delta H_{norm_{3,1,1}}$   | $\Delta V_{norm_{3,1,1}}$   | $\Delta H_{norm_{3,1,2}}$   | $\Delta V_{norm_{3,1,2}}$   |
|          |                |                    | 2          | $\Delta H_{norm_{3,2,1}}$   | $\Delta V_{norm_{3,2,1}}$   | $\Delta H_{norm_{3,2,2}}$   | $\Delta V_{norm_{3,2,2}}$   |
|          |                |                    | 5          | $\Delta H_{norm_{3,5,1}}$   | $\Delta V_{norm_{3,5,1}}$   | $\Delta H_{norm_{3,5,2}}$   | $\Delta V_{norm_{3,5,2}}$   |
|          |                |                    | 10         | $\Delta H_{norm_{3,10,1}}$  | $\Delta V_{norm_{3,10,1}}$  | $\Delta H_{norm_{3,10,2}}$  | $\Delta V_{norm_{3,10,2}}$  |
|          |                |                    | 20         | $\Delta H_{norm_{3,20,1}}$  | $\Delta V_{norm_{3,20,1}}$  | $\Delta H_{norm_{3,20,2}}$  | $\Delta V_{norm_{3,20,2}}$  |
|          |                |                    | 50         | $\Delta H_{norm_{3,50,1}}$  | $\Delta V_{norm_{3,50,1}}$  | $\Delta H_{norm_{3,50,2}}$  | $\Delta V_{norm_{3,50,2}}$  |
|          |                |                    | 100        | $\Delta H_{norm_{3,100,1}}$ | $\Delta V_{norm_{3,100,1}}$ | $\Delta H_{norm_{3,100,2}}$ | $\Delta V_{norm_{3,100,2}}$ |

3



4

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

$$v_{50} = -0.10 + (1.48 - 0.778 * (T_{avg} / D_{avg})^2) * (\Delta H_{trimavg_{50}} / \Delta V_{trimavg_{50}})^2$$

Calculate the creep compliance correction factors for each time **j** ( $C_{cpl_j}$ ):

$$C_{cpl_j} = 0.634 * (\Delta V_{trimavg_j} / \Delta H_{trimavg_j})$$

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

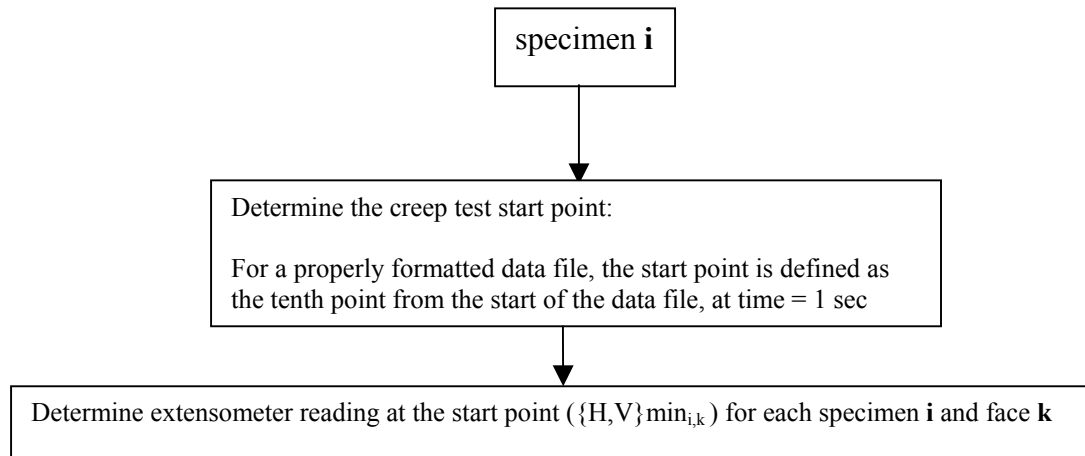
$$D_j = (\Delta H_{trimavg_j}) * (D_{avg}) * (T_{avg}) * (C_{cpl_j}) / ((P_{avg}) * (\text{gauge length}))$$

Report the following:

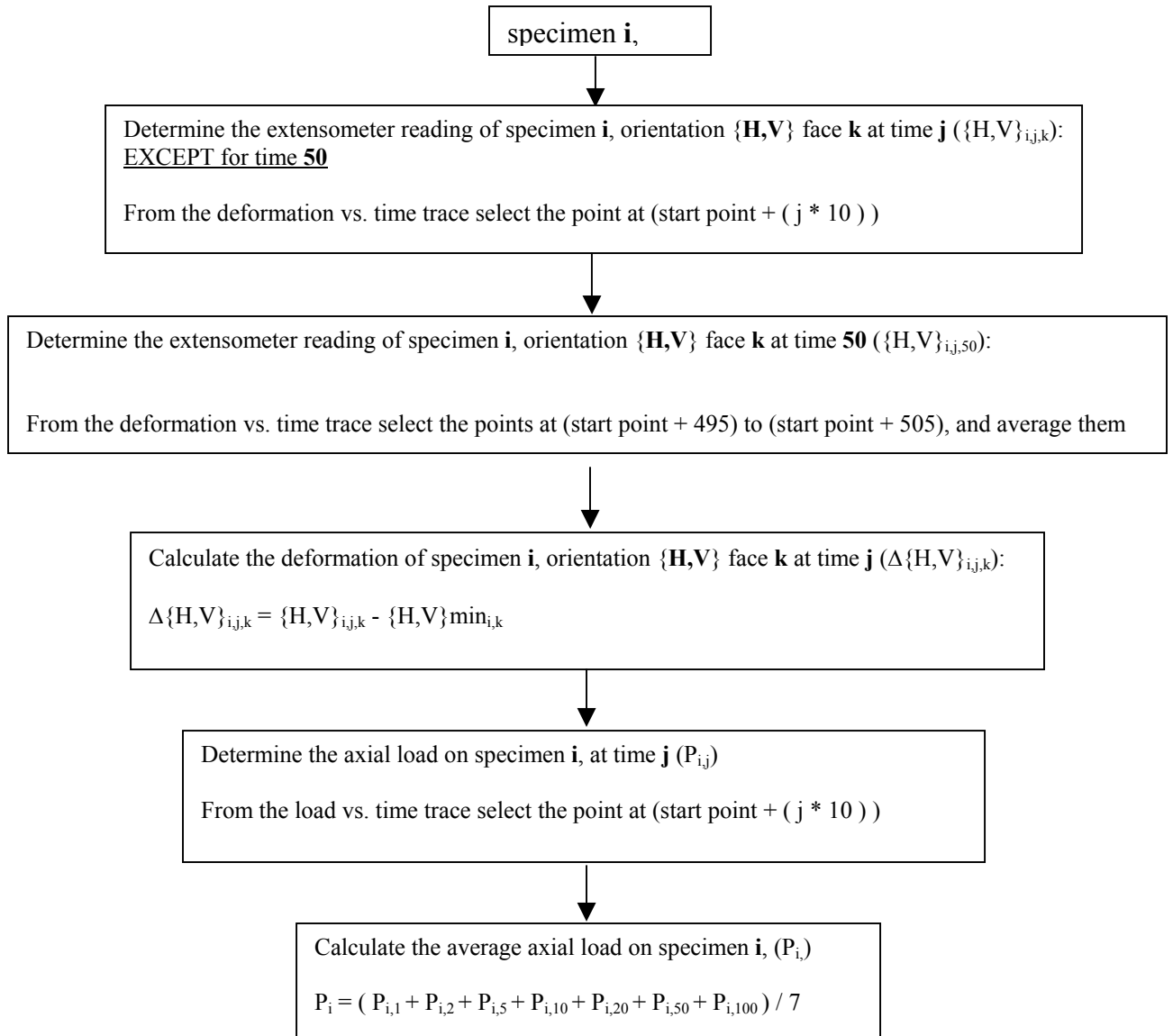
| Time (sec) | $D_i$     |
|------------|-----------|
| 1          | $D_1$     |
| 2          | $D_2$     |
| 5          | $D_5$     |
| 10         | $D_{10}$  |
| 20         | $D_{20}$  |
| 50         | $D_{50}$  |
| 100        | $D_{100}$ |

$v_{50}$

### B3.3.2 Subroutine 1



## B3.3.3 Subroutine 2



## B4. INDIRECT TENSILE STRENGTH DATA ANALYSIS ALGORITHM

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: 
$$P_{i,ts_i+1.5} > P_{i,ts_i+1.0} > P_{i,ts_i+0.5} > P_{i,ts_i}$$

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

Eq. B29: 
$$P_{t+1.5} - P_t > 40lbs.$$

#### 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 prior 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 ( $P_{i,tf_i}$ )

##### 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 ( $P_{i,tf_i}$ )

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 ( $T_{avg}$ ) and diameter ( $D_{avg}$ ) as shown below:

Eq. B32

$$T_{avg} = \frac{T_1 + T_2 + T_3}{3}$$

Eq. B33

$$D_{avg} = \frac{D_1 + D_2 + D_3}{3}$$

#### B4.2.11 Calculate the Deformation Normalization Factors ( $C_{norm_i}$ )

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

Eq. B34

$$C_{norm_i} = \frac{T_i}{T_{avg}} + \frac{D_i}{D_{avg}}$$

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

Eq. B35

$$\Delta\{H,V\}_{norm_{i,j}} = C_{norm_i} \times \Delta\{H,V\}_{i,j}$$

#### 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 one 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  $\Delta\{H,V\}_{trimavg}$ .

## 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 as  $\Delta\{H,V\}_{trimavg}$ .

## 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  $\Delta\{H,V\}_{trimavg}$ .

B4.2.14 Calculate Poisson's Ratio ( $\nu$ )

Eq. B36

$$\nu = -0.10 + 1.48 \left( \frac{\Delta H_{trimavg}}{\Delta V_{trimavg}} \right)^2 - 0.778 \left( \frac{\Delta H_{trimavg}}{\Delta V_{trimavg}} \right)^2 * \left( \frac{T_{avg}}{D_{avg}} \right)^2$$

B4.2.15 Calculate "Used" Poisson's Ratio ( $\nu_{used}$ )B4.2.15.1 Case 1:  $\nu > 0.5$ 

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

B4.2.15.2 Case 2:  $\nu < 0.05$ 

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

B4.2.15.3 Case 3:  $0.05 < \nu < 0.5$ 

If the  $\nu$  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:

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

## B4.2.17 Calculate the Indirect Tensile Strength

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

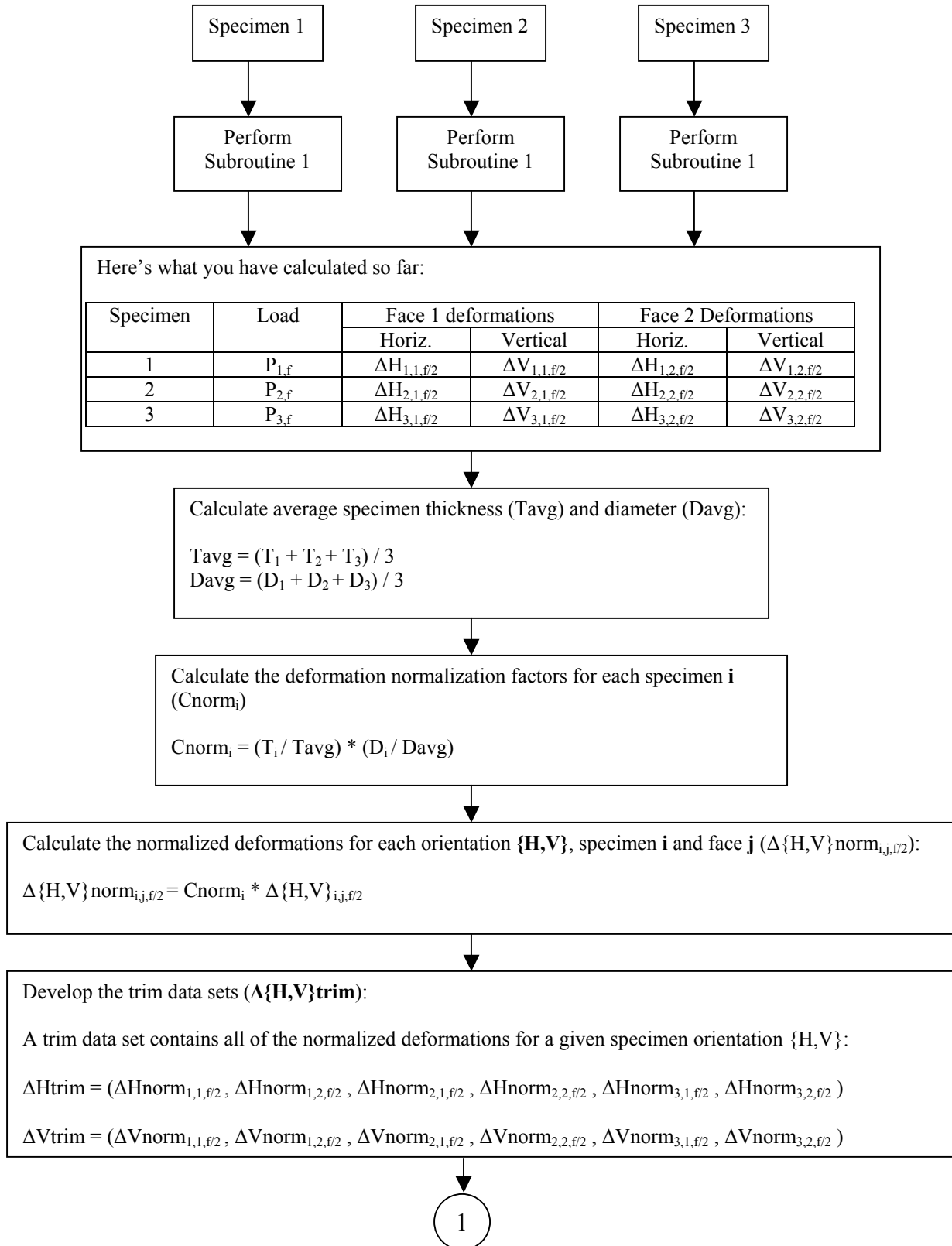
$$\text{Eq. B38} \quad ITS_i = \frac{2P_{i,tf_i} CSX_i}{\pi T_i D_i}$$

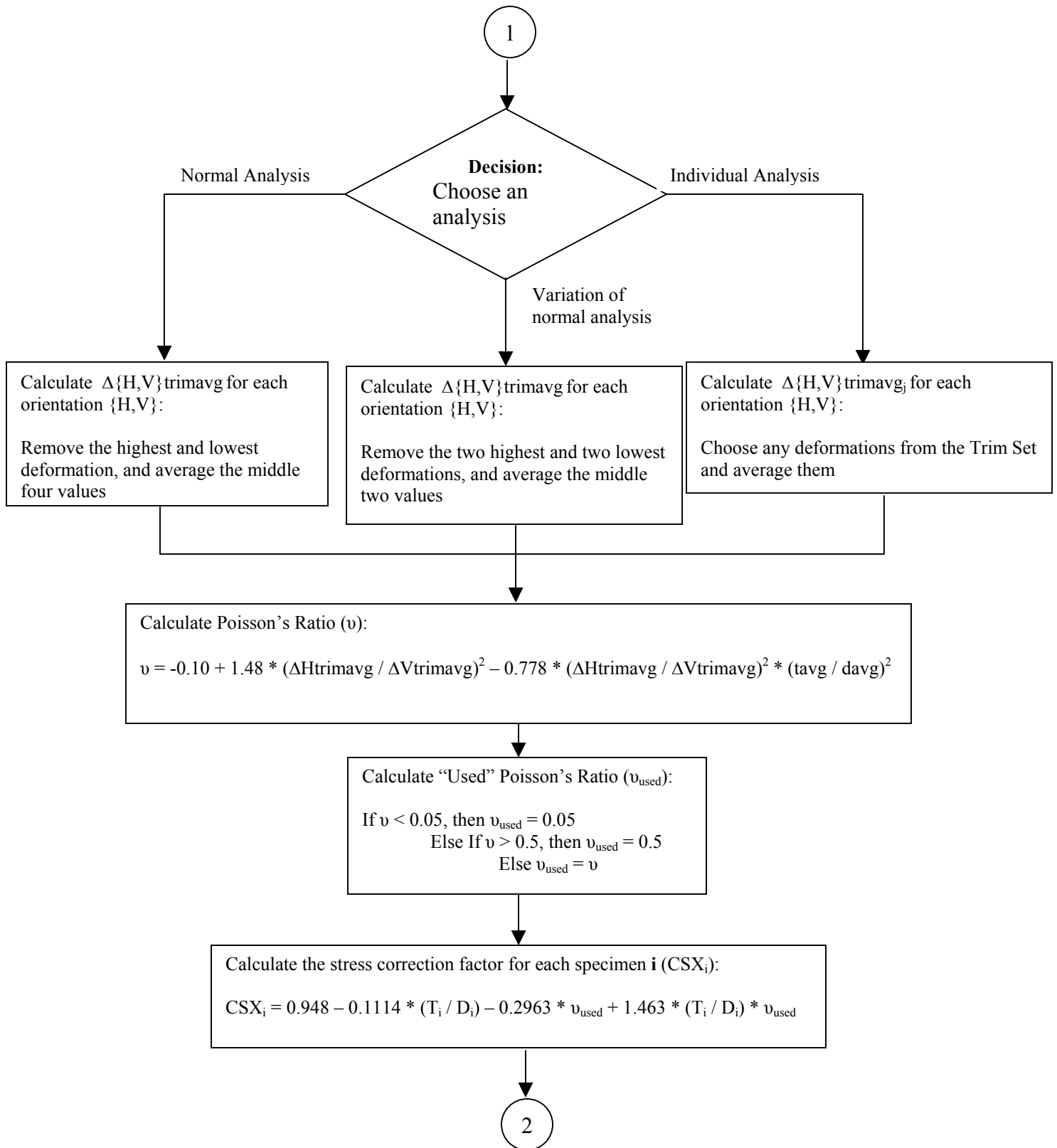
## B4.2.18 Calculate the Average Indirect Tensile Strength

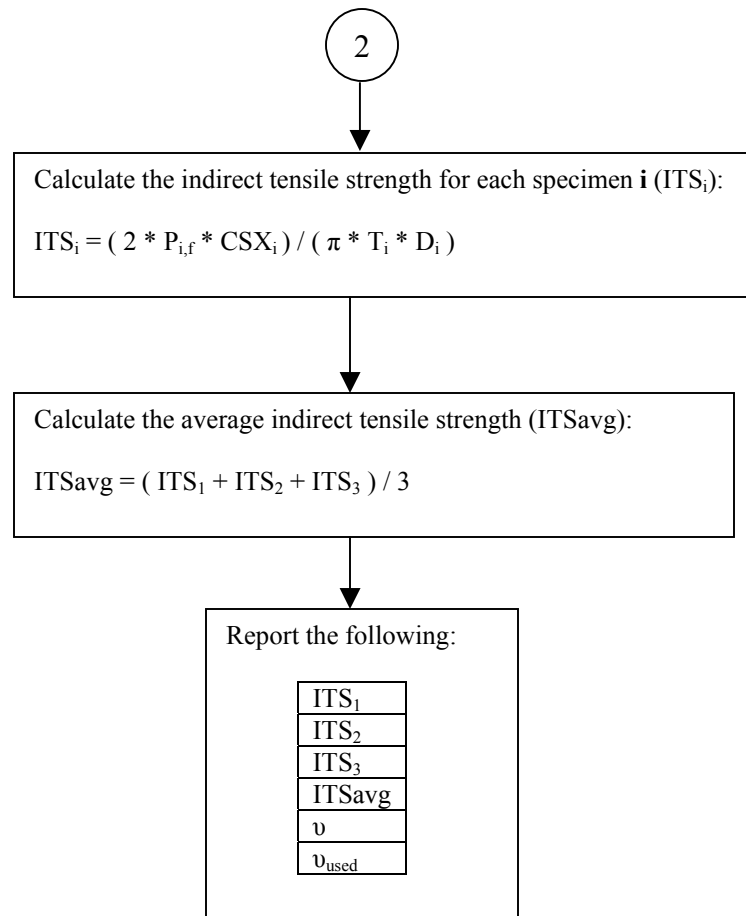
$$\text{Eq. B39} \quad ITS_{avg} = \frac{ITS_1 + ITS_2 + ITS_3}{3}$$

### B4.3 Indirect Tensile Strength Analysis Flowcharts

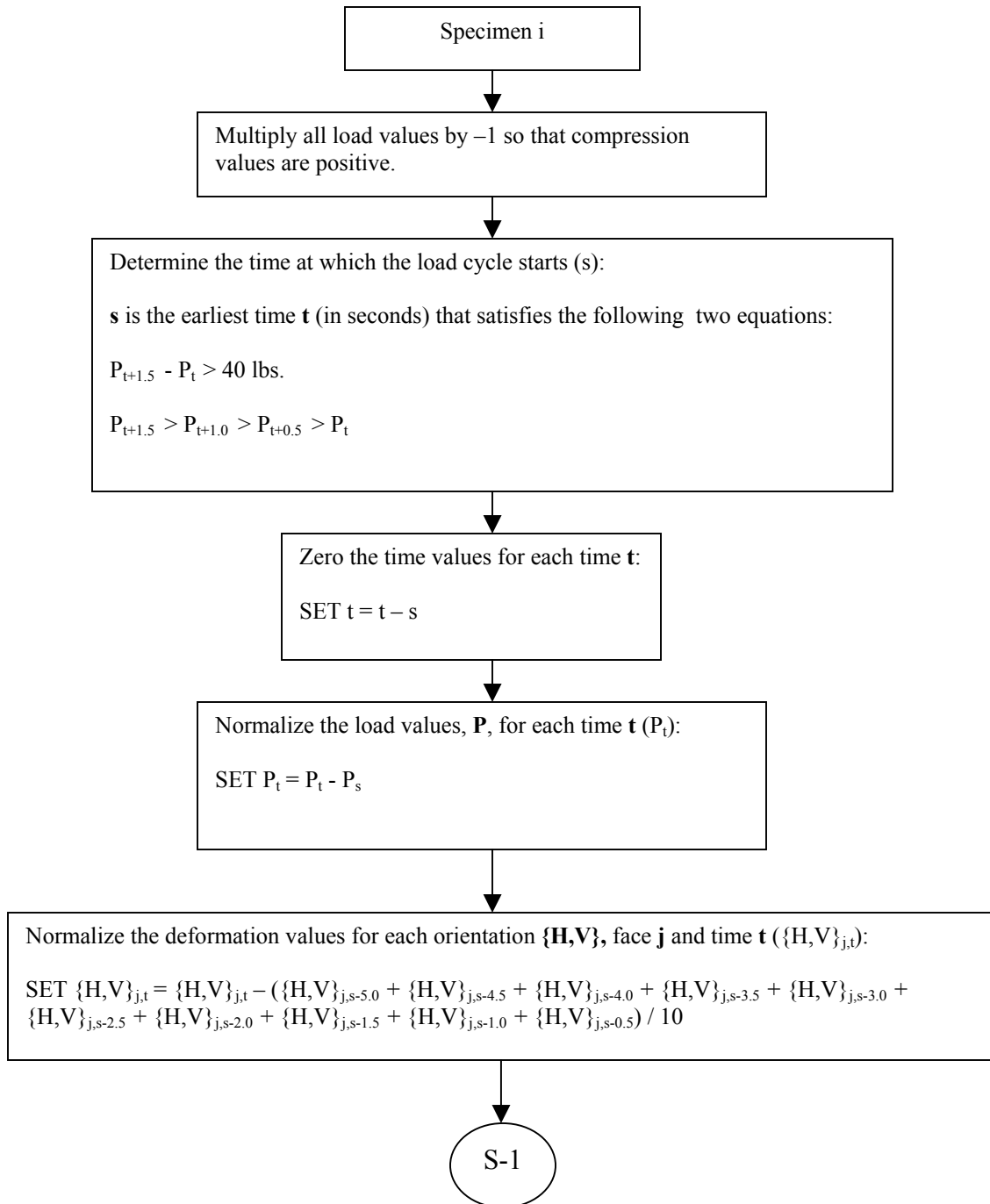
#### B4.3.1 Main Procedure

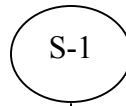






## B.4.3.2 Subroutine 1





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: \_\_\_\_\_