Appendix G: Posttest Data Correction

G.1 Data Uncertainty

Before a discussion of gage uncertainty can begin, the terms accuracy, precision, and uncertainty must be defined. As per standard practice, accuracy is defined as the deviation of an instrument's reading from a **known** input. Precision indicates an instrument's ability to reproduce a certain reading with a given accuracy. Uncertainty is defined as the plus or minus deviation range of a reading from the true value. In many experimental situations (certainly in the PCCV experiments), this true value is not known, however, the fairly high confidence exists in the uncertainty range.

Each gage used on the PCCV model had an associated uncertainty. Efforts were made to ensure that the level of uncertainty associated with each gage was appropriate for the magnitude of the expected data. This was done to avoid losing meaningful data because of relatively high inaccuracies of instruments.

G.2 Post Test Data Conversion and Correction

After the high pressure PCCV test was conducted, the data collected by the DAS during this final test was subjected to conversion and correction. The purpose of the conversion was to convert the data from raw form (usually volts) into engineering units. The purpose of the corrections was to correct the data for any offsets or external effects such as temperature. The specific details per instrument type are detailed in the sections below.

G.2.1 Corrections Made to Strain Gage Raw Data

Basic strain data reduction was accomplished through two major steps: 1) firmware reduction from measurements of the bridge-balancing voltages to values of strain and 2) post-test data corrections to compensate for various effects (i.e. temperature effects, transverse strain, etc.).

The first step will not be discussed here except to note that the data acquisition firmware automatically converts the voltages received from the strain gages to strain data. Therefore, for the PCCV test, the raw data from strain gages was in microstrain. The last steps (referred to here as the data corrections) are discussed in the following sections.

The least count requirement for the strain gages used in this test will be ± 0.01 % strain. The data acquisition system used in the PCCV high pressure test recorded seven significant digits for each data point. This is not meant to imply that the data was believed to be accurate to that extent. A study on the uncertainty of the data from the various instruments was performed.

The strain gage raw data obtained during the PCCV High Pressure Test was in the units of microstrain. Three types of data correction were done to the raw strain gage data. These are: corrections for gage specific gage factors, corrections for temperature effects, and corrections for transverse sensitivity.

G.2.1.1 Instrument Specific Gage Factor Correction

The data acquisition system (DAS) used in the PCCV High Pressure Test assumed a single gage factor for all strain gages. This factor (2.089) was determined by taking the average value of the gage factors of the strain gages used in the test. The standard practice in data acquisition is to use the value 2.0 for the gage factor while acquiring data. This value was used in the internal firmware of the DAS hardware to determine the strain values output by the system. However, each strain gage has associated with it a *specific* gage factor that is identified and provided by the manufacturer. The data from each gage was corrected, posttest, to reflect the correct GFAC for that gage.

To output strain gage readings in units of strain, the firmware must convert from the output voltage. The following equations were used.

$$\varepsilon = \frac{-4\,V_R}{GFAC\left(1+2V_R\right)} \qquad \text{(G-1)}$$

where $$V_R = \left(\frac{V_{out}}{V_S}\right)_{strained} - \left(\frac{V_{out}}{V_S}\right)_{unstrained}$$

ε = “raw” strain

Vout = output voltage of gage bridge

Vs = bridge excitation voltage

As stated above, during the acquisition of the PCCV High Pressure Test data, a single GFAC was input into Equation G-1 for all strain gages.

Post test, the gage specific GFAC for each gage was used to correct the raw data. Equation 2 below was used to accomplish this.

$$\varepsilon' = \varepsilon\left(\frac{GFAC_{general}}{GFAC_{specific}}\right) \qquad \text{(G-2)}$$

G.2.1.2 Corrections for Wire Length Change in Resistance

Because of the long lead wire lengths required for the instrumentation of the PCCV, consideration was given to correcting for changes in the GFACs due to the slight change in resistance. It was decided that this was not necessary because the strain gages were wired in a three-wire configuration, which effectively reduces lead wire resistance effects by 50% over a two-wire configuration, reducing the error to a very small value.

G.2.1.3 Corrections for Temperature Effects on the Lead Wires

Corrections to account for changes in lead wire resistance due to temperature changes over the test duration were also considered, but rejected for the reason mentioned above.

G.2.1.4 Corrections for Temperature Effects on the Strain Gages

There are two corrections that may be made for temperature effects on strain gages. The first is an adjustment of the strain gage data for apparent strain. Apparent strain is a value of strain that appears in the raw data as an artifact of the temperature at which the data was taken. This strain amount must be removed from the raw data to compensate for this effect. If the strain readings were taken at the temperature at which the strain gages were calibrated, there would be no apparent strain.

Correction for Apparent Strain

For the strain gages to be used in the PCCV test, the equation provided by the manufacturer for calculating apparent strain is a fourth order polynomial, shown below. The constants in this equation vary depending on the lot number of each strain gage.

$$\varepsilon_{apparent} = A_0 + A_1T + A_2T^2 + A_3T^3 + A_4T^4 \qquad \text{(G-3)}$$

where T = testing temperature at time data point was taken, in Celsius.

This value is then subtracted from the correction 1 value.

$$\varepsilon'' = \varepsilon' - \varepsilon_{\text{apparent}} \tag{G-4}$$

Although the strain of interest in the PCCV High Pressure Test will be that strain caused by pressure induced expansion of the model, no attempt was made to eliminate from the strain data the amount of strain caused by thermal expansion of the model.

Corrections for GFAC Temperature Effects

A correction to adjust the gage specific gage factor (GFAC) for temperature, was not done. The manufacturer provides a GFAC for each gage. This factor is determined at a temperature of 24°C. The GFAC value will change with temperature. For the temperature changes during the PCCV test, this correction affected GFAC values by much less than 1%. Therefore, although the impact of this correction was assessed post-test, this correction was not performed on the data.

G.2.1.5 Corrections for Transverse Strain Sensitivity

The final set of corrections to the strain gage data involved correcting for transverse strain sensitivity. These corrections were performed only on the rosette gage data, the strip gage data and data from any hoop/meridional gage pairs. For the strip gages, data from previously identified cross axis gages (of the type SSGH) were used in these corrections. Transverse sensitivity refers to the response of the gages due to cross axis strain.

The strip gages and hoop/meridional gage pairs were treated as a 90°, two element rosette gage. The equation used to correct for transverse sensitivity for these is:

$$\varepsilon_{\text{corr}} = \frac{(1 - \nu_o K_t)(\varepsilon'' - K_t \varepsilon''_{\text{cross-axis}})}{1 - K_t^2} \tag{G-5}$$

where

ν_0 = Poisson's ratio of the material on which the manufacturer's gage factor was measured, usually 0.285

K_t = transverse sensitivity coefficient which is supplied by the gage manufacturer.

$\varepsilon''_{\text{cross-axis}}$ = the strain reading from the cross-axis gage taken at the same time as ε''. (This reading must have been corrected with the previously discussed corrections before being used here.)

G.2.1.6 Transverse Sensitivity Corrections for Rosette Gages

For the rosette gages, the following equations were used. Consider a three-gage rectangular rosette with the gage elements numbered consecutively. Elements 1 and 3 correspond to the elements that are 90° apart and element 2 is the center 45° gage.

$$\varepsilon_{1\text{corr}} = \frac{(1 - \nu_o K_t)(\varepsilon''_1 - K_t \varepsilon''_3)}{1 - K_t^2}$$

$$\varepsilon_{2\text{corr}} = \frac{(1 - \nu_o K_t)(\varepsilon''_2 - K_t(\varepsilon''_1 + \varepsilon''_3 - \varepsilon''_2))}{1 - K_t^2} \tag{G-6}$$

$$\varepsilon_{3\mathrm{corr}} = \frac{(1-\nu_o K_t)(\varepsilon_3'' - K_t \varepsilon_1'')}{1-K_t^2}$$

When these corrections were applied to a selected group of gages in areas of liner strain concentration, it was observed that the difference between the uncorrected and the corrected data was very small, on the order of 1%, for strains of approximately 2%. The difference becomes larger as the strains become smaller and is considerably greater for strains on the order of .05%. Because the difference is very small for the larger strains, the correction was not done.

G.2.1.8 Corrections to Rebar Strain Gages

One final correction was investigated for the strain data from gages installed on rebar. During the gage installation process, a small portion of the rebar must be ground flat to provide a suitable installation surface. This changes the cross-sectional area of the rebar at that location and the strain data should be compensated for this. A correction factor to account for this was considered, but later rejected because of inconsistent and non-reproducible results in lab experiments

G.2.2 Corrections Made to LVDT Raw Data

Linear Variable Displacement Transducers (LVDTs) output raw data that vary linearly with displacement. Data reduction for the LVDTs starts with the conversion of the raw signal (in volts) to displacement (in inches). The following single step reduction will provide the displacement of the device, either positive or negative, from its **null** (not necessarily original) position.

$$D_{\mathrm{null}} = V_{\mathrm{raw}_{\mathrm{time}=t}} \left[\frac{1}{CF_{\mathrm{LVDT}}} \right] \tag{G-7}$$

where D_{nul} = displacement from the null position (in),

V_{raw} = raw signal from gage at time t (V),

CF_{LVDT} = LVDT calibration factor (V/in).

Note that the polarity of the output voltage is important for these measurements as the device reads in either direction around the null point that represents zero output voltage. The device will be initially spring loaded.

As shown below, for each LVDT location, the initial displacement reading ($V_{time=0}$) will be algebraically combined with each subsequent reading. The initial reading will be considered an offset. Thus, for each reading, the determination of the actual displacement of the LVDT with respect to the ***initial displacement*** is obtained as follows.

$$D = \left(V_{\mathrm{raw}_{\mathrm{time}=t}} - V_{\mathrm{raw}_{\mathrm{time}=0}}\right) \left[\frac{1}{CF_{\mathrm{LVDT}}} \right] \tag{G-8}$$

where D = displacement from original position (in),

V_{raw} = raw signal from gage at time indicated (V).

Figure G.1 illustrates the layout.

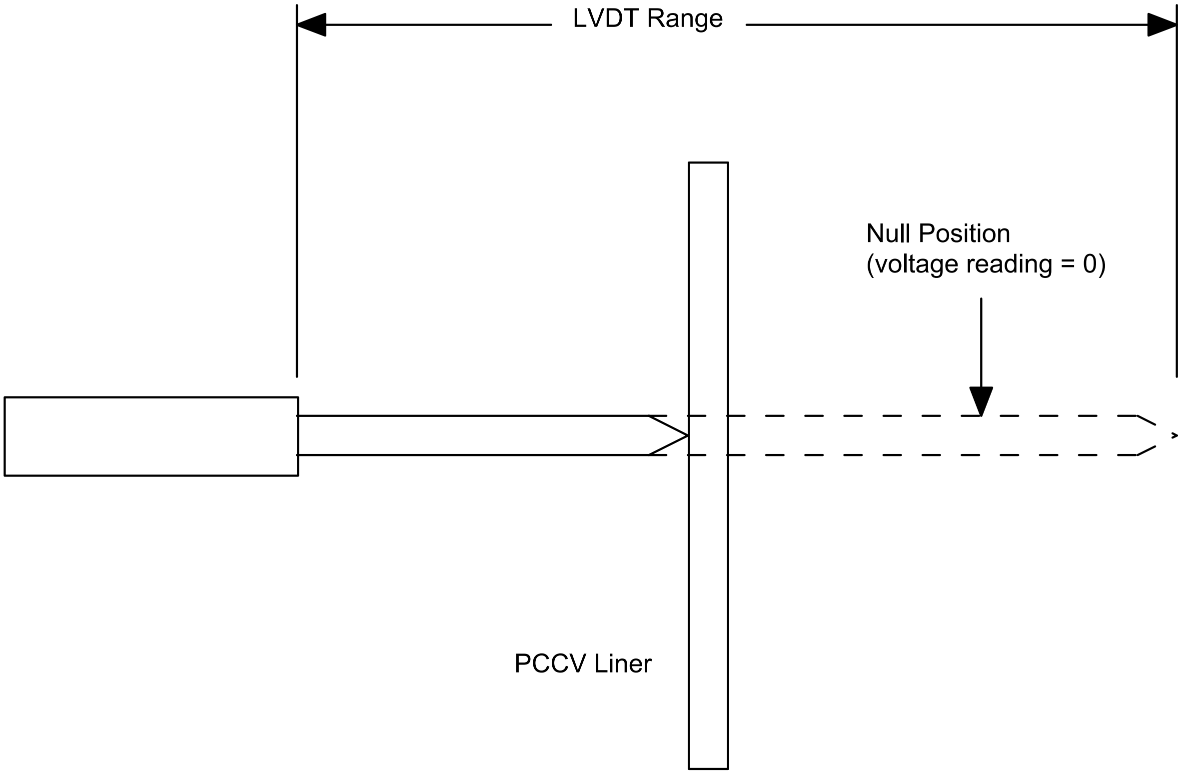

Figure G.1 Geometry for LVDT Measurements

Most of the LVDTs were mounted to the internal framework inside the PCCV model. Because the motion of the internal frame during the tests could affect the measurements, the corrections for motion would be similar to those specified for CPOTs (see G.2.6).

G.2.3 Corrections Made to Inclinometer Raw Data

Conversion of the inclinometer tilt data is accomplished by subtracting the initial raw data point value (in volts) from the current raw data point value (volts) and dividing the result by the calibration factor. This will remove the initial offset angle and provide as final results only the change in angle at any time or pressure.

$$\text{Change in Tilt Angle } (^\circ) = \frac{\text{Raw Data}_{\text{time} = t}\,(\text{V}) - \text{Raw Data}_{\text{time} = 0}\,(\text{V})}{\text{Calibration Factor (volts/}^\circ)} \qquad \text{(G-9)}$$

G.2.4 Corrections Made to Thermocouple and RTD Raw Data

All temperature sensor measurements, including both thermocouples and RTDs, are entirely reduced through firmware calculations. Thus, no post-test data reduction is needed. The “raw data” is in the units of °C.

G.2.5 Corrections Made to Pressure Transducer Raw Data

The pressure transducers are voltage type devices and will be factory and SNL calibrated to provide a pressure value (in psia) given a voltage output from the transducers. The following data reduction were used:

$$\mathrm{P(psia)} = [\mathrm{Signal(V)}]\left[\mathrm{CalibrationFactor}\frac{\mathrm{(psia)}}{\mathrm{(mV)}}\right]\left[1000\left(\frac{\mathrm{mV}}{\mathrm{V}}\right)\right] \tag{G-10}$$

To convert the pressure readings into psig, the initial pressure gage reading was subtracted from subsequent readings.

$$\mathrm{P(psig)} = [\mathrm{Signal(V)} - \mathrm{Signal}_{\mathrm{initial}}\mathrm{(V)}]\left[\mathrm{CalibrationFactor}\frac{\mathrm{(psia)}}{\mathrm{(mV)}}\right]\left[1000\left(\frac{\mathrm{mV}}{\mathrm{V}}\right)\right] \tag{G-11}$$

As the final desired pressure units are MPa, the pressure data in psig was then converted to MPa and reported as gage pressure.

G.2.6 Corrections Made to Cable Potentiometers

G.2.6.1 General Corrections

The cable potentiometers (CPOTs) each have a sensitivity factor. This sensitivity is of the form *mV/(V*in*). The signal in mV is normalized by the excitation voltage and divided by the sensitivity factor to obtain the CPOT length in inches. It is necessary to monitor the excitation voltage used for each measurement.

The first step in the reduction uses Equation G-12 below.

$$\mathrm{length(in)} = [\mathrm{Signal(V)}]\left[\frac{1}{\mathrm{Sens.Factor}}\frac{\mathrm{(V-in)}}{\mathrm{(mV)}}\right]\left[\frac{1000\mathrm{(mV)}}{\mathrm{(V)}}\right]\left[\frac{1}{\mathrm{V}_{\mathrm{excit.}}\mathrm{(V)}}\right] \tag{G-12}$$

For each cable potentiometer location, the ***initial length reading*** was algebraically combined with each subsequent reading to provide the differential displacement throughout the experiment. This operation is shown in Equation G-13.

$$\mathrm{Displacement(in)} = [\mathrm{length}]_{\mathrm{current}} - [\mathrm{length}]_{\mathrm{initial}} \tag{G-13}$$

The geometry showing the use of Equation G-13 is shown in Figure G.2. Note that this assumes that the angle between the cable's original horizontal line and its displaced line is small so that the true horizontal and vertical components of the displacement are equal to the indicated displacement.

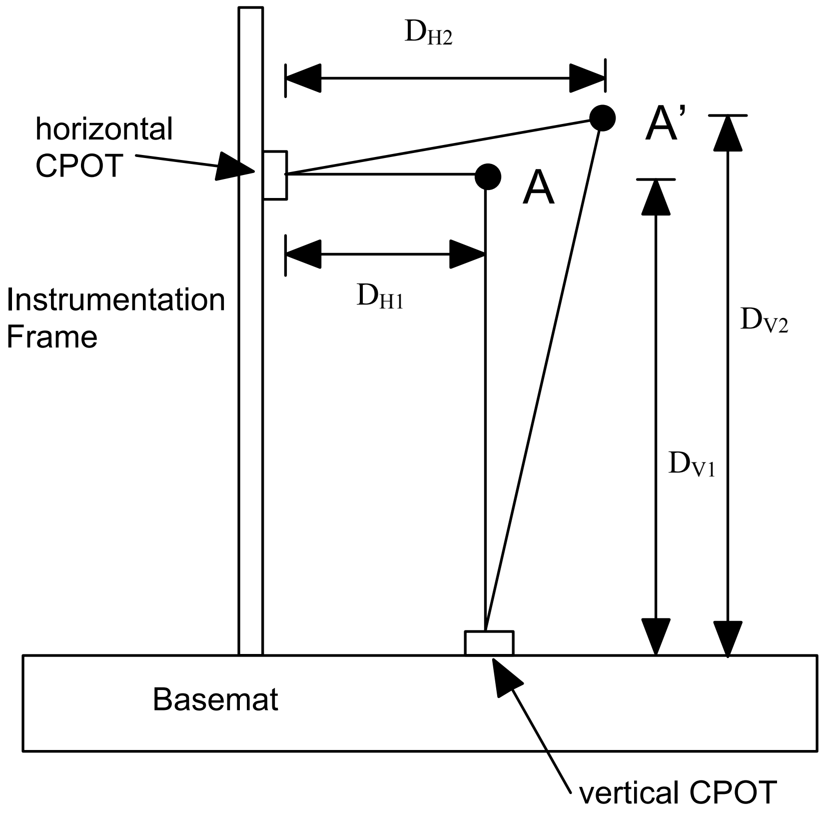

Figure G.2 Displacement Measurements (Showing Offset Subtraction)

horizontal displacement = $D_{H2} - D_{H1}$

vertical displacement = $D_{V2} - D_{V1}$

G.2.6.2 Corrections for Movement of Instrumentation Frame

For the PCCV model tests, there was the possibility of instrumentation frame movement caused by thermal expansion. The PCCV high pressure test duration was more than one day. The effect of thermal cycling from day to night temperature changes was characterized, and it was determined that the movement of the frame affected the measurements by a very small amount and no corrections were performed.

G.2.6.3 Correction in Horizontal Displacement Measurements for Vertical Translations

A sketch of the geometry for this case is shown in Figure G.3. Note that the liner motion imparts a vertical component of elongation of the cable-type displacement transducer. Vertical displacement measurements of the liner attachment point would be required to resolve the purely horizontal movement. Several of the CPOT attachment locations on the PCCV liner had both horizontally and vertically aligned gages. Thus, the true horizontal and vertical motions of those points was resolved.

The vertical displacements were corrected in a similar manner for horizontal translations.

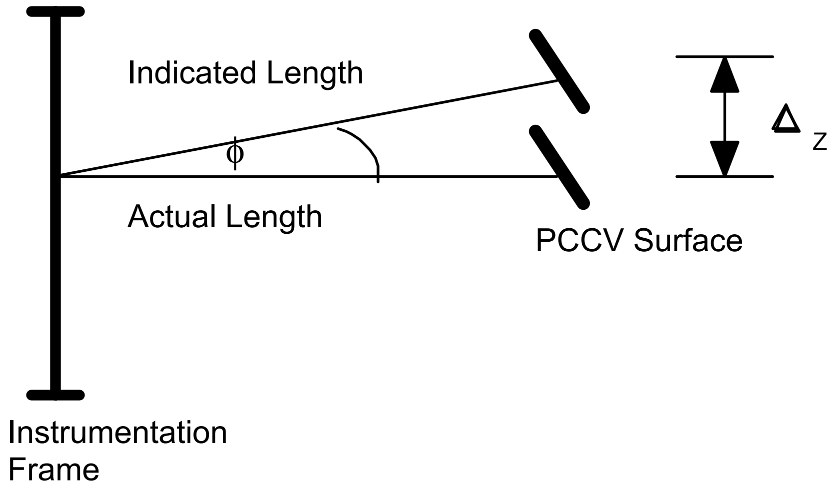

Figure G.3 Geometry for Vertical Movement of Liner at Horizontal Gage Locations