RSFitOSC User Guide

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RSFitOSC is based on RSFit3000, and so shares many of the same features. The user guide for RSFit3000 can be found at `https://github.com/rmskarbek/RSFit3000`. RSFitOSC consists of two files: RSFitOSC.m, and RSFitOSC.fig. To run the program, both files must be on the MATLAB path. Then the program can be run like any other m-file, by entering the name in the MATLAB command window. Note, opening the fig-file will open a window with a static image of the GUI, but the program will not be operating.

1 Loading Data

1. To begin, load data into the MATLAB workspace and click the **Update Listbox** button on the GUI (Figure 1a). This will load the names of the variables in the workspace into the GUI; the variable names will appear in the **List Box**. Any time variables are created or deleted in the workspace, clicking the **Update Listbox** button is required to pass the current variable names to the GUI.

2. The following data are required to perform fits: friction coefficient, load point displacement, normal stress, and time. Each of these data sets must be loaded into the MATLAB workspace as vectors with identical sizes. To proceed, type the proper variable names into the corresponding fields in the **Experimental Data Panel**.

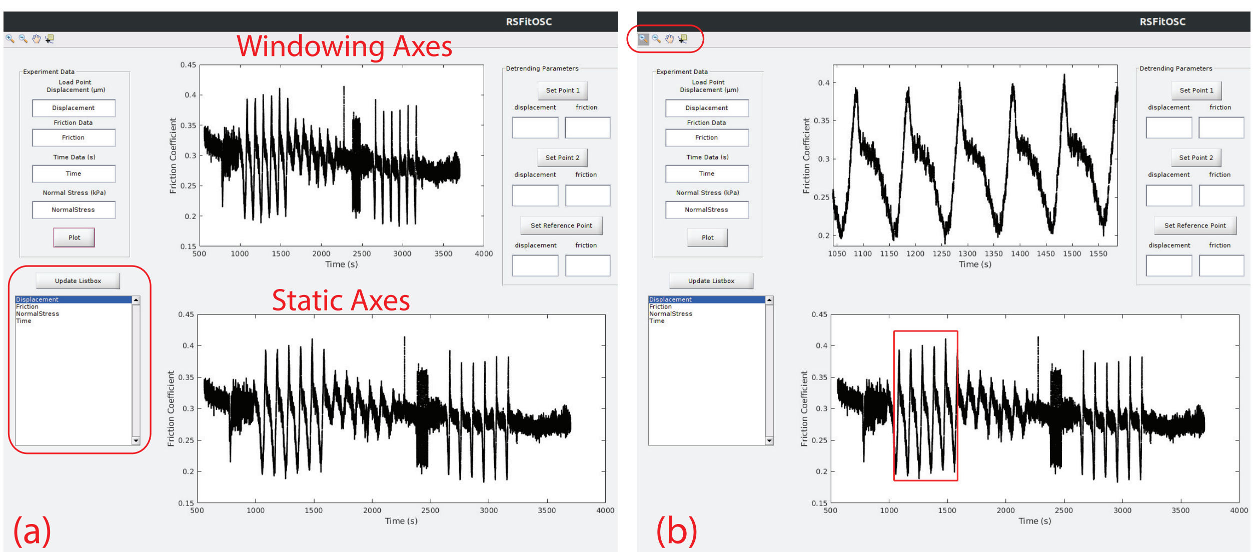


Figure 1: **Loading Data**. **(a)** The **Listbox** (red outline) displays the names of the variables that were in the MATLAB workspace the last time the **Update Listbox** button was pressed. **(b)** Use the zoom and pan tools (red outline) to isolate a single friction event in the **Windowing Axes**. A red box will show the current zoomed location on the **Static Axes**.

3. When all fields have valid entries, click the **Plot** button. When the **Plot Button** is clicked, initially identical plots of friction coefficient against load point displacement appear in the **Static Axes** and **Windowing Axes** (Figure 1a).

4. To continue, use the zoom and pan tools to isolate an event of interest in the **Windowing Axes** (Figure 1b). A red box will appear on the **Static Axes** showing the location of the windowed data within the entire data set.

2 Detrending

RSFitOSC contains the same detrending features as RSFit3000, which are described below. However, we emphasize that the effects of detrending oscillation event data are unknown. Our current recommendation is to reject any events that have strong strain-weakening or -hardening trends.

On start-up, the **Detrending Panel** is set to proceed without detrending. To continue to the fitting procedure, click the **Detrend Button** after windowing an event of interest. If detrending is desired, follow the steps below. The example shown in Figure 2 is from the RSFit3000 guide.

1. To detrend the data, select two points (t_1, μ_1) and (t_2, μ_2) on the windowed data (Figure 2a). First click the **Set Point 1** button, this will activate the data cursor mode on the GUI. Select a data point in the **Windowing Axes**, the load point displacement and friction values for the selected point will appear in the fields below the **Set Point 1** button. Do the same for the **Set Point 2** button. Be sure to select points so that the time for Point 1 is less than that for Point 2.

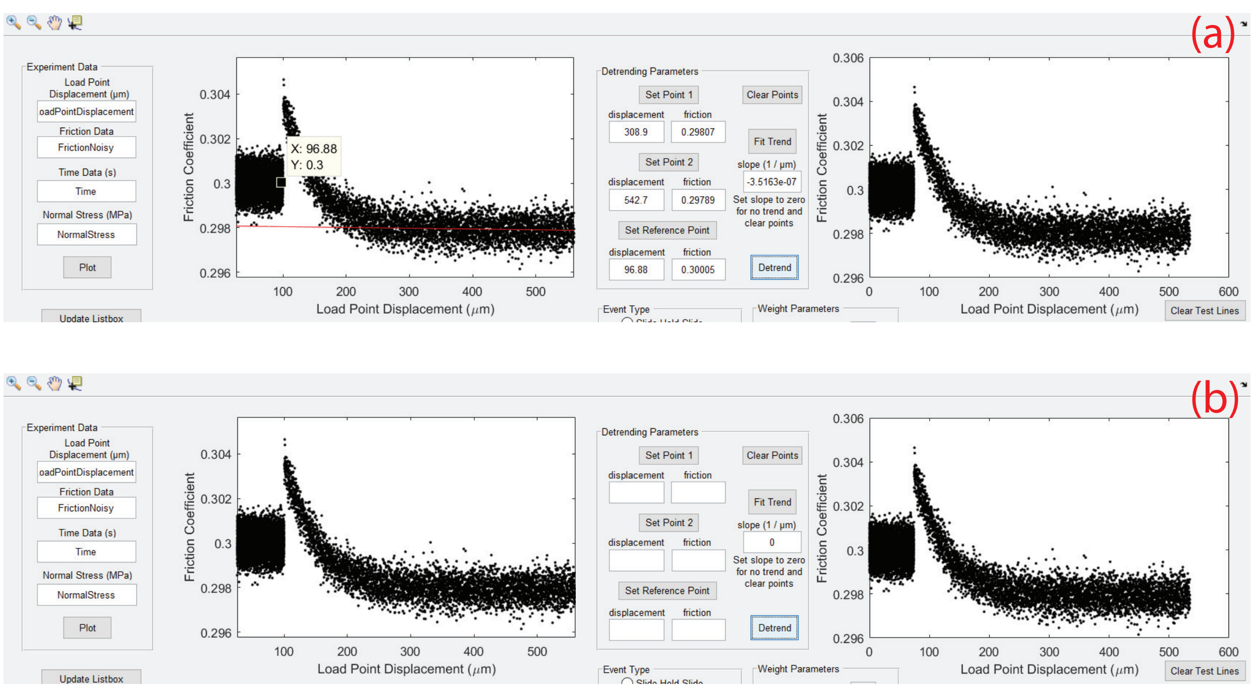


Figure 2: **Detrending (a)** Select Points 1 and 2, and the Reference Point on the **Windowing Axes**. **(b)** If no detrending is desired, click the **Clear Points** button, then set the slope value to "0" and click the **Detrend** button.

2. Click the **Fit Trend** button. This will fit a line to the data points that are between **Point 1** and **Point 2**. The line will be plotted in red on the **Windowing Axes**, and the slope of the fitted line will appear in the field below the **Fit Trend** button.

3. Select a Reference Point (t_r, μ_r) by clicking the **Set Reference Point** button. We recommend choosing a point at the start of the event. Now the data can be detrended by clicking the **Detrend Button**. Detrended friction values μ' are calculated according to $\mu' = \mu + m(t_r - t)$, where $m = (\mu_2 - \mu_1)/(t_2 - t_1)$.

4. Upon clicking the **Detrend Button**, the detrended and windowed data will appear in the **Fitting Axes**.

To continue without detrending the data, click the **Clear Points** button if any previous points have been set (Figure 1b). Then manually enter "0" into the **slope** field, and click the **Detrend Button**.

3 Fitting

When the **Detrend Button** is pressed, the program will estimate the mean load point velocity v_m, the load point velocity signal amplitude v_a, the signal period T, the signal phase γ, and the mean normal stress σ during the event. These values will appear in the **Load Point Signal Parameters Panel**. Any of these parameters can be changed manually by entering values in the appropriate field. A figure of the load point displacement vs. time will also appear (Figure 3b). This figure will show the actual load point displacement data (black), and that predicted using the estimated

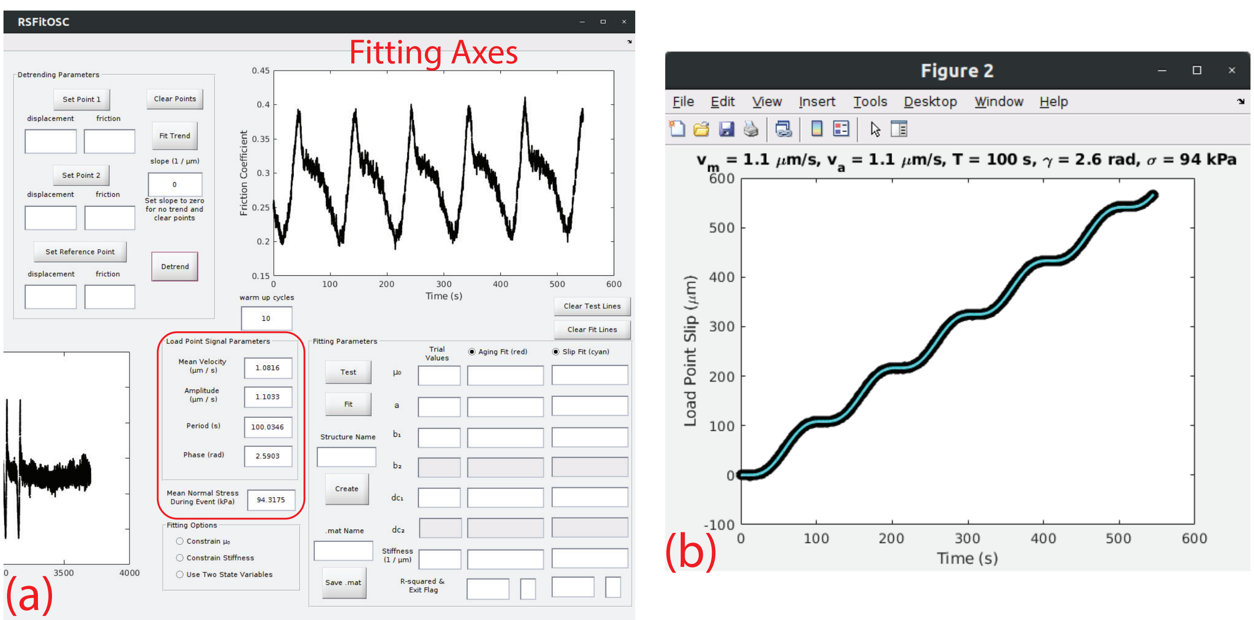


Figure 3: Three things will happen when the **Detrend Button** is clicked: **(a)** the estimated values of v_m, v_a, T, γ, and σ will appear in the **Load Point Signal Parameters Panel** (red outline); the windowed data will appear in the **Fitting Axes**, zero-referenced to time; and **(b)** a plot of the load point displacement vs. zero-referenced time will appear in a new window.

parameter values (cyan), according to the equation

$$\delta_l = v_m t + \left(\frac{v_a}{\omega'}\right)\left[\sin\left(\omega' t + \gamma\right) - \sin\left(\gamma\right)\right] \ , \tag{1}$$

where $\omega' = 2\pi\omega = 2\pi/T$ is the angular frequency.

3.1 Fitting Options

There are three options available for performing a fit: use of 1) μ_0 or 2) stiffness k as fitting parameters, and 3) use of two state variables. Any of these options may be combined with one another. Selecting any combination of the **Constrain μ_0**, **Constrain Stiffness**, or **Use Two State Variable** options will activate/deactivate the corresponding fields in the **Fitting Parameters Panel**.

3.2 Fitting Procedure

1. Select desired **Fitting Options**.
2. Set the number of warm-up cycles. The default number is 10 (Figure 4a).

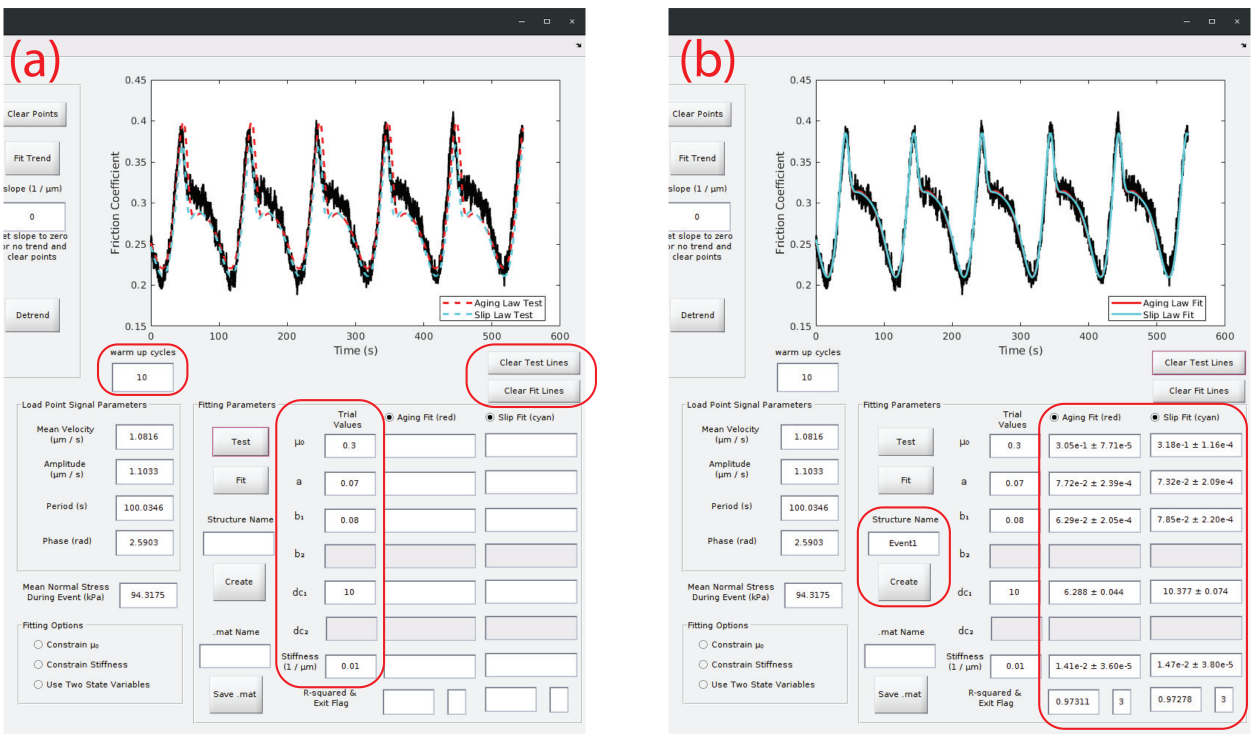


Figure 4: **Fitting Parameters (a)** Set the number of warm-up cycles and enter trial values for all of the active fields. In this example the b_2 and d_{c2} fields are deactivated because the **Use Two State Variables** option is not selected. After clicking the **Test Button**, dashed lines showing the results of spring-slider simulations using the trial values will appear on the **Fitting Axes**. At any time, the test or fit lines can be cleared from the **Fitting Axes** by clicking the **Clear Test Lines** or **Clear Fit Lines** buttons. **(b)** The fitting routine will run when the **Fit Button** is clicked. The results will appear in the **Fitting Parameters Panel**, and on the **Fitting Axes** as solid lines.

3. Select whether to perform an aging law fit, a slip law fit, or both.

4. Enter trial values for μ_0, a, b_1, d_{c1}, k (Figure 4a). If using two state variables, enter trial values for b_2 and d_{c2} as well. Values for μ_0 and k must be entered regardless of whether the options to constrain these two values are selected.

5. After entering the trial values, click the **Test Button**. The program will run a spring-slider simulation using the trial values, the load point signal parameters, and the number of entered warm-up cycles. The results of the simulation will be plotted as dashed lines over the data in the **Fitting Axes** (Figure 4a).

6. If the test lines do not closely overlie the data, any of the trial values can be changed to run another test. This process should be repeated until the test lines overlie the data as much as possible. Obtaining trial values in this manner is critical to obtaining good fitted parameter values.

7. After generating satisfactory parameter guesses, click the **Fit Button**, and the program will carry out the nonlinear least squares fitting routine. Information regarding the number of solution attempts, and the parameter values for each attempt will be displayed in the MATLAB Command Window as the fitting routine is running.

8. When the routine has completed, the fitted parameter values, along with the error intervals, will be displayed in the corresponding fields in the **Fitting Parameters Panel**. The results of a spring-slider simulation using the fitted values will be plotted over the data as solid lines in the **Fitting Axes** (Figure 4b). The R^2 value, and an exit flag indicating why the solver stopped will also appear at the bottom of the **Fitting Parameters Panel**.

9. Save the fit parameters and data using the **Create Structure Button** (Figure 4b, see below).

10. Window a new event in the **Windowing Axes** and repeat the procedures described above to obtain more fits, as desired.

3.2.1 Exit Flags

Exit Flag	Meaning
1	Local minimum of the objective function found
3	Relative sum of squares of the objective function is changing by less than the **FunctionTolerance**
4	Norm of the step size is changing by less than the **StepTolerance**
0	Number of iterations exceeded **MaxIterations**, or number of function evaluations exceeded **MaxFunctionEvaluations**

Table 1: This is a list of the exit flags and their meanings.

Exit flags 3 and 4 are the most common result. The values of **StepTolerance**, **FunctionTolerance**, **MaxIterations**, and **MaxFunctionEvaluations** can be changed using the built-in MATLAB function **optimoptions**. These options can be set on Line 838 in RSFit3000.m.

3.3 Solver Failures

Sometimes the ODE solver will not be able to complete a simulation. For example, this can happen if the combination of parameters leads to stick-slip events. ODE solver failures can generally be avoided by starting with a set of trail values that closely matches the data. If the solver does fail, an error message will appear in the MATLAB command window showing the parameter values that led to the failure. This can be helpful in understanding why the solver failed. Changing the fitting options can sometimes lead to a successful fit. Additionally, a number of other warnings and error messages associated with the solver failure will also be displayed.

4 Data Structure

When a satisfactory fit has been completed, enter a name in the **Structure Name** field, and click the **Create Structure Button**. A structure with the entered name will appear in the MATLAB workspace. This structure contains all of the relevant information necessary to produce the fit. The fields contained in the structure are as follows:

- **Load Point Displacement Data** – a vector of windowed load point displacement values.
- **Friction Data** – a vector of windowed friction coefficient values.
- **Friction Data Detrended** – a vector of detrended friction coefficient values. If no trend was removed, these values will be identical to the **Friction Data**.
- **Time Data** – a vector of windowed time values.
- **Normal Stress Data** – a vector of windowed normal stress values.
- **Detrend Parameters** – a sub-structure containing the coordinates of **Point 1**, **Point 2**, **Reference Point**, and the slope of the fitted detrending line.
- **Fitting Options** – a sub-structure indicating what options were used to generate the fit, and the number of warm-up cycles.
- **Signal Parameters** – a sub-structure containing the load point signal parameters for the windowed event; the mean normal stress during the event; and the time at the beginning of the event window (TimeOfEvent).
- **Trial Parameters** – a sub-structure containing trial values of μ_0, a, b_1, d_{c1}, k, and optionally b_2 and d_{c2} as well. If one state variable was used, the trial values for both b_2 and d_{c2} will be listed as zero.
- **Aging Law Parameters and Slip Law Parameters** – sub-structures containing the fitted parameter values and error intervals for aging and slip law fits, respectively. The field for each fitted parameter is stored as a 1×2 array. The first column contains the parameter value, and the second column contains the error interval. If one state variable was used, the fields for b_2 and d_{c2} will contain zeros. If either μ_0 or the stiffness were constrained, these parameters will have "0" as the error interval. The exit flag, R^2 value, and covariance matrix will also be stored in separate fields. See below for information on the contents of the covariance matrix.

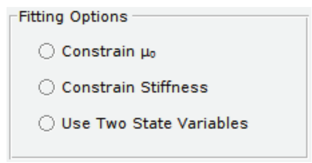
- **Aging Law Fit and Slip Law Fit** – Arrays with two, or three columns. First column: load point displacement data used for the fit. Second column: predicted detrended friction coefficient values. If the data has not been detrended there will only be two columns. If the data has been detrended, there will be a third column containing: predicted friction coefficient values with the trend added back in.

4.1 Covariance Matrix

The contents of the covariance matrix depend on what fitting options are selected. Depending on these options, the rows and columns of the matrix correspond to different parameters, as listed below. The covariance matrix is an $M \times M$ matrix, where M is the number of fitted parameters.

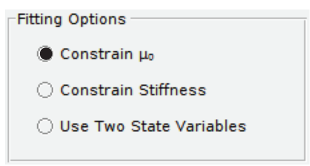
1. No options selected

$$\begin{array}{cc} & \begin{array}{ccccc} \mu_0 & a & b_1 & d_{c1} & k \end{array} \\ \begin{array}{c} \mu_0 \\ a \\ b_1 \\ d_{c1} \\ k \end{array} & \left(\begin{array}{ccccc} \; & \; & \; & \; & \; \\ & & & & \\ & & & & \\ & & & & \\ & & & & \end{array} \right) \end{array}$$



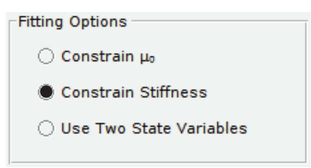
2. **Constrain** μ_0 selected

$$\begin{array}{cc} & \begin{array}{cccc} a & b_1 & d_{c1} & k \end{array} \\ \begin{array}{c} a \\ b_1 \\ d_{c1} \\ k \end{array} & \left(\begin{array}{cccc} \; & \; & \; & \; \\ & & & \\ & & & \\ & & & \end{array} \right) \end{array}$$



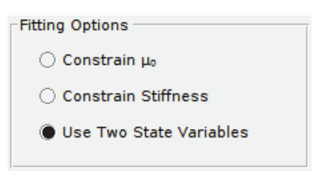
3. **Constrain Stiffness** selected

$$\begin{array}{cc} & \begin{array}{cccc} \mu_0 & a & b_1 & d_{c1} \end{array} \\ \begin{array}{c} \mu_0 \\ a \\ b_1 \\ d_{c1} \end{array} & \left(\begin{array}{cccc} \; & \; & \; & \; \\ & & & \\ & & & \\ & & & \end{array} \right) \end{array}$$



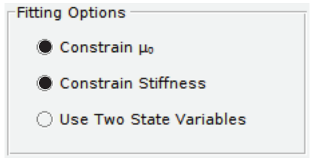
4. **Use Two State Variables** selected

$$\begin{array}{cc} & \begin{array}{ccccccc} \mu_0 & a & b_1 & d_{c1} & k & b_2 & d_{c2} \end{array} \\ \begin{array}{c} \mu_0 \\ a \\ b_1 \\ d_{c1} \\ k \\ b_2 \\ d_{c2} \end{array} & \left(\begin{array}{ccccccc} \; & \; & \; & \; & \; & \; & \; \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & & \end{array} \right) \end{array}$$



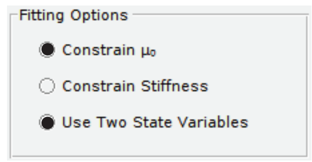
5. **Constrain** μ_0, **Constrain Stiffness** selected

$$\begin{array}{cc} & \begin{matrix} a & b_1 & d_{c1} \end{matrix} \\ \begin{matrix} a \\ b_1 \\ d_{c1} \end{matrix} & \begin{pmatrix} & & \phantom{d_{c1}} \\ & & \\ & & \end{pmatrix} \end{array}$$



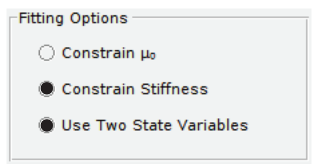
6. **Constrain** μ_0, **Use Two State Variables** selected

$$\begin{array}{cc} & \begin{matrix} a & b_1 & d_{c1} & k & b_2 & d_{c2} \end{matrix} \\ \begin{matrix} a \\ b_1 \\ d_{c1} \\ k \\ b_2 \\ d_{c2} \end{matrix} & \begin{pmatrix} & & \phantom{d_{c1}} & & & \phantom{d_{c2}} \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \end{pmatrix} \end{array}$$



7. **Constrain Stiffness**, **Use Two State Variables** selected

$$\begin{array}{cc} & \begin{matrix} \mu_0 & a & b_1 & d_{c1} & b_2 & d_{c2} \end{matrix} \\ \begin{matrix} \mu_0 \\ a \\ b_1 \\ d_{c1} \\ b_2 \\ d_{c2} \end{matrix} & \begin{pmatrix} & & & \phantom{d_{c1}} & & \phantom{d_{c2}} \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \end{pmatrix} \end{array}$$



8. All options selected

$$\begin{array}{cc} & \begin{matrix} a & b_1 & d_{c1} & b_2 & d_{c2} \end{matrix} \\ \begin{matrix} a \\ b_1 \\ d_{c1} \\ b_2 \\ d_{c2} \end{matrix} & \begin{pmatrix} & & \phantom{d_{c1}} & & \phantom{d_{c2}} \\ & & & & \\ & & & & \\ & & & & \\ & & & & \end{pmatrix} \end{array}$$