Tutorial on Hill-type Discrete Elements

Contents

1 Introduction

This tutorial describes how to set up and use Hill-type discrete elements in FEBio Studio. Hill-type discrete elements can be used to model the mechanical properties of skeletal muscle that arise from active contraction and passive resistance to deformation.

The geometry to set up the model has been created for you, so you can focus on the Hill-type discrete element. Please find the FEBio Studio project file, "Hill_Tutorial.fsprj" in the model database (also available on Canvas under Homework 5). The geometry for this tutorial is shown in the figure below. It consists of two rigid bodies (tetrahedral elements) and we will connect them with a discrete element.

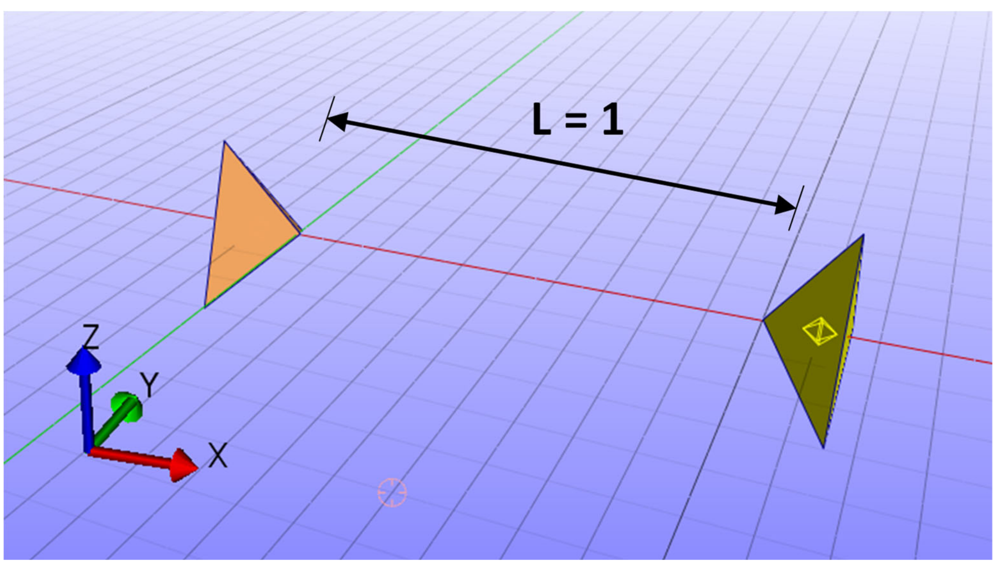


Figure 1 - Model Geometry. The discrete hill element will lie between two tetrahedral rigid bodies, and have a unit length

The model tree and an explanation of the model are presented below:

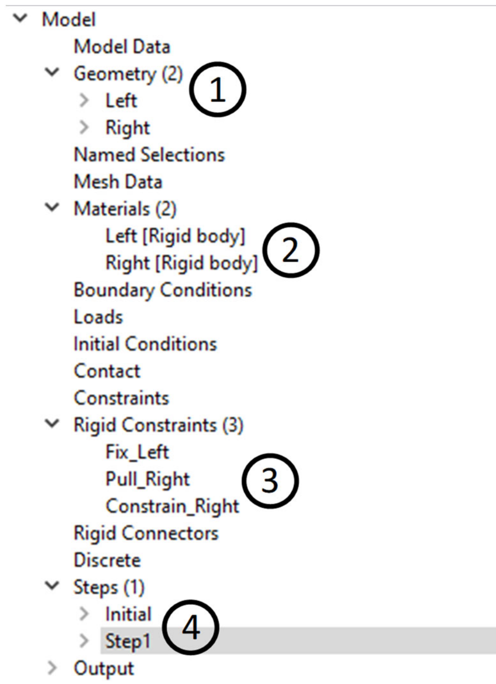


Figure 2 - Model Tree. The model comes with 2 objects, 2 rigid body materials, 3 rigid constraints, and an analysis step

1) The model contains two bodies, “left” and “right” according to their position. These are the tetrahedrons seen in the image above.
2) There are 2 rigid body materials, one assigned to each body. Rigid bodies cannot undergo any deformation. They are very useful in biomechanical modelling of very stiff structures, such as bone, along with softer structures, such as soft tissues.
3) There are 3 constraints. Rigid bodies have special boundary conditions that are called “Rigid Constraints”. The first one fixes the left rigid body in space by constraining all 6 degrees of freedom. The second constraint prescribes the displacement of the right rigid body along the positive X axis by a distance of 1. This means our muscle will start with a length of 1 and end with a length of 2. The third constrains the other 5 degrees of freedom of the right rigid body.
4) An analysis step has been added. This determines some of the solution parameters that control the nonlinear solution process for the finite element problem using Newton’s method.

2 Step 1: Creating the discrete element set

The first step is to create a discrete element set in FEBio Studio. This is done in two steps. First, a new discrete group is created that contains the discrete elements. Next, the discrete elements are created by selecting the two nodes that will be connected by the discrete element.

2.1 Creating the discrete element group

Activate the **Build** panel and select the **Create** tab. Then click the *Spring* icon ( ). A new discrete element group has to be created to which the discrete elements will be assigned. This step is necessary because there are discrete elements in FEBio that are not of the Hill type, such as passive springs. In the parameters panel that appears, click the *New…* button, next to the *Group* drop-down box. In the dialog box that appears, enter a name (e.g. muscle) and select the *Hill* type. Click OK to close the dialog box. The group will now show up in the *Group* drop-down box. If needed, multiple groups can be created in this manner. This can be useful if the model contains several different types of muscle.

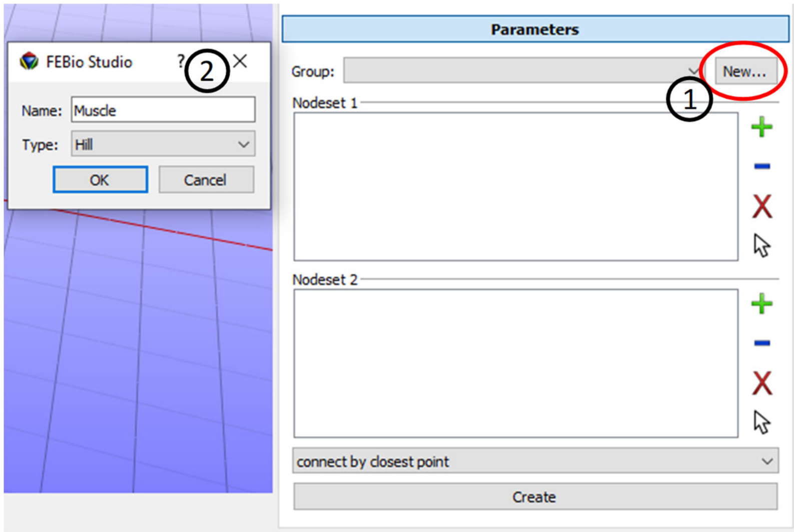
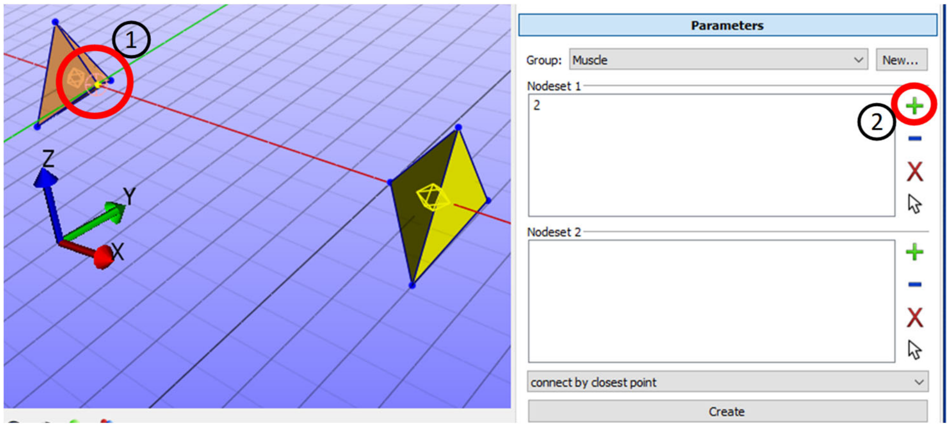


Figure 3 - Creating Hill Group

2.2 Creating the discrete element

After creating the group, the nodes that make up the discrete elements need to be selected. In this tutorial, a single discrete element will be created. Activate node selection by clicking the corresponding toolbar button on the main toolbar ( ).

First, select the node on the *Left* object that is closest to the opposite object. Assign that node to *Nodeset 1* in the *Parameters pane* by clicking the green plus icon (+). Then, select the node on the *Right* object that is closest to the opposite object and assign that to *Nodeset 2*. Then click on the *Create* button.



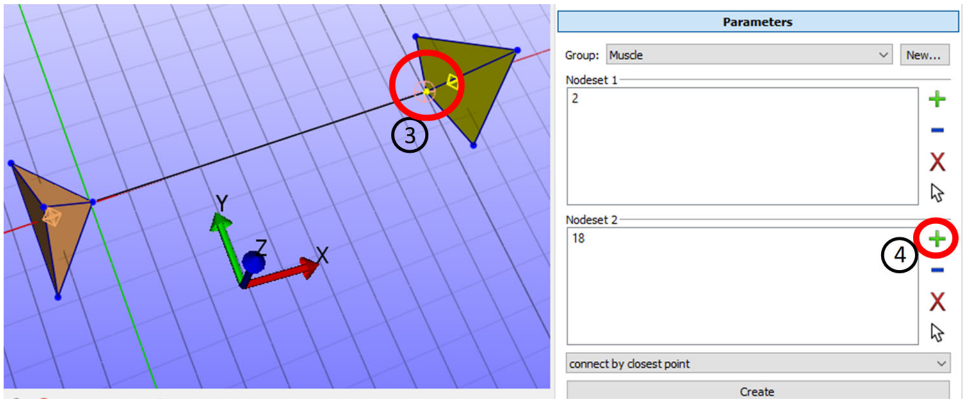


Figure 4 - Creating Hill Element by Attaching Nodes

Now the discrete element is shown in the Graphics View. (You might have to turn off the grid to see it clearly by pressing the ‘G’ shortcut.)

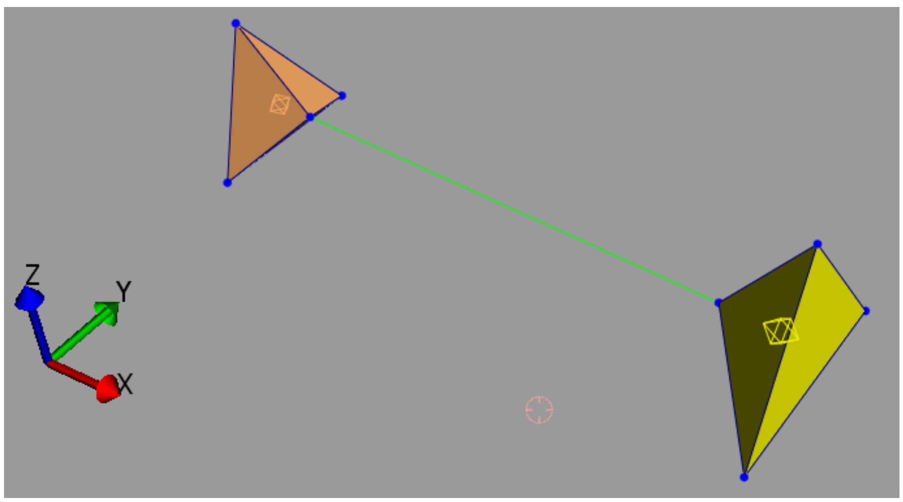


Figure 5 - Graphic View of Hill Element

3 Step 2: Defining the Hill parameters

3.1 Defining scalar parameters

Once the discrete elements are created, a new item will be shown on the model tree under the *Discrete* branch. The label of the item is the name that was assigned to the discrete element group (i.e. muscle in this case). Select this item to see the parameters that can be defined.

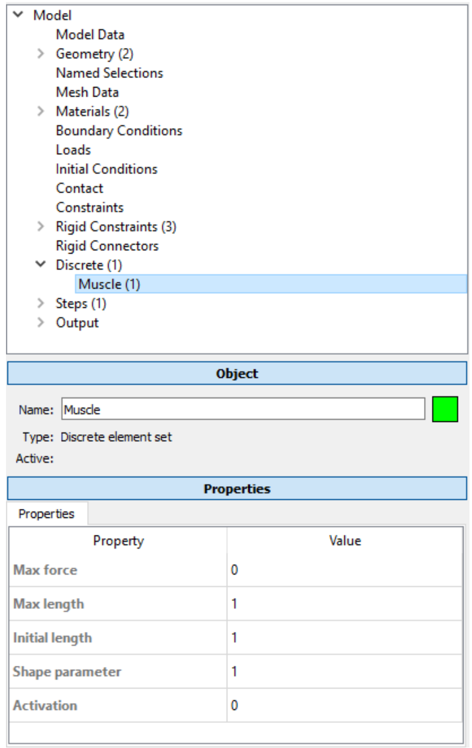


Figure 6 - Hill Parameters in Model Tree

Note that the parameters shown here are only the scalar parameters. This discrete material also has some parameters that are defined via curves, but they are not listed here. They are shown in the *Curve Editor* and will be explained below in section 3.2.

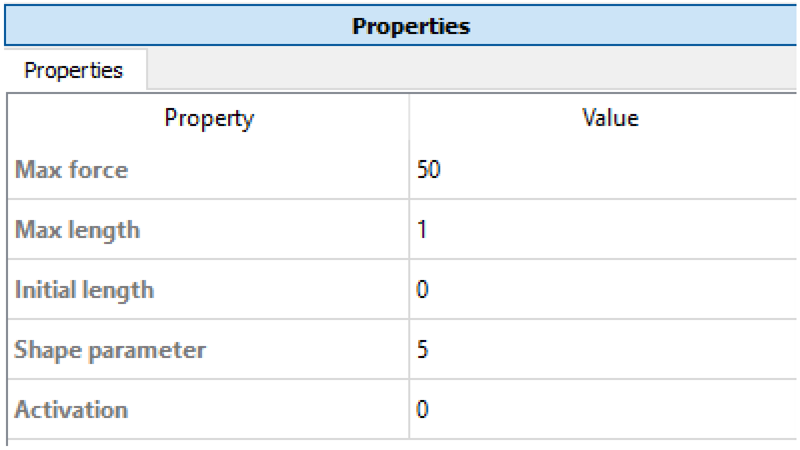
The *Max Force* property is the maximum force the muscle can produce. Physiologically, this happens under 1) tetanized neural activation 2) at the optimum muscle length and 3) isometric contraction (contraction without movement). From a modelling perspective, this is the tensile force developed in the discrete element at the optimum length (*Max Length)* and 100% activation. **Set the *Max Force* to 50 N.**

The *Max Length* property is the optimum muscle length. This corresponds to the peak of the force-length curve. **Set the *Max Length* to 1.** This means the force generated from the active contraction will be largest right at the start of the muscle pull.

The *Initial Length* property sets the reference length of the discrete element. **Set the *Initial Length* to 0.** This tells FEBio to set the initial length to the length of the discrete element in the model.

The *Shape parameter* is a dimensionless parameter that controls the rate of the rise of the exponential function that defines the passive force-length relationship for the parallel elastic component of the Hill model. **Set the *shape parameter* to 5.**

The *Activation* parameter varies between 0 and 1 and scales the amount of active force generated by the muscle. **Set the *Activation* to 0.** This means our model will not have any contribution from active muscle contraction.



Property	Value
Max force	50
Max length	1
Initial length	0
Shape parameter	5
Activation	0

Figure 7 - Setting Hill Element Parameters

3.2 Setting up parameters with a curve

The Hill discrete material allows you to specify a Force-Length curve, a Force-Velocity curve and a Velocity Scale curve. Since these parameters require curves, they are not displayed in the Properties pane of the Model panel, but instead are listed in the **Curve Editor**.

Open the **Curve Editor** by selecting the menu *Tools\Curve Editor* or choosing the curve editor button from the main toolbar.

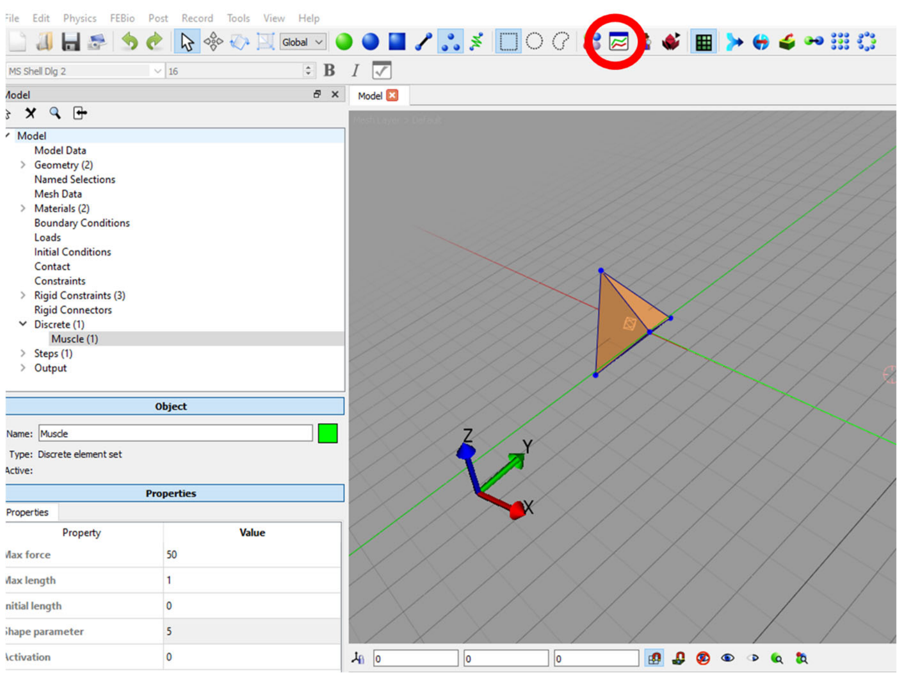


Figure 8 - Curve Editor Button on Toolbar

The Curve Editor window appears. It is divided into two panels. The left panel shows a model tree and lists all the parameters to which curves can be assigned. The right panel shows the curve of the parameter that is selected in the left panel.

General Information about the Curve Editor

Curves can be edited by moving, inserting, or deleting nodes.

- **To move a node**: Click on a node and, holding down the left mouse button, drag it to the desired position. Alternatively, with a node selected, you can also directly enter the coordinates of the node in the two edit fields below the graph.
- **To insert a node**: Shift+click with the left mouse button on the curve at the position where the node is to be inserted.
- **To delete a node**: Select the node and click the *Delete Node* button below the graph ().

You can also create the curve by sampling a mathematical equation. To do that, click the equation icon at the top toolbar of the Curve Editor (Σ). In the dialog that appears, enter the equation and the sampling parameters and click OK. This will generate a curve based on the equation. The nodes of this curve can still be edited as any other curve.

We will begin by setting the displacement profile of the right rigid body. In the model tree of the curve editor, expand the *Rigid Constraints*, then the *Pull_Right* contraint, and left-click on "value."

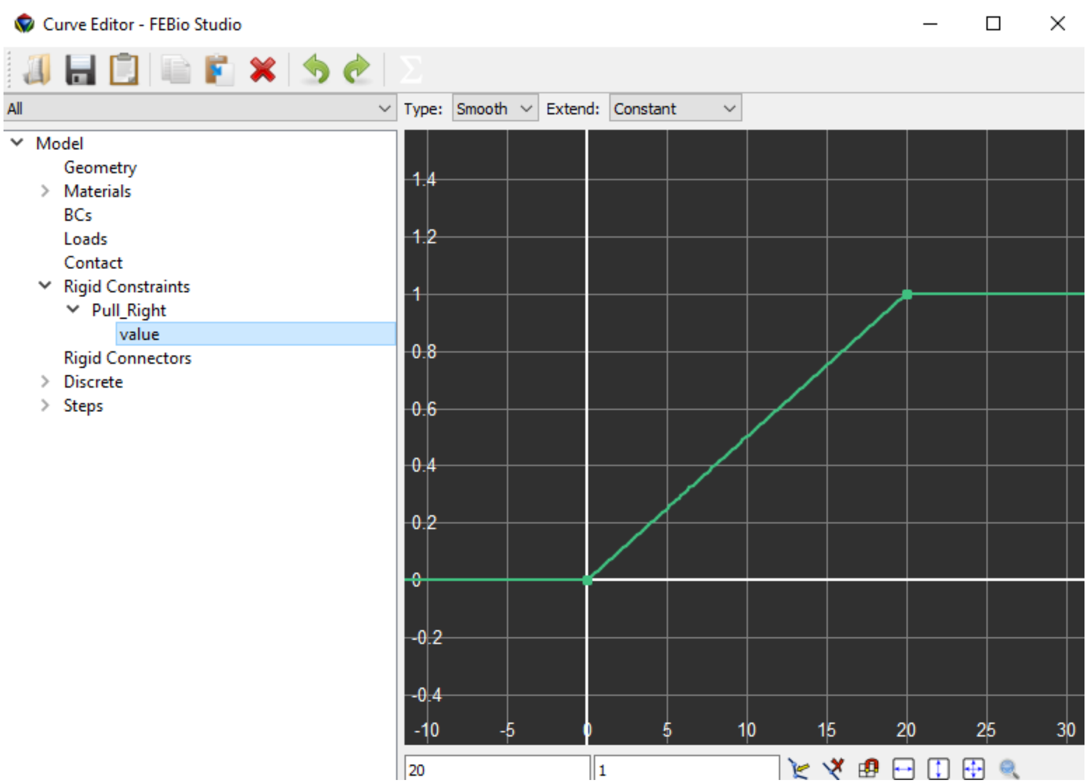


Figure 9 - Curve Editor UI View

The curve editor allows us to specify how the rigid body will be displaced as a function of time. Thus, this also enables us to choose the velocity (the slope of the curve). Our analysis step occurs from a time of 0 to 1, and we would like our discrete element to be stretched by a unit of length of 1 at time = 1. However, FEBio does not evaluate the forces at time 0. So our displacement will start at t = 0.1. Left click on the second point in the curve editor, and enter 1,1 for its position. Then, add a point between the two points using shift+click, and enter (0.05, 0). Make sure the *Type* is set to Linear. You may need to play with the zooming buttons to see a similar view to the image below.

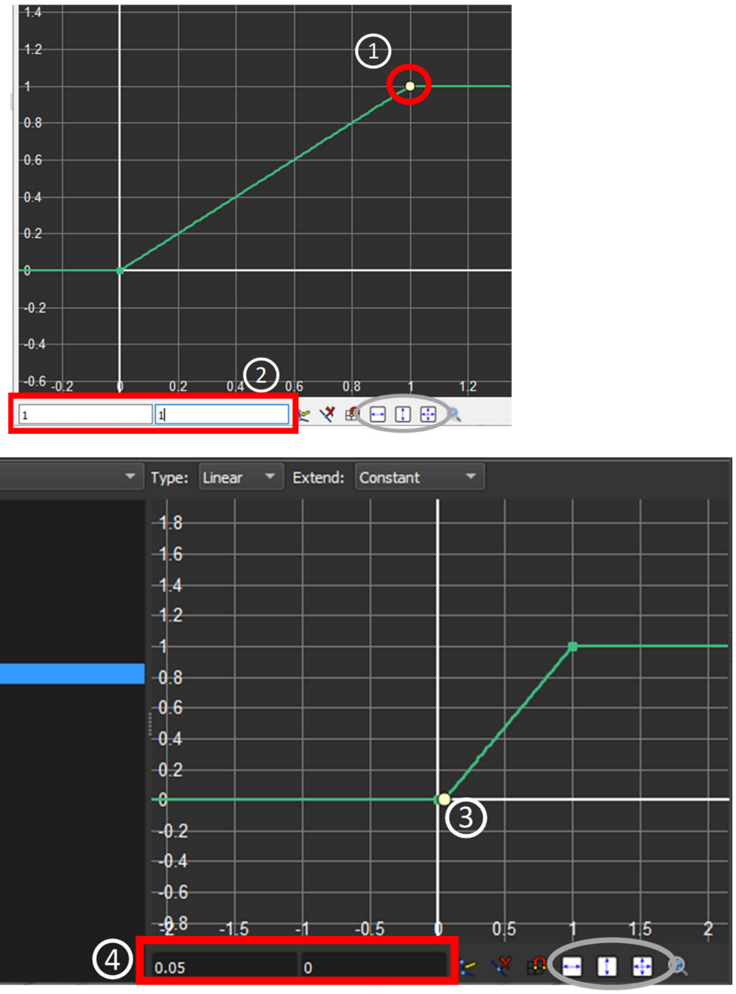


Figure 10 - Modifying The Prescribed Displacement Curve

Next, we will set the values of the tension-length curve. In the model tree of the curve editor, expand *Discrete*, then *Muscle*, then *Ftl,* and left-click on "points." In our computational model, the X axis represents normalized length and the Y axis represents normalized force. Thus the maximum force should occur at a normalized length of 1, corresponding to optimal muscle length, and the maximum force should have a value of 1. Enter 3 points: **1.** at (0,0) **2.** at (1,1), and **3.** at (2,0). Make sure the *Type* is set to smooth. This controls the interpolation between points.

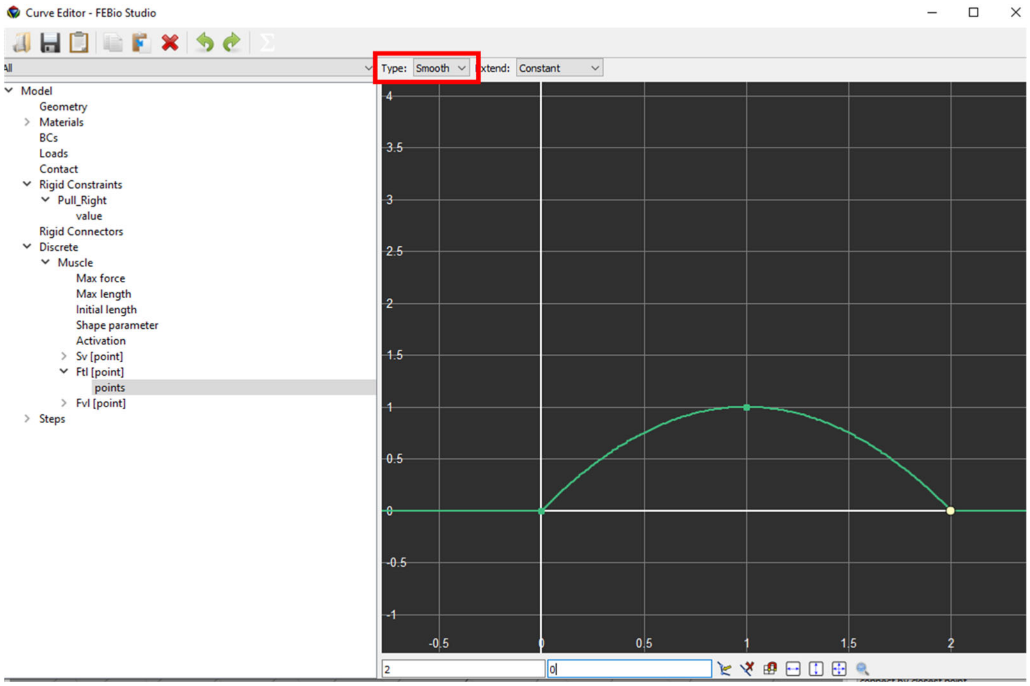


Figure 11 - Modifying Tension-Length Curve: Setting the interpolation between points to smooth

Press the Zoom to fit button, and zoom out using your mouse scroll.

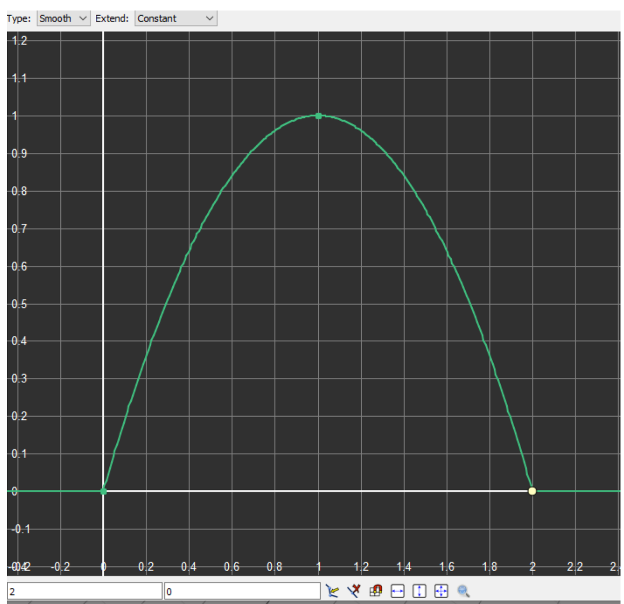


Figure 12 - Modifying the Tension-Length Curve - zooming the editor window to fit boudns

Now we will make the curve more like a bell distribution by setting individual points. We will use an image of a curve used for tension-length muscle relationship. Right-clicking on the Graph brings up a popup menu. Select the *Select Background Image* option. A dialog box appears that allows you to set the background image of the Graph panel. Choose the "force_length.png" file that is available on Canvas under this homework folder. Now, we will position the axes such that the axes in the image match our curve editor graph. Click the *Map to Rectangle* button (). By dragging the left mouse button over the graph, draw the rectangle that bounds the area on the image that contains the curve. When completed, a dialog box appears that will allow you to specify the curve bounds that correspond to the rectangle. Set the X interval to be from 0 to 2, and the Y interval from 0 to 1. Click OK to position the axes such that they match the bounds.

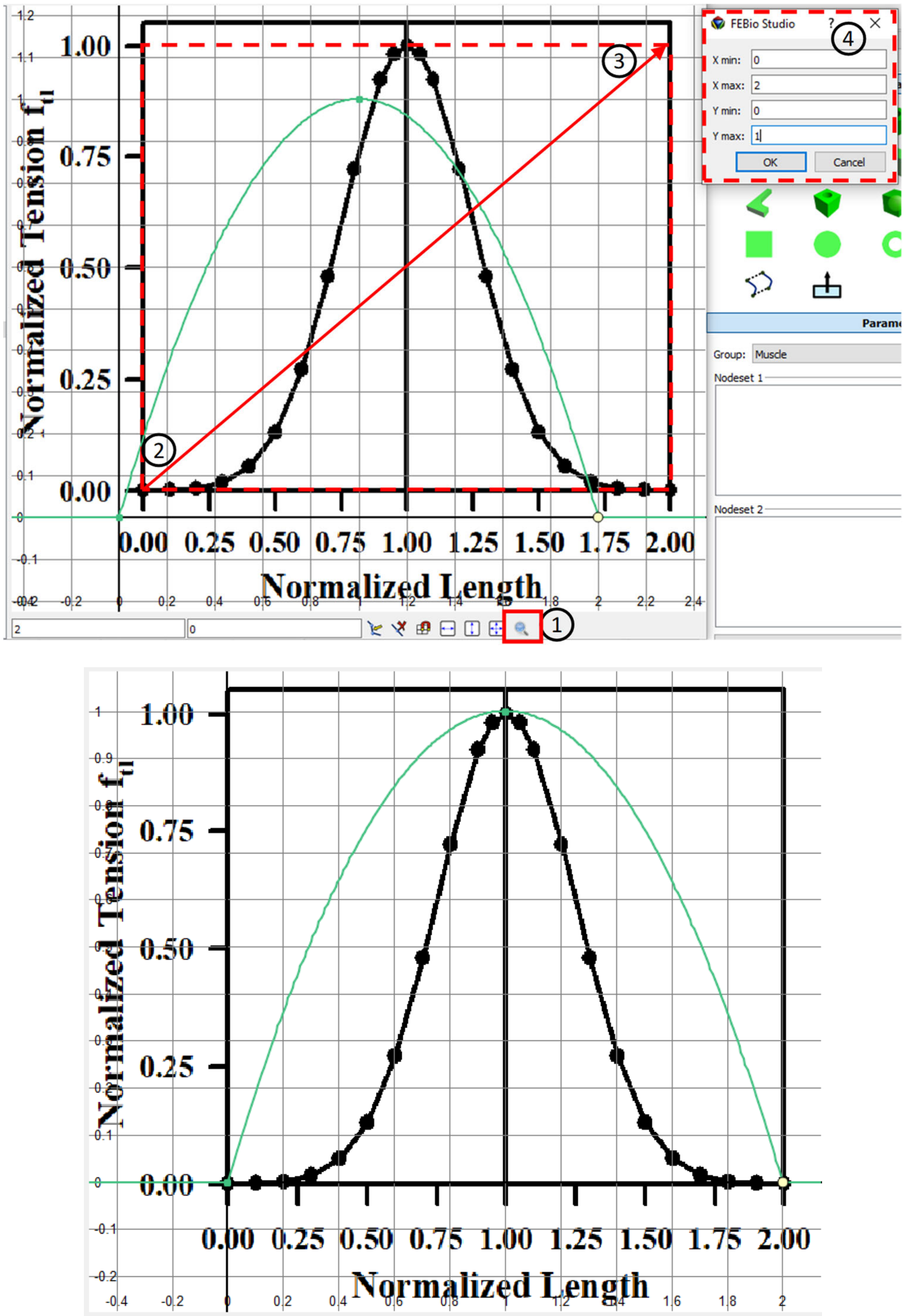


Figure 13 - Adding Background Image and Rescaling Image area to Match Curve Bounds

Now, the curve can be created by adding and positioning nodes using shift+click. Then, we can dispose of the background image by right-clicking and selecting *Clear Background Image.*

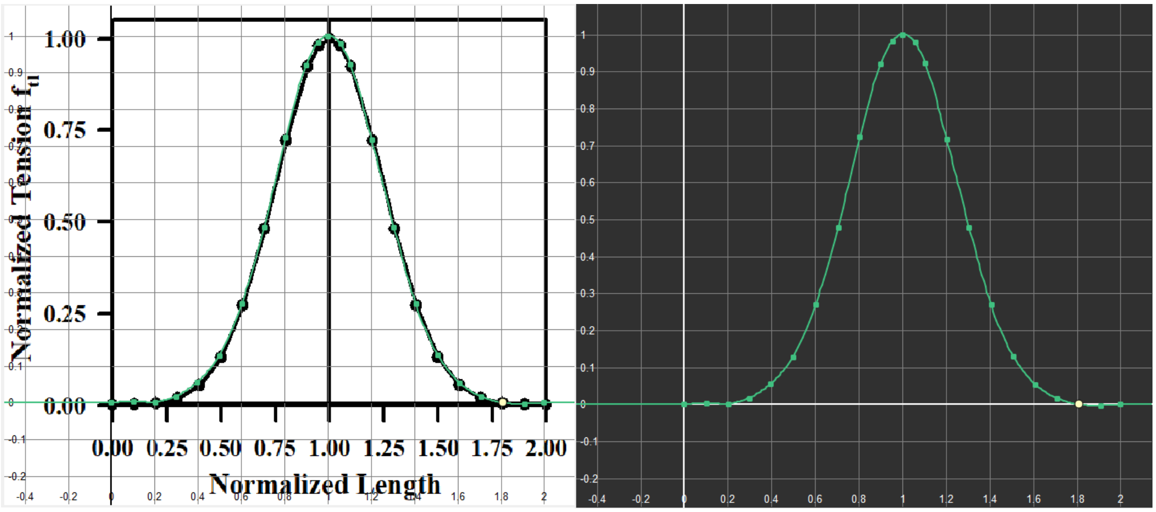


Figure 14 - Final Tension-Length Curve

4 Step 3: Running the model and analyzing the results

Now we are ready to run the model with FEBio. Click on the Run FEBio button from the main toolbar and name your Job “Hill_Tutorial_0_Activation.”

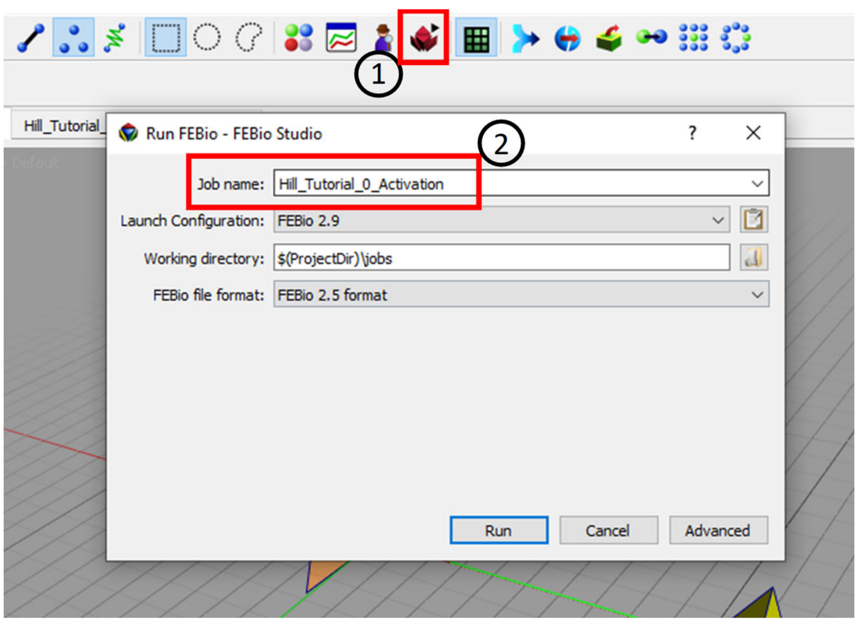


Figure 15 - Running A Job in FEBio Studio

Open the plot file with FEBio Studio to view the results.

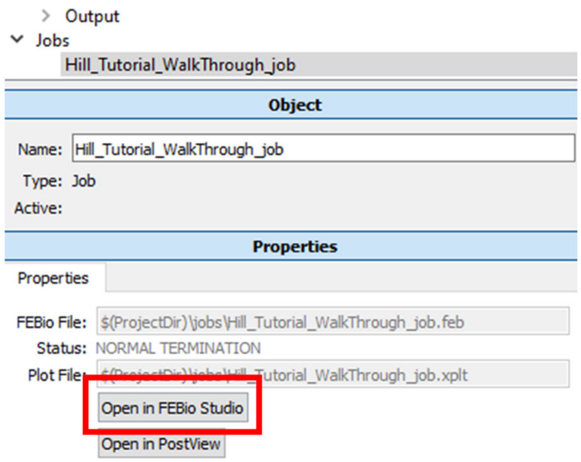


Figure 16 - Analyzing a Model in FEBio Studio

Currently, FEBio does not store output variables for discrete elements (this will likely change in future versions). Thus, we will probe the forces imposed on the rigid bodies to look at the properties of the Hill element. Select the *Select Elements* tool, and click on the right rigid body.

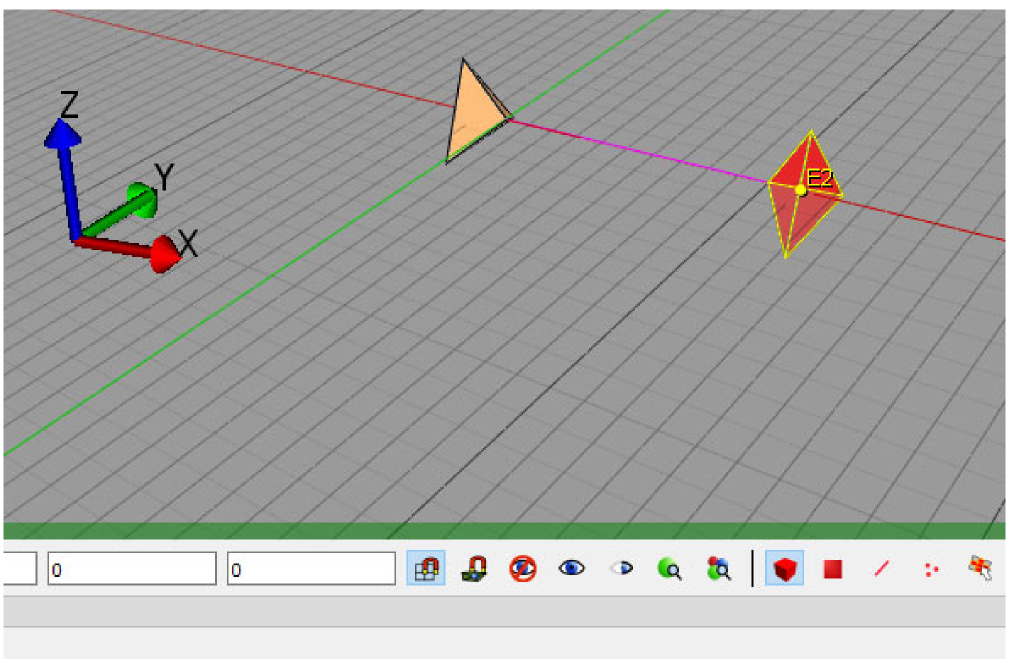


Figure 17 - Selecting an Element

Select *Post -> New Graph.* Choose the type as *Scatter,* the X axis as *X-Displacement*, and the Y axis as *X – Rigid Force.* By plotting the displacement versus the force, we are probing the force-length property of the Hill element. The output should look similar to the image below.

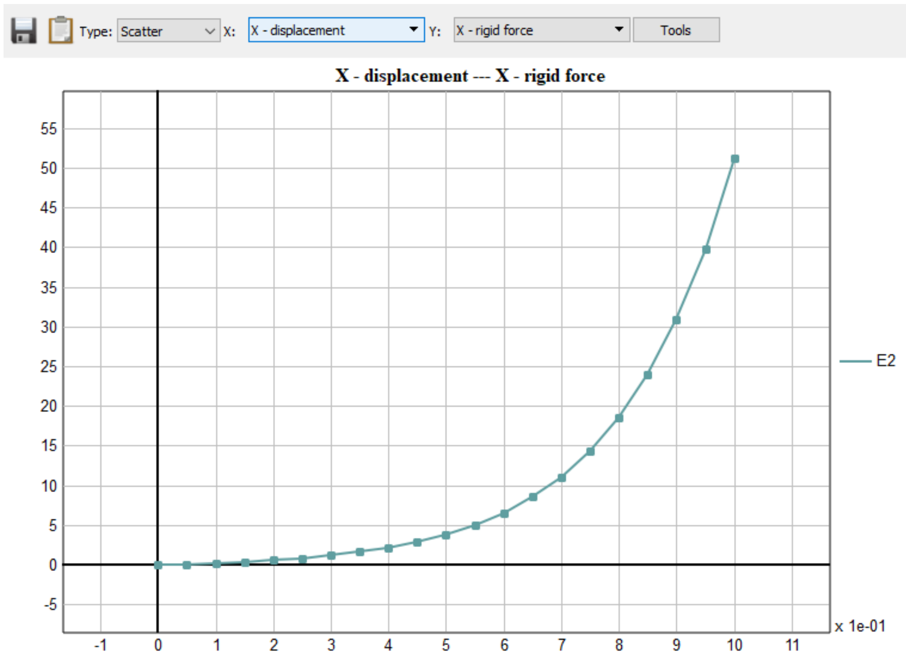


Figure 18 - Plot of Displacement Versus Force

Because the max length occurs at L = 1, our reference configuration, we are essentially recreating half of the Force-length curve with varying activation levels.

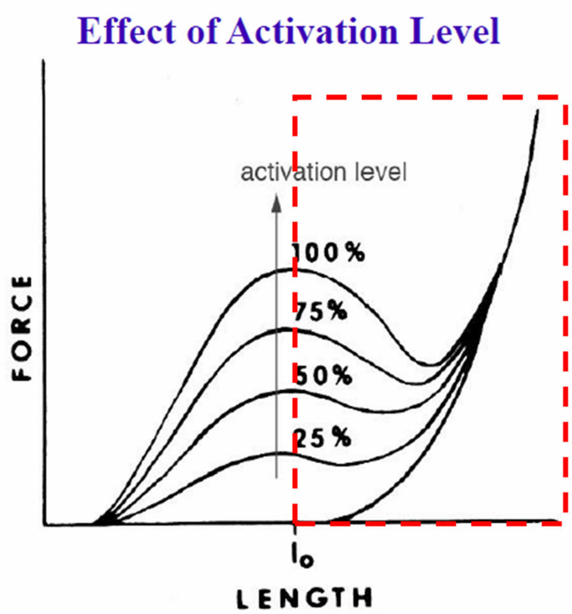


Figure 19 - Mechanical Properties of Msucle with Varying Activation Levels

Congratulations! You learned you to use discrete elements in a model, and use the Curve Editor to set complex parameters.