

**Dureza  
(Indentation Curve Analysis Software),**  
by D. Shuman and A. Costa

**Reference paper:**

Shuman DJ, Costa ALM, Andrade MS. Calculating the elastic modulus from nanoindentation and microindentation reload curves. Mater Charact. 2007; 58(4):380-389

**Help File**

**MENU Topics:**

**File:**

Import (.TXT; .CSV)

Open (.DRZ)

Save As (.DRZ)

Save

Save As

Print

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**Edit:**

Copy (Ctrl+C)

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**Analysis:**

Elastic Modulus

Hardness

**Graininess Functions:**

Shows the change in displacement along the unloading or reloading curve.

**Help:**

Help

About

**Import Indentation Files (.TXT; .CSV)**

First enter the line number where the displacement and force data start. Then select the data separator type. The edit box will show a double line ( || ) where it found a separator. Then select the correct units and column number for the data.

The time and segment data are optional, click the check box if you want them to be imported.

## SAVE .DRZ:

The save as unload function automatically separates all of the unload curves from a series of load unload curve cycles or steps. This function will display a message box with the number of curve files saved.

## Examples of Importer File Formats

This function opens the standard comma separators (.CSV) text files that were save as using the Dureza save as function.

## Data (.CSV)

This function saves the curve data as it is displayed on the Dureza software window with the curve corrections (Instrument Setup). The calculation for the elastic modulus hardness and other curve dimensions are also saved in a format that is easy to analysis with a spreadsheet program.

## Import Example 1:

Import Indentation Test Data Text File Setup

Number of Header Lines (H>):

Separator Type ( See the I symbol ): ☐ Comma ☒ Tab ☐ Space ☐ Other

Decimal Type ☒ Period ☐ Comma

Column Number:

Displacement	Force	<input checked="" type="checkbox"/> Time	<input type="checkbox"/> Segments
<input type="text" value="1"/>	<input type="text" value="2"/>	<input type="text" value="3"/>	<input type="text" value="4"/>
<input type="radio"/> cm	<input type="radio"/> N		
<input type="radio"/> mm	<input type="radio"/> mN		
<input type="radio"/> $\mu$ m	<input checked="" type="radio"/> $\mu$ N		
<input checked="" type="radio"/> nm			

0.000000	13.688827	0.000000	0
0.182596	13.658890	0.012240	
0.547594	13.677047	0.024480	
0.364997	13.706985	0.036720	
-1.826060	14.027192	0.048960	
0.912981	13.539139	0.061200	
0.912981	13.539139	0.073440	
0.182499	13.697877	0.085680	
0.912884	13.578126	0.097920	
0.547691	13.638002	0.110160	
0.912981	13.539139	0.122400	
0.912786	13.617172	0.134640	
1.095577	13.509201	0.146880	

H> Tue Aug 24 20:41:33 2010  
H>  
H>  
H> Number of Points = 5000  
H>  
H> Depth (nm) | Load ( $\mu$ N) | Time (s)  
7> 0.000000 | 13.688827 | 0.000000  
8> 0.182596 | 13.658890 | 0.012240  
9> 0.547594 | 13.677047 | 0.024480  
10> 0.364997 | 13.706985 | 0.036720  
11> -1.826060 | 14.027192 | 0.048960  
12> 0.912981 | 13.539139 | 0.061200  
13> 0.912981 | 13.539139 | 0.073440  
14> 0.182499 | 13.697877 | 0.085680  
15> 0.912884 | 13.578126 | 0.097920  
16> 0.547691 | 13.638002 | 0.110160  
17> 0.912981 | 13.539139 | 0.122400  
18> 0.912786 | 13.617172 | 0.134640  
19> 1.095577 | 13.509201 | 0.146880  
20> 1.278076 | 13.518251 | 0.159120  
21> 2.008364 | 13.437545 | 0.171360  
22> 1.278076 | 13.518251 | 0.183600  
23> 1.460770 | 13.449325 | 0.195840  
24> 1.278076 | 13.518251 | 0.208080  
25> 1.277979 | 13.557296 | 0.220320  
26> 0.912688 | 13.656275 | 0.232560  
27> 1.095577 | 13.509201 | 0.244800  
28> 2.191155 | 13.329574 | 0.257040  
29> 1.278076 | 13.518251 | 0.269280  
30> 1.277979 | 13.557296 | 0.281520  
31> 1.095577 | 13.509201 | 0.293760  
32> 1.095577 | 13.509201 | 0.306000  
33> 1.095382 | 13.587234 | 0.318240  
34> 1.278174 | 13.479263 | 0.330480  
35> 1.095675 | 13.470271 | 0.342720  
36> -0.547691 | 13.739711 | 0.354960  
37> 0.547691 | 13.638002 | 0.367200  
38> 1.460575 | 13.527358 | 0.379440  
39> -0.730482 | 13.847566 | 0.391680  
40> 0.730288 | 13.608064 | 0.403920

### Import File Example 2:

**Import Indentation Test Data Text File Setup**

Number of Header Lines (H>):

Separator Type ( See the I symbol ):

☒ Comma   ☐ Tab   ☐ Space   ☐ Other

Decimal Type

☒ Period   ☐ Comma

Column Number:

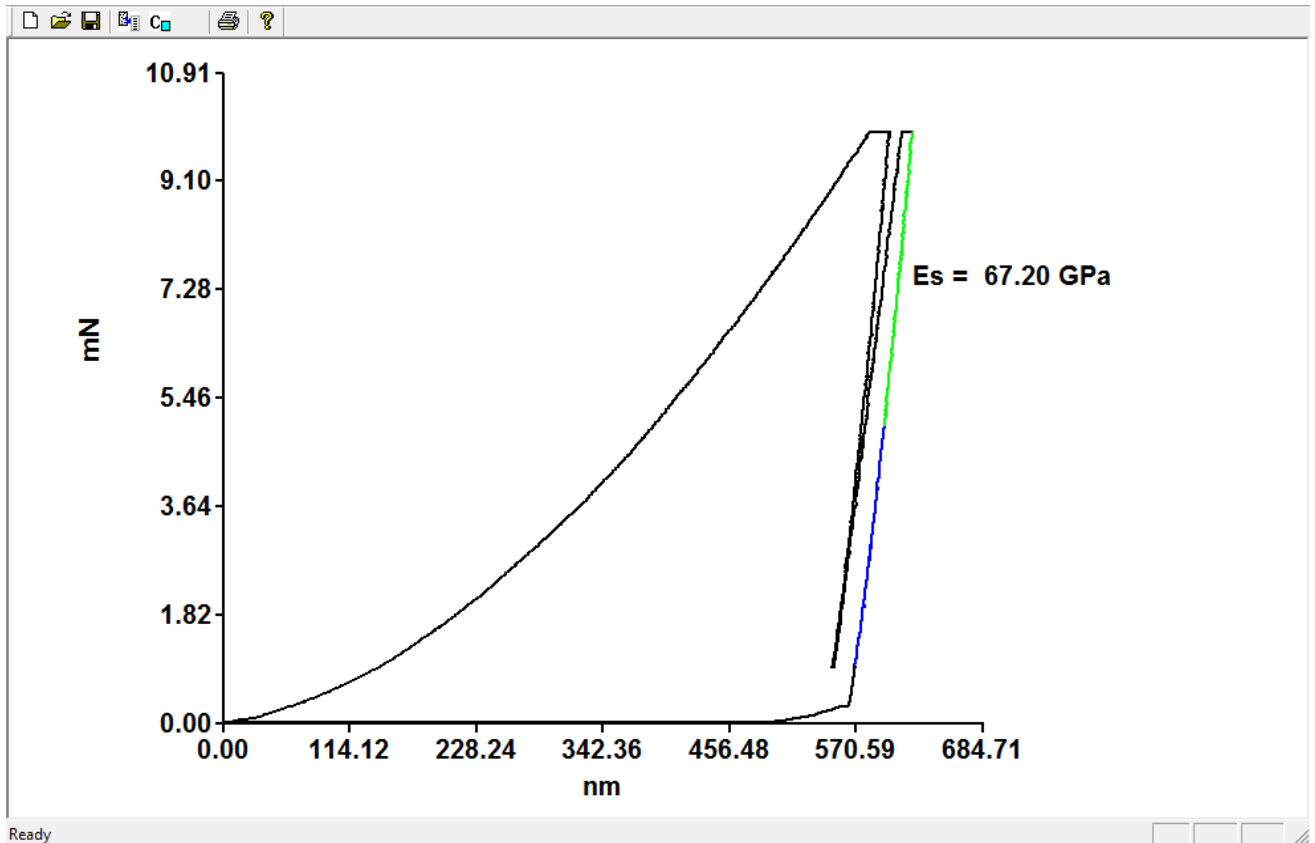
Displacement	Force	<input checked="" type="checkbox"/> Time	<input type="checkbox"/> Segments
<input type="text" value="3"/>	<input type="text" value="4"/>	<input type="text" value="6"/>	<input type="text" value="7"/>
<input type="radio"/> cm <input type="radio"/> mm <input checked="" type="radio"/> µm <input type="radio"/> nm	<input type="radio"/> N <input checked="" type="radio"/> mN <input type="radio"/> µN		

-2.359	-0.008	-4.800	0
-2.333	-0.010	-4.750	
-2.307	-0.011	-4.700	
-2.279	-0.015	-4.650	
-2.253	-0.014	-4.600	
-2.228	-0.016	-4.550	
-2.203	-0.017	-4.500	
-2.178	-0.018	-4.450	
-2.151	-0.020	-4.400	
-2.128	-0.021	-4.350	
-2.106	-0.050	-4.300	
-2.080	-0.052	-4.250	
-2.051	-0.025	-4.200	

```
H> | Sample name | 
H> | Sample No. | 1
H> | Test force | 50.000 | mN
H> | Loading speed | 1 | ( 13.2390mN/sec)
H> | Hold time | 5 | sec
H> | Test count | 1
H> | Parameter name | 10
H> | Parameter | 10
H> | Comment | 
H> 
H> 
H> 
H> 
H> 
H> 
H> 
H> 
H> 
H> Test result | FS50mN(1)
H> | Force | Depth1 | Depth2 | Depth3 | Depth4 | DHT115-1 | DHT115
H> | mN | um | um | um | um | Pa | um |
H> | 50.508213 | 0.563354 | 0.223389 | 0.271471 | 0.291884 | 614.0526
H> 
H> 
H> 
H> 
H> 
H> Raw data
H> 97 | Data no | Depth | Force | DHT115 | Time
H> | | um | mN | sec
47> | | -2.359 | -0.008 | | -4.800
48> | | -2.333 | -0.010 | | -4.750
49> | | -2.307 | -0.011 | | -4.700
50> | | -2.279 | 0.015 | | -4.650
51> | | -2.253 | -0.014 | | -4.600
```

### Main Output Window:

Once a file is load here is what you will typically see. This is the Indent Grapher output window for an aluminum sample. It is where you will analyze and compare various indentation curves. You can import several curve files at the same time. The left and right click can be used to do calculations or change the graph view.



### Saving Results:

#### Save

#### Save As

The Save and Save As will save just the file names that are open. They can be open again at a later date as a group of files.

#### Save As .DRZ

The DRZ file format also uses comma separators. The .DRZ is the file format created by the IndentGrapher. The segment types are LOAD, UNLOAD, RELOAD, TOP\_HOLD, BOTTOM\_HOLD.

#### Format of a .DRZ

```
Depth (um) , Force (mN) , Time (s) , Segment
1.000000e-003, 5.500000e-002, 0.300000, LOAD
4.000000e-003, 1.380000e-001, 0.350000, LOAD
1.000000e-002, 2.210000e-001, 0.400000, LOAD
1.600000e-002, 3.320000e-001, 0.450000, LOAD
2.300000e-002, 4.980000e-001, 0.500000, LOAD
3.000000e-002, 6.910000e-001, 0.550000, LOAD
3.800000e-002, 9.130000e-001, 0.600000, LOAD
4.300000e-002, 1.134000e+000, 0.650000, LOAD
```

```
4.900000e-002,1.328000e+000,0.700000,LOAD
5.600000e-002,1.549000e+000,0.750000,LOAD
6.100000e-002,1.799000e+000,0.800000,LOAD
6.700000e-002,2.020000e+000,0.850000,LOAD
7.100000e-002,2.242000e+000,0.900000,LOAD
7.500000e-002,2.463000e+000,0.950000,LOAD
8.200000e-002,2.685000e+000,1.000000,LOAD
8.700000e-002,2.879000e+000,1.050000,LOAD
9.100000e-002,3.100000e+000,1.100000,LOAD
9.300000e-002,3.350000e+000,1.150000,LOAD
9.600000e-002,3.543000e+000,1.200000,LOAD
1.040000e-001,3.765000e+000,1.250000,LOAD
1.110000e-001,4.014000e+000,1.300000,LOAD
1.160000e-001,4.235000e+000,1.350000,LOAD
1.210000e-001,4.457000e+000,1.400000,LOAD
1.250000e-001,4.679000e+000,1.450000,LOAD
1.310000e-001,4.872000e+000,1.500000,LOAD
1.350000e-001,5.122000e+000,1.550000,LOAD
.... etc...
```

### **Analysis Types:**

Each of these functions makes an XY graph using all the indentation curve files. It can be used to compare the modulus and hardness versus load depth or curve number. The more curves you select with the Import or Open function the longer it will take to process all the data. The Dureza software calculates the modulus or hardness based on the current Instrument settings.

### **Analysis Graininess Functions:**

The elastic modulus variation along the unload and reload curves are caused by the grain size, microstructure orientation compared to the indenter, dislocation pileup, or testing machine noise. First a power-law fits is done to a constant elastic modulus range of the unload curve. Then the difference from the fit to the entire lenght of the unload curve is calculated and graphed.

This is a figure of the indentation loading and unloading curve for an aluminum sample. The graph on the right shows the variation in depth from the power law fit along the unloading curve. The green part of the curve was used for the power law fitting data. The difference was then calculated along the entire length of the unloading curve as show in the graph.

### **Elastic Modulus Analysis:**

Equations used to calculate the elastic modulus or Poisson's ration of either the sample or the indenter.

$$\text{Load: } P = \alpha(h - hf)^m$$

$$\text{Machine Compliance Factor: } h_j = h_i - C_f P_i$$

$$\text{Slope}(dP/dh): S = \alpha m(h - hf)^{(m-1)}$$

$$\text{Sneddon's: } hc = h_{max} - \epsilon(P_{max}/S)$$

$$\text{Projected Area of Contact at the contact depth}(hc): A_p = a_0 hc^2 + a_1 hc$$

Example:  $a_0 = 24.56$  for an ideal Berkovich or Vickers Indenter;  $a_1$  is for tip rounding

$$\text{Reduced Elastic Modulus: } E_R = (Sh_{max} \sqrt{\pi}) / (2 \sqrt{A_p})$$

note: The  $S_{h_{max}}$  is the slope at the maximum depth for the indentation after correction  $C_f$ .

$$\text{Elastic Modulus of Sample: } E_s = (1 - V_s^2) / ((1/E_R) - ((1 - V_i^2)/E_i))$$

$$\text{Poisson's Ratio of Sample: } V_s = \sqrt{(1 - E_s(1/E_R - (1 - V_i^2)/E_i))}$$

$$\text{Elastic Modulus of Indenter: } E_i = (1 - V_i^2) / ((1/E_R) - ((1 - V_s^2)/E_s))$$

$$\text{Poisson's Ratio of Indenter: } V_i = \sqrt{(1 - E_i(1/E_R - (1 - V_s^2)/E_s))}$$

### Hardness Analysis:

The hardness analysis function opens when you click on the top hold part of the load and unloading. Then select hardness type. The hardness analysis can be calibrated by changing the area function and machine frame compliance factors. After these values are set they should not be changed regular hardness analysis. Make sure you verify your hardness tester using a calibration block before each use. Document the results and plot them to see if the test instrument is out of calibration.

**Hardness**

☒  $HM = F/A_s(h_{max})$   
☐  $HV = (H(IH) * A_p(hc)) / (9.80665 * A_s(hc))$   
☐  $HRA = 114.7595 - 298587.7 * (6.6982e-6 + 4.4760e-9 * HV) / HV^{0.5}$

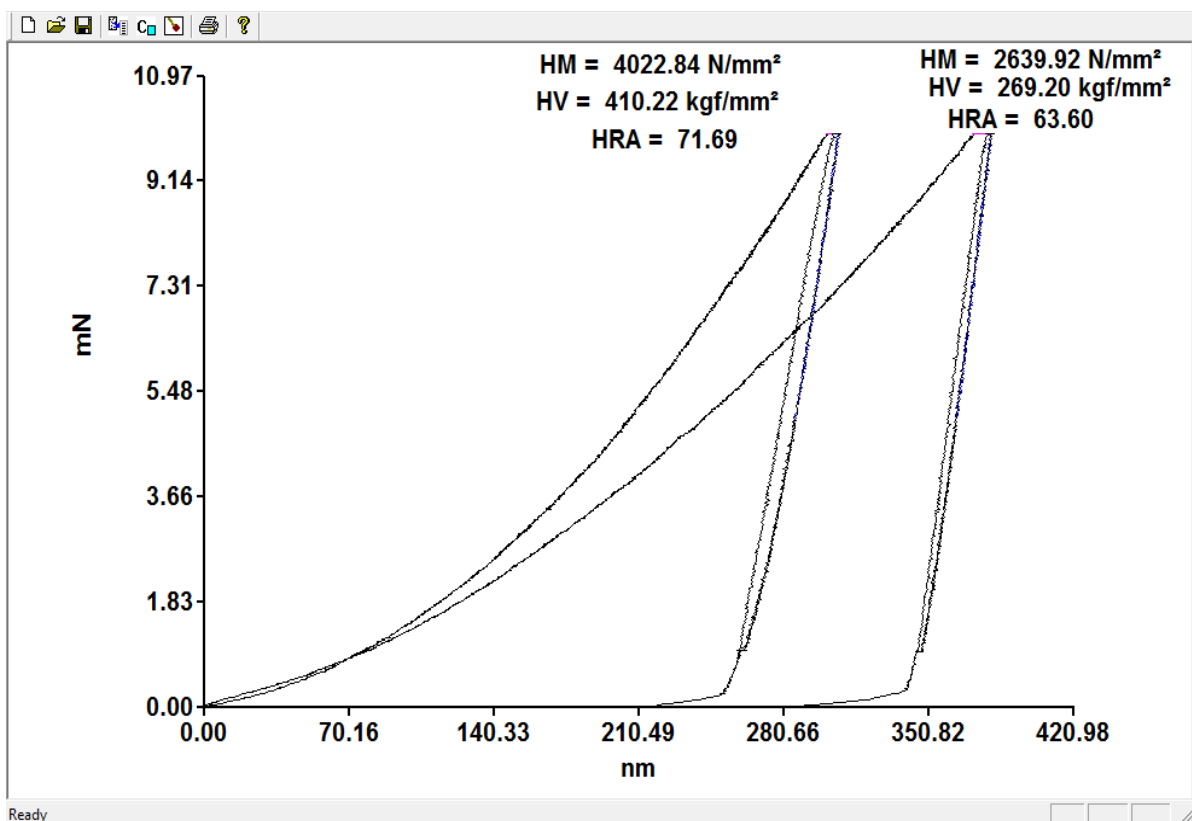
Indenter Projected Area Equation:  
 $A_p(h) = 24.56 h^2 + 0.0 h$

Indentation Surface Area Equation:  
 $A_s(h) = 26.44 h^2 + 0.0 h$

Machine Frame Compliance: 0.0 nm/mN

Sneddon's Material Epsilon (default 0): 0

OK Cancel



This figure shows the hardness results for ferritic and perlite steel.

#### Setup:

These are the basic methods for instrumented indentation analysis as discussed in ISO 14577.

This dialog box is used to setup the Sneddon's epsilon which is usually 0.75 for most materials. The poisson's ratio is 0.17 for fused quartz and is usually 0.30 for metals.

### Machine Frame Compliance (Cf):

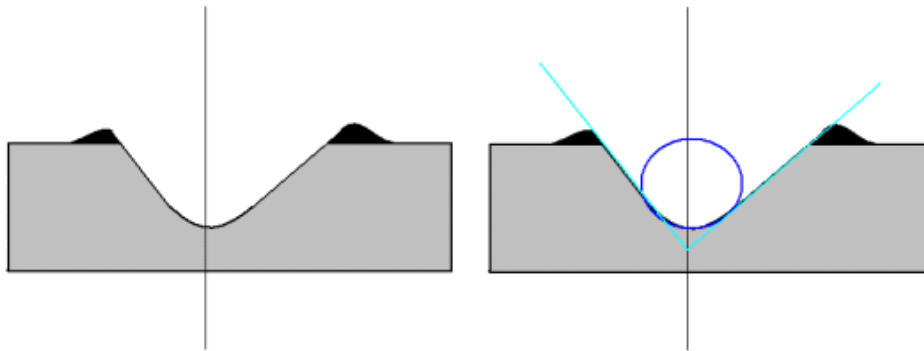
The compliance correction factor accounts for the machine elastic deformation of the machine during loading (Cf).

### Force Accuracy:

The Instrument Force Accuracy is used to separate the curve load, top\_hold, unload, bottom\_hold and reload sections. It is usually between 0.25 and 1 mN and depends on the quality of the testing machine and setup. The Instrument Displacement Accuracy is not used.

### Area Function

Indenter tip rounding or damage must be accounted. The smaller the indentation size the greater the error caused by tip rounding. The figure below shows a light blue line for the ideal indenter shape and the circle shows the result of tip rounding. Usually only the first and second coefficients are needed to be considered ( $A_p = C_1 h^2 + C_2 h$ ). For simplification the project area ( $A_p$ ) function first coefficient ( $C_1$ ) is dependent on the indenter conical angle and the second coefficient ( $C_2$ ) the tip rounding.



### Advanced Functions

#### Graininess E(h)

This shows a graph of the elastic modulus measured along the entire length of the unloading or reloading curve. The size of the sample section is set by using the maximum force percent and minimum force percent values. The initial force range is used to determine the  $h_{max\_ref}$  used for all of the other calculations. The  $P_{max}$  is the same for all of the section calculation for the elastic modulus. Multiple graininess curves can be graphed to together. The color of the graininess curve is identical to the load-unload curve unless its color is changed.

Equation for graininess maximum height:  $h_{max\_ref} = (P_{max}/\alpha)^{(1/m)} + h_f$



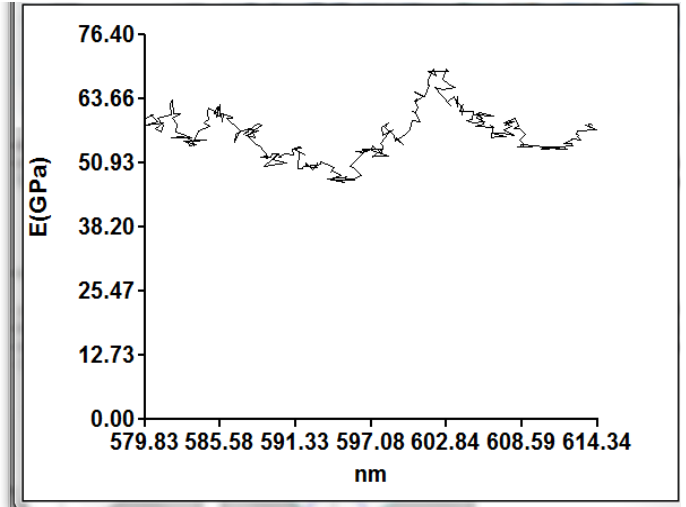
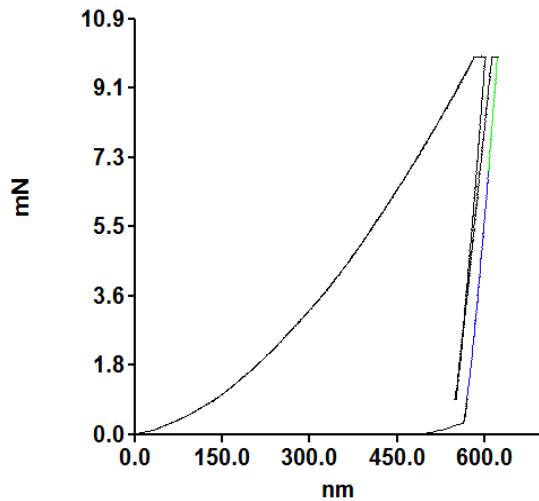


Figure of Graininess curve showing the change in elastic modulus with indentation depth for an aluminum 5050 sample.

#### Other Functions:

Loading Rate, Displacement Rate, and Power Law Equation. You can click on the loading curve to add the filename to the graph or calculated the displacement rate or loading rate.

Displacement Rate =  $(d(\text{clicked point}) - d(\text{minimum for that segment})) / (t(\text{clicked point}) - t(\text{minimum for that segment}))$

Force Rate =  $(f(\text{clicked point}) - f(\text{minimum for that segment})) / (t(\text{clicked point}) - t(\text{minimum for that segment}))$

