

Chapter 13

Nonlinear Simulations

13.1 Basics of Nonlinear Simulations

13.2 Translational Joint

13.3 Microgripper

13.4 Snap Lock

13.5 Review

Section 13.1

Basics of Nonlinear Simulations

Key Concepts

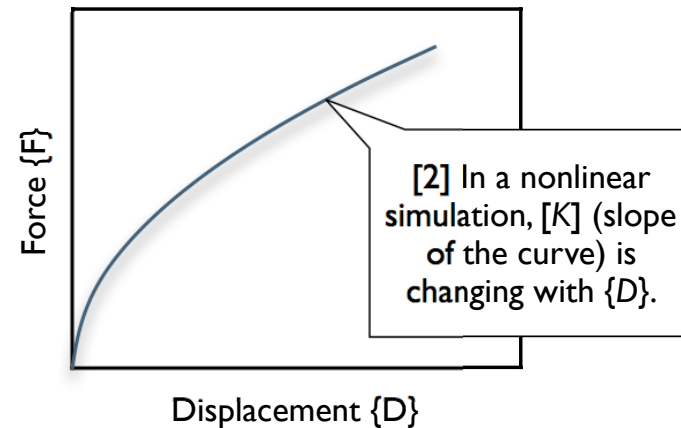
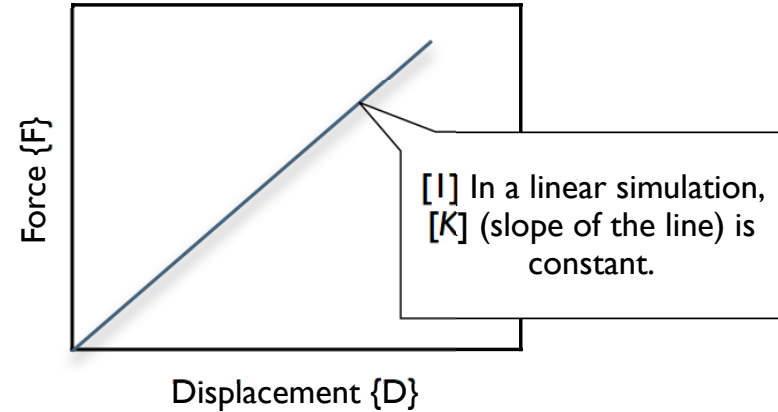
- Nonlinearities
- Causes of Structural Nonlinearities
- Steps, Substeps, and Iterations
- Newton-Raphson Method
- Force/Displacement Convergence
- Solution Information
- Line Search
- Contact Types
- Contact versus Target
- Contact Formulations
- Additional Contact Settings
 - Pinball Region
 - Interface Treatment
 - Time Step Controls
 - Update Stiffness

Nonlinearities

- In a nonlinear simulation, the relation between nodal force $\{F\}$ and nodal displacement $\{D\}$ is nonlinear.
- we may write

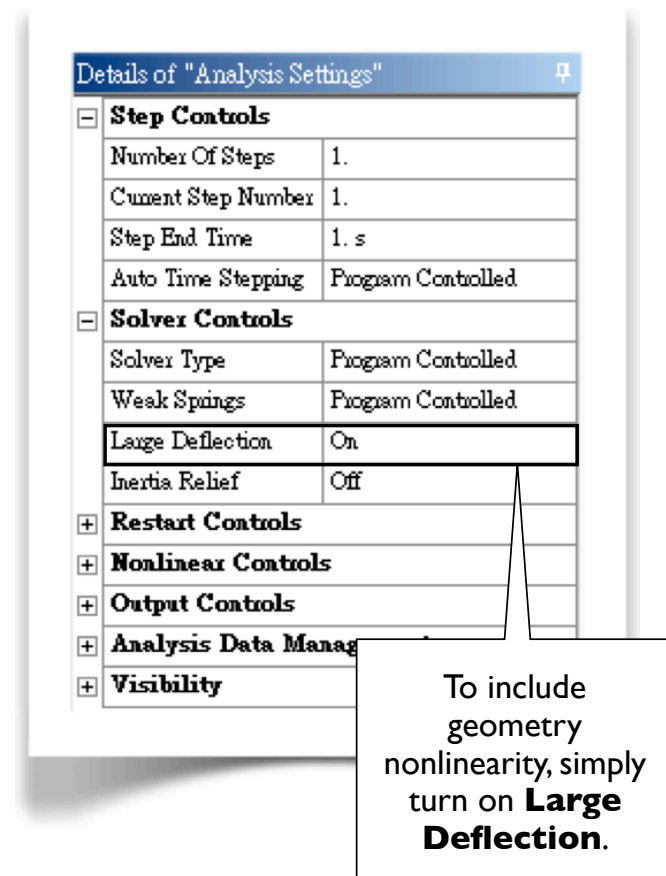
$$[K(D)]\{D\} = \{F\}$$

- Challenges of nonlinear simulations come from the difficulties of solving the above equation.



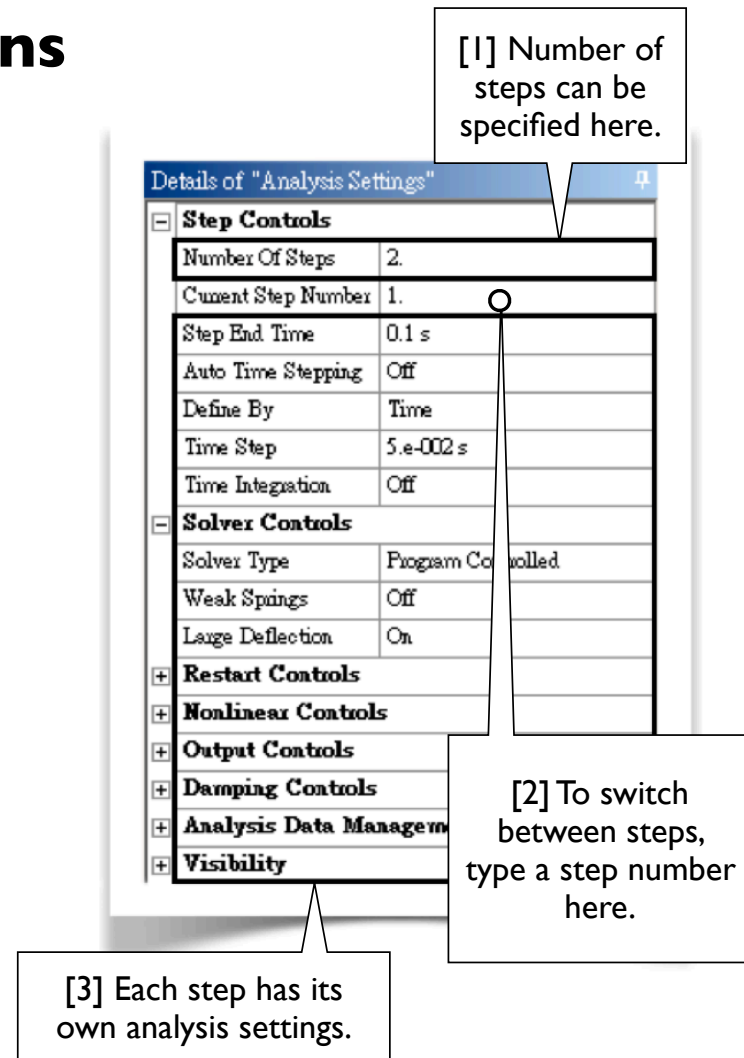
Causes of Structural Nonlinearities

- Geometry Nonlinearity
 - Due to Large Deflection
- Topology Nonlinearity
 - Contact Nonlinearity
 - Etc.
- Material Nonlinearity
 - Due to Nonlinear Stress-Strain Relations

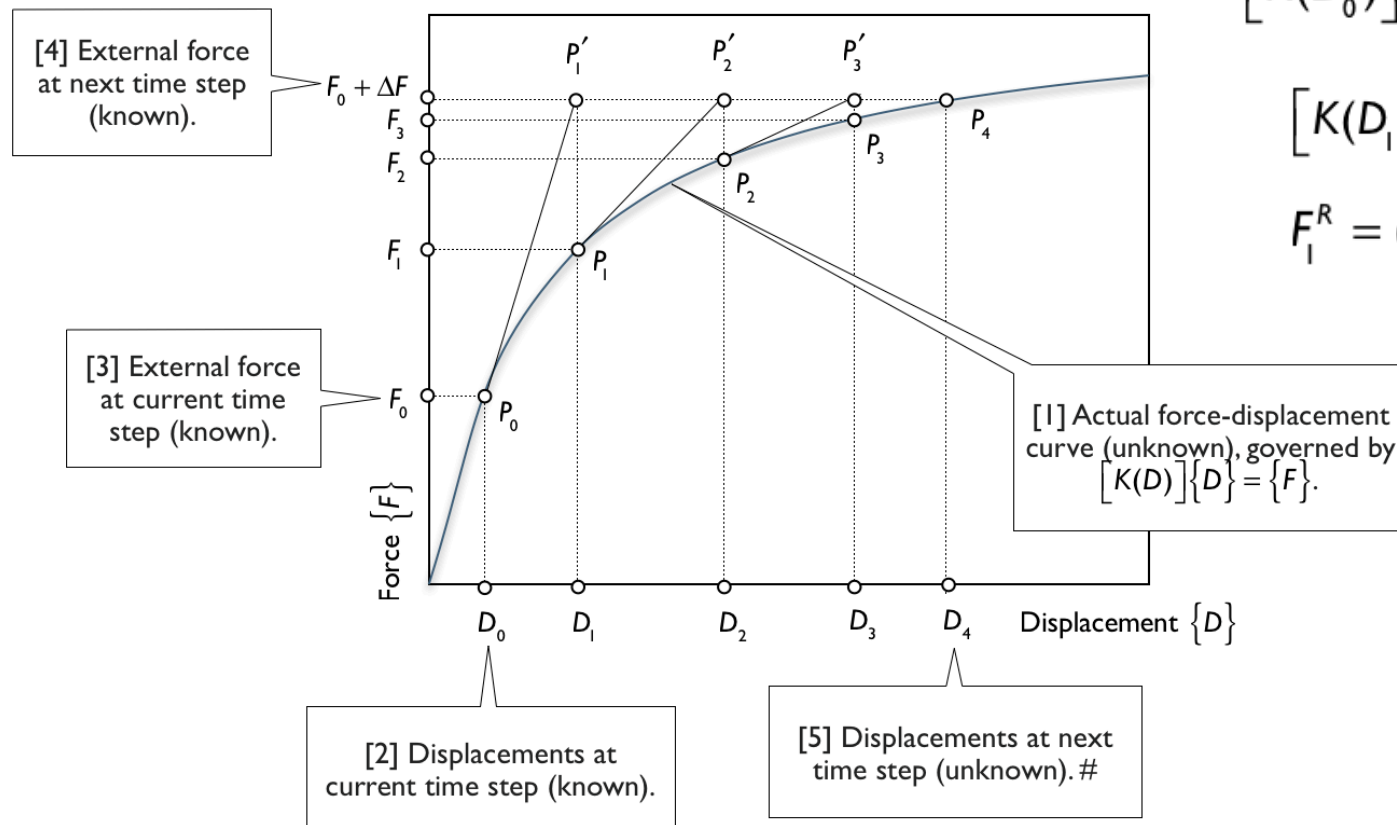


Steps, Substeps, and Iterations

- Steps (Load Steps)
 - Each step can have its own analysis settings.
- Substeps (Time Steps)
 - In dynamic simulations, time step is used for integration over time domain.
 - In static simulation, dividing into substeps is to achieve or enhance convergence.
- Iterations (Equilibrium Iterations)
 - Each iteration involves solving a linearized equilibrium equation.



Newton-Raphson Method



$$[K(D)]\{D\} = \{F\}$$

$$[K(D_0)]\{\Delta D\} = \{\Delta F\}$$

$$[K(D_1)]\{D_1\} = \{F_1\}$$

$$F_1^R = (F_0 + \Delta F) - F_1$$

Force/Displacement Convergence

[3] When shell elements or beam elements are used, **Moment Convergence** can be activated.

[4] When shell elements or beam elements are used, Rotation Convergence can be activated.

Details of "Analysis Settings"	
+ Step Controls	
+ Solver Controls	
+ Restart Controls	
- Nonlinear Controls	
Force Convergence	On
-Value	Calculated by solver
-Tolerance	0.5%
-Minimum Reference	1.e-002 N
Moment Convergence	On
-Value	Calculated by solver
-Tolerance	0.5%
-Minimum Reference	10. N-mm
Displacement Convergence	On
-Value	Calculated by solver
-Tolerance	0.5%
-Minimum Reference	0. mm
Rotation Convergence	On
-Value	Calculated by solver
-Tolerance	0.5%
-Minimum Reference	0. "
Line Search	Program Controlled
Stabilization	Off
+ Output Controls	
+ Analysis Data Management	
+ Visibility	

[1] You can turn on **Force Convergence** and set the criterion.

[2] You can turn on **Displacement Convergence** and set the criterion.

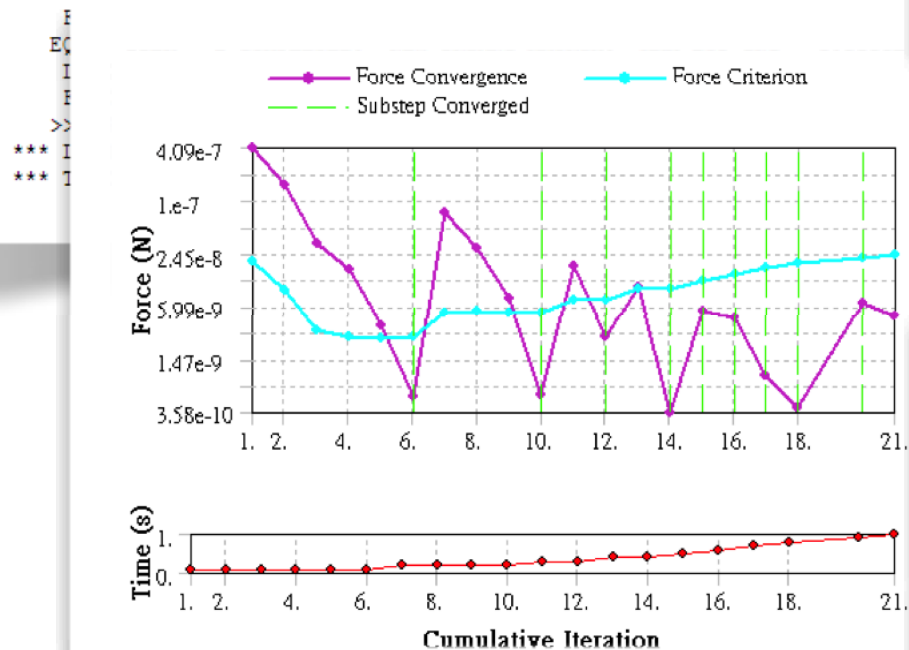
$$\text{Criterion} = \text{Tolerance} \times \text{maximum}(\text{Value}, \text{Minimum Reference})$$

Solution Information

```

FORCE CONVERGENCE VALUE = 0.9949E-01 CRITERION= 0.2227E-01
EQUIL ITER 1 COMPLETED. NEW TRIANG MATRIX. MAX DOF INC= 0.9229E-
LINE SEARCH PARAMETER = 1.000 SCALED MAX DOF INC = 0.9229E-02
FORCE CONVERGENCE VALUE = 0.6719E-02 CRITERION= 0.2173E-01 <<< CON
>>> SOLUTION CONVERGED AFTER EQUILIBRIUM ITERATION 1
*** LOAD STEP 1 SUBSTEP 9 COMPLETED. CUM ITER = 20
*** TIME = 0.900000 TIME INC = 0.100000

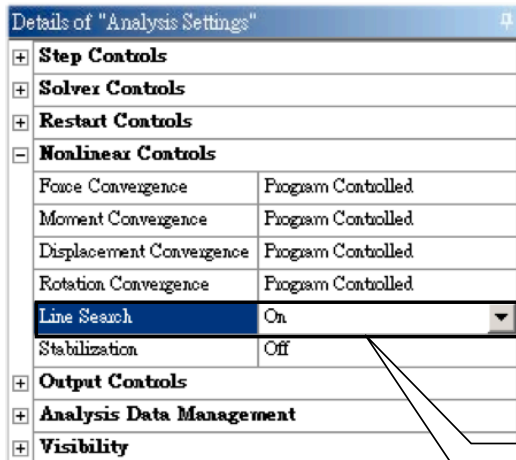
```



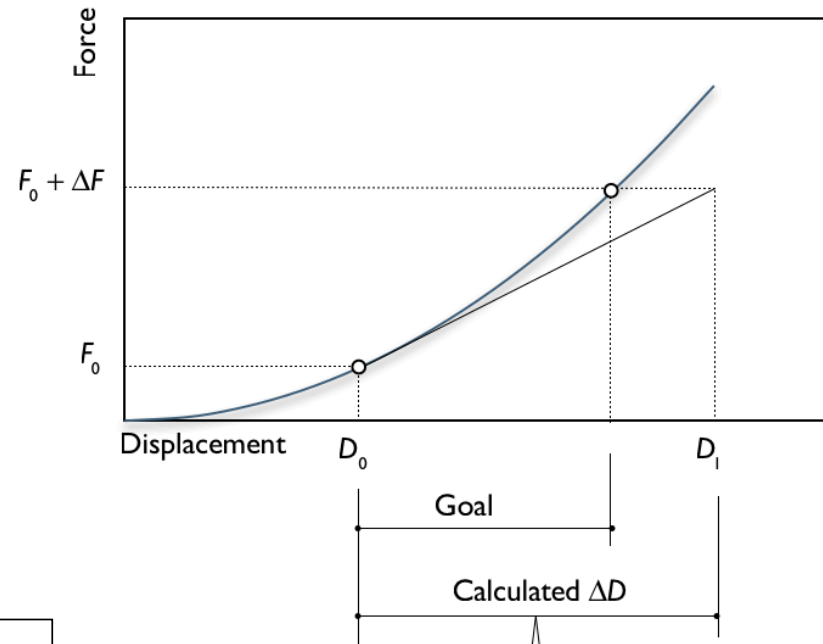
Details of "Solution Information"	
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

Details of "Solution Information"	
Solution Information	
Solution Output	Force Convergence
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

Line Search



[2] Line search can be turned on to scale down the incremental displacement. By default, it is **Program Controlled**.



[1] In some cases, when the F - D curve is highly nonlinear or concave up, the calculated ΔD in a single iteration may overshoot the goal.

```

FORCE CONVERGENCE VALUE = 327.2      CRITERION= 0.2962
EQUIL ITER 1 COMPLETED. NEW TRIANG MATRIX. MAX DOF INC= -0.1956
LINE SEARCH PARAMETER = 0.5779      SCALED MAX DOF INC = -0.1131
FORCE CONVERGENCE VALUE = 179.4      CRITERION= 0.2133
EQUIL ITER 2 COMPLETED. NEW TRIANG MATRIX. MAX DOF INC= 0.1267E-01
LINE SEARCH PARAMETER = 1.000      SCALED MAX DOF INC = 0.1267E-01
FORCE CONVERGENCE VALUE = 34.92      CRITERION= 0.2253
EQUIL ITER 3 COMPLETED. NEW TRIANG MATRIX. MAX DOF INC= 0.1004
LINE SEARCH PARAMETER = 0.6958      SCALED MAX DOF INC = 0.6985E-01
FORCE CONVERGENCE VALUE = 30.58      CRITERION= 0.2916
EQUIL ITER 4 COMPLETED. NEW TRIANG MATRIX. MAX DOF INC= 0.1047E-01
LINE SEARCH PARAMETER = 1.000      SCALED MAX DOF INC = 0.1047E-01
FORCE CONVERGENCE VALUE = 5.867      CRITERION= 0.3076
EQUIL ITER 5 COMPLETED. NEW TRIANG MATRIX. MAX DOF INC= 0.1734E-01
LINE SEARCH PARAMETER = 0.8577      SCALED MAX DOF INC = 0.1487E-01
FORCE CONVERGENCE VALUE = 2.724      CRITERION= 0.3313
EQUIL ITER 6 COMPLETED. NEW TRIANG MATRIX. MAX DOF INC= 0.3472E-03
LINE SEARCH PARAMETER = 1.000      SCALED MAX DOF INC = 0.3472E-03
FORCE CONVERGENCE VALUE = 0.2257      CRITERION= 0.3382      <<< CONVERGED
>>> SOLUTION CONVERGED AFTER EQUILIBRIUM ITERATION 6
*** LOAD STEP 2 SUBSTEP 114 COMPLETED. CUM ITER = 1889
*** TIME = 1.89395 TIME INC = 0.288325E-01
*** AUTO TIME STEP: NEXT TIME INC = 0.43249E-01 INCREASED (FACTOR = 1.5000)

```

Contact Types

- Bonded
- No Separation
- Rough
- Frictionless
- Frictional
- Linear versus Nonlinear Contacts

Details of "Frictional - Prong To Insert" 

Scope	
Scoping Method	Geometry Selection
Contact	4 Edges
Target	4 Edges
Contact Bodies	Prong
Target Bodies	Insert
Shell Thickness Effect	No
Definition	
Type	Frictional
☐ Friction Coefficient	Bonded No Separation Frictionless Rough
Scope Mode	Frictionless
Behavior	Frictional
Tam Contact	Forced Frictional Sliding
Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Elastic Slip Tolerance	Program Controlled
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Stabilization Damping Factor	0.
Pinball Region	Program Controlled
Time Step Controls	None
Geometric Modification	
Interface Treatment	Add Offset, No Ramping
☐ Offset	0. mm
Contact Geometry Correction	None

Contact versus Target

- During the solution, Workbench will check the contact status for each point (typically a node or an integration point) on the **Contact** faces against the **Target** faces.
- If **Behavior** is set to **Symmetric**, the roles of **Contact** and **Target** will be symmetric.
- If **Behavior** is set to **Asymmetric**, the checking is only one-sided.

[1] To specify a contact region, you have to select a set of **Contact** faces (or edges), and select a set of **Target** faces (or edges).

Details of "Frictional - Prong To Insert"

[-] Scope	
Scoping Method	Geometry Selection
Contact	4 Edges
Target	4 Edges
Contact Bodies	Prong
Target Bodies	Insert
Shell Thickness Effect	No
[-] Definition	
Type	Frictional
☐ Friction Coefficient	0.1
Scope Mode	Manual
Behavior	Symmetric
Tam Contact	Program Controlled
Suppressed	No
[+] Advanced	
[+] Geometric Modification	

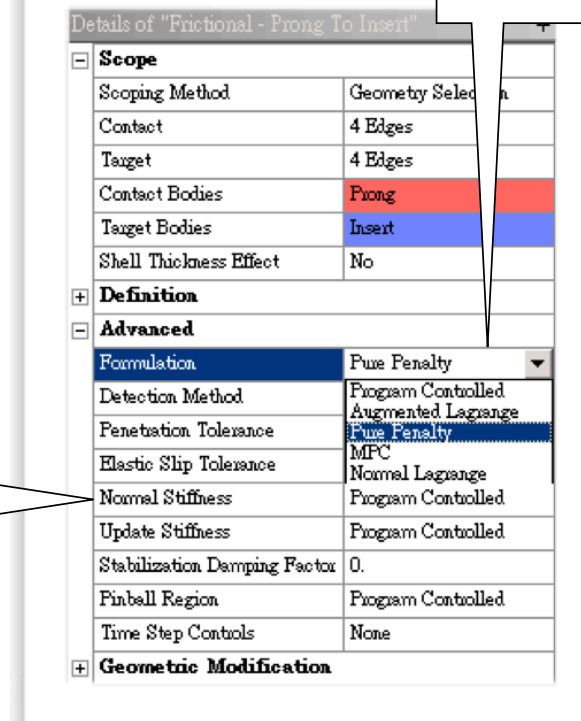
[2] If **Behavior** is set to **Symmetric**, the roles of **Contact** and **Target** will be symmetric.

Contact Formulations

- MPC (multi-point constraint)
- Pure Penalty
- Normal Lagrange
- Augmented Lagrange

[2] **Normal Stiffness** is input here.
The input value (default to 1.0) is regarded as a scaling factor to multiply a stiffness value calculated by the program.

[1] Workbench offers several formulations to enforce contact compatibility.



Additional Contact Settings

- Pinball Region
- Interface Treatment
- Time Step Controls
- Update Stiffness

Details of "Frictional - Prong To Insert"		
[-] Scope		
Scoping Method	Geometry Selection	
Contact	4 Edges	
Target	4 Edges	
Contact Bodies	Prong	
Target Bodies	Insert	
Shell Thickness Effect	No	
[+] Definition		
[-] Advanced		
Formulation	Pure Penalty	
Detection Method	Program Controlled	
Penetration Tolerance	Program Controlled	
Elastic Slip Tolerance	Program Controlled	
Normal Stiffness	Program Controlled	
Update Stiffness	Each Iteration	☐
Stabilization Damping Factor	0.	
Pinball Region	Program Controlled	☐
Time Step Controls	None	☐
[-] Geometric Modification		
Interface Treatment	Add Offset, No Ramping	☐
☐ Offset	0. mm	☐
Contact Geometry Connection	None	

Section 13.2

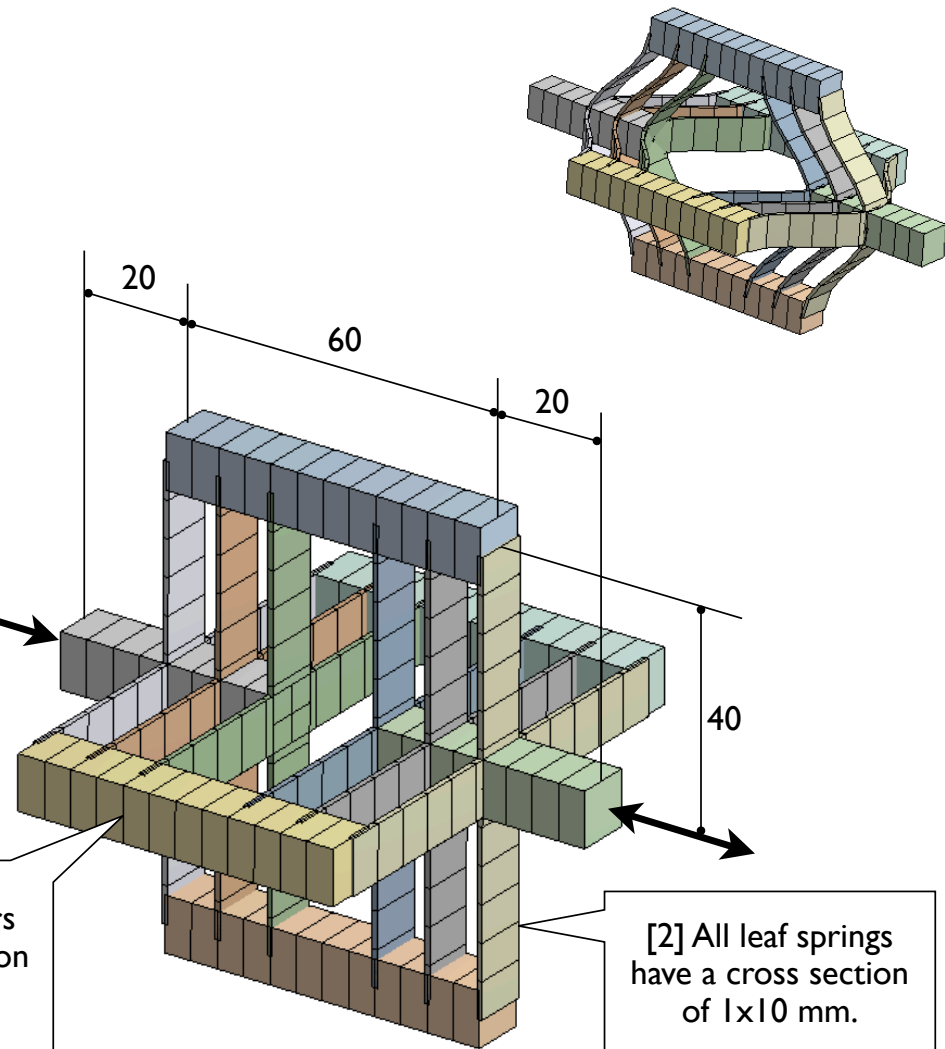
Translational Joint

Problem Description

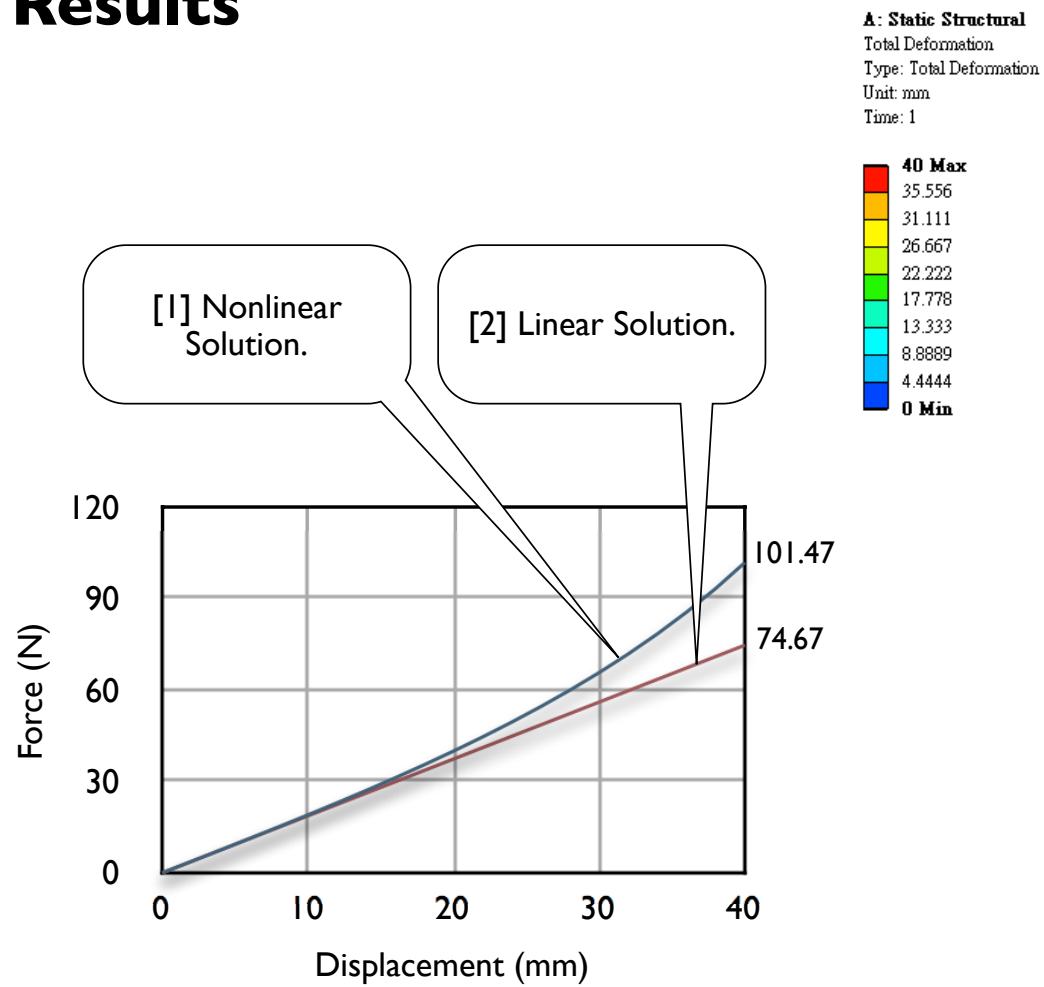
[1] The translational joint is used to connect two machine components, so the relative motion of the components is restricted to translation and in this direction.

[3] All connectors have a cross section of 10x10 mm.

[2] All leaf springs have a cross section of 1x10 mm.

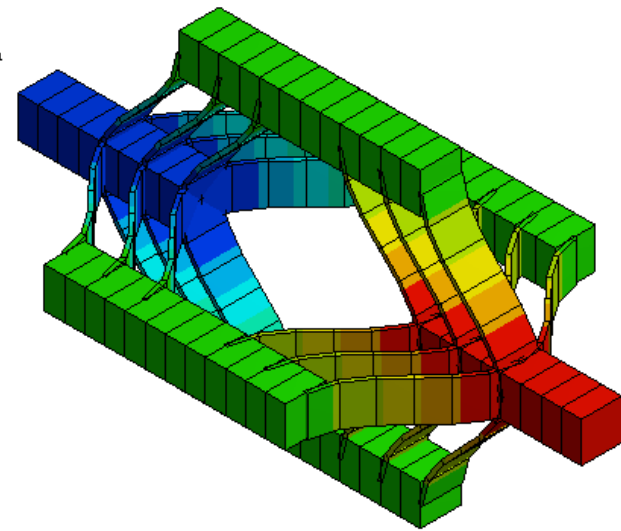


Results



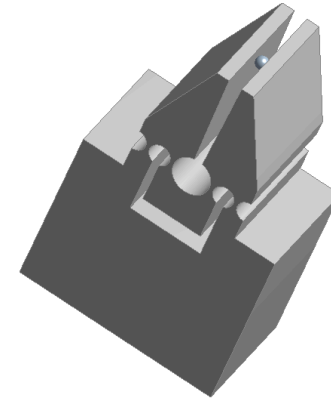
A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1

40 Max
35.556
31.111
26.667
22.222
17.778
13.333
8.8889
4.4444
0 Min



Section 13.3

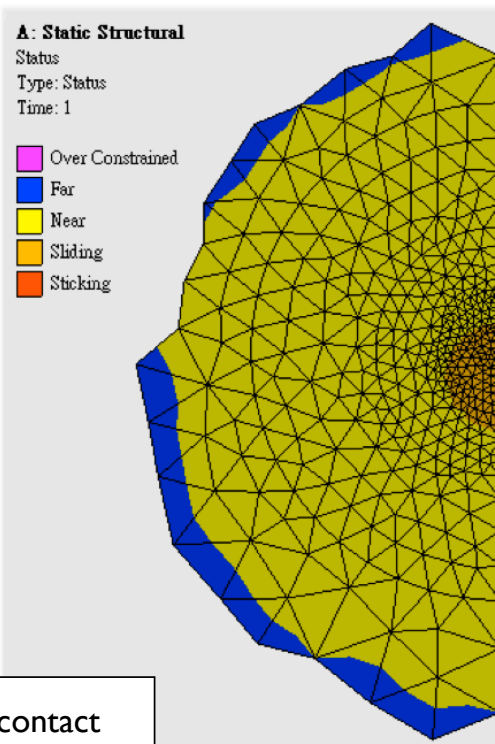
Microgripper



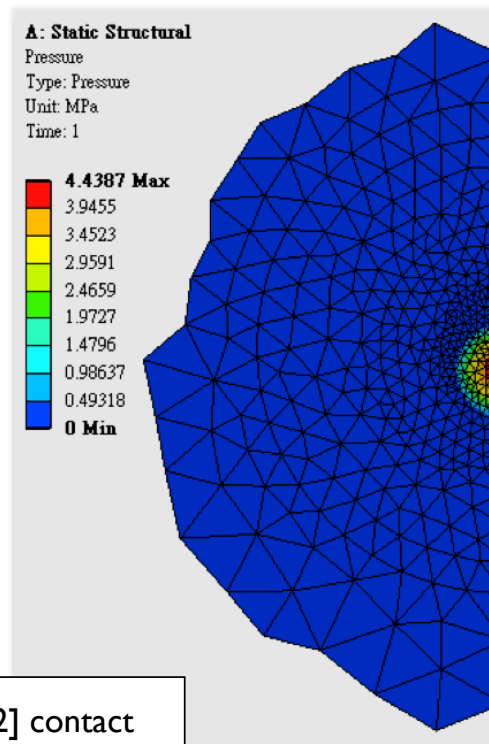
Problem Description

The microgripper is made of PDMS and actuated by a SMA (shape memory alloy) actuator; it is tested by gripping a glass bead in a lab. In this section, we want to assess the gripping forces on the glass bead under an actuation force of $40 \mu\text{N}$ exerted by the SMA device.

Results



[1] contact status.



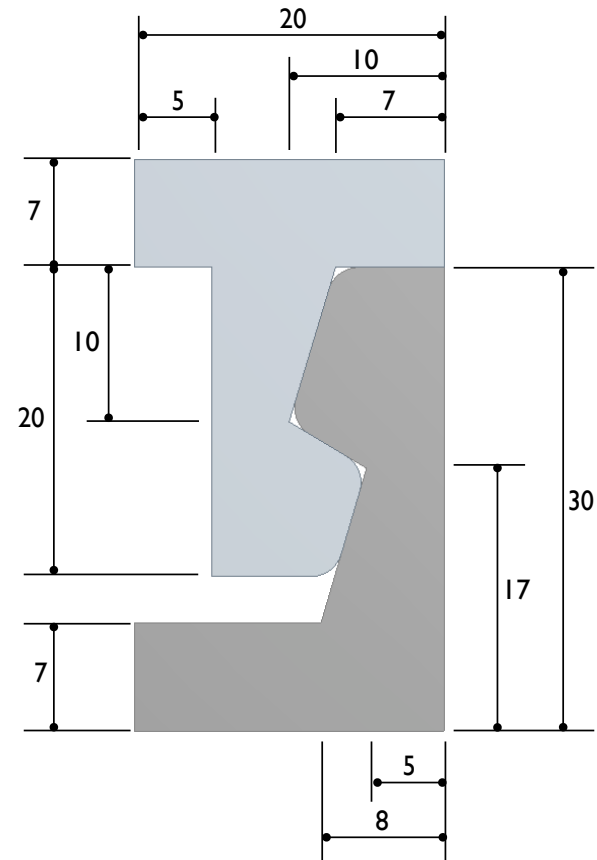
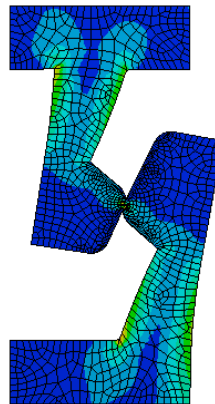
[2] contact pressure.

Section 13.4

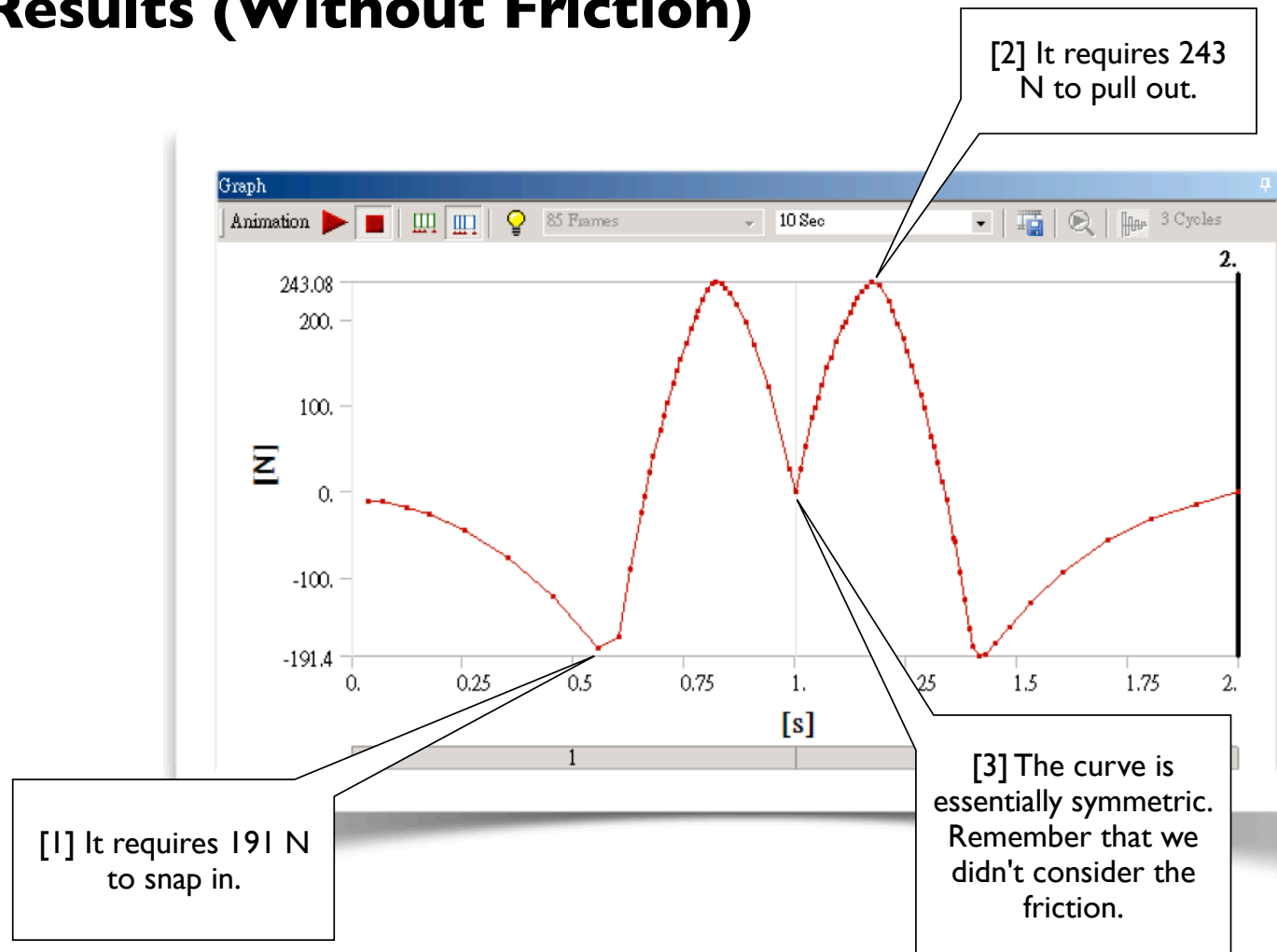
Snap Lock

Problem Description

The purpose of this simulation is to find out the force required to push the insert into the position and the force required to pull it out.



Results (Without Friction)



Results (With Friction)

