



FEniCS Course

Lecture 6: Static hyperelasticity

Contributors

Anders Logg

Static hyperelasticity

$$\begin{aligned} -\operatorname{div} P &= B && \text{in } \Omega \\ u &= g && \text{on } \Gamma_D \\ P \cdot n &= T && \text{on } \Gamma_N \end{aligned}$$

- $X \in \Omega$ is a coordinate in the reference domain
- $x = x(X)$ is the deformation
- $u = x - X$ is the displacement
- $P = P(u)$ is the first Piola–Kirchhoff stress tensor
- B is a given body force per unit volume
- g is a given boundary displacement
- T is a given boundary traction

Variational problem

Multiply by a test function $v \in \hat{V}$ and integrate by parts:

$$-\int_{\Omega} \operatorname{div} P \cdot v \, dx = \int_{\Omega} P : \operatorname{grad} v \, dx - \int_{\partial\Omega} (P \cdot n) \cdot v \, ds$$

Note that $v = 0$ on Γ_D and $P \cdot n = T$ on Γ_N

Find $u \in V$ such that

$$\int_{\Omega} P : \operatorname{grad} v \, dx = \int_{\Omega} B \cdot v \, dx + \int_{\Gamma_N} T \cdot v \, ds$$

for all $v \in \hat{V}$

Stress–strain relations

- $F = \frac{dx}{dX} = \frac{d(X+u)}{dX} = I + \text{grad } u$ is the deformation gradient
- $C = F^\top F$ is the right Cauchy–Green deformation tensor
- $E = \frac{1}{2}(C - I)$ is the Green–Lagrange strain tensor
- $W = W(E)$ is the strain energy density
- $S_{ij} = \frac{\partial W}{\partial E_{ij}}$ is the second Piola–Kirchhoff stress tensor
- $P = FS$ is the first Piola–Kirchhoff stress tensor

St. Venant–Kirchhoff strain energy function:

$$W(E) = \frac{\lambda}{2}(\text{tr}(E))^2 + \mu \text{tr}(E^2)$$

Useful FEniCS tools (I)

Defining subdomains/boundaries:

```
class MyBoundary(SubDomain):  
    def inside(self, x, on_boundary):  
        return on_boundary and \  
            x[0] < 1.0 - DOLFIN_EPS
```

*How should this be modified to **not** include the upper and lower right corners?*

Marking boundaries:

```
my_boundary_1 = MyBoundary1()  
my_boundary_2 = MyBoundary2()  
boundaries = FacetFunction("size_t", mesh)  
boundaries.set_all(0)  
my_boundary_1.mark(boundaries, 1)  
my_boundary_2.mark(boundaries, 2)  
ds = Measure("ds", subdomain_data=boundaries)  
a = ...*ds(0) + ...*ds(1) + ...*ds(2)
```

Useful FEniCS tools (II)

Computing derivatives of expressions:

```
E = variable(...)  
W = ...  
S = diff(W, E)
```

Computing form derivatives:

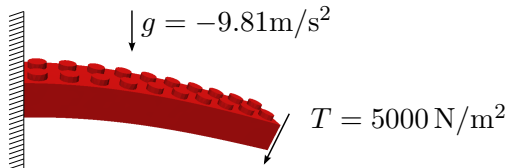
```
u = Function(V)  
du = TrialFunction(V)  
F = ...u...*dx  
J = derivative(F, u, du)
```

Solving nonlinear variational problems (Newton's method):

```
solve(F == 0, u, bcs)  
solve(F == 0, u, bcs, J=J)
```

The FEniCS challenge!

Compute the deflection of a regular 10×2 LEGO brick. Use the St. Venant–Kirchhoff model and assume that the LEGO brick is made of PVC plastic. The LEGO brick is subject to gravity of size $g = -9.81 \text{ m/s}^2$ and a downward traction of size 5000 N/m^2 at its end point.



To check your solution, compute the average value of the displacement in the z -direction.

The student(s) who first produce the right answer will be rewarded with an exclusive FEniCS surprise!

Mesh and material parameters:

<http://fenicsproject.org/pub/course/data/>