Chrono::FEA
Validation
ANCF Cable

ANCF cable elements validated against published literature (see unit test test_ANCFCable.cpp)

*Chrono’s implementation has been verified against: Gerstmayr and Shabana, 2006, “Analysis of thin beams and cables using the absolute nodal coordinate formulation”, Nonlinear Dynamics 45: 109–130
ANCF Beam

• $H = 0.5\text{m}$; $W = 0.1\text{m}$; $L = 2.0\text{m}$; 4 ANCF finite elements

• $E = 2.07e11$ Pa; Poisson ratio = 0.3; $k_1, k_2$ Timoshenko coefficients

• Force = $-5e5 0.5^3$ N

• Results match up to numerical precision with published in the literature: "Structural and continuum mechanics approaches for a 3D shear deformable ANCF beam finite element: Application to static and linearized dynamic examples", Journal of Computational and Nonlinear Dynamics, April 2013, Vol. 8/021004.

• Verified for small and large deformation

ANCF cable elements validated against published literature (see unit test uteanf_ANCFBeam.cpp)
ANCF shell

Isotropic

test_ANCFShell_Iso.cpp

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>E (MPa)</th>
<th>G (MPa)</th>
<th>Density</th>
<th>Vertical Force</th>
<th>Simulation type</th>
<th>Ansys element</th>
<th>Converged disp</th>
</tr>
</thead>
<tbody>
<tr>
<td>1mx1mx0.01m</td>
<td>210</td>
<td>80.8</td>
<td>500 kg/m³</td>
<td>-50N</td>
<td>Dynamic</td>
<td>Shell181 (EAS)</td>
<td>-0.649m</td>
</tr>
</tbody>
</table>
## ANCF shell

**Orthotropic and Composite**

![3D model of ANCF shell](image)

### Dimensions

<table>
<thead>
<tr>
<th>Ex (MPa)</th>
<th>G (MPa)</th>
<th>Ey=Ez (MPa)</th>
<th>Density</th>
<th>Vertical Force</th>
<th>Simulation type</th>
<th>Number of layers</th>
<th>Thickness of each layer</th>
<th>Fiber angle</th>
<th>Converged disp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>38.5</td>
<td>100</td>
<td>500 kg/m³</td>
<td>-10N</td>
<td>Dynamic</td>
<td>2</td>
<td>0.005m</td>
<td>20 degrees</td>
<td>-0.80207m</td>
</tr>
</tbody>
</table>

### Simulation type

- **Dynamic**

### Converged Disp.

-10N Dynamic simulation for ANCF Shell Orthotropic (test_ANCFShell_Ort.cpp)
EAS Brick element

Isotropic and MR

test_EASBrickIso.cpp
test_EASBrickMooneyR_Grav.cpp

8-noded brick element

- Classical tri-linear element
- Implements Enhanced Assumed Strain formulation to alleviate locking
- Constitutive equations: Linear isotropic and Mooney-Rivlin

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>$C_{10}$ (kPa)</th>
<th>$C_{01}$ (kPa)</th>
<th>Vertical Force</th>
<th>Simulation type</th>
<th>Converged disp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1mx1mx 0.1m</td>
<td>50</td>
<td>10</td>
<td>-50N</td>
<td>Dynamic</td>
<td>-0.5762 m</td>
</tr>
</tbody>
</table>

Plate geometry made up of brick elements
Brick 9: Capped Drucker-Prager – Punch Test

### Soil Material Properties

- **\( \sigma_{yield} = 210926 \text{ Pa} \)**
- **\( \beta = 51.7848^\circ \)**
- **\( \phi = 51.7848^\circ \)**
- **\( R = 0.5 \)**
- **\( \rho = 2149 \text{ kg/m}^3 \)**
- **\( E = 54.1 \text{ MPa} \)**
- **\( \nu = 0.293021 \)**

### Chrono verification parameters

- **Applied force**: \( -27000 \sin(\pi t) \)
- **Contact stiffness**: 165000 N/m
- **Contact detection threshold**: 0.009m
- **Element number**: 12*12*8
- **Soil box dimension**: 0.48m*0.48*0.6m
- **Rigid punch dimension**: 0.2m*0.2m*0.1m
- **Bottom node fixed**
Corotational Euler-Bernoulli beam: Princeton benchmark

L = 0.508m, T = 3.2024mm, H = 12.77mm,
Young modulus E = 71.7GPa, Poisson ratio = 0.31, G = 27.37GPa.

Three loading conditions are tested:
P1 = 4.448N,
P2 = 8.896N,
P3 = 13.345N for increasing values of the angle

More info: Tasora, A. “Validation of Euler-Bernoulli corotational beams in Chrono::Engine”, Chrono white paper
Kinematically exact Reissner shell element

Clamped half cylinder with sliding constraints at the sides

Large bending in a rolled band

Comparison with results in literature and with analytical solutions