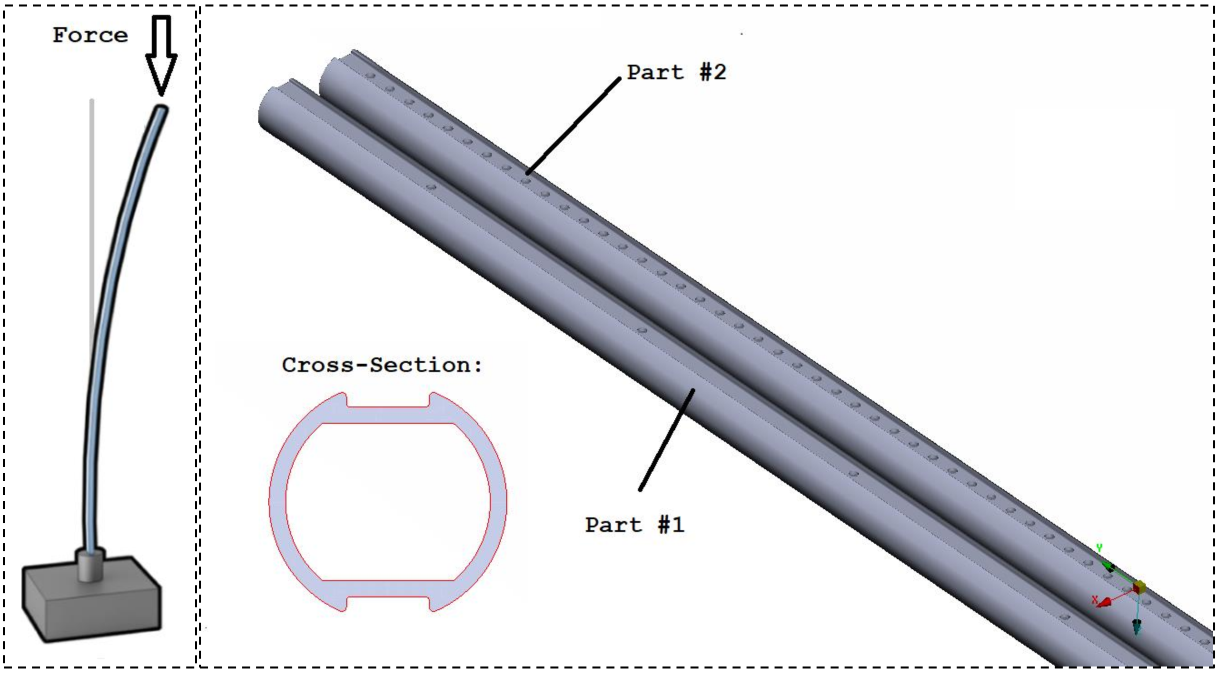
Aluminum poles - Buckling analysis report

Objective of the analysis: to find out numerically critical strength of aluminum poles with boundary conditions shown on Picture 1.



[Picture 1] Boundary conditions of numerical experiment and overall view on the poles.

Several Methods were used for analysis:

- Analytical estimation (Euler buckling + local buckling)
- Linear buckling (NASTRAN SOL105)
- Non-linear buckling (NASTRAN SOL106 with LGDISP)

1. Analytical Estimation

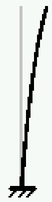
Overall buckling

Input data:

$E := 68.9\ GPa$ $\quad A := 177\ mm^2$ $\quad k_{Holes\_Pole\_2} := 0.038$

$L := 2372\ mm$ $\quad J_1 := 12715\ mm^4$

$\mu := 2$ $\quad J_2 := 15040\ mm^4$



Pole #1 (neglecting holes):

$$P_{Euler\_Pole\_1} := \frac{\pi^2 \cdot E}{(\mu \cdot L)^2} \cdot J_1 = 384\ N \qquad \sigma_{Euler} := \frac{P_{Euler\_Pole\_1}}{A} = 2.17\ MPa$$

Pole #2 (estimating holes):

$$P_{Euler\_Pole\_2} := \frac{\pi^2 \cdot \left(E \cdot \left(1 - k_{Holes\_Pole\_2}\right)\right)}{(\mu \cdot L)^2} \cdot \left(J_1 \cdot \left(1 - k_{Holes\_Pole\_2}\right)\right) = 356\ N$$

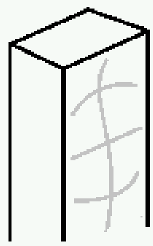
Local buckling: estimation of weaker (planar) side

Extra Input data:

$\delta := 2\ mm$ $\quad k_{Boundary} := 3.6$

$b := 15\ mm$

$$k_{Holes\_on\_Side} := \frac{168 \cdot \dfrac{\pi \cdot (5\ mm)^2}{4}}{L \cdot b} = 0.093$$



Critical force:

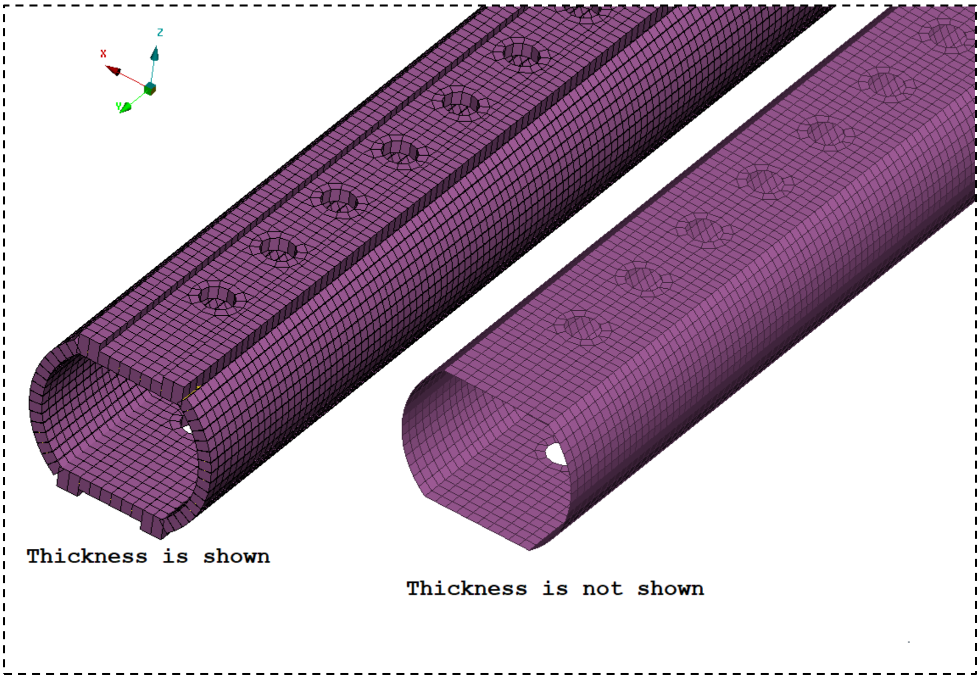
$$P := \frac{k_{Boundary} \cdot E}{\left(\dfrac{b}{\delta}\right)^2} \cdot (b \cdot \delta) \cdot \left(1 - k_{Holes\_on\_Side}\right)^3 = 98800\ N$$

Key points from analytical calculation:

- Expected critical load for **Pole #1 = 384 N**, for **Pole #2 = 356 N**
- Critical stress is in aluminum linear zone (σ_Euler << σ_Yield_Al_6061)
- Local buckling is of no interest, since P_Local >> P_Overall

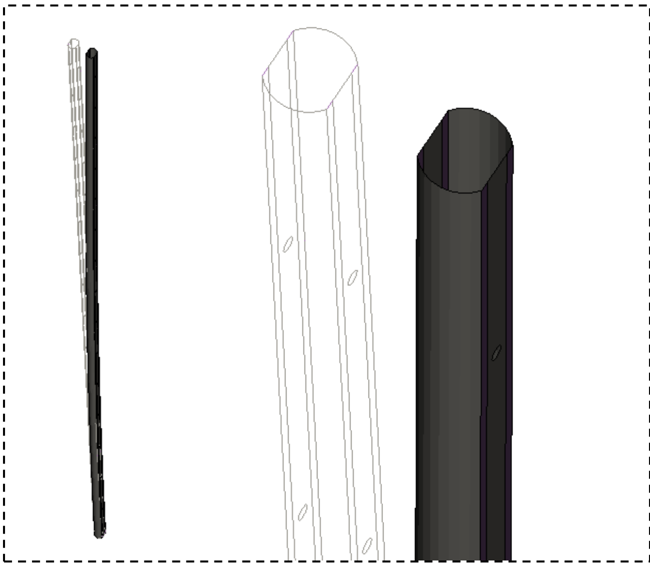
2. Numerical linear buckling

Finite-element model used for both linear and non-linear analysis is shown on Picture 2. Nastran CQUAD4 and CTRIA3 elements are used. CQUADs are used with offset and variable thickness.



[Picture 2] Finite element model of Pole #2.

First buckling form is identical to Pole #1 and Pole #2 and is shown on Picture 3.



[Picture 3] First buckling form of Pole #1.

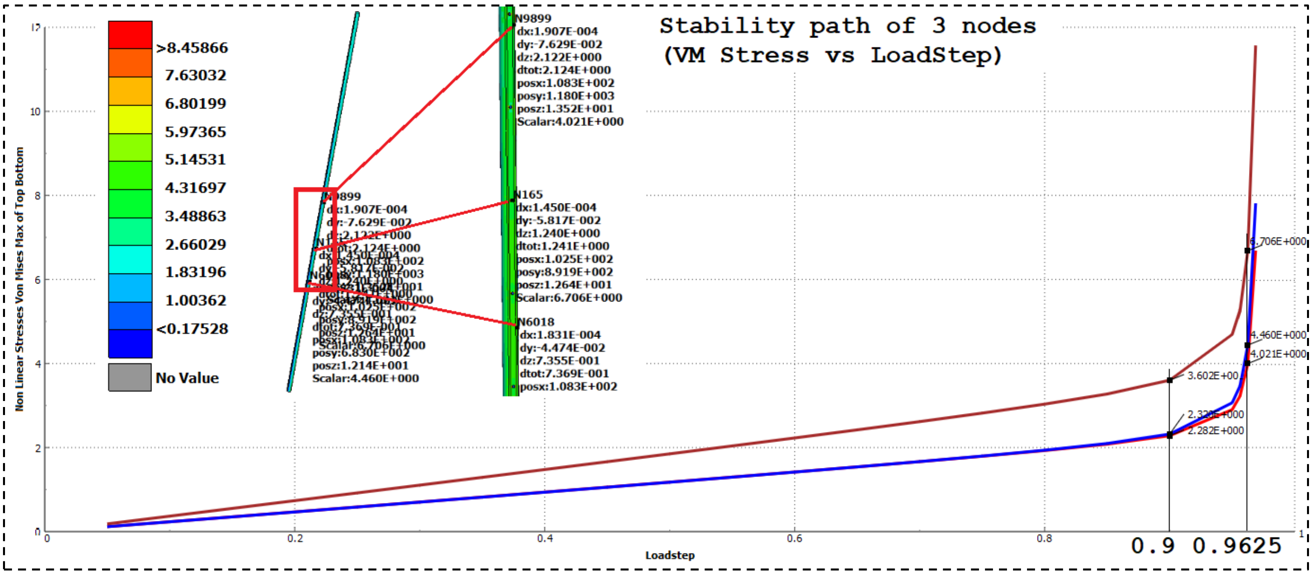
Resulting critical forces are:
For Pole #1 = **398 N**
For Pole #2 = **362 N**

3. Numerical non-linear buckling

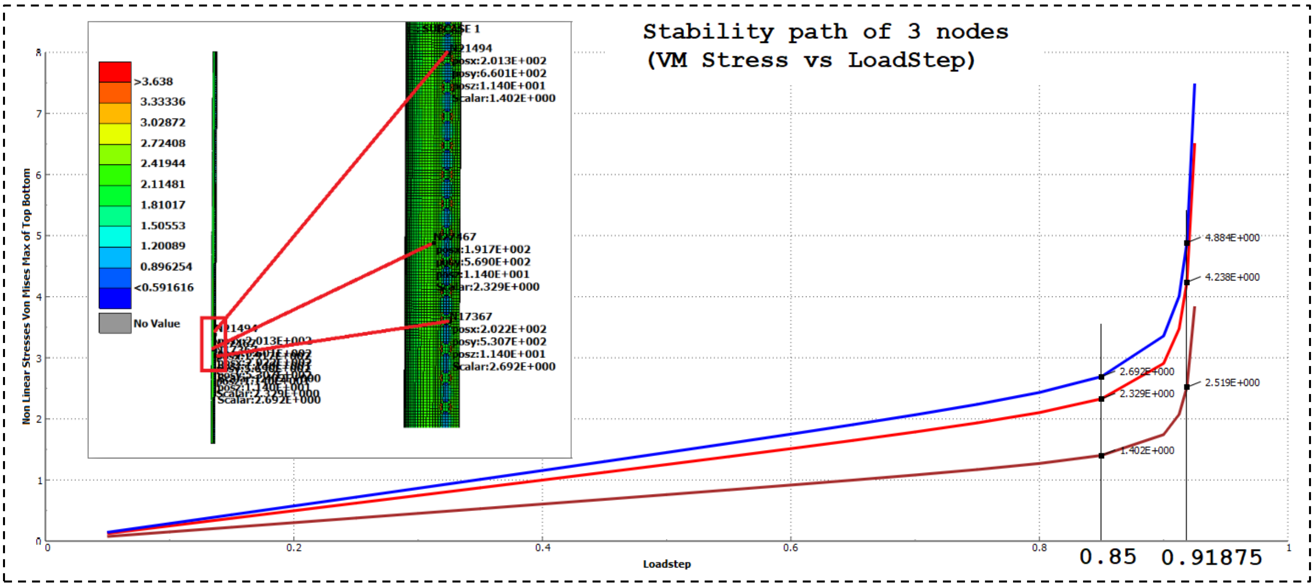
Buckling in non-linear cases is analyzed with the help of Stability Path. Since Poles have very simple structure, any nodes can be chosen for Stability Path, as shown on Pictures 4 and 5.

<u>Results for Pole #1 are:</u>
Pole #1 was analyzed with Load = 410 N.
Non-linear effects start at = 0.9 x 410 N = 369 N
Stresses begin to raise exponentially (defining critical load) at = 0.9625 x 410 N = **395 N**

<u>Results for Pole #2 are:</u>
Pole #2 was analyzed with Load = 390 N.
Non-linear effects start at = 0.85 x 390 = 331.5 N
Stresses begin to raise exponentially (defining critical load) at = 0.91875 x 390 = **358 N**



[Picture 4] Stability path for Pole #1 (100% load = 410 N).



[Picture 5] Stability path for Pole #2 (100% load = 390 N).

4. Conclusions

Summary of various critical force calculation methods is shown in the table:

	Analytical	Numerical Linear	Numerical Non-Linear
Pole #1 Critical Force	384 N	398 N	395 N
Pole #2 Critical Force	356 N	362 N	358 N

Final Results, bases on the safest method (analytical):

Pole #1 Critical Force	**384 N**
Pole #2 Critical Force	**356 N**

*Please, notice that **safety factor** should be considered on the top of Critical Force (based on industry standards) before assuming final permissible load!*

Engineering center Frontier Machines
Engineering stress analysis of any difficulty
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