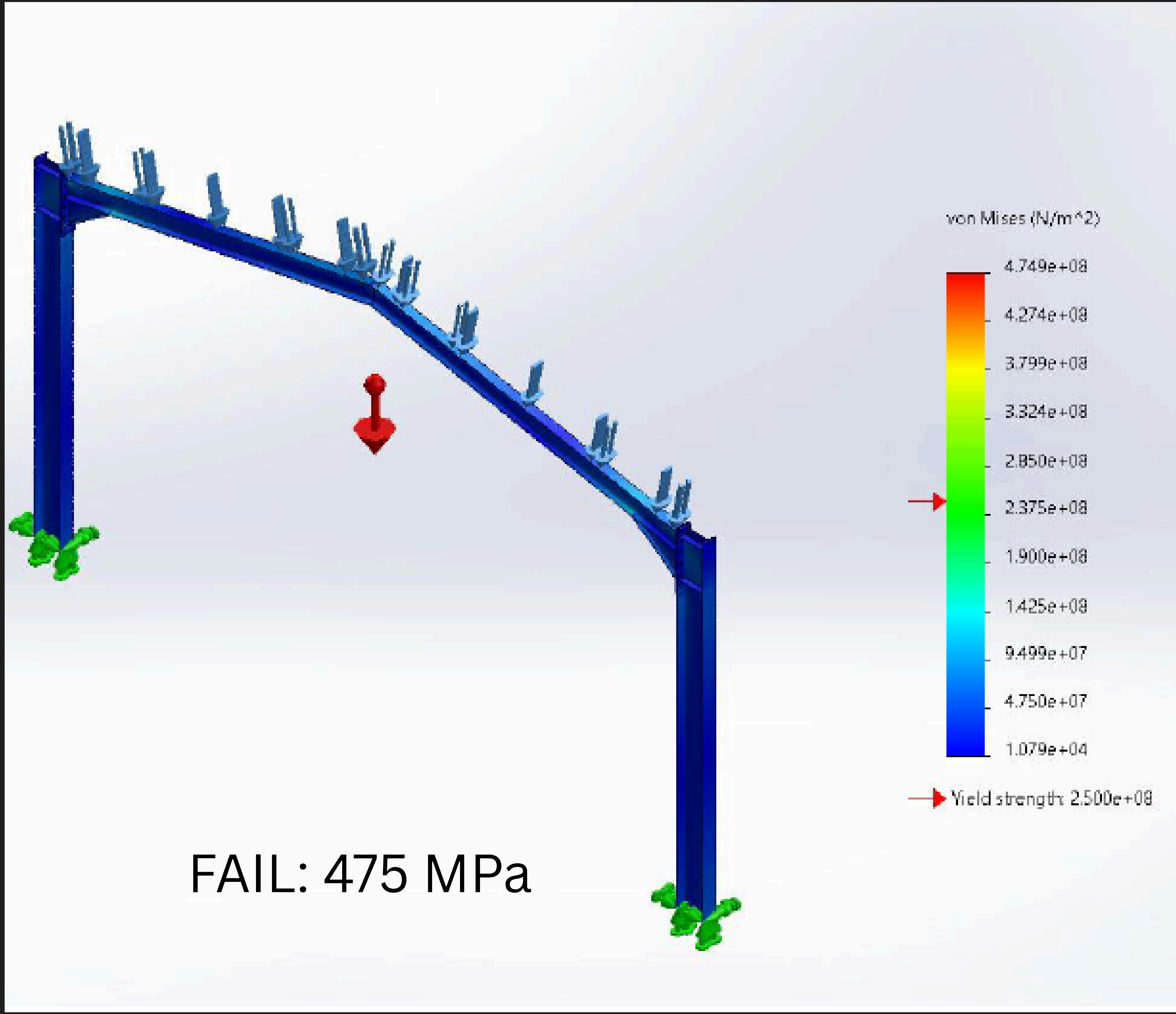
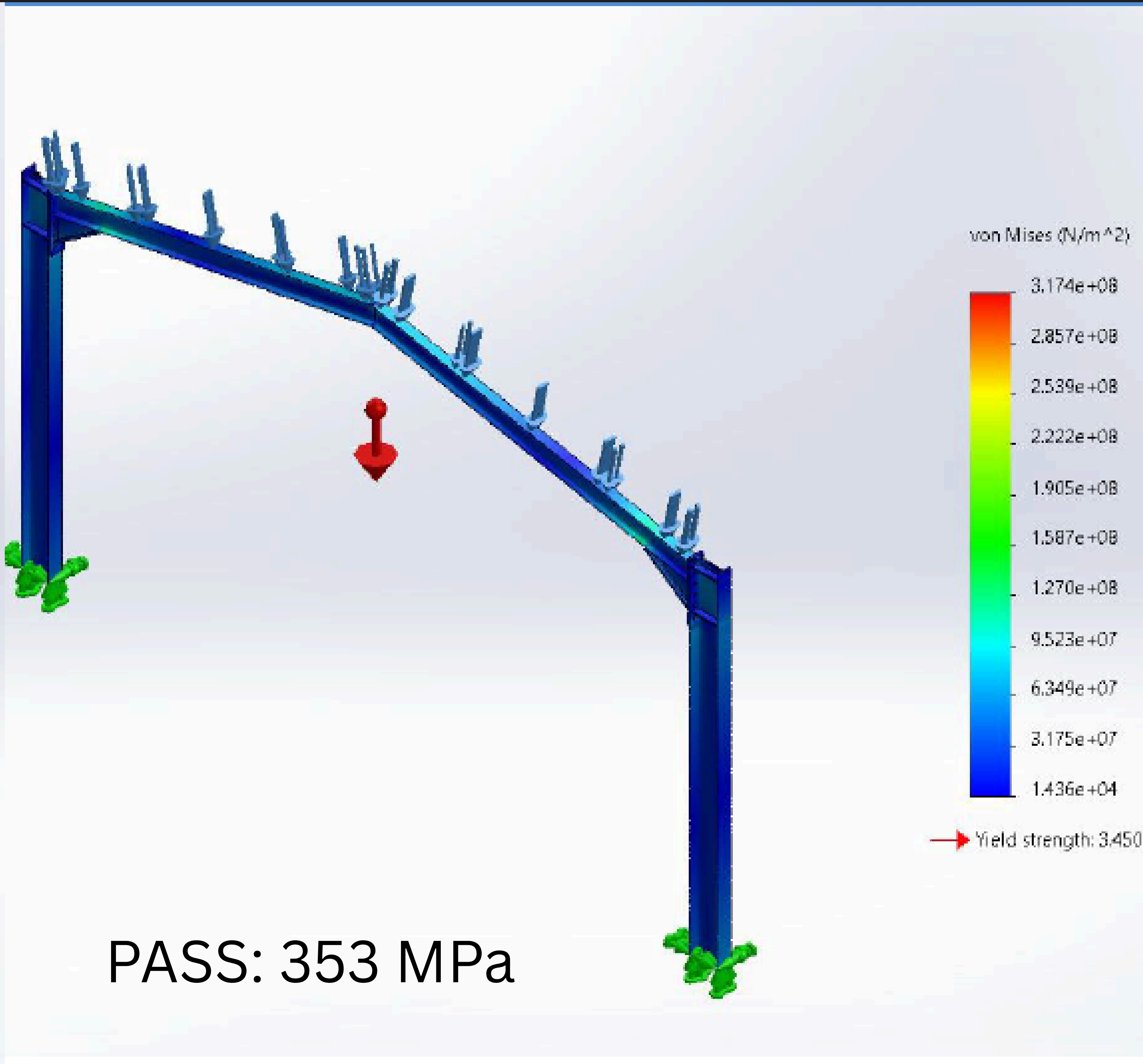
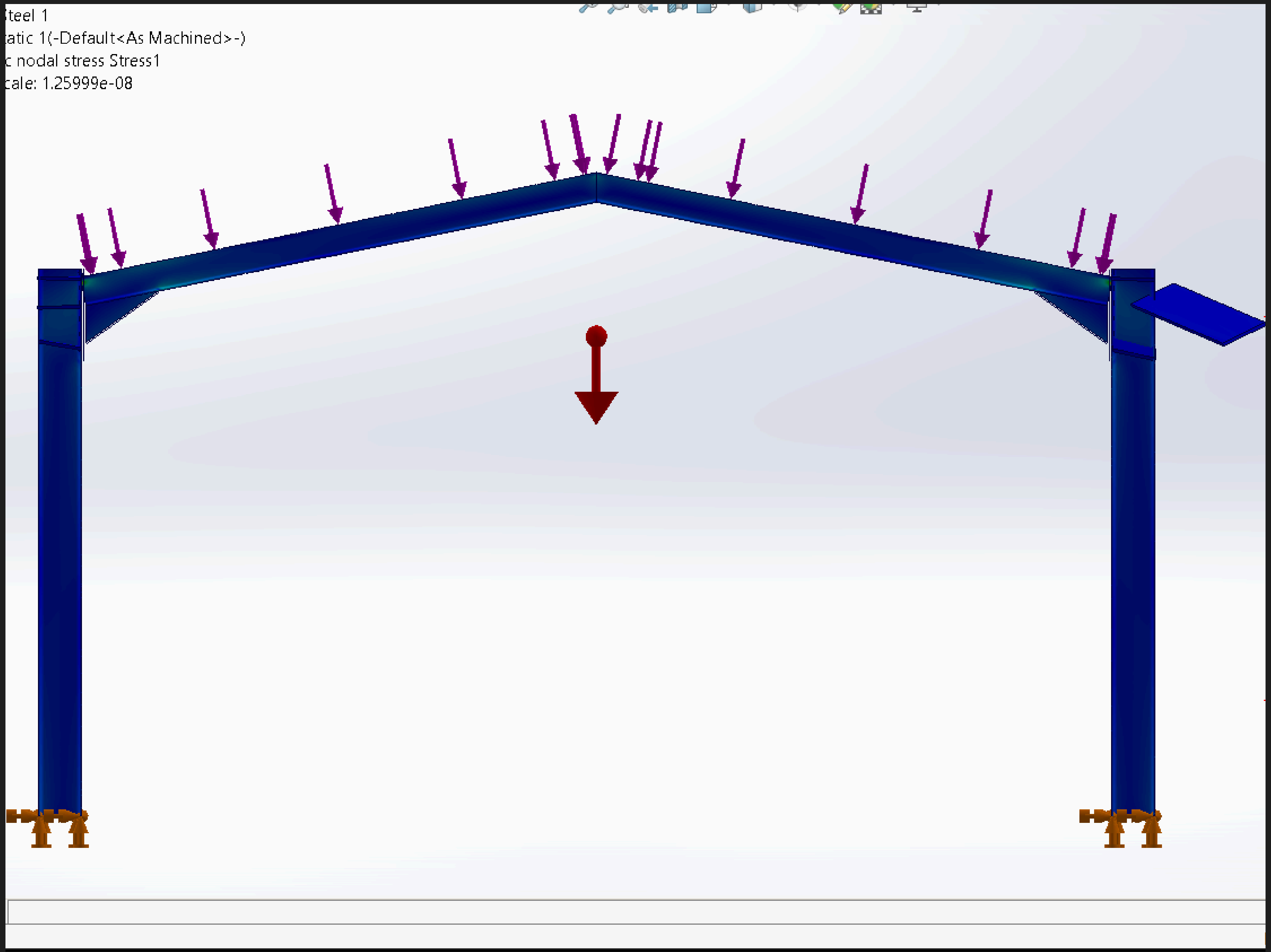
Why My Simulation Failed (And How I Fixed It)

Optimizing a Steel Warehouse using Six Sigma & FEA





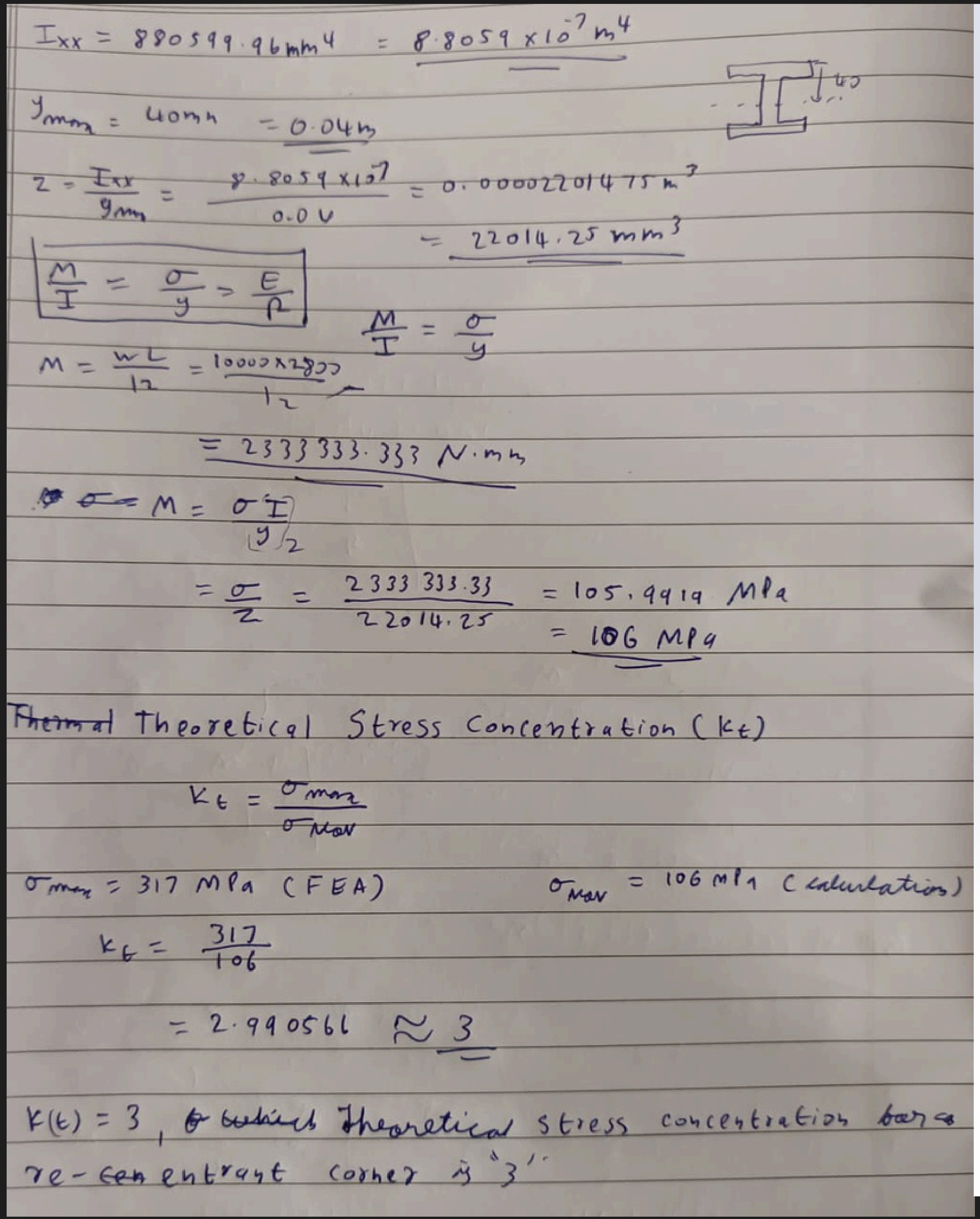
The Failure



- **The Problem:** Internal stiffeners disconnected from the column web during simulation.
- **Root Cause:** Default 'Beam Elements' (1D lines) could not form bonded contact sets with the 3D faces of the plates.
- **Result:** Infinite displacement (10km error).

The Theory Check: Hand Calc vs. FEA

Validating the Simulation with Beam Theory



$I_{xx} = 880599.96\,mm^4 = \underline{8.8059 \times 10^{-7}\,m^4}$

$y_{max} = 40mm = \underline{0.04m}$

$Z = \frac{I_{xx}}{y_{max}} = \frac{8.8059 \times 10^{-7}}{0.04} = 0.0000220147 5\,m^3$

$= \underline{22014.25\,mm^3}$

$\boxed{\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}}$

$\frac{M}{I} = \frac{\sigma}{y}$

$M = \frac{wL}{12} = \frac{10000 \times 2800}{12}$

$= \underline{2333333.333\ N \cdot mm}$

$M = \frac{\sigma I}{y/2}$

$= \frac{\sigma}{Z} = \frac{2333333.33}{22014.25} = 105.9919\ MPa$

$= \underline{106\ MPa}$

~~Thermal~~ Theoretical Stress Concentration (K_t)

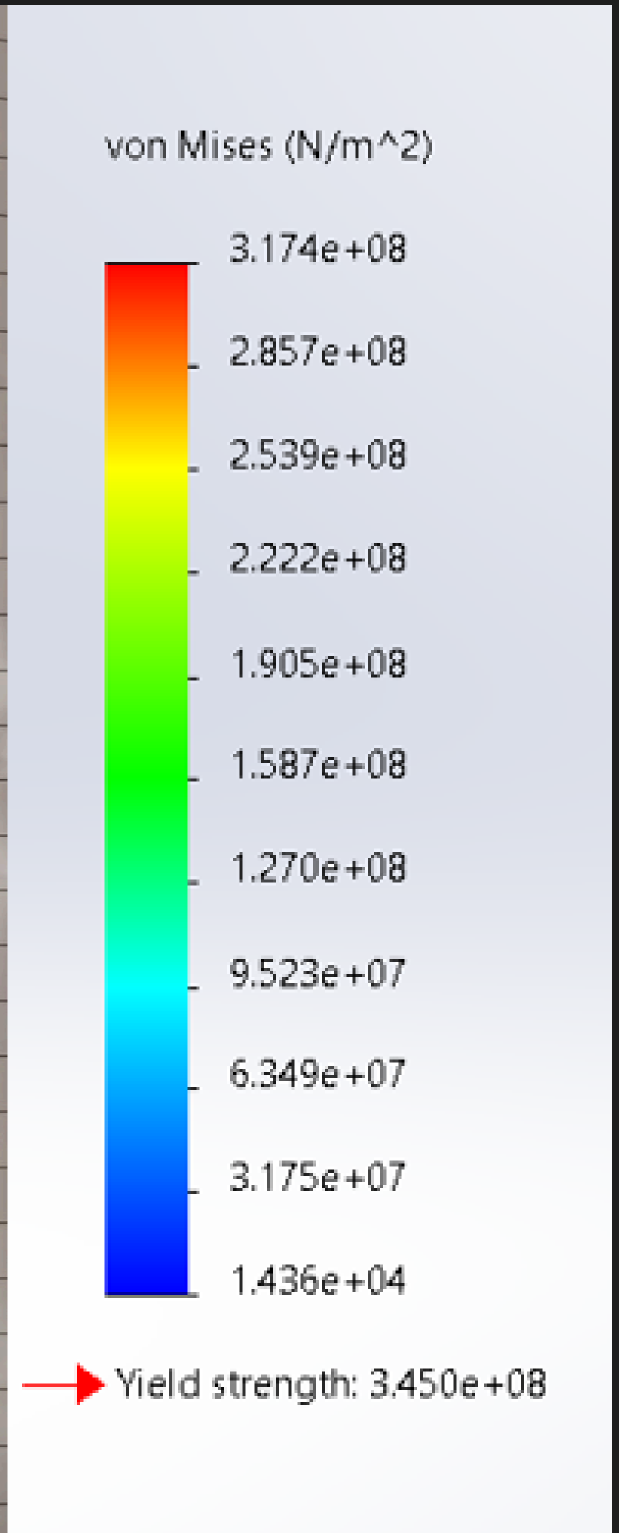
$K_t = \frac{\sigma_{max}}{\sigma_{NOM}}$

$\sigma_{max} = 317\ MPa$ (FEA) $\sigma_{NOM} = 106\ MPa$ (calculation)

$K_t = \frac{317}{106}$

$= 2.990566 \approx \underline{3}$

$K(t) = 3$, which theoretical stress concentration for a re-entrant corner is "3".



- My manual beam calculation predicted a nominal stress of **106 MPa**. The FEA simulation revealed a peak stress of **317 MPa**.
- The ratio approx **3.0** matches the theoretical Stress Concentration Factor (**Kt**) for a sharp corner, validating that the simulation is capturing the correct geometric physics.

The Theory Check: Hand Calc vs. FEA

Validating the Simulation with Beam Theory

$\delta_{max} = \frac{wL^3}{384EI}$ (for Fixed-Fixed (Rigid Ends))

$W = 10{,}000\,N$, $L = 2.8\,m$, $E = 2 \times 10^{11}\,Pa$, $I = 8.806 \times 10^{-7}\,m^4$

$$\delta_{max} = \frac{10000 \times (2.8)^3}{384 \times 2 \times 10^{11} \times 8.806 \times 10^{-7}}$$

$$= 0.003245\ m$$

$$\delta_{max} = 3.246\ mm$$

Theoretical $\delta_{max} = 3.246\,mm$

FEA Result $= 5.12\,mm$

Comparison & Inference

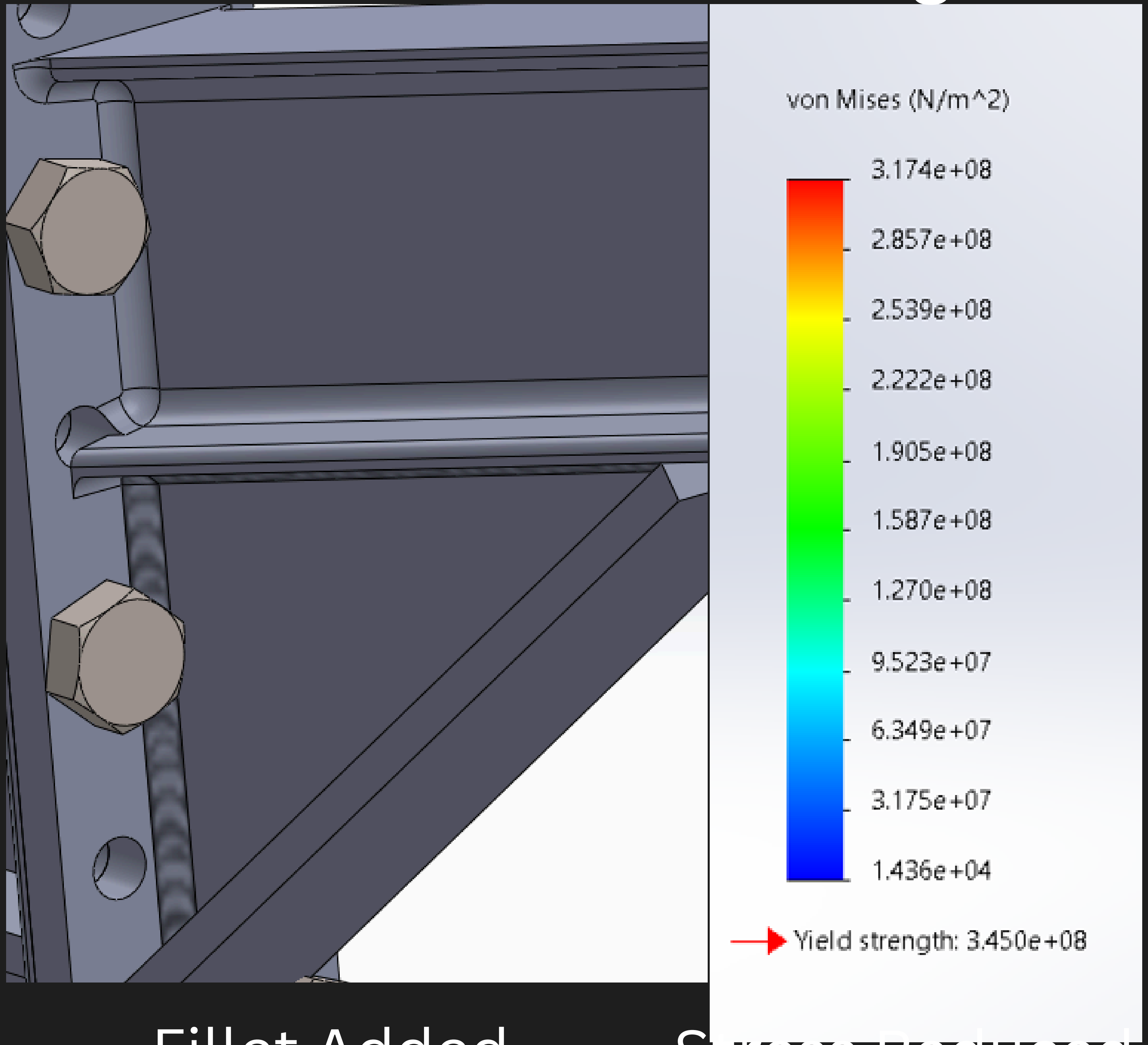
- **Theoretical (Perfectly Fixed)**: 3.24 mm
- **FEA Result (Actual Frame)**: 5.12 mm

Inference:

- **The FEA result 5.12 mm** is higher than the theoretical fixed beam **3.24 mm** but significantly lower than a pinned beam **16.2 mm**. This indicates that:
- **Column Flexibility**: The hand calculation assumes the supports are "infinitely rigid walls." In reality, the steel columns possess elasticity and bow slightly outward under load, allowing the roof to sag further than a perfectly fixed beam.
- **Structural Behavior**: The result confirms that the frame is functioning as a Semi-Rigid to Rigid structure, successfully resisting the majority of the bending rotation at the corners.

The Optimization (The Fix)

Engineering a Safer Design



Fillet Added (Simulating Weld)

Stress Reduced to 317 MPa

- Geometric Refinement: Introduced fillet radii at connection points to simulate weld beads, eliminating the sharp-corner stress singularity.
- Mesh Strategy: Converted beams to Solid Elements to enable accurate face-to-face bonding with stiffeners.
- Material Upgrade: Switched to **ASTM A992** Steel **(Sy = 345 MPa)** to align with modern structural standards.

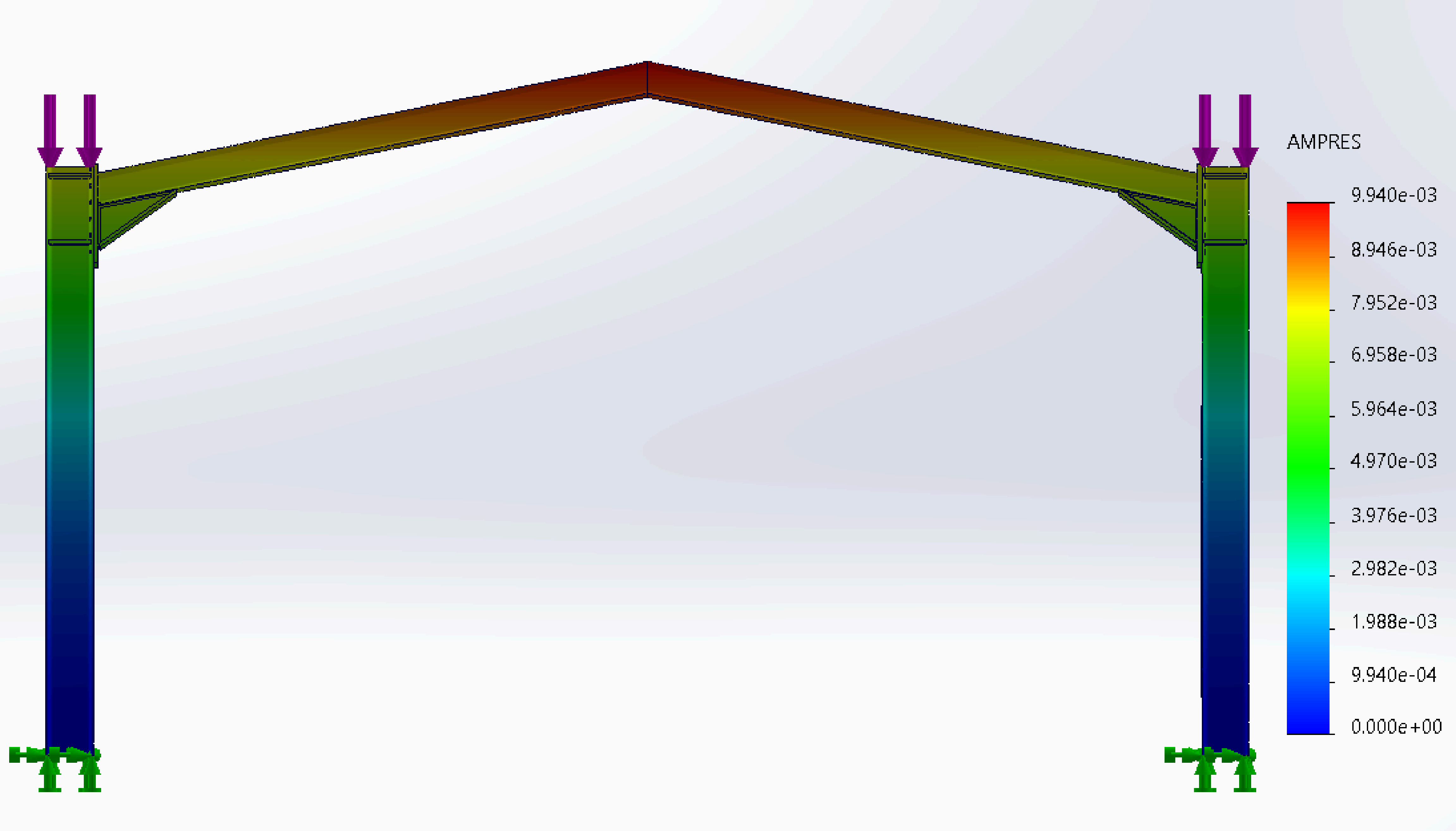
Final Validation & Equilibrium Check

Parameter	Hand Calc / Theory	FEA Result	Conclusion
Total Reaction Force	20,167 N	20,167 N	✅ Equilibrium
Max Stress	106 MPa (Nominal)	353 MPa (Peak)	✅ Matches Kt
Max Deflection	3.246 mm	5.12 mm	✅ Safe (Span/500)

- **Static Equilibrium**: $\Sigma F_y = 0$ is satisfied. The ground reaction matches the applied load perfectly.
- **Stiffness**: Max deflection is only 5.12 mm, confirming the frame is rigid and behaving elastically.
- **Stability: Buckling Load Factor (BLF) = 5.05, meaning the structure can handle 5x the load before collapsing.**

Structural Stability Analysis

Ensuring the Columns Won't Collapse



- **The Test**: Performed a Linear Buckling Analysis to ensure the tall columns won't fail due to instability."
- **The Result**: Buckling Load Factor (BLF) = **5.0498**.
- **Conclusion**: The structure theoretically requires 5x the applied load **(50 kN)** to buckle. Since we are only applying **10 kN**, the design is Extremely Stable.

- Anything > 3.0 is considered safe in industry.
- A BLF of 5.05 means your columns are extremely strong and stable.

The Conclusion

The Takeaways

- It’s not just about CAD: This project taught me that simulation tools are useless without a deep understanding of Structural Mechanics and Material Behavior.

- The Six Sigma Approach: By applying the DMAIC methodology, I turned a failing model (475 MPa) into a safe, optimized design (353 MPa).

- Ready for Industry: I have verified the results against theory, ensuring the design is feasible, efficient, and safe.

What’s Next? Part 3: MATLAB Verification"(Building a custom Matrix Stiffness Solver to prove the math)

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