Portfolio Homework 12 → Grace LoPiccolo

Step 1: Rigid Bar Mechanism

The goal is to design a 2D mechanism inside a 150 cm x 50 cm design window that uses a single-rod three pin joints (2 on the ground), and one linear actuator to lift the maximum possible weight to the highest possible height

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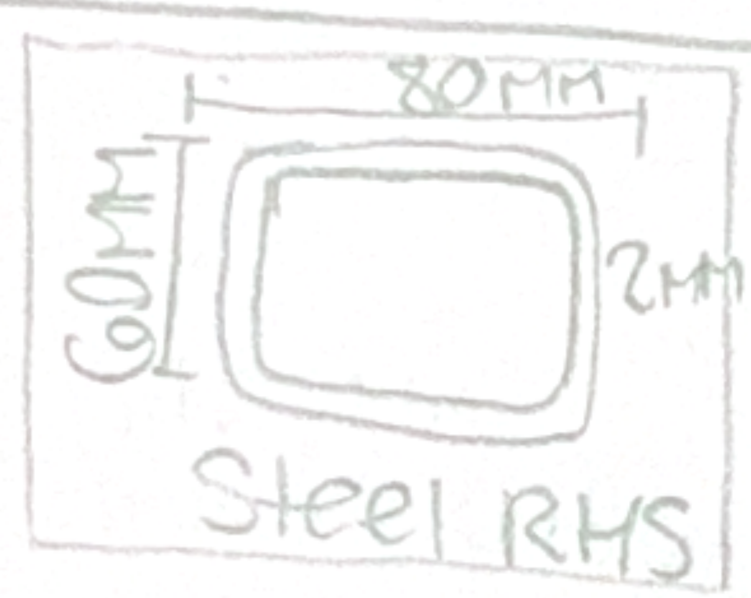
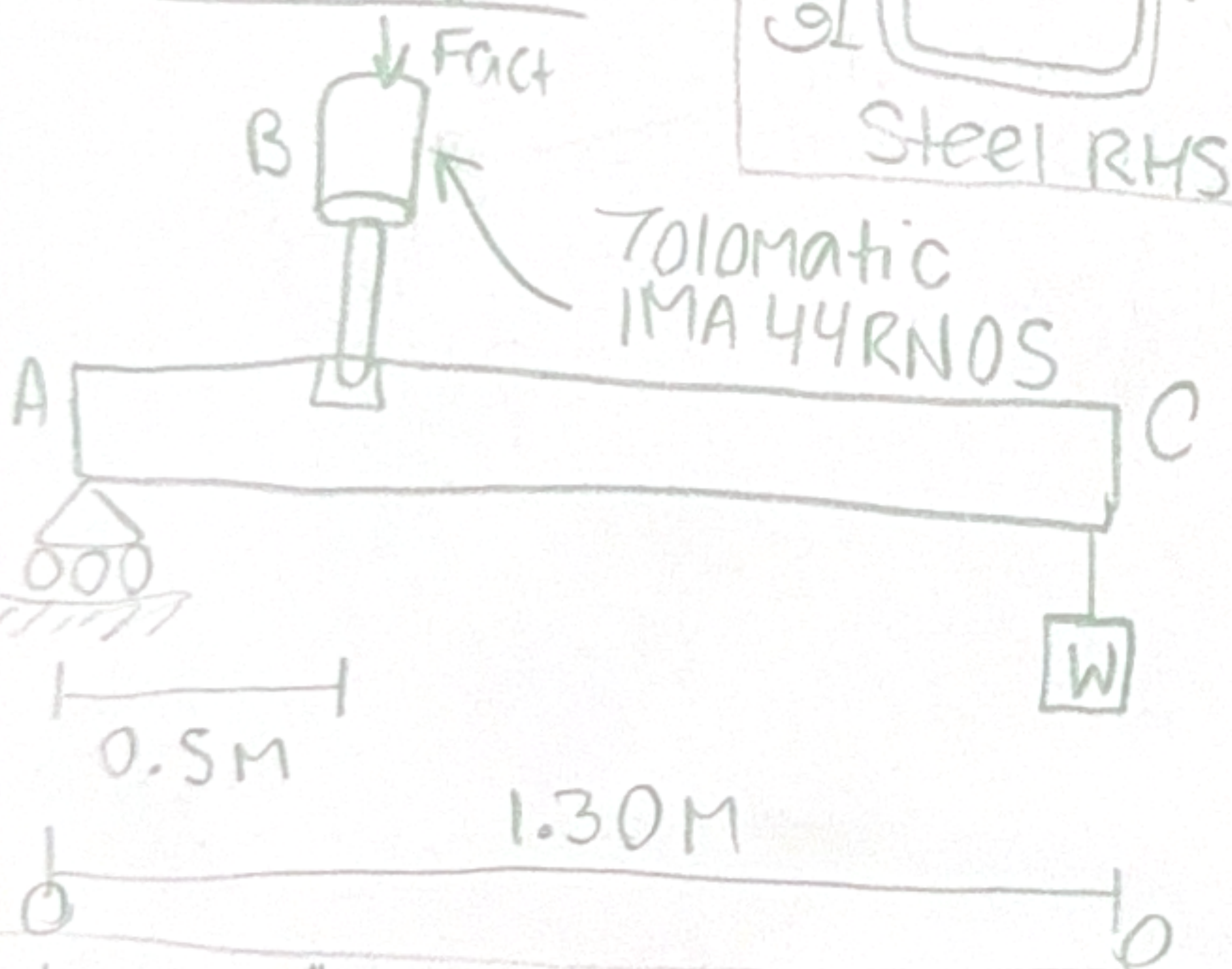
My design





In the "lifted" configuration I analyze: the bar is horizontial and the actuator force is essentially vertically upward at B

$$\sum M_A = 0 \rightarrow F_{act}\,a - WL = 0$$

$$W = a/L\ F_{act}$$

$$W_{max} = \frac{a}{L} F_{act,max} = \frac{0.5}{1.3}(7.34\times10^3) = 2.8\ kN$$

$$\boxed{\text{This geometry + actuator supports a maximum lifted weight of approx. 2.8 kN at C}}$$

Actuator selection and constraints:

from the Tolomatic IMA catalog I chose the size IMA44 RN05 roller-screw actuator. The table on p.4 lists a continuous thrust capacity of 7.34 kN for this model

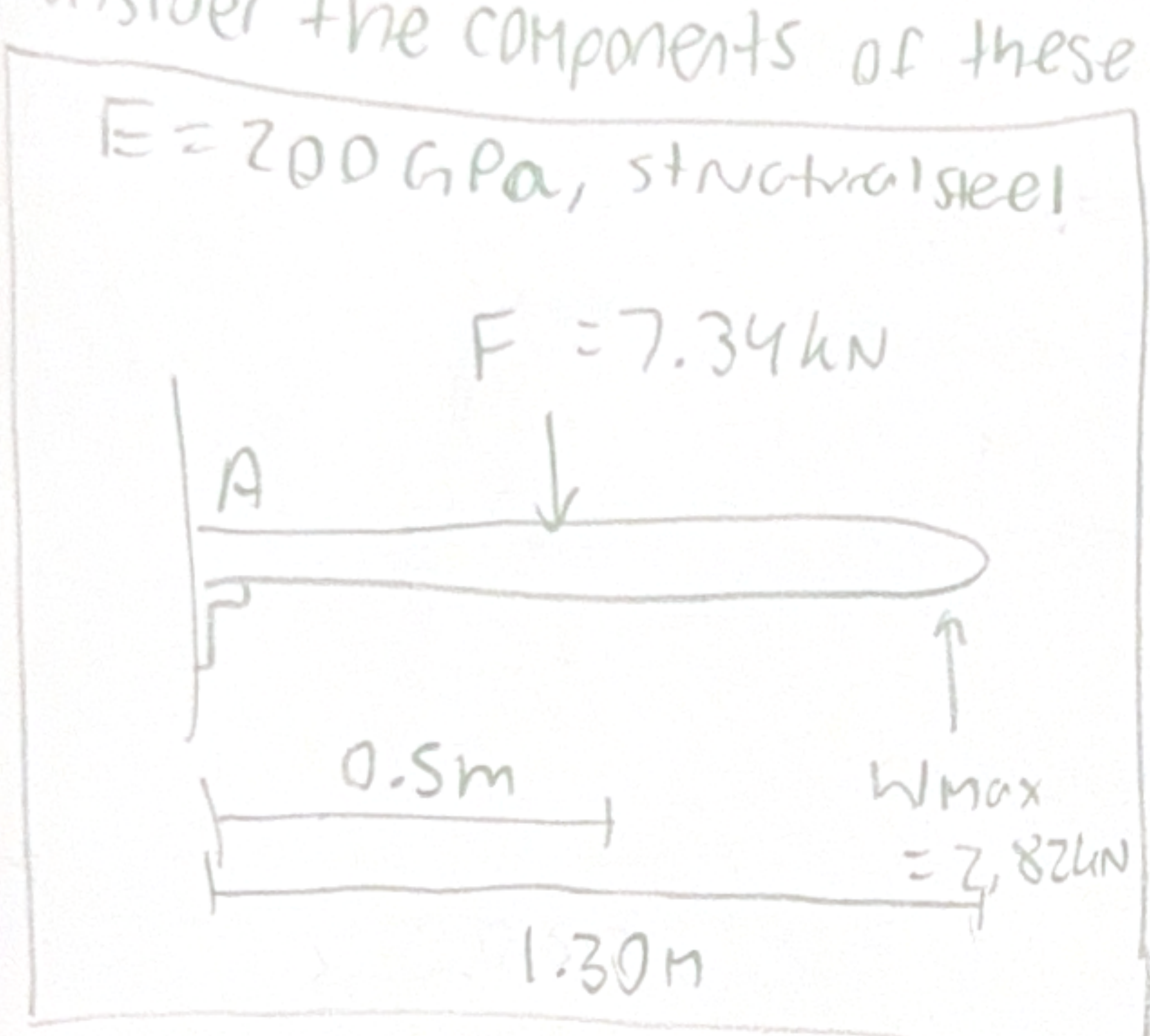
I use this continuous thrust as the design limit $F_{act,max} = 7.34 kN$.

Other assumptions:

- Quasi-static lifting
- Supports and actuator are rigid
- Bar is treated as a rigid body as of this step

Step 2: Bar as a Flexible Beam

Now the bar is treated as a beam that bends under the combined action of the actuator force and the weight. I only consider the components of these forces transverse to the beam



$$\delta_C = \frac{WL^3}{3EI} - \frac{Fa^2(3L-a)}{6EI}$$

$W = \frac{a}{L}F$, so $\delta_C = \frac{F}{6EI}\left(2aL^2 - a^2(3L-a)\right)$

$2aL^2 - a^2(3L-a) \approx 1027.6\ \mathrm{N \cdot m^3}/F$

$\delta_C = \frac{k}{EI}$, $k \approx 1.03\times10^3\ \mathrm{N\cdot m^3}$

$\delta_{allow} = 0.02L = 0.026\,m$

$$I_{min} = \frac{k}{E\delta_{allow}} \approx \frac{1.03\times10^3}{(200\times10^9)(0.026)} = 2.0\times10^{-7}\,m^4$$

Any design with $I \geq I_{min}$ will keep vertical deflection under 2% of the span

For solid circular bar (comparison)

$I_{solid} = \frac{\pi r^4}{4} \approx 2.35\times10^{-8}\,m^4$

$\delta_C^{solid} = k/EI_{solid} = 0.22\,m \rightarrow 17\%L > 2\%$ ✗

To make the beam as light as possible while satisfying $I \geq I_{min}$, I compared a solid circular bar and a thin-walled rectangular tube. RHS has a much larger I/A ratio than a solid bar with the same cross-sectional area

Steel rectangular hollow section

Outer height = 80mm
Outer width = 60mm
thickness = 2mm

$A = 2t(b+h-2t) = 2(0.002)(0.06+0.08-0.004)$
$= 5.11\times10^{-7}\,m^4$

$I = 5.11\times10^{-7} > I_{min} = 2.0\times10^{-7}$

$$\delta_C = k/EI \approx \frac{1.03\times10^3}{(200\times10^9)(5.11\times10^{-7})} = 0.01\,m$$

$$\frac{\delta_C}{L} = \frac{0.01}{1.30} = 0.77\% < 2\%\ \text{limit} ✓$$

$m = \rho A L = (7850)(5.44\times10^{-4})(1.30) = 5.6\,kg$

Final Design summary

- single bar with pins at A and B, actuator between B and ground pin D, weight at C
- Tolomatic IMA44RN05 roller-screw
- continuous thrust at 7.34 kN
- $W_{max} = 2.8\,kN$

Beam, steel: 80 × 60 × 2 mm, L = 1.3m

$\delta_C = 10\,mm \rightarrow .77\% < 2\%$ ✓

Mass = 5.6 kg