29.05.2024

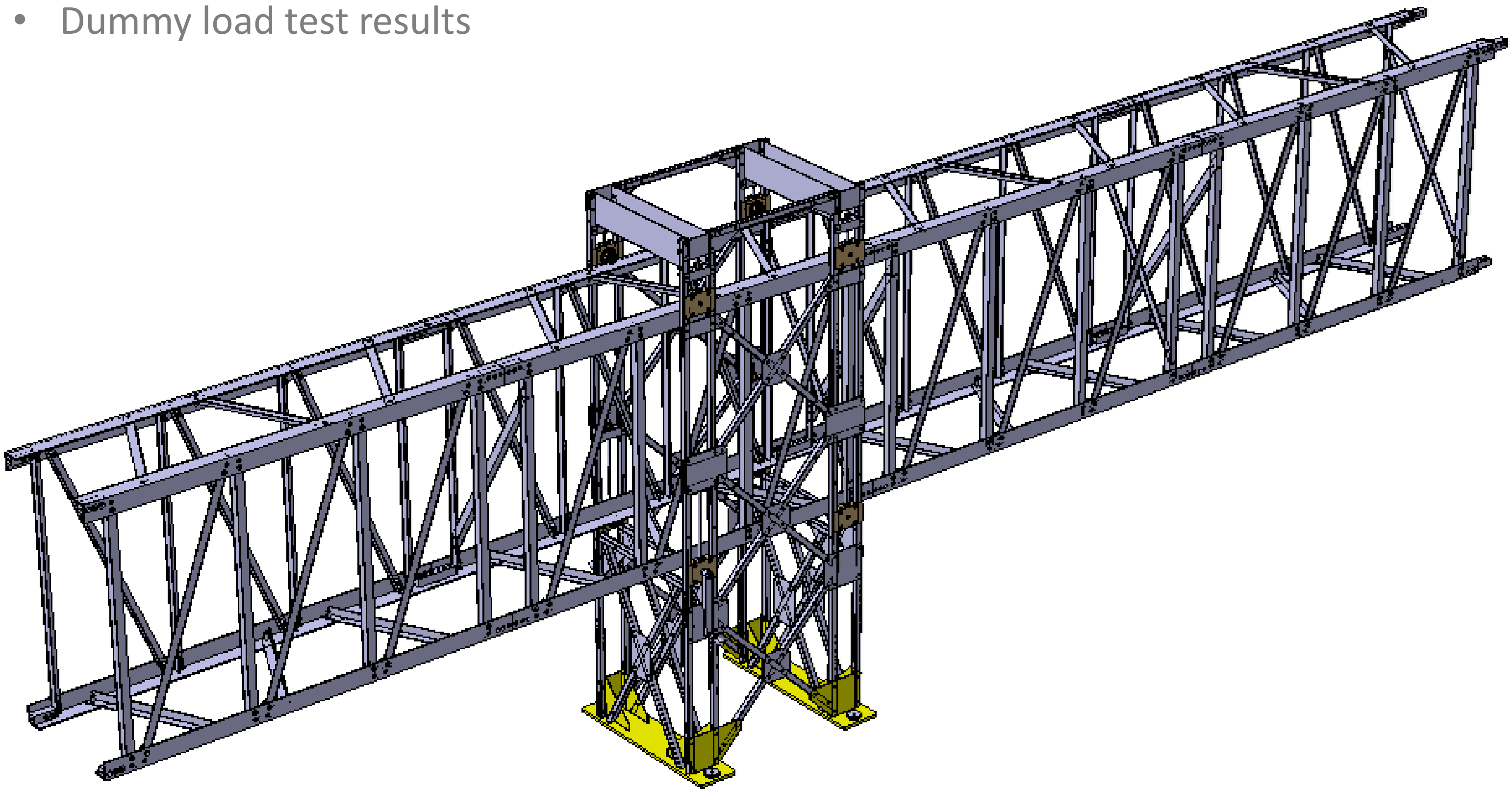
# Design and testing of a dynamic support frame structure for the CMS tracker installation process

Mikko Barinoff, Nicolas Siegrist, Hans Postema

on behalf of the CMS Tracker -group

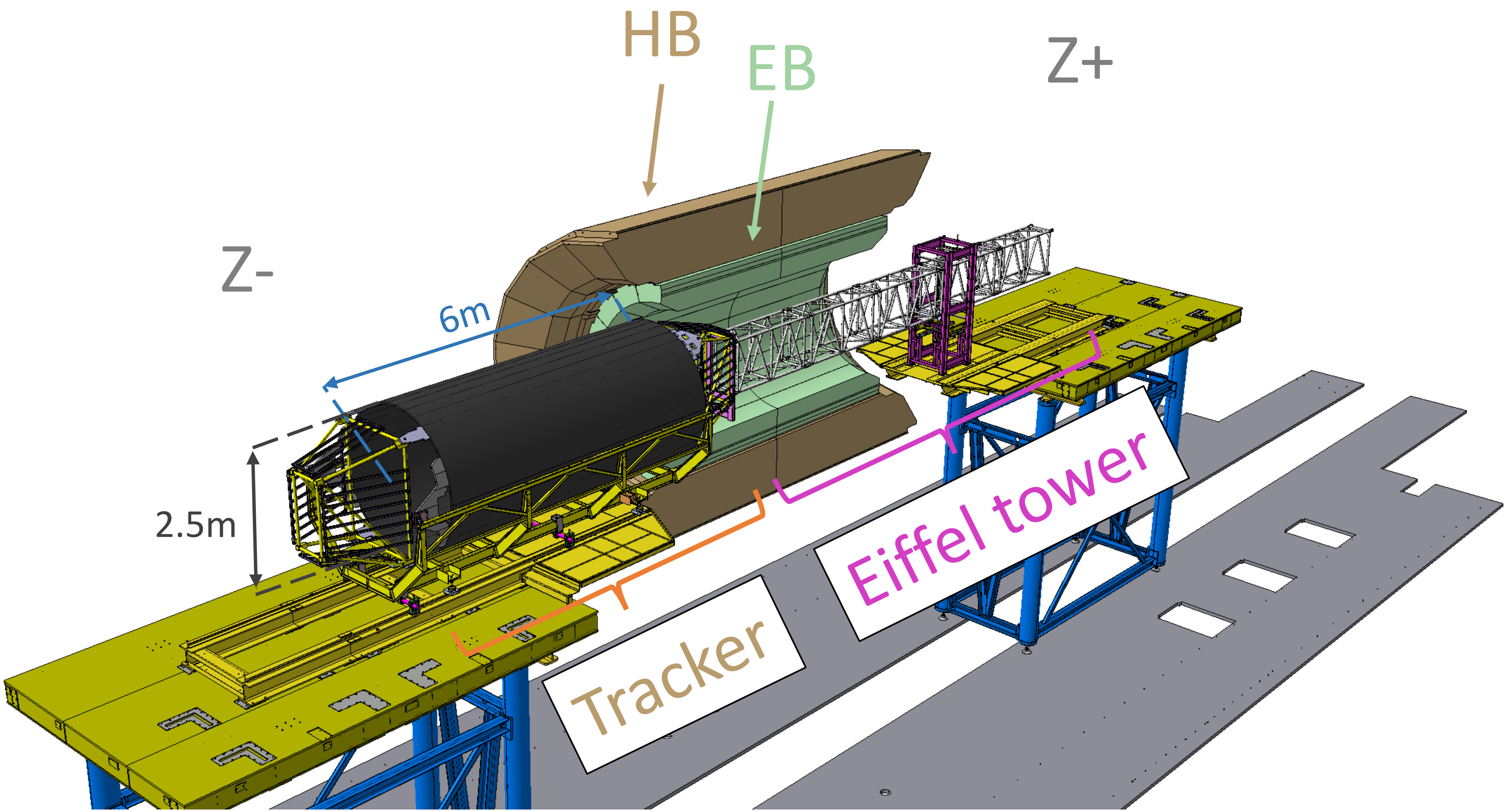
# Contents

- Introduction to the eiffel tower concept
- Study of the old structure, motivation and overview of the new design
- Design validation
    - Dummy load test results



# Eiffel tower concept

# Eiffel tower concept

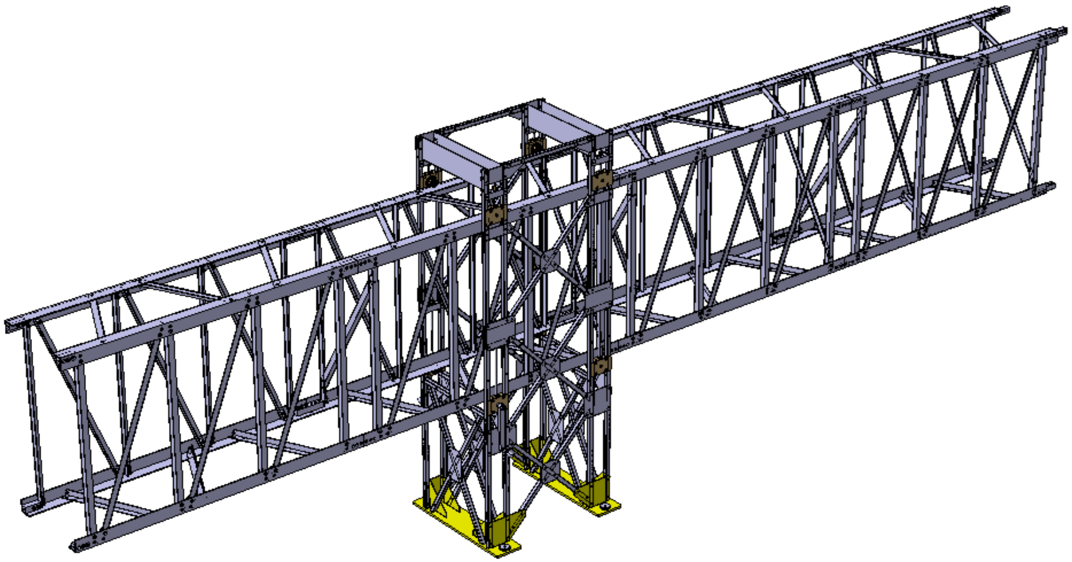


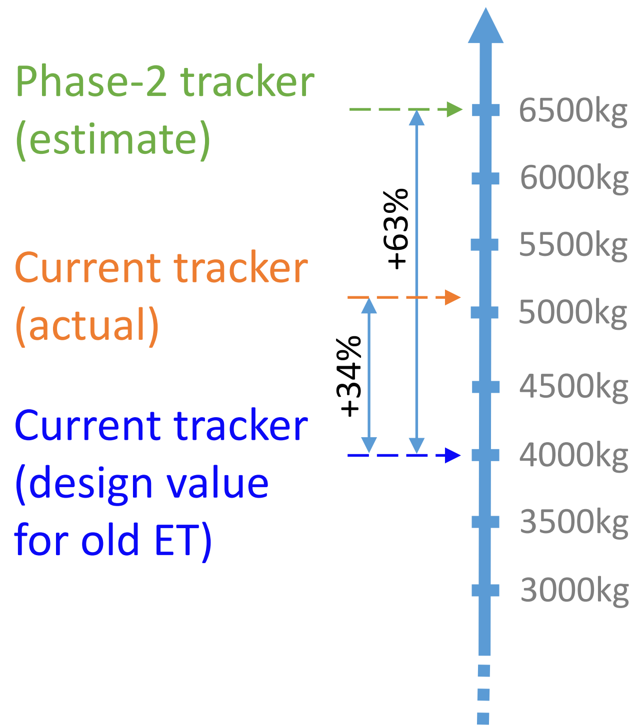

(video)

# Study of the old structure

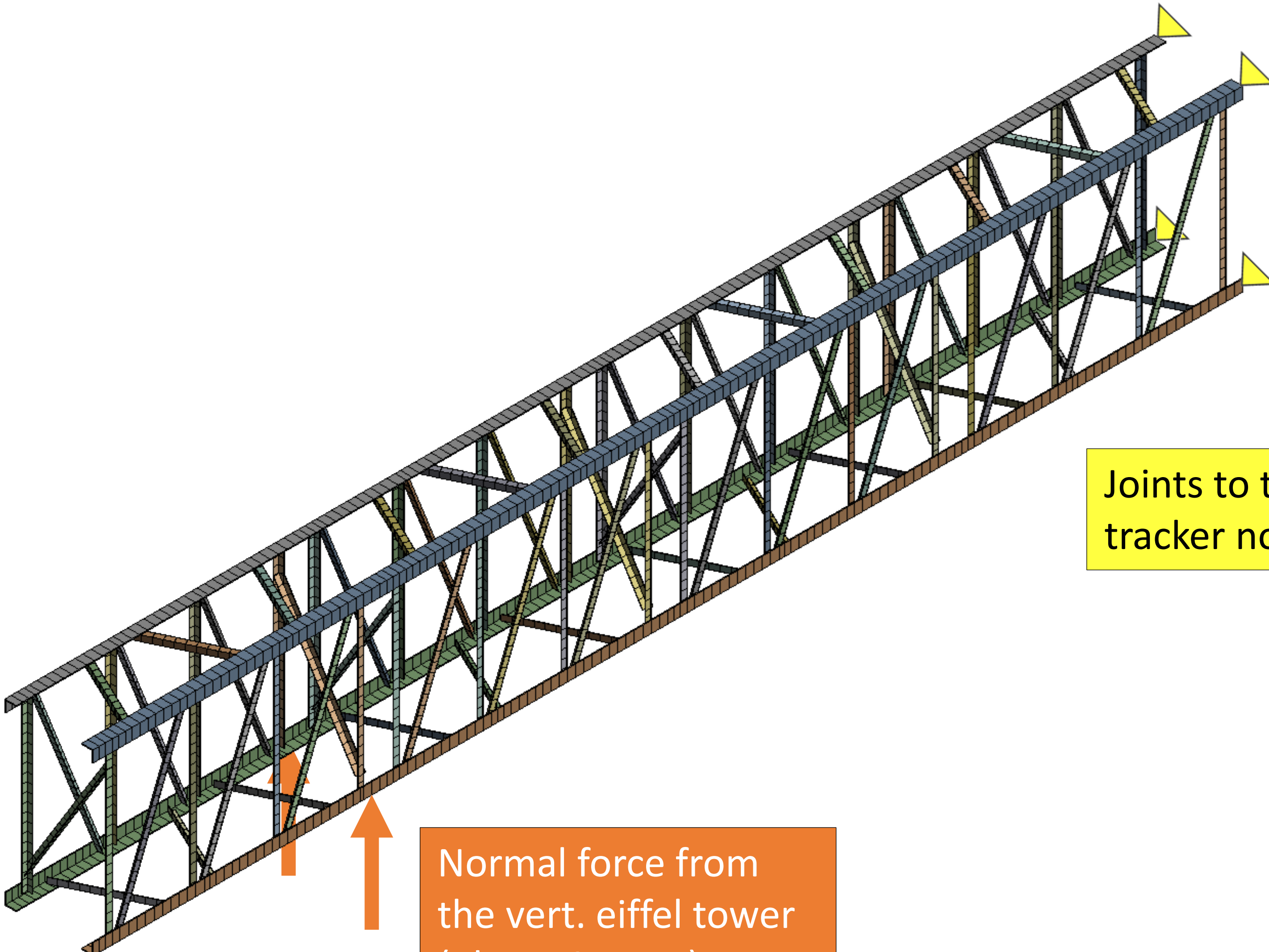
# Starting point of the study

- Can we re-use the old eiffel tower?





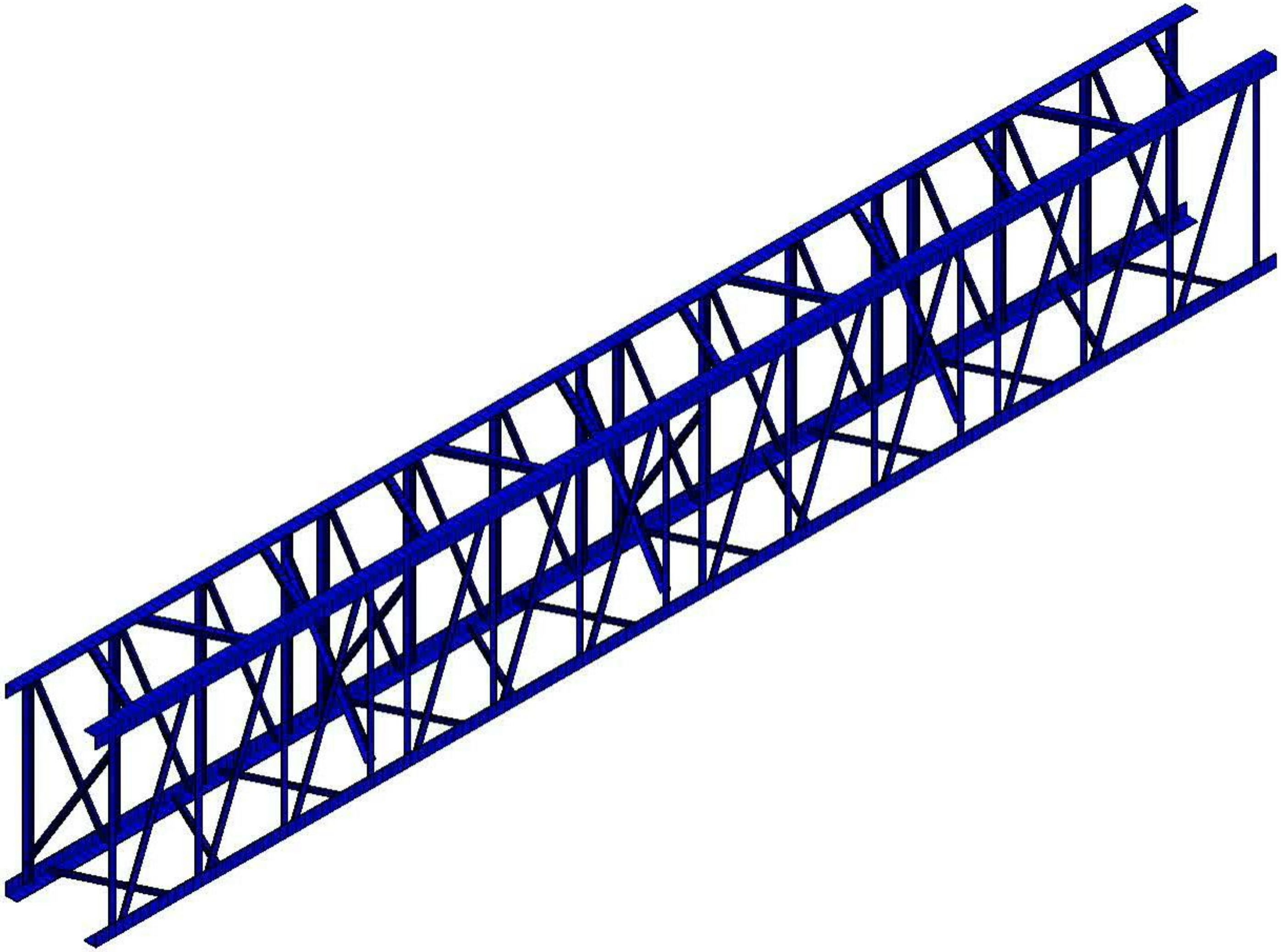
# Structural study of the old Eiffel tower



Joints to the tracker nose cone

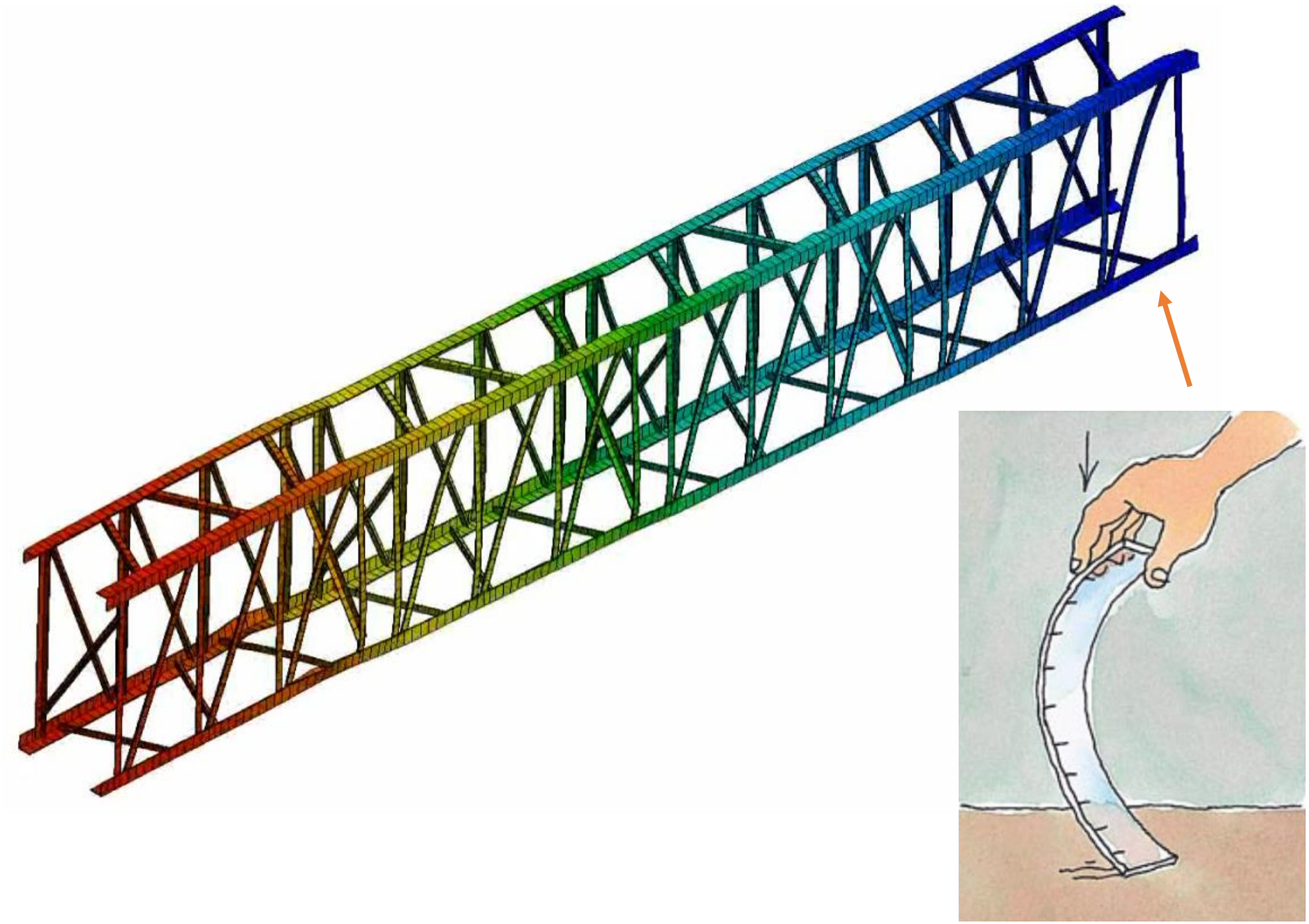
Normal force from the vert. eiffel tower (phase-2 mass)

# Structural study of the old Eiffel tower



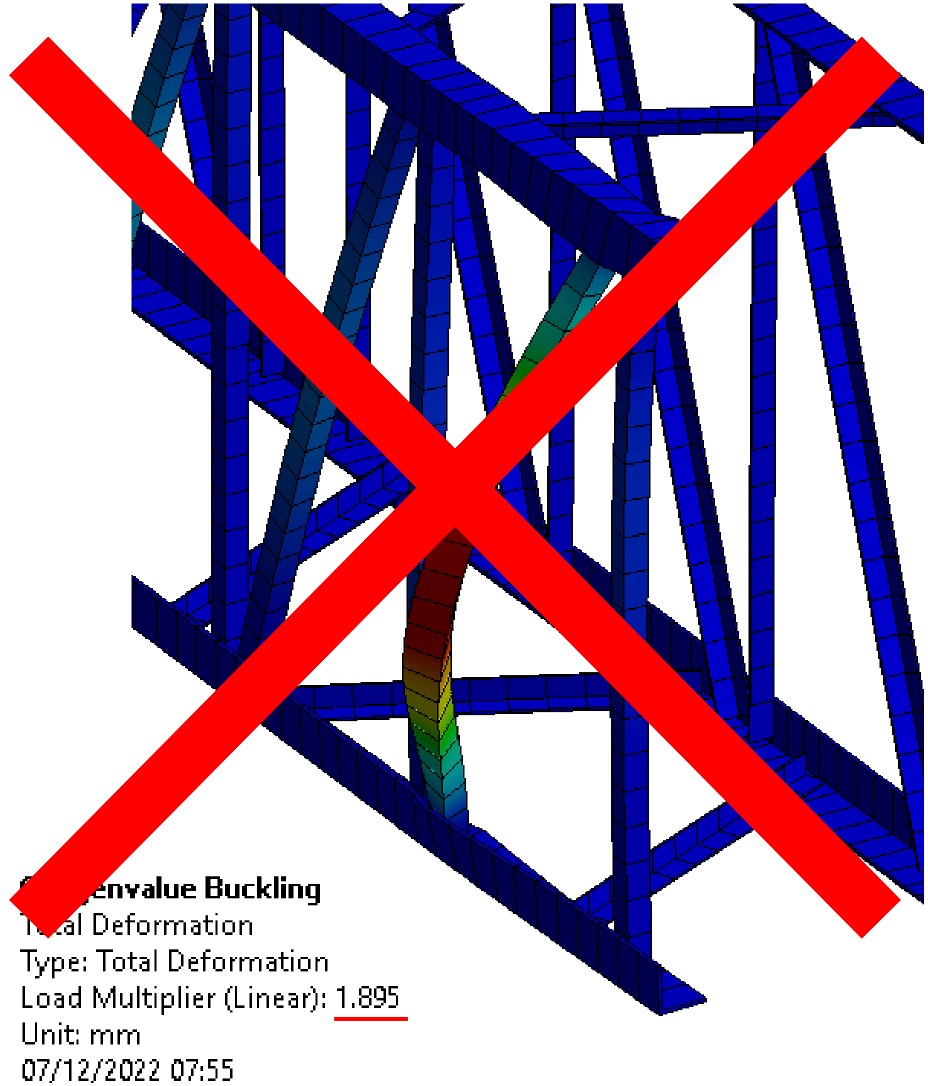
(video)

# Structural study of the old Eiffel tower



Buckling

# Structural study of the old Eiffel tower



# New eiffel tower design

# Make or buy?

# New eiffel tower design

Google

Installation tooling for particle trackers

Images | Videos | News | Books | Finance

About 0 results (0,37 seconds)

Your search - **Installation tooling for particle trackers** - did not match any documents.

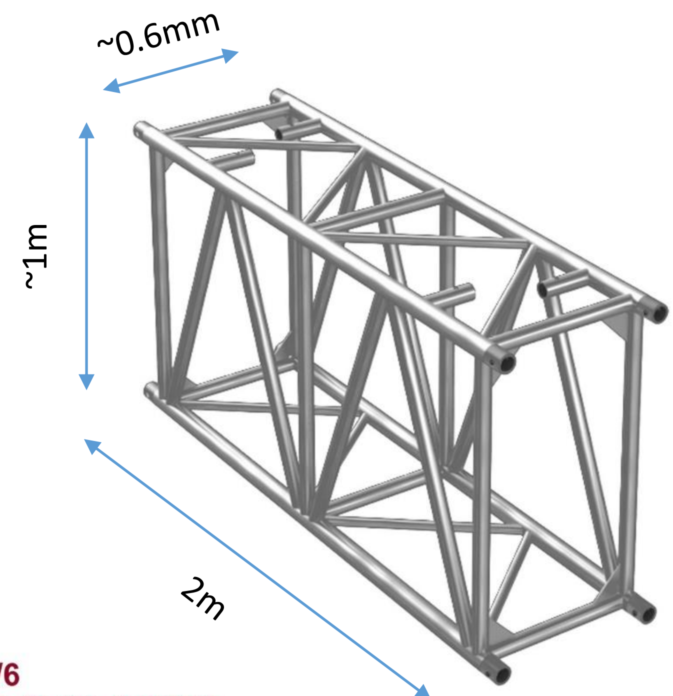
Suggestions:

- Make sure that all words are spelled correctly.
- Try different keywords.
- Try more general keywords.
- Try fewer keywords.

# Inspiration for the new design

# New horizontal eiffel tower

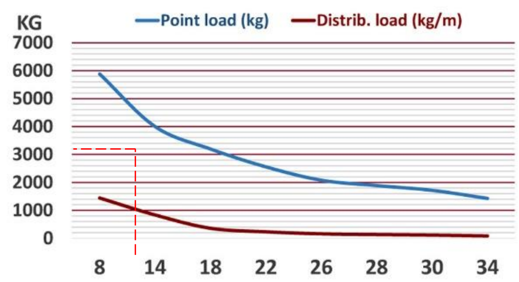
- Duratruss DT 104/6-200 DT High Load Rigging Truss
  - Welded from 60x6 aluminum tube
- Would imply re-designing the vertical Eiffel tower and an adapter between the truss and the tracker nose-cone



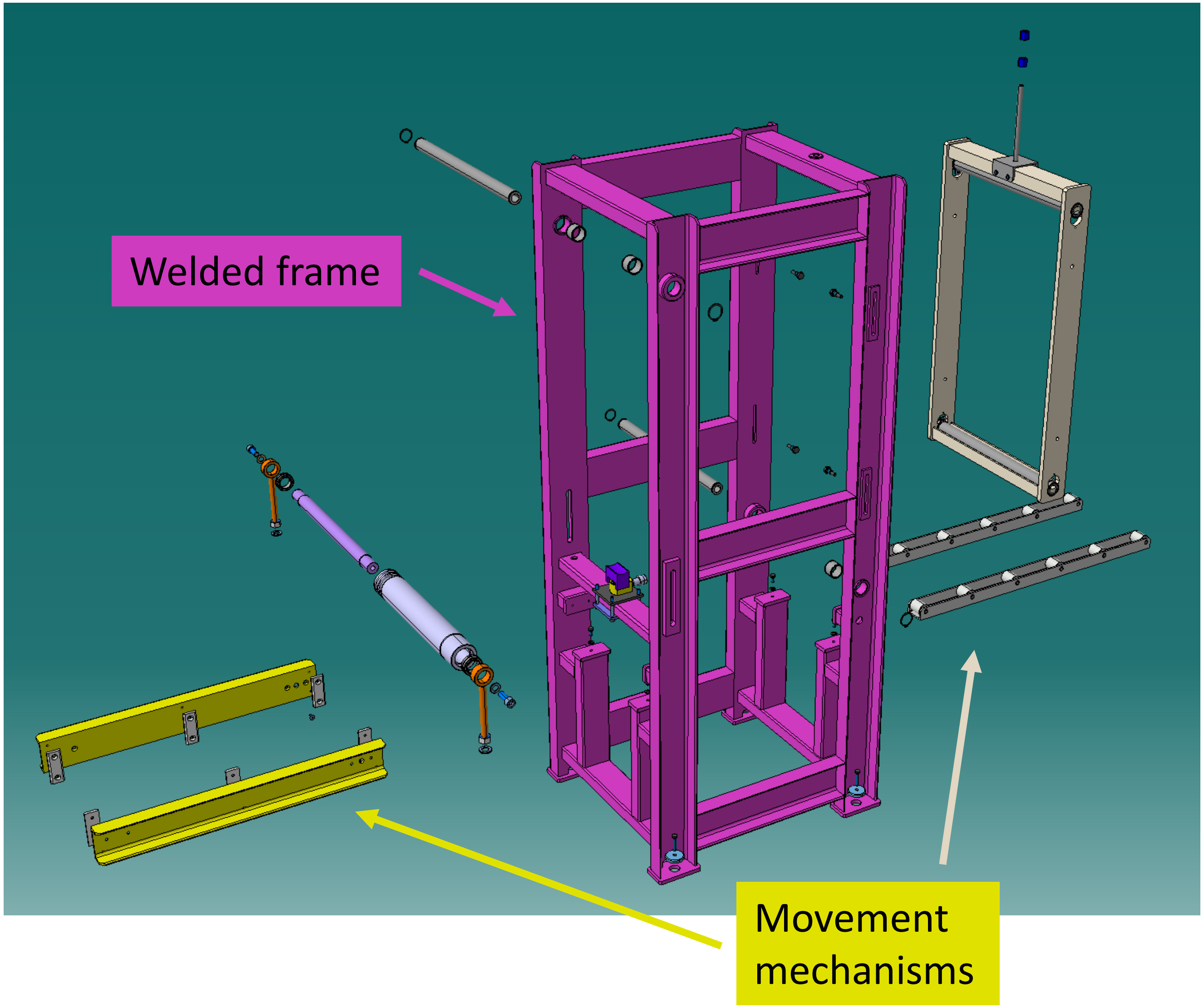

**DT 104/6**

**LOAD CHART - EN -1090 - EUROCODE**

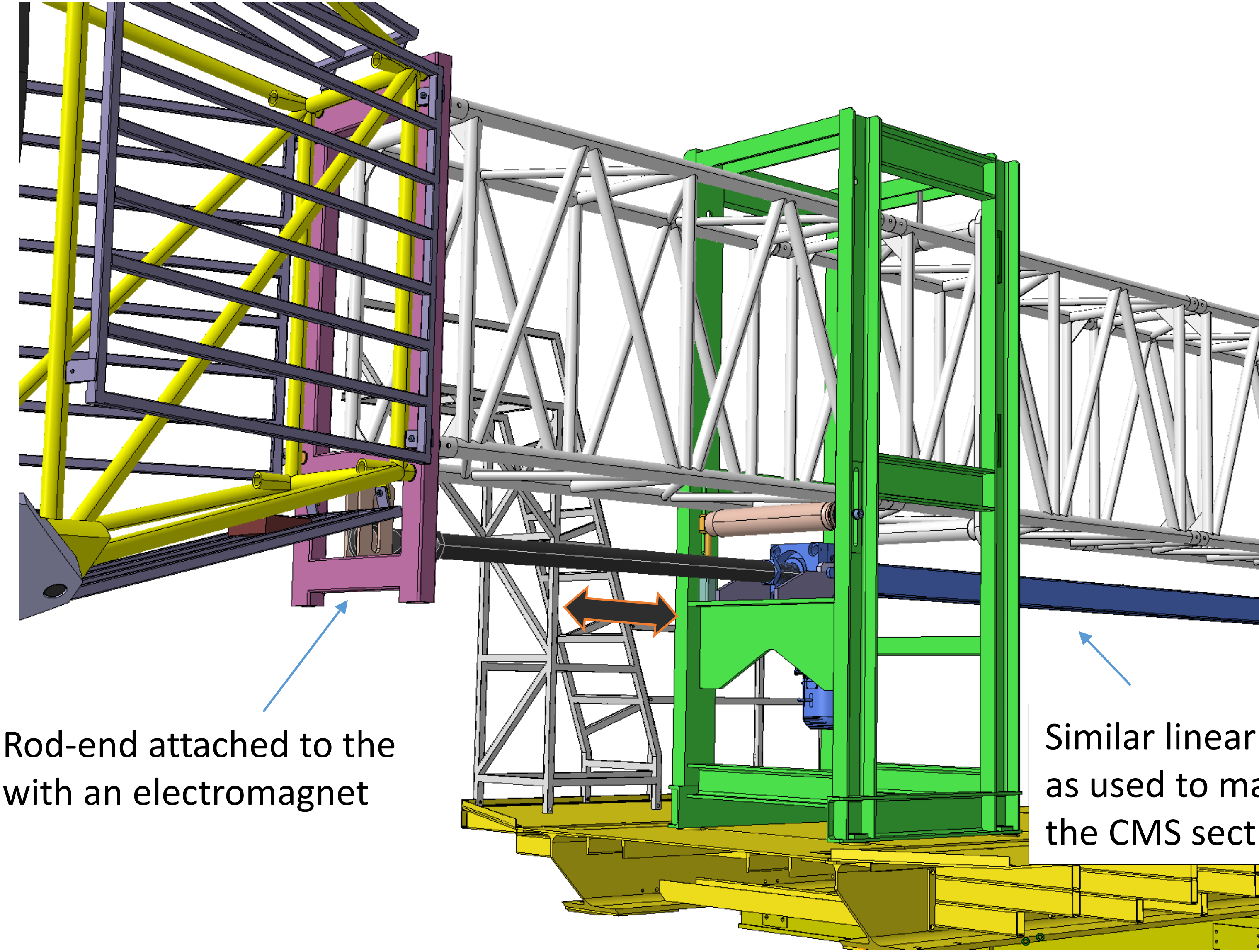
| Length (m) | 8 | 14 | 18 | 22 | 26 | 28 | 30 | 34 |
|---|---|---|---|---|---|---|---|---|
| Point load (kg) | 5880 | 4000 | 3196 | 2557,8 | 2079,6 | 1886,8 | 1716,7 | 1428,4 |
| Deflection (mm) | 9,8 | 36,8 | 64,4 | 98,3 | 139,1 | 162,5 | 188 | 245,7 |
| Distrib. load (kg/m) | 1441,6 | 835,7 | 358,7 | 232,5 | 160 | 134,8 | 114,4 | 84 |
| Deflection (mm) | 11,9 | 48,3 | 80 | 119,9 | 168,1 | 195,3 | 224,8 | 290,2 |




# New vertical eiffel tower



# New vertical eiffel tower



Rod-end attached to the with an electromagnet

Similar linear actuator as used to manipulate the CMS sections

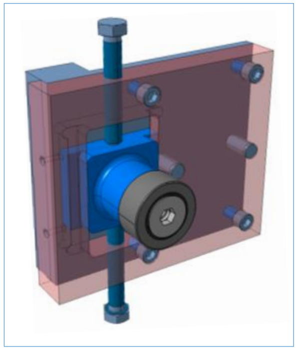
# New eiffel tower design

Horizontal tower assembled from the truss elements

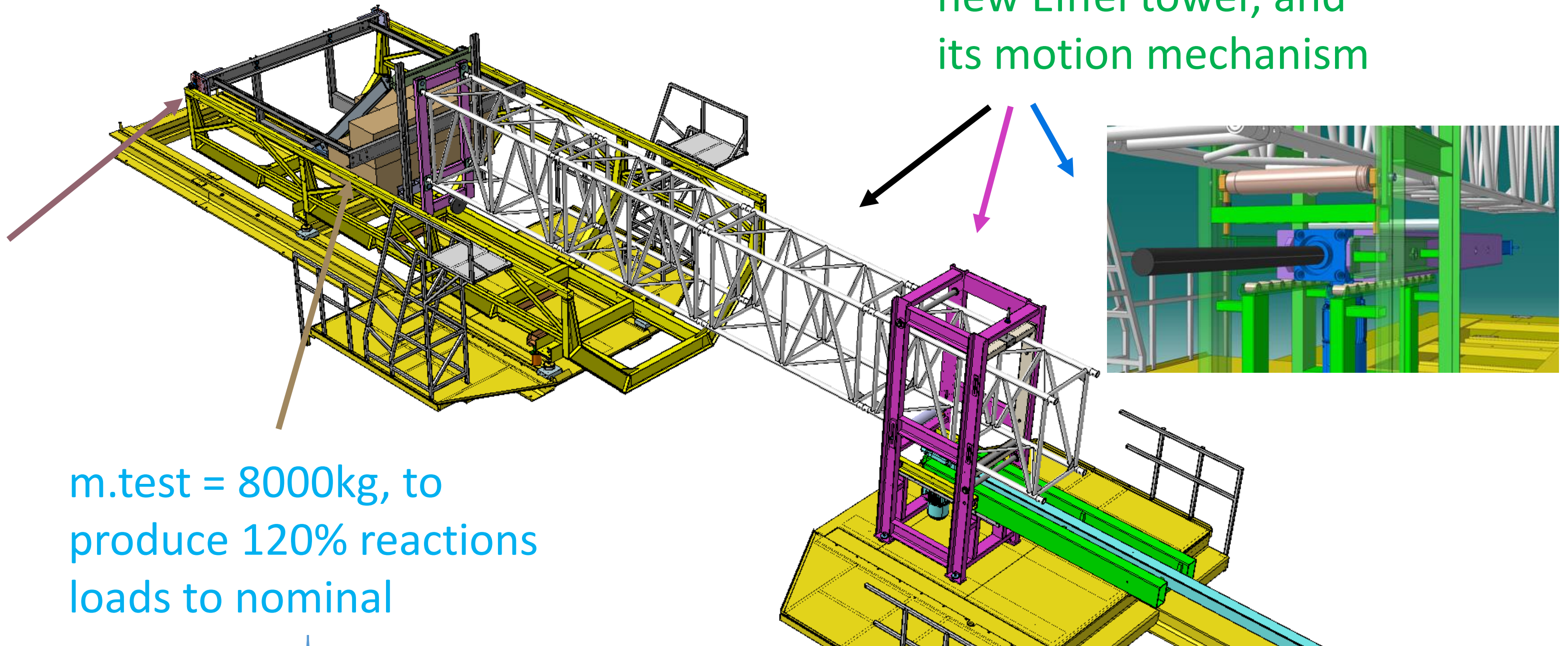
Custom design vertical eiffel tower welded from steel beams

# Testing

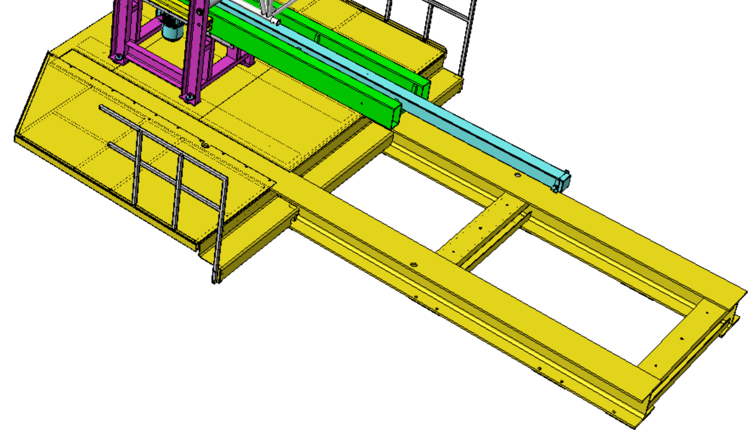
# Test plan



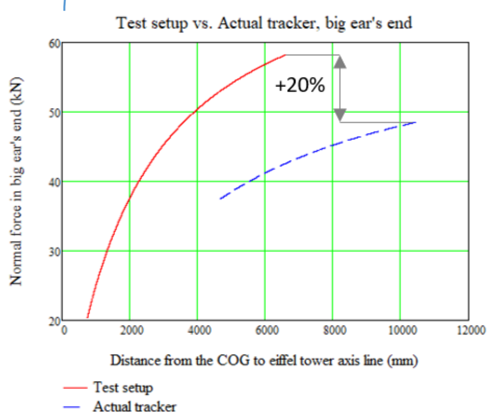
Test and validate the new big ear load transfer mechanisms

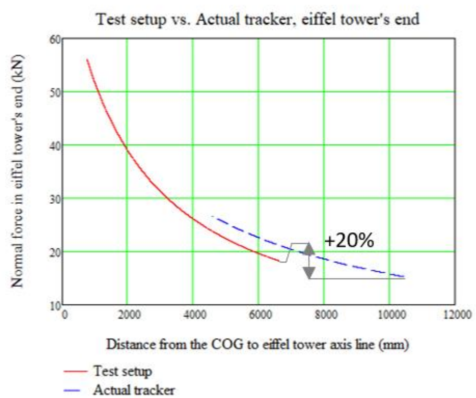


Test and validate the new Eiffel tower, and its motion mechanism

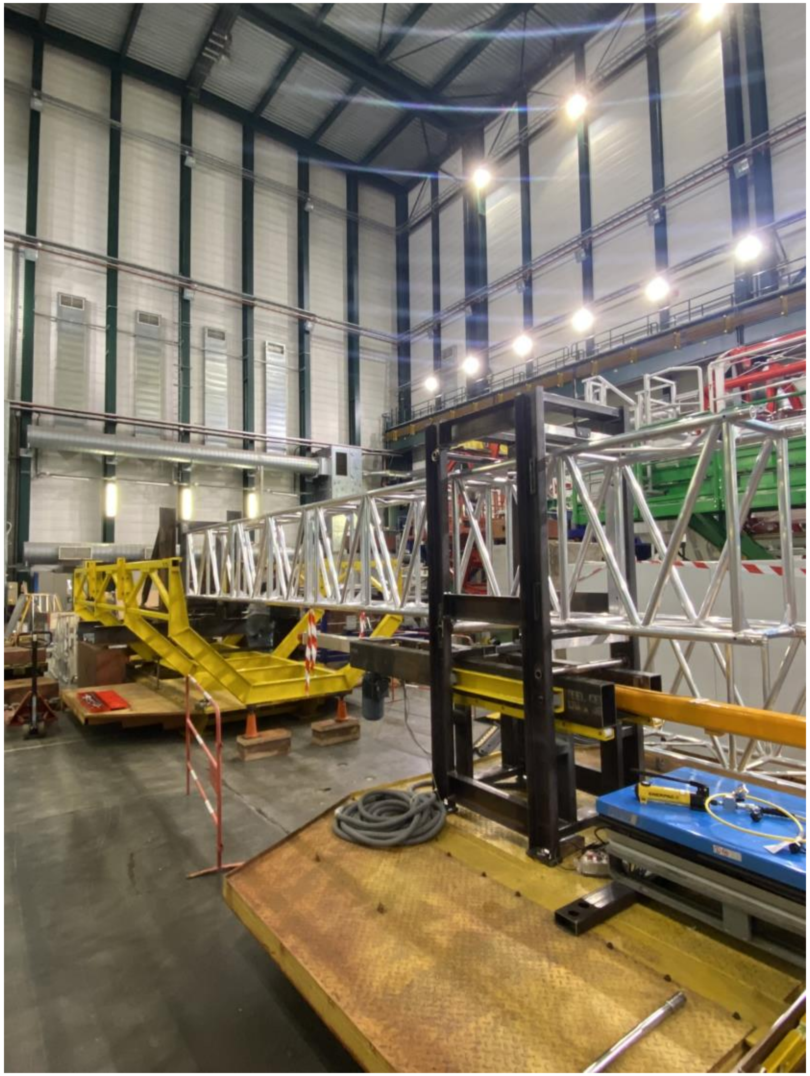


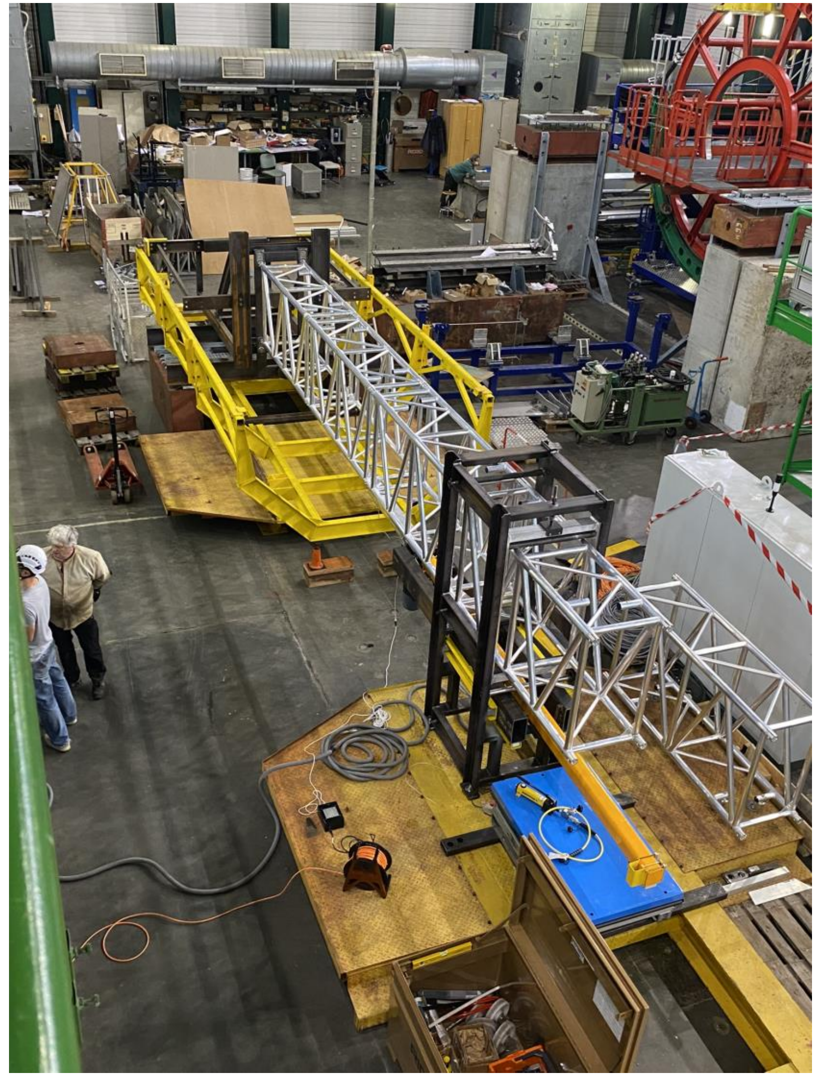
m.test = 8000kg, to produce 120% reactions loads to nominal



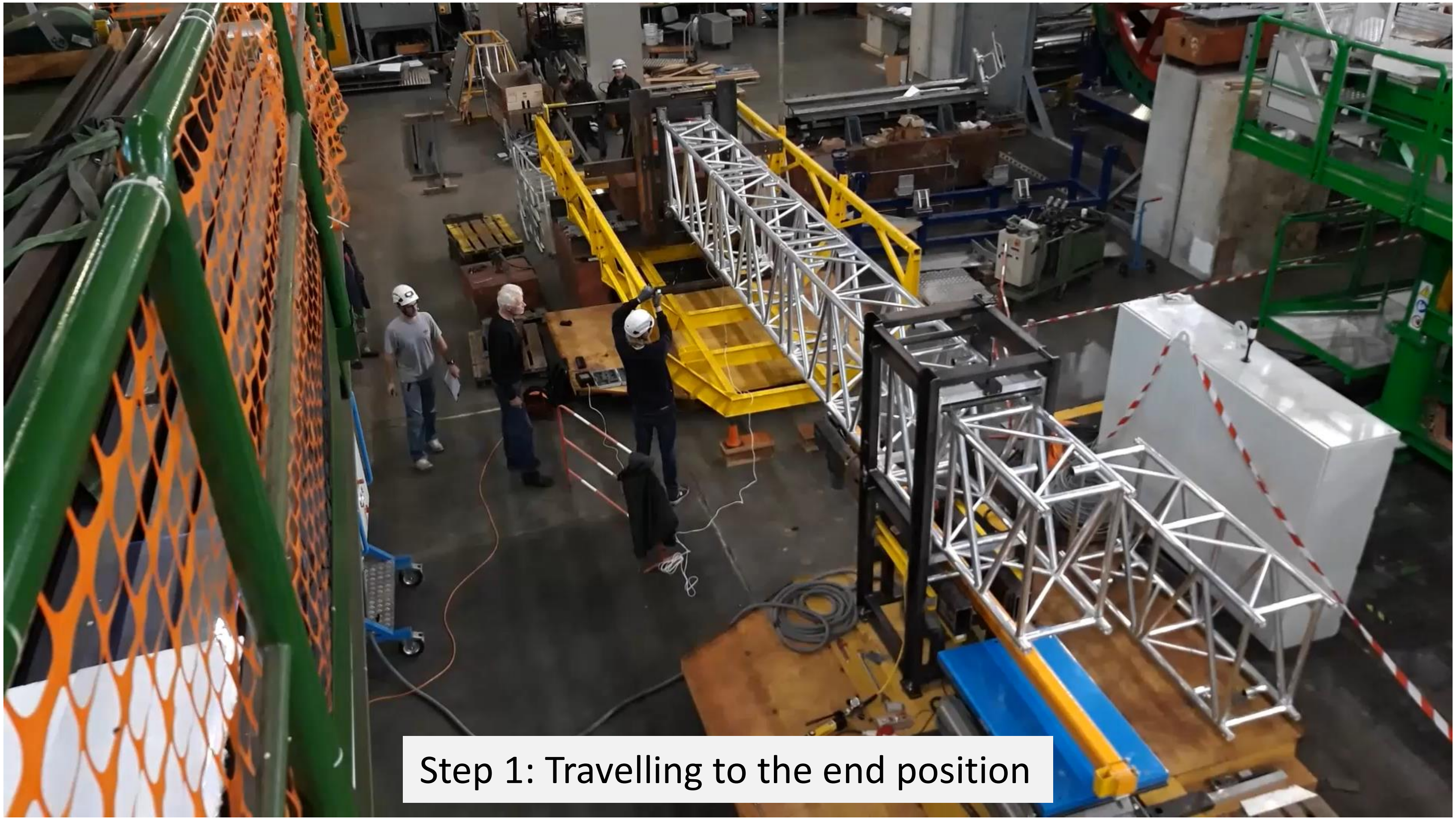
# Setup at P5





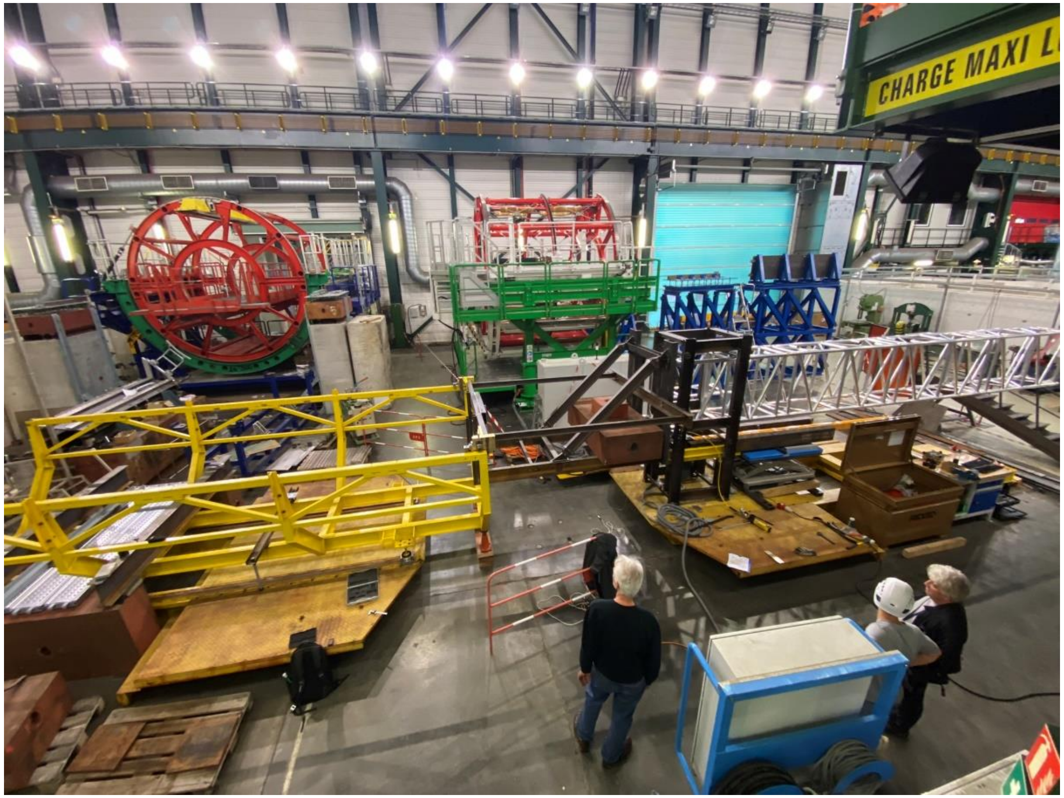
# Test, scenario #1

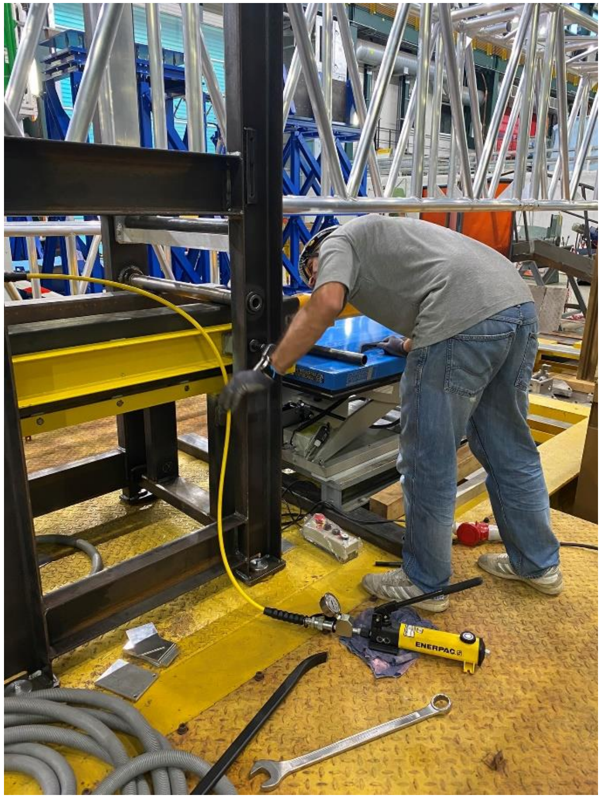
# Test, scenario #1




(video)

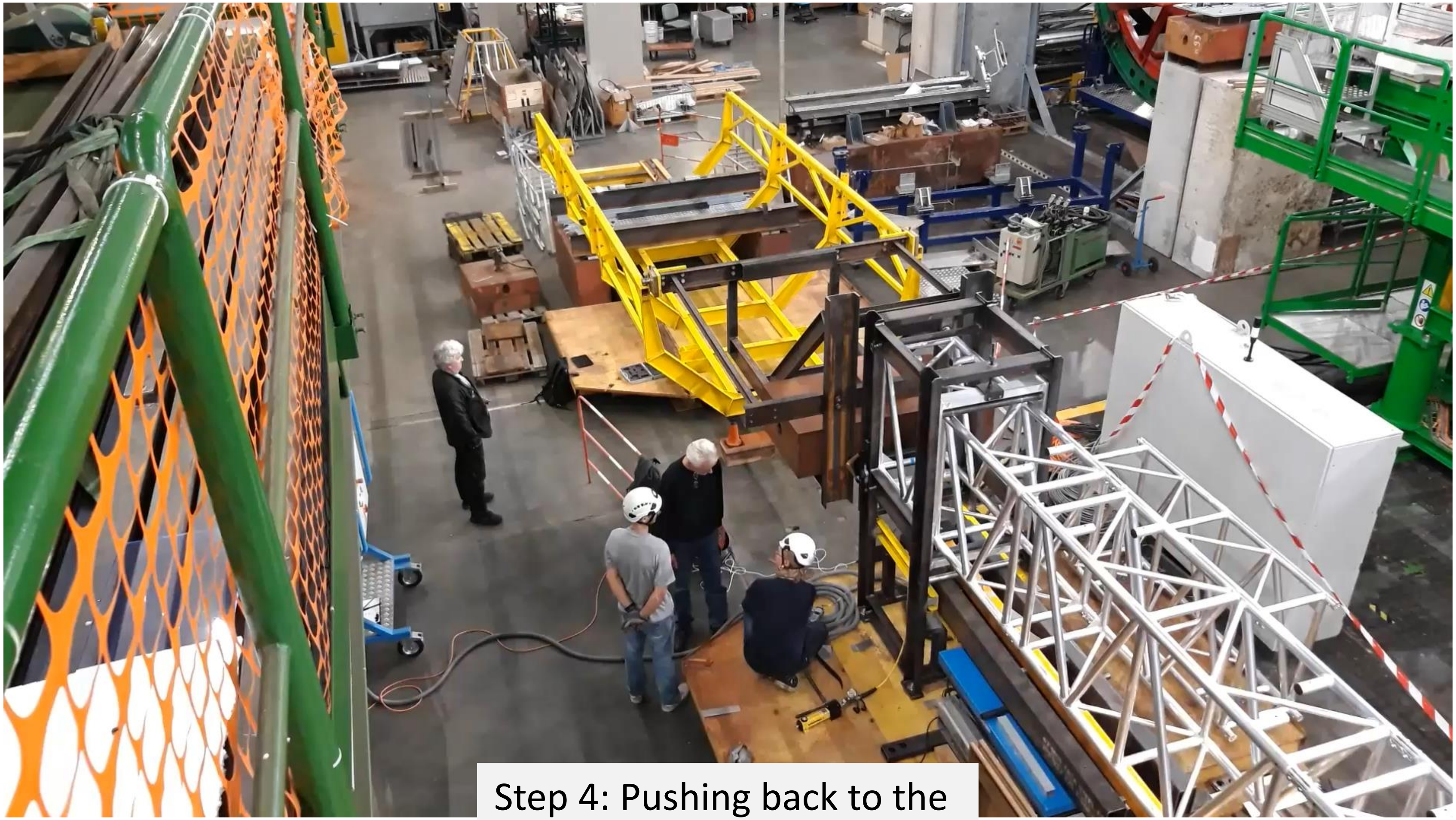
# Test, scenario #1




Step 3: Heaviest loading case on the vertical eiffel tower, testing the height adjustment

# Test, scenario #1

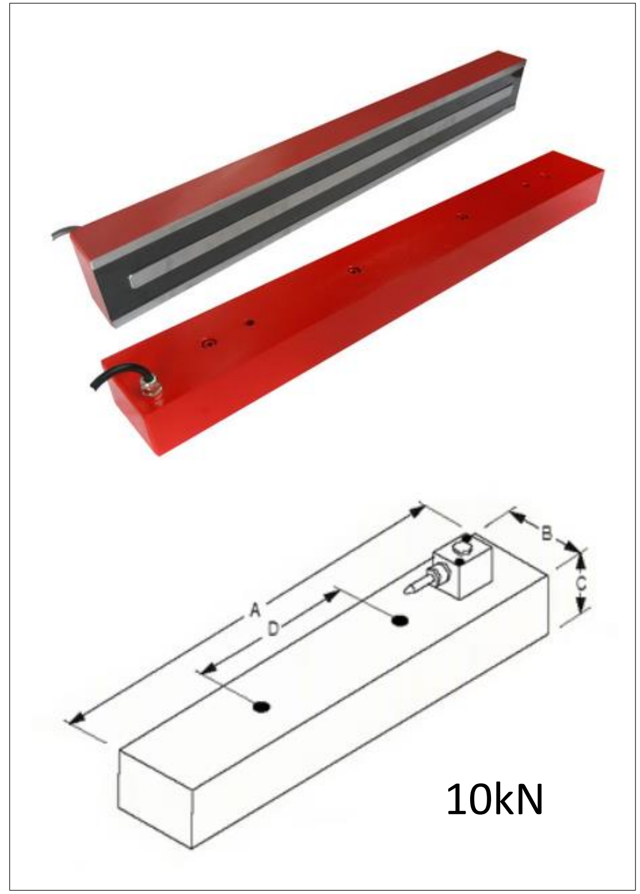


Step 4: Pushing back to the fully extended, lowering the load to the table

(video)

# Test, scenario #1, challenges


# New magnet

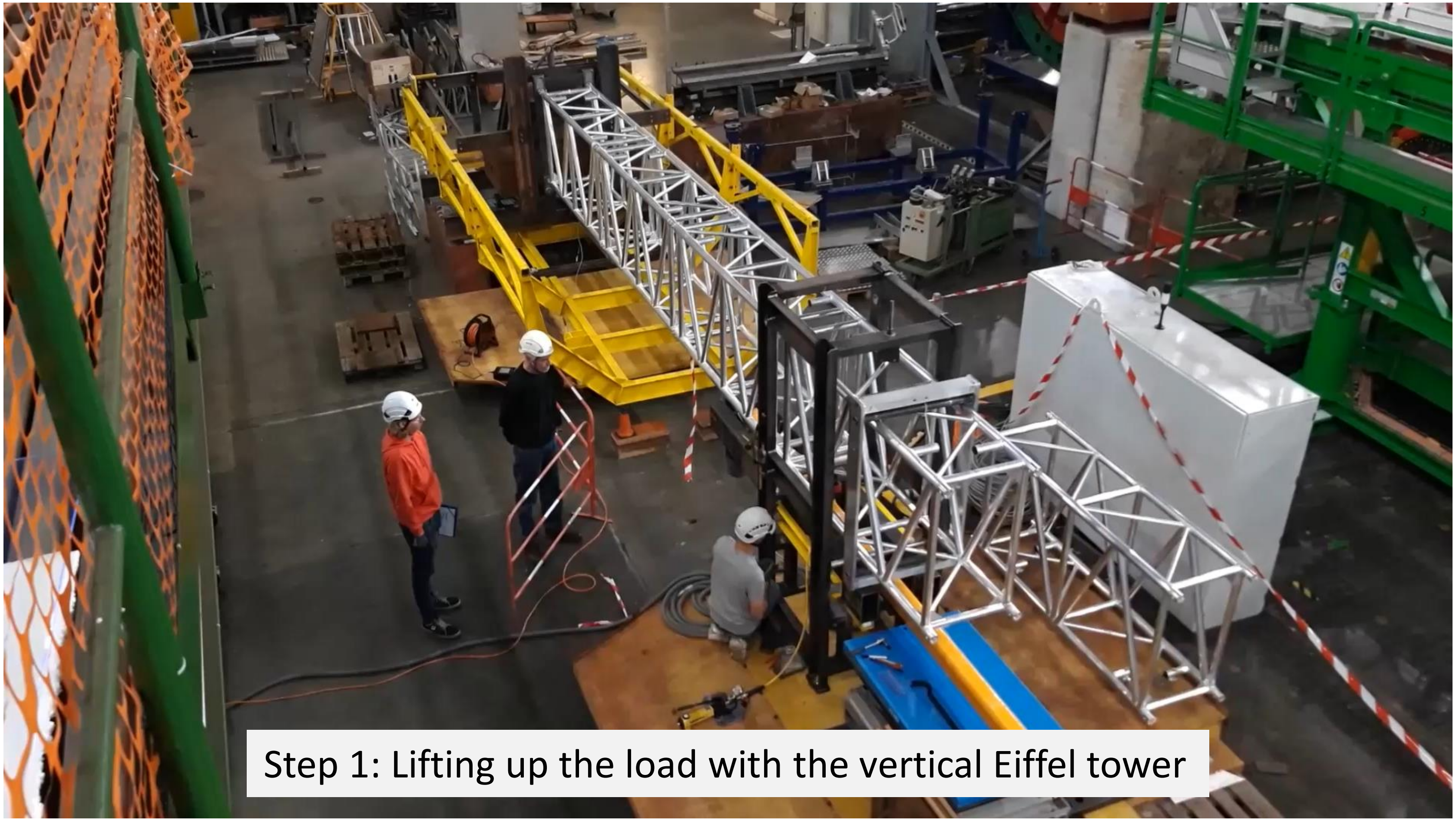


# New magnet

# Test, scenario #2

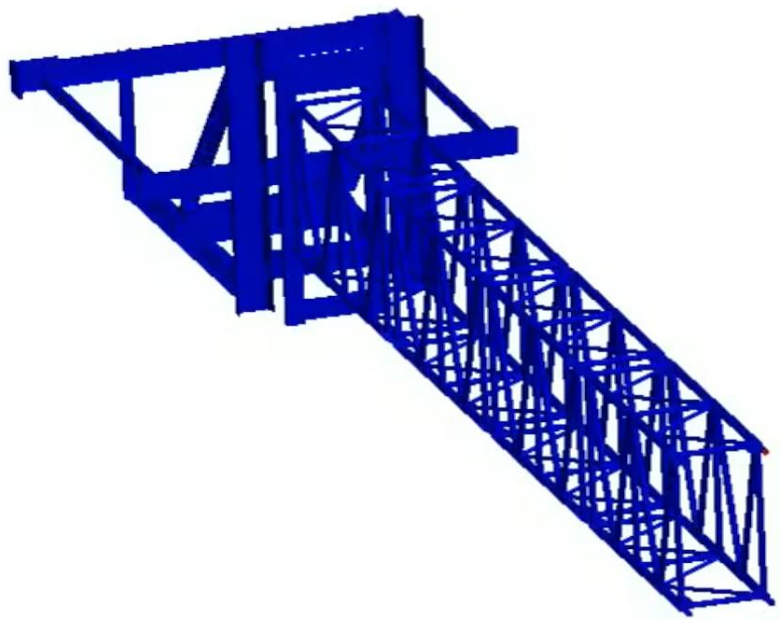

Step 0: 7000kg loaded in

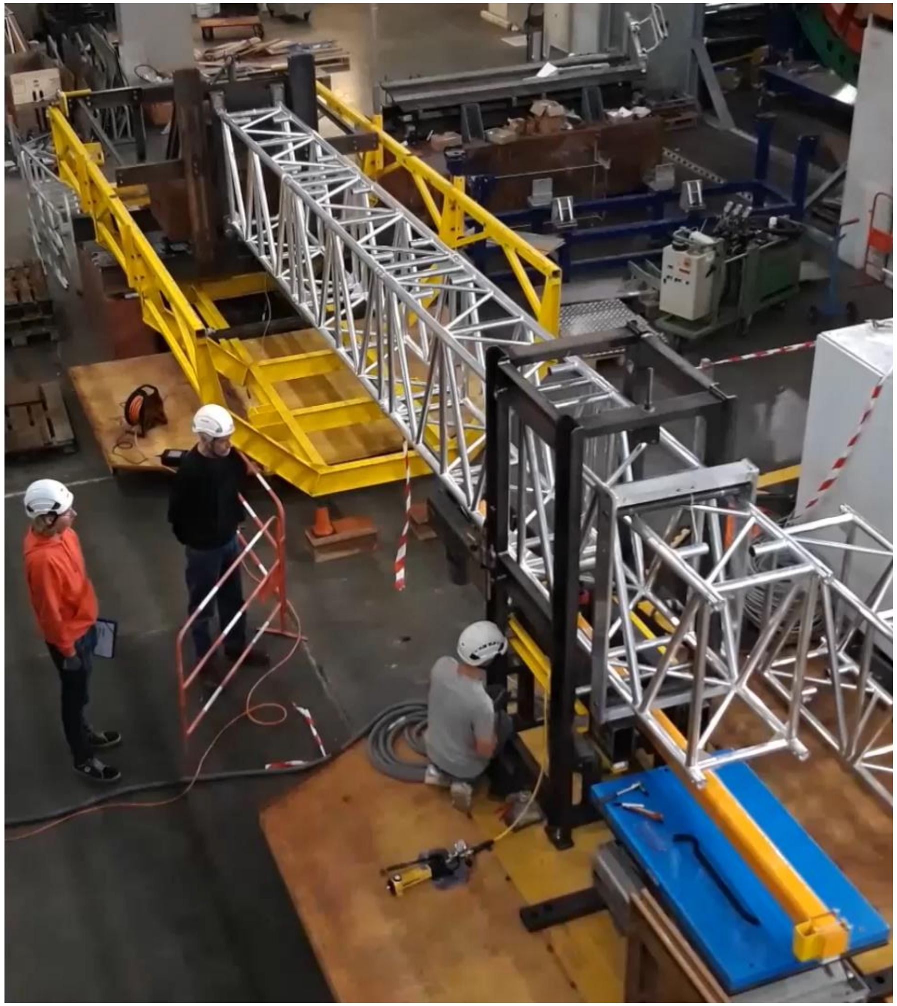
# Test, scenario #2




(video)

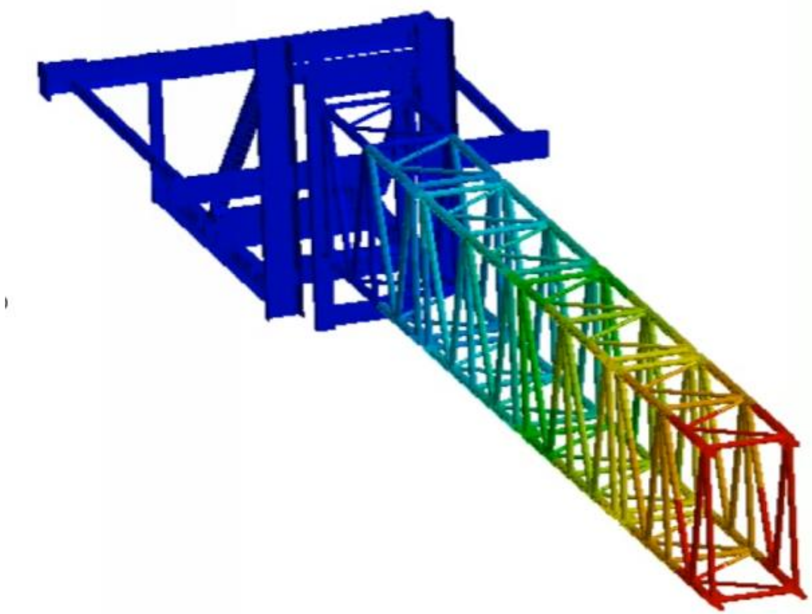
# Test, scenario #2



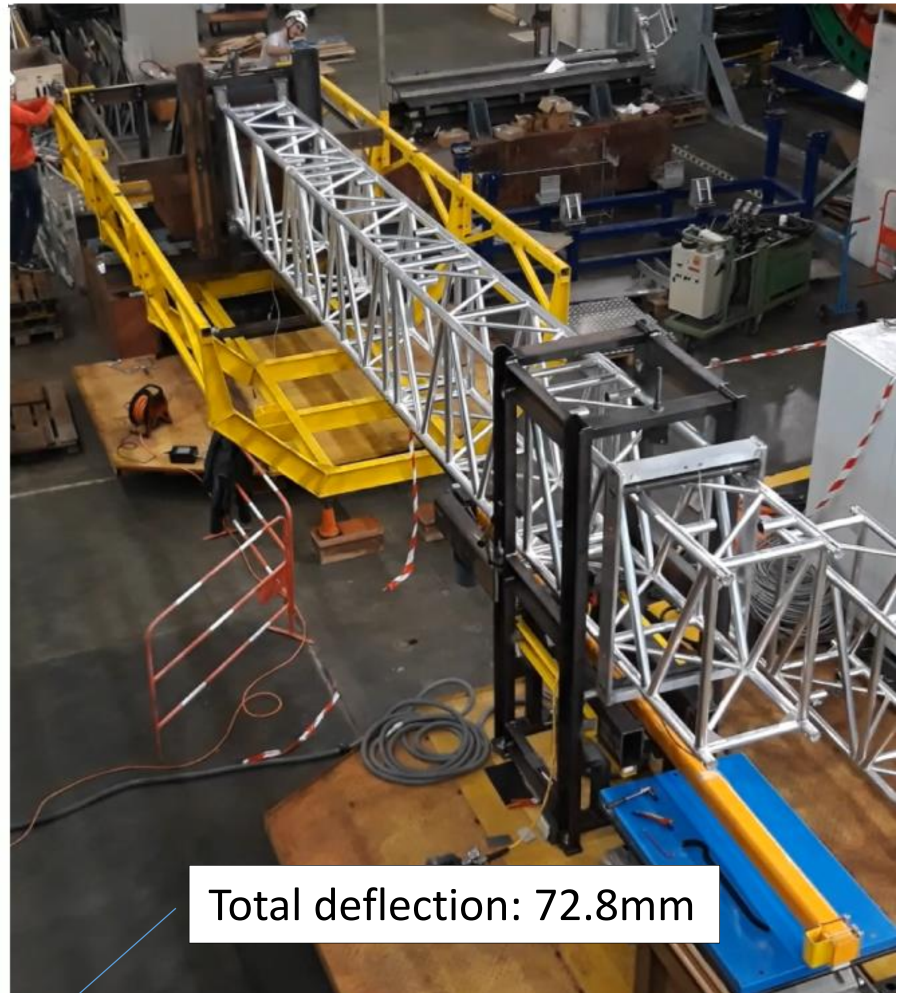


(video)

# Test, scenario #2



Total deflection: 68.0mm



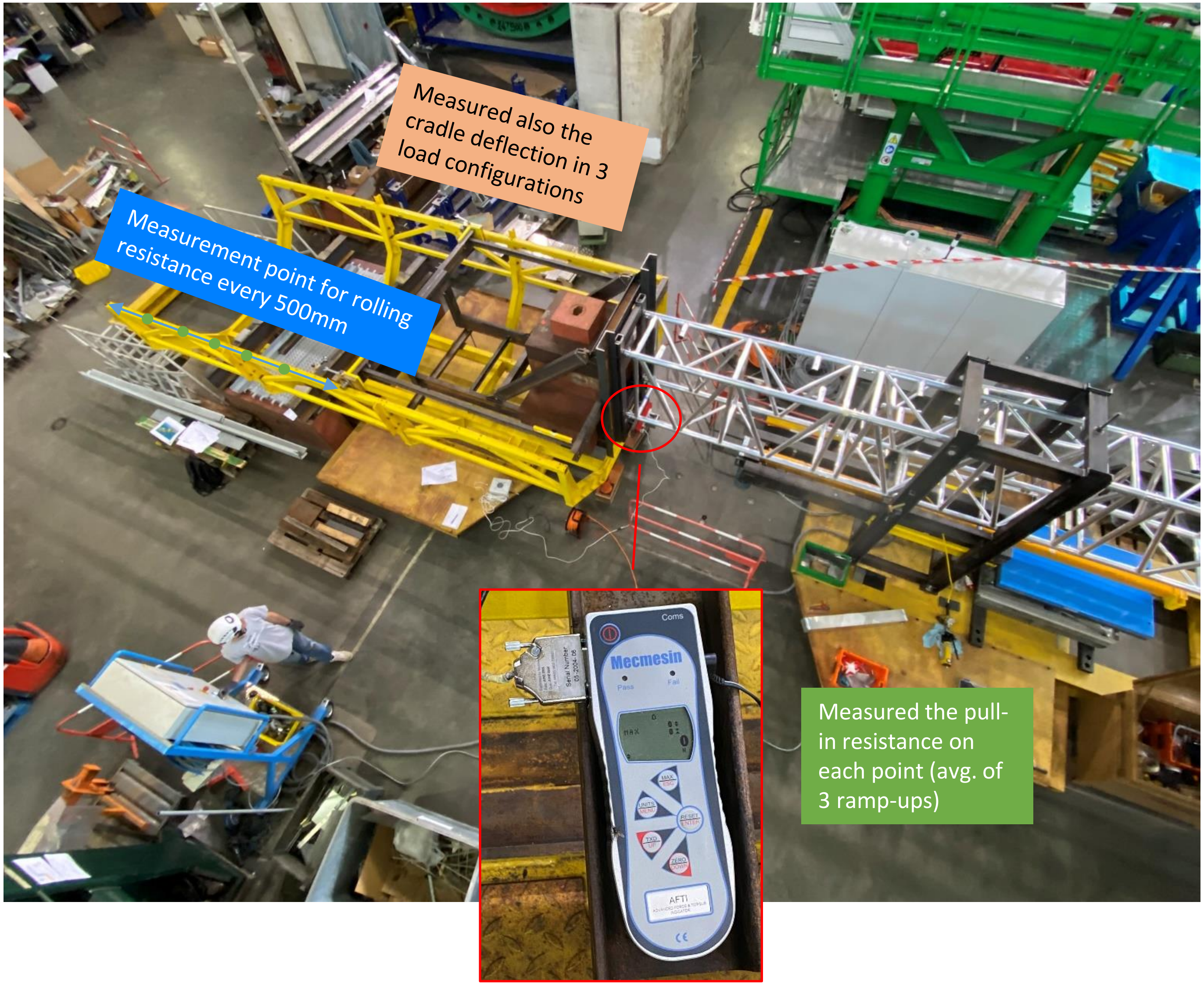
Total deflection: 72.8mm

-7%

# Test, scenario #2

(video)

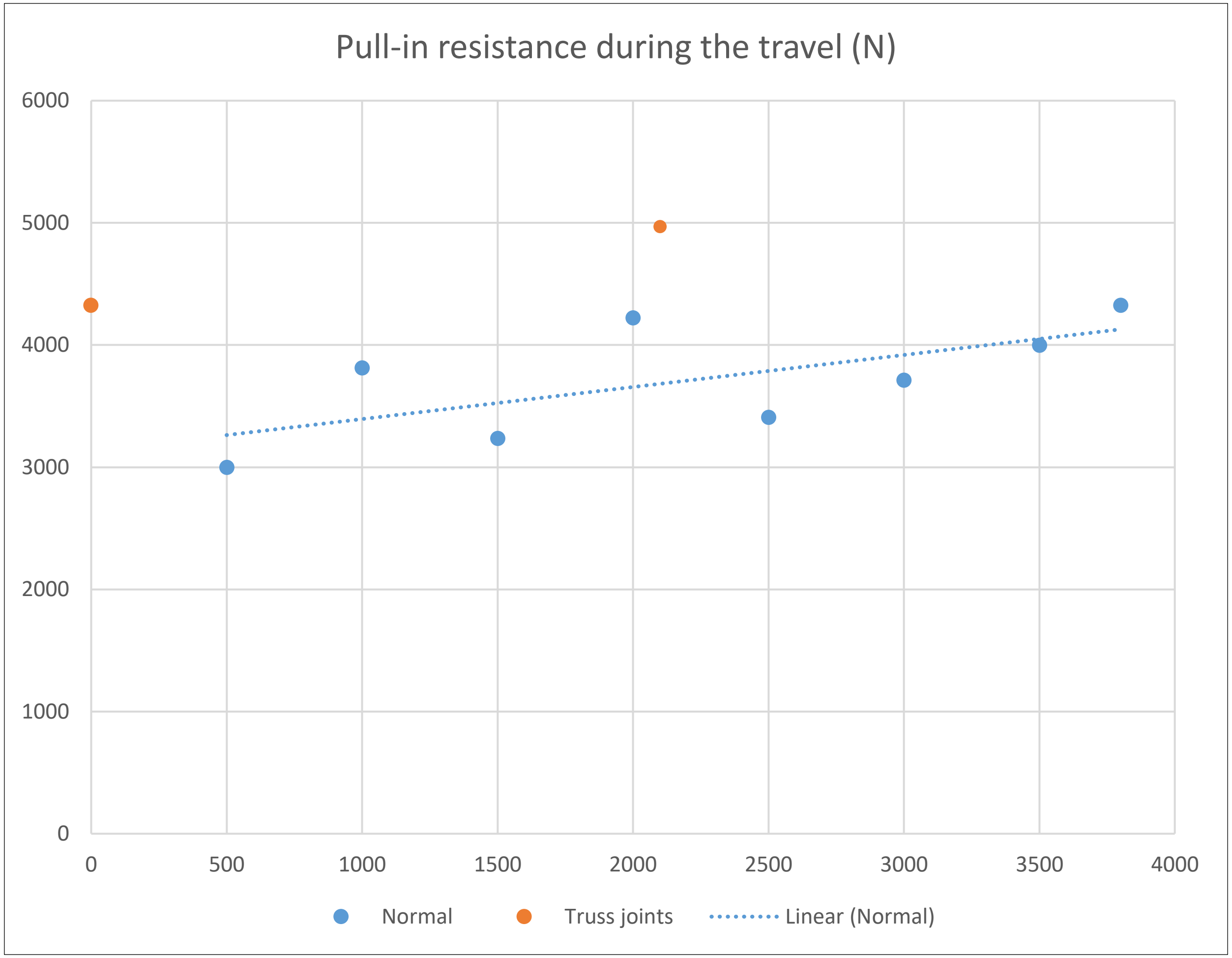
# Test, scenario #2



# Test, scenario #2

Special measurement point when rolling over the truss element joints

# Results


Pull-in resistance during the travel (N)
6000
5000
4000
3000
2000
1000
0
0
500
1000
1500
2000
2500
3000
3500
4000
Normal
Truss joints
Linear (Normal)

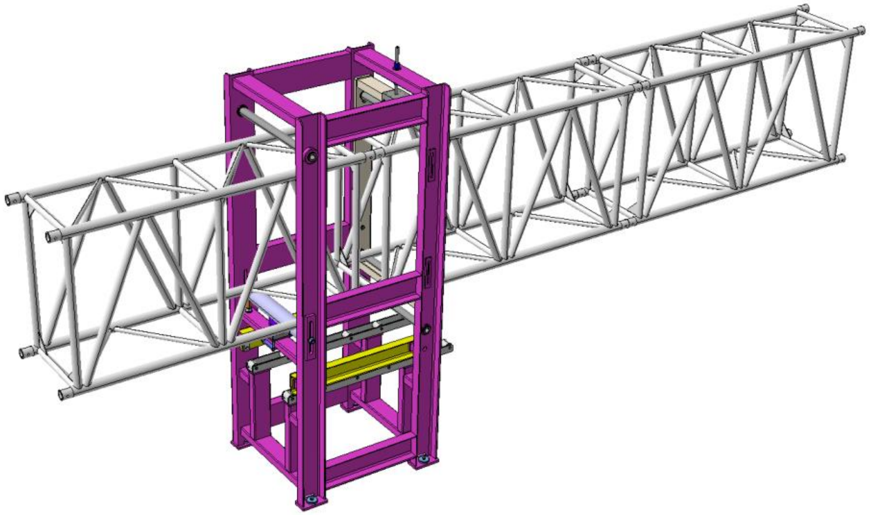
# Test, scenario #2, challenges

(video)

Some surface damage (mainly paint peel-off) was seen on the cradle beam

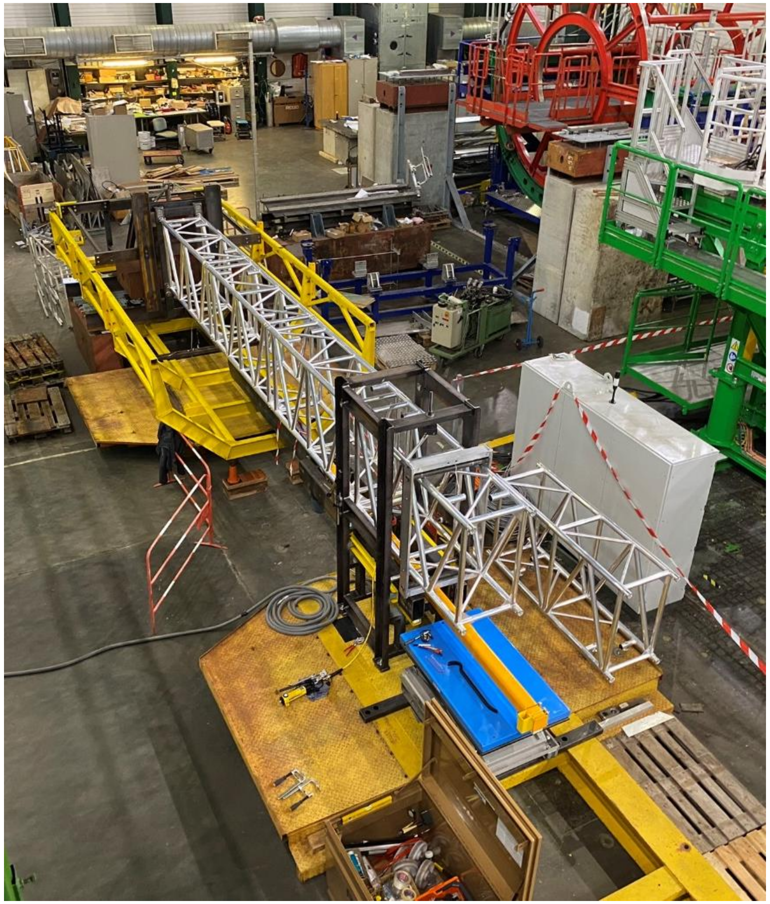
# Conclusions (design)

- The old structure would’ve not been fit for the phase-2 loading conditions without notable adaptations
- It was easier to build a completely new one to implement all the “secondary” improvement in parallel as well
- The horizontal tower assembled from off-the-shelf welded truss elements, the vertical tower was custom built at P5



# Conclusions (testing)

- Static structural configurations
  - Got all the worst case static load configurations done as planned
  - Structurally, no issues observed
  - Simulated value on the maximum deflection within 7% of the measured value
    - Good result, as limits in the measurement are a bit faint
- Z-direction motion mechanism
  - Got both of the motion configurations done as planned
  - The first magnet was too small, changed the to one which is 2x in capacity (10kN)
    - Highest measured rolling resistance values with that around 5kN
- The cradle deflections to be analyzed, will be used to benchmark the cradle FEM-models



# Thanks!

Photos and videos:

- [Dry test]
- [Scenario 1]
- [Scenario 2]
- [Scenario 2 (new magnet)]

Documentation (in work)

- https://edms.cern.ch/document/2872784

# Spares

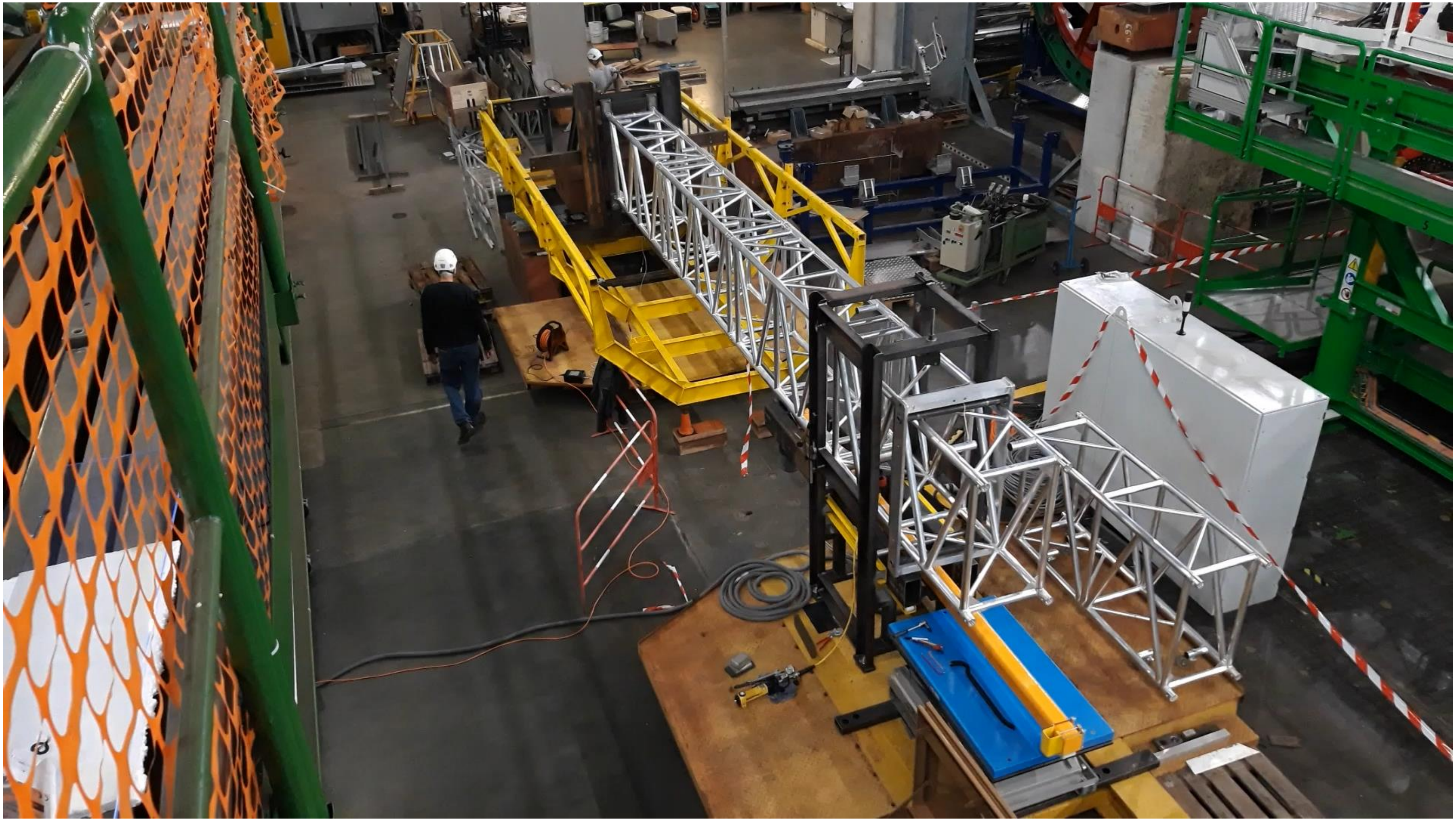
# Dry run

(video)

# Scenario #1

(video)

# Scenario #2

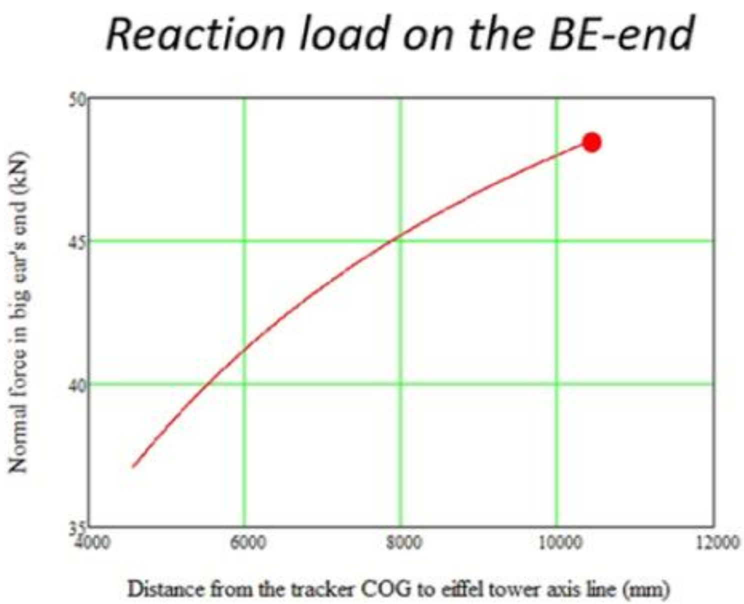


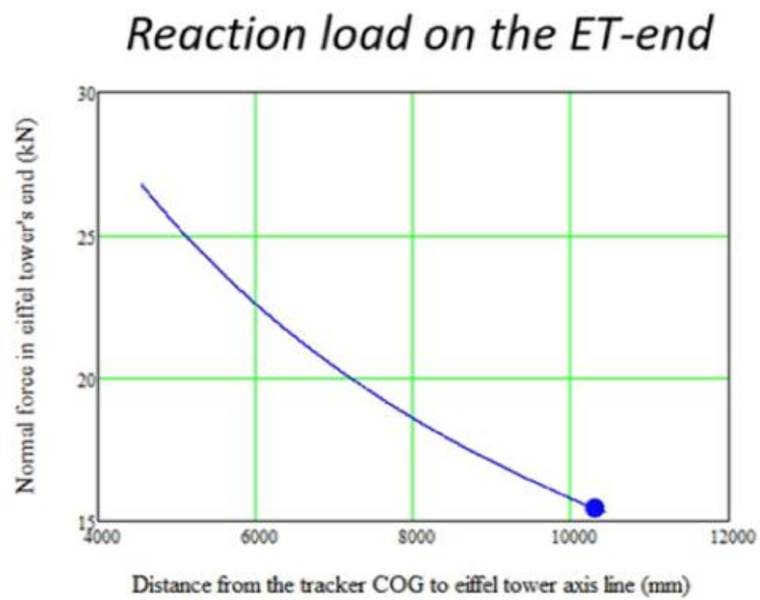
(video)

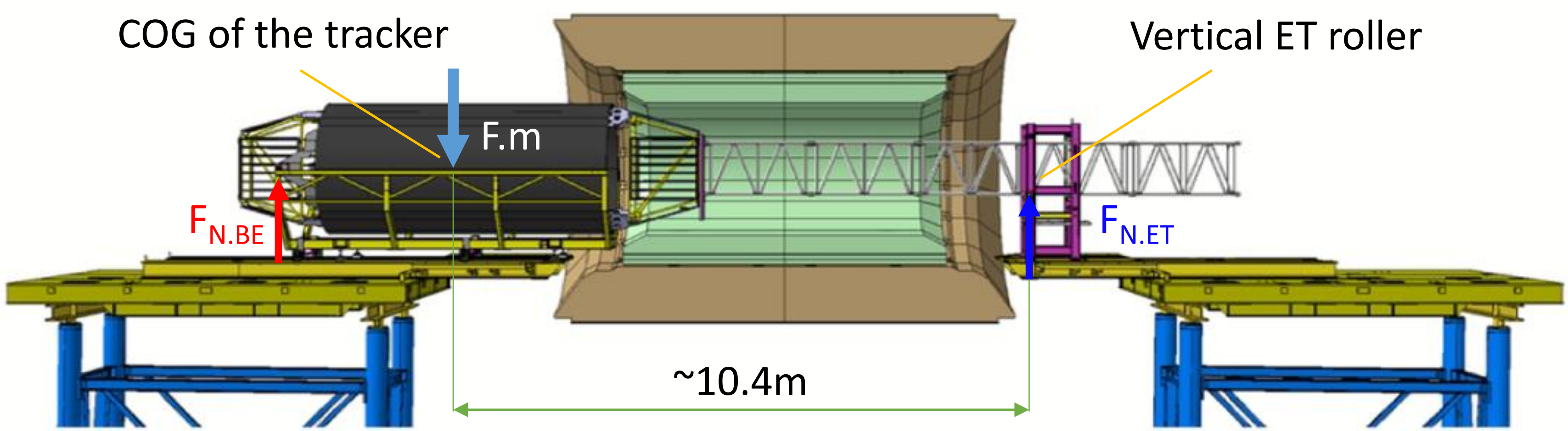
# Scenario #2 (new magnet)

(video)

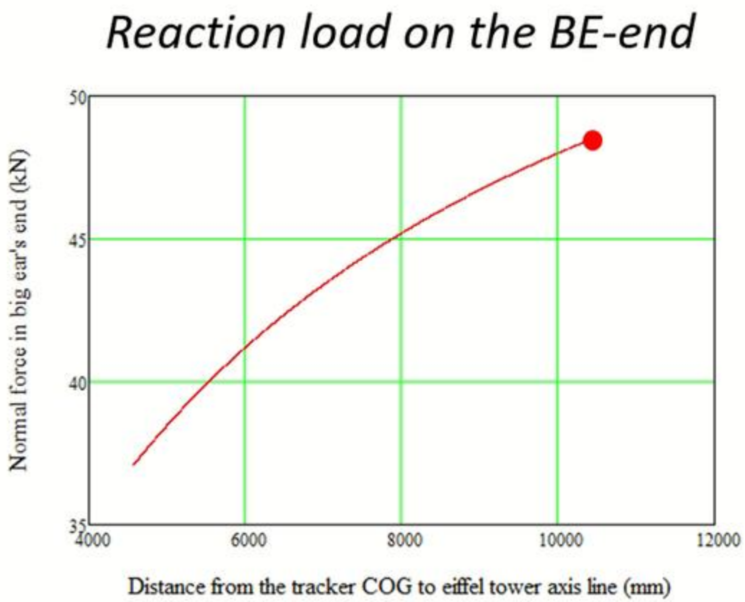
# Phase-2 reaction loads

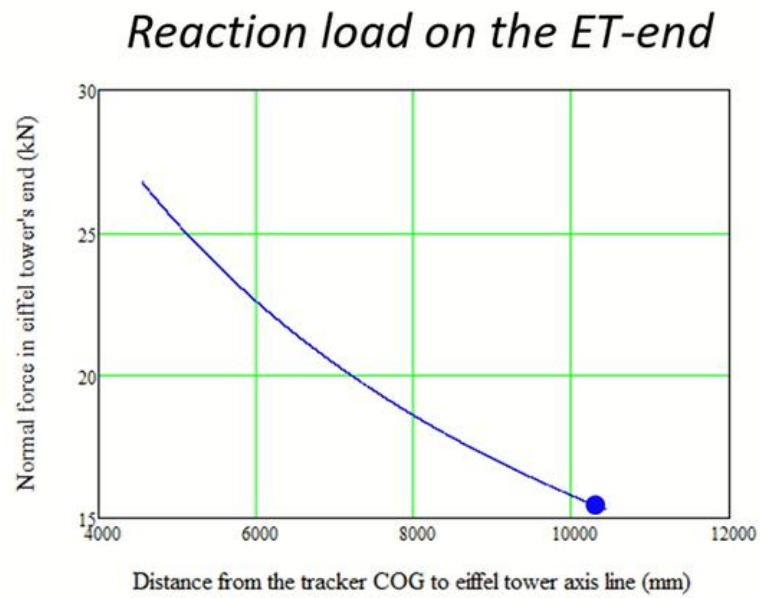


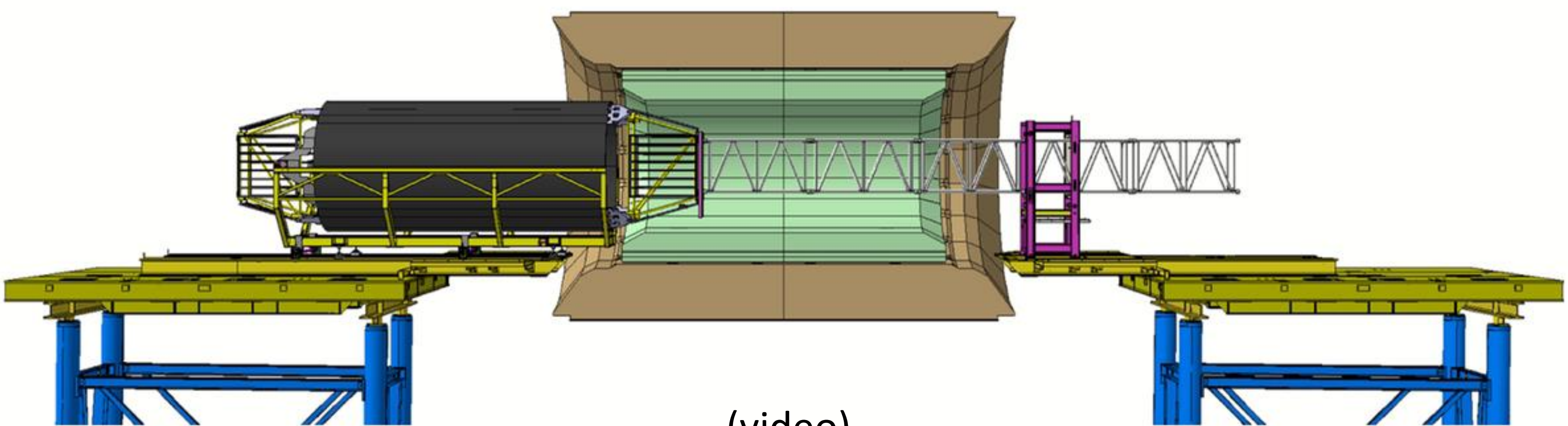



# Phase-2 reaction loads

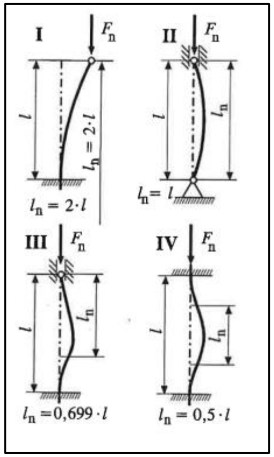


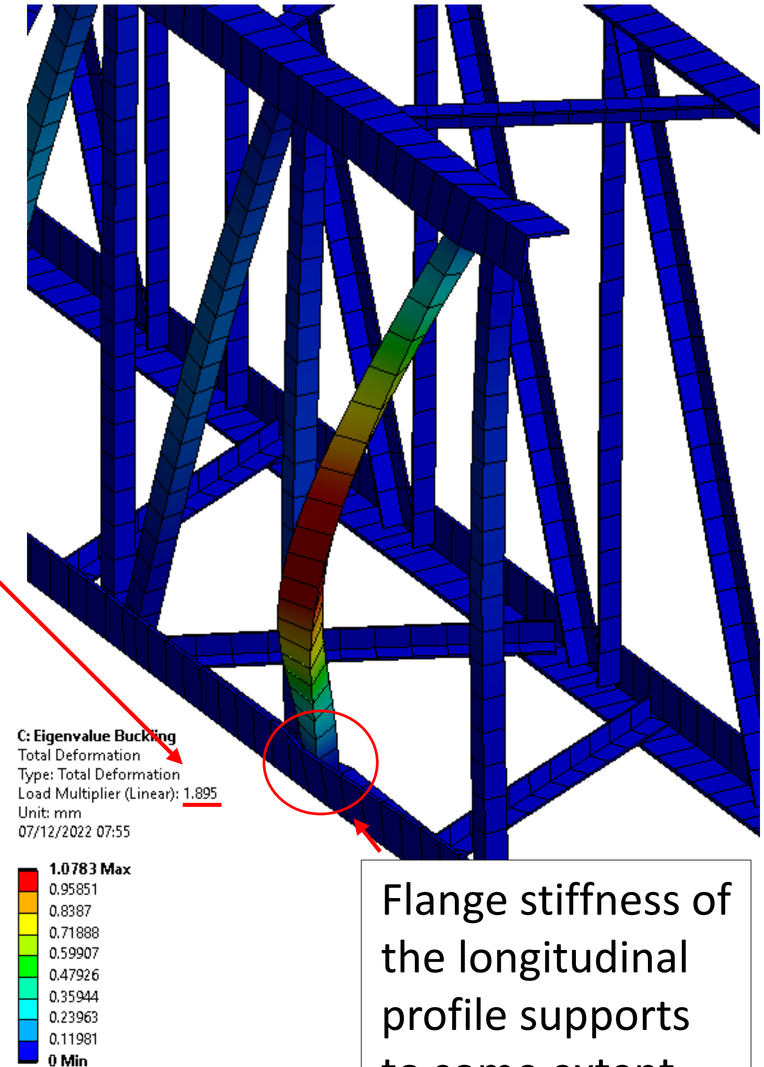
(video)

# Structural study of the old Eiffel tower




Linear load multiplier is comparable to classical Euler's analysis, which is always non-conservative!

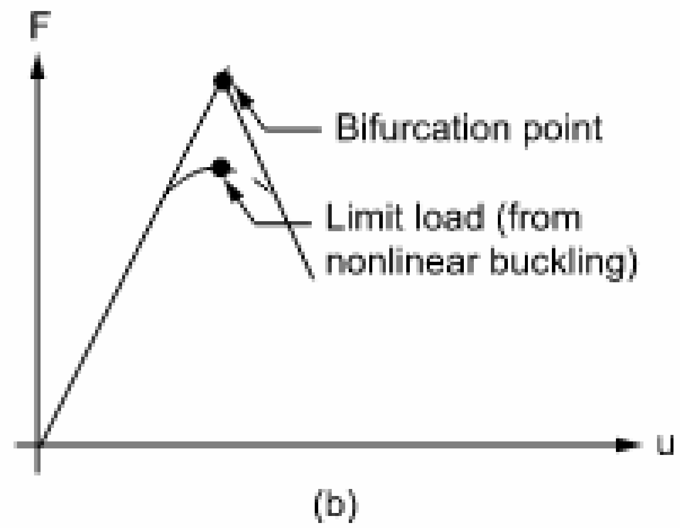
| Critical bucling force | Safety factor | Buckling modes: |
|---|---|---|
| $F_{n1} := \frac{\pi^2 \cdot E \cdot I_b}{(4l)^2} = 1.929 \cdot kN$ | $\frac{F_{n1}}{F_c} = 0.167$ | I |
| $F_{n2} := \frac{\pi^2 \cdot E \cdot I_b}{l^2} = 7.717 \cdot kN$ | $\frac{F_{n2}}{F_c} = 0.67$ | II |
| $F_{n3} := 2.046 \frac{\pi^2 \cdot E \cdot I_b}{l^2} = 15.789 \cdot kN$ | $\frac{F_{n3}}{F_c} = 1.37$ | III |
| $F_{n4} := \frac{4 \cdot \pi^2 \cdot E \cdot I_b}{l^2} = 30.868 \cdot kN$ | $\frac{F_{n4}}{F_c} = 2.678$ | IIII |




Flange stiffness of the longitudinal profile supports to some extent

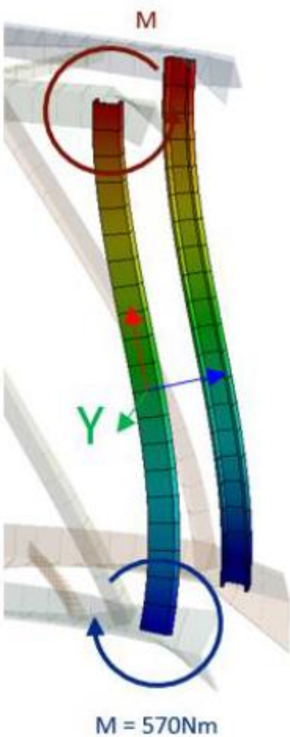
# Horizontal Eiffel tower - stability

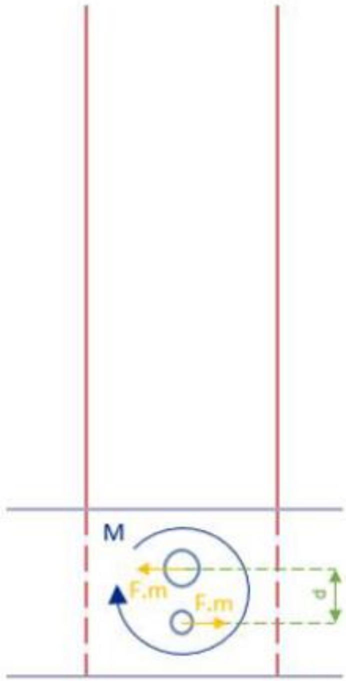
An Eigenvalue Buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. This method corresponds to the textbook approach to an elastic buckling analysis: for instance, an eigenvalue buckling analysis of a column matches the classical Euler solution. However, imperfections and nonlinearities prevent most real-world structures from achieving their theoretical elastic buckling strength. Therefore, an Eigenvalue Buckling analysis often yields quick but non-conservative results.




(Ansys Help 2022 R1)

# Structural study of the old Eiffel tower



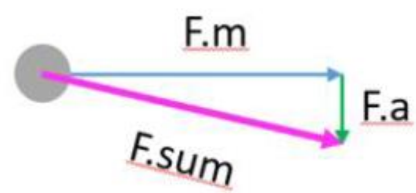




$d := 31.5\,\text{mm}$ distance between bolts

$M := 570\,\text{N}\cdot\text{m}$ moment through the joint

$F_M := \frac{M}{d} = 18.095\,\text{kN}$ shear component by moment

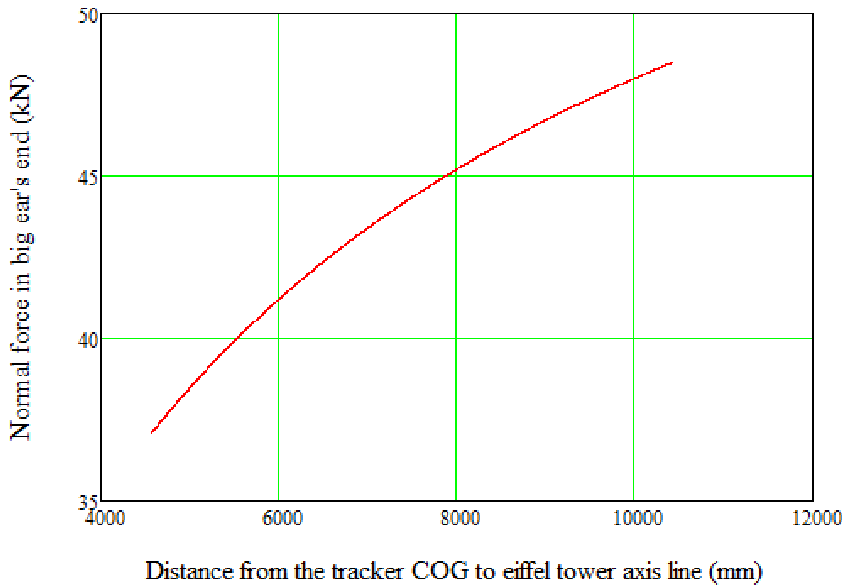
$F_a := 4450\,\text{N}$ shear component by axial force



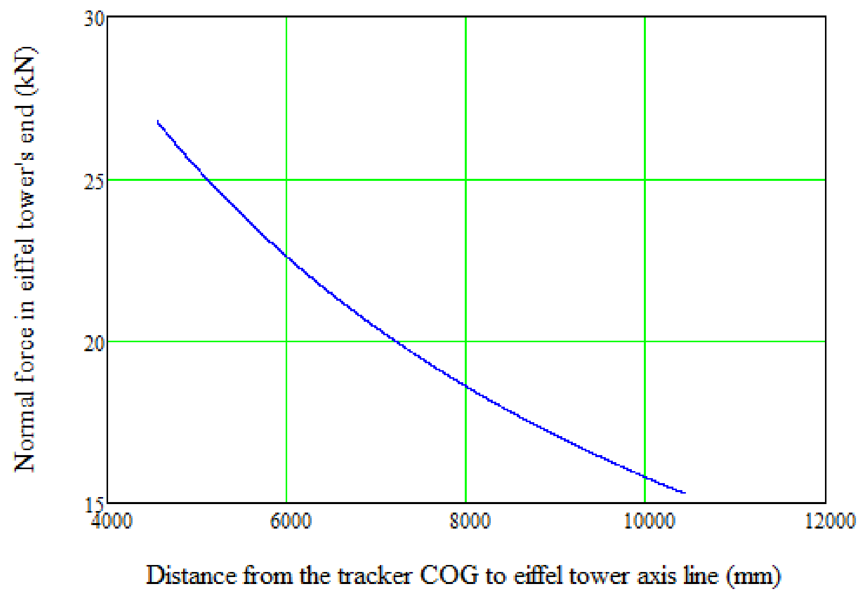

$F_{sum} := \sqrt{F_M^2 + F_a^2} = 18.634\,\text{kN}$ sum shear force on the bolt

# Reaction loads

### *Reaction load on the BE-end*

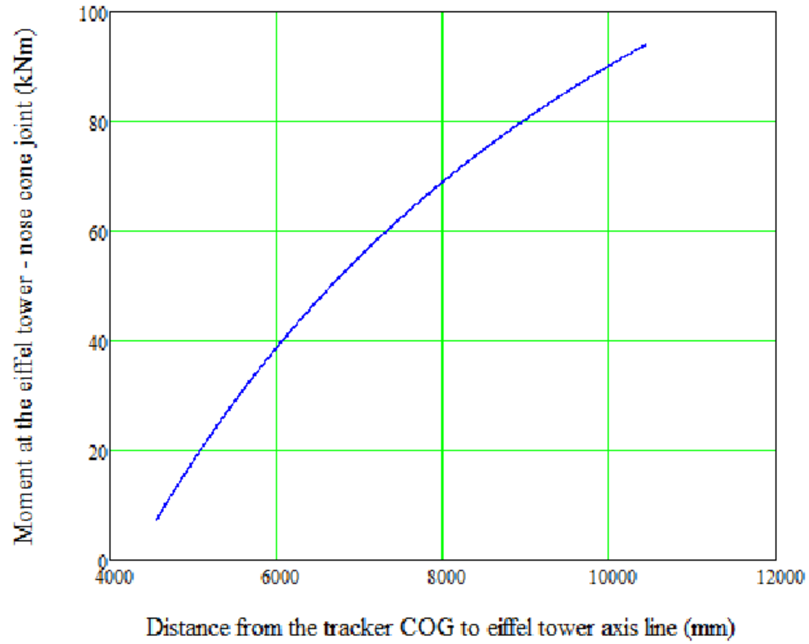



### *Reaction load on the ET-end*



## Appendix F: The moment in the inner end of the truss during the installation travel

$$M_{light\_end}(b) := \overbrace{\frac{m_{test}\cdot g\cdot a}{a+b}}^{F}\cdot\overbrace{(b - 4283\text{mm})}^{l}$$




The moment on the inner end of the truss decreases along the installation travel.

# Extraction of the current- vs. installation of the Phase-2 tracker

- For the extraction of the current tracker, some elements of the tooling are going to be already replaced with new designs
  - Mainly the roller assemblies on the ears, and Eiffel tower push/pull mechanism
- Ideally, most of the installation tooling could be re-used with the phase-2 -tracker with minor modifications due to changed interfaces
- The Phase-2 –tracker will be heavier than the current tracker
  - Current tracker: 5350kg (as measured, minus the mass of cradle)
  - Phase-2 tracker: ~6500kg (A. Filenius & G. Reales 02/03/2021)
- To avoid duplicate work, all the dimensioning and validation of the new designs are done already with phase-2 boundary conditions

**Summary**

| | Weight | Uncertainty | |
|---|---|---|---|
| TK in simulation | 3963 | | |
| cooling fluid | -153 | -53 | 77 |
| pixel tube and beam pipe supports | 45 | | |
| services from TST to PP1 | 670 | -10 | 20 |
| installation and packaging stuff | 1648 | -100 | 100 |
| Total | 6173 | -163 | 197 |

So far compares well with the measurements of 6330 kg and 6350 kg (3% difference)

1.6 tons still to be verified by direct measurements

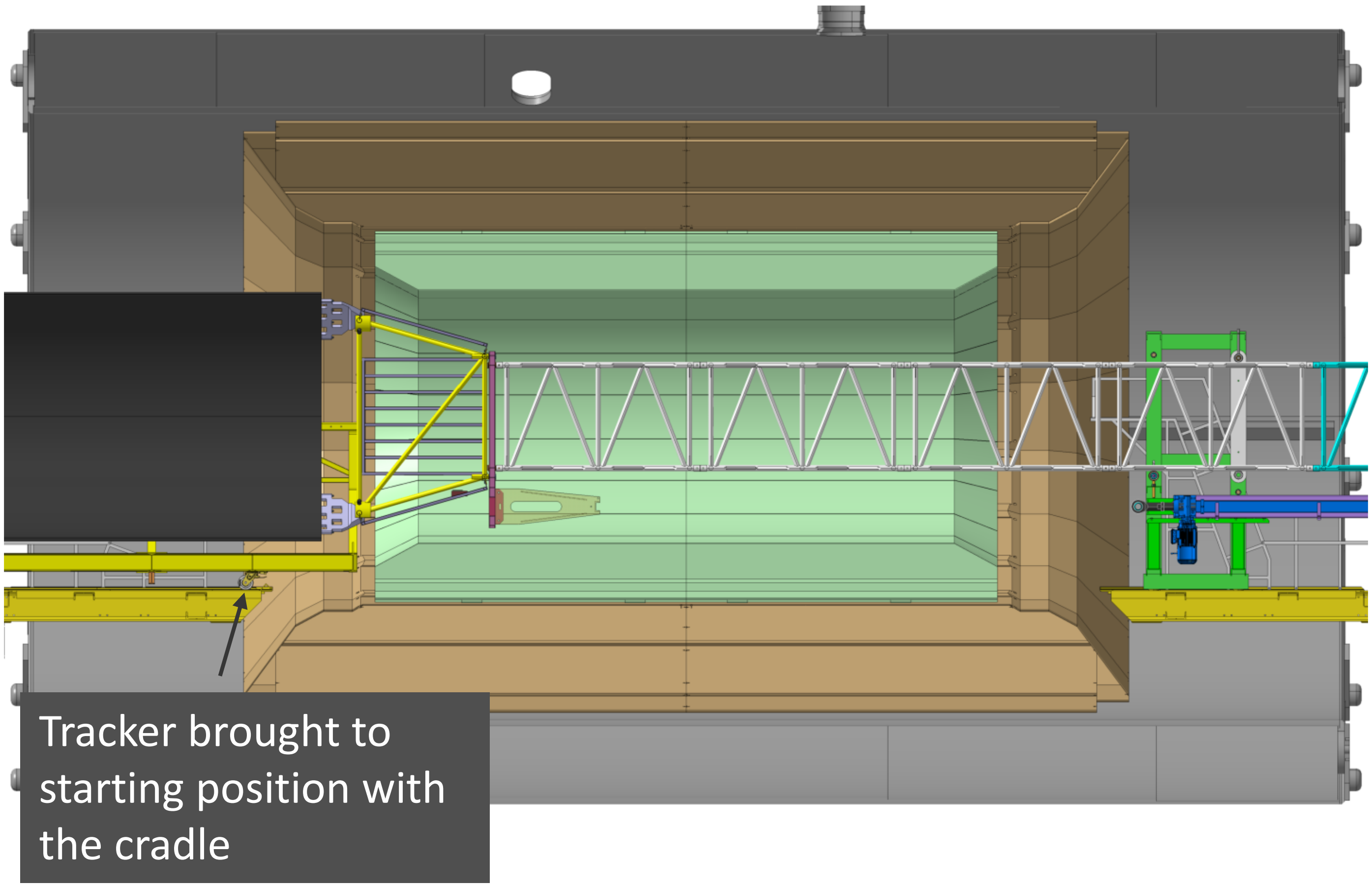
Final word in a few weeks

(2008, current tracker weighing)

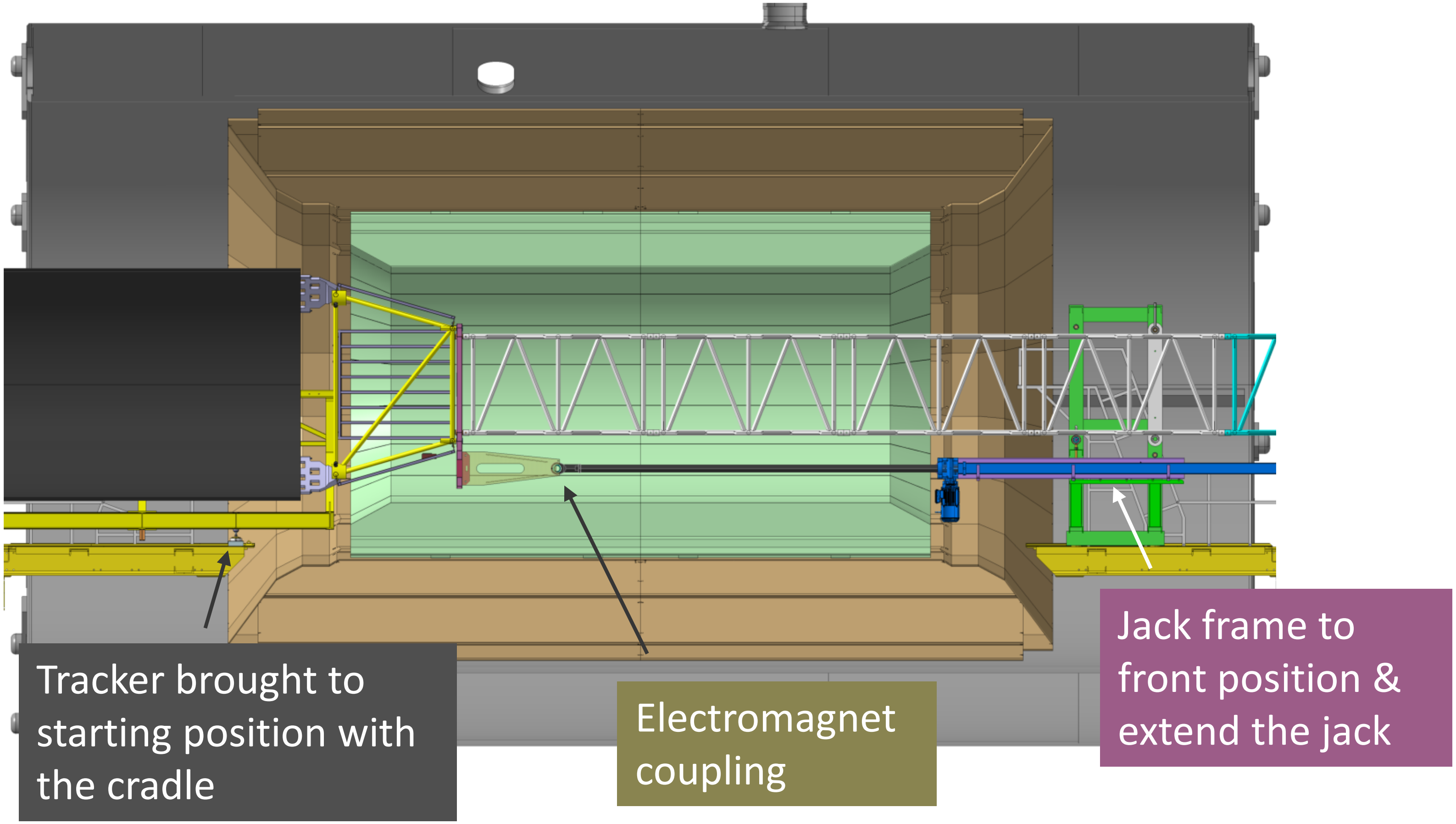
| Group | Item | Mass (kg) | Group mass (kg) |
|---|---|---|---|
| Detector assemblies | TBPS flat | 40 | 3274 |
| | TBPS tilted | 120 | |
| | TB2S | 500 | |
| | TEDD | 800 | |
| | BTL Tray | 1814 | |
| Detector mechanics | BTST | 316 | 793 |
| | TK rails | 37 | |
| | Banana | 9 | |
| | BTL I-Beams | 70 | |
| | Service support ribs | 18 | |
| | Electrical PP0 Frames | 19 | |
| | TBPS/TB2S periphery seals | 11 | |
| | Bulkhead | 220 | |
| | ITST Small section | 16 | |
| | ITST Large section | 57 | |
| | Service sup. Mech. On TB2S wheel | 20 | |
| Integration tooling | Steel nose cone | 164 | 630 |
| | Steel nose cone link | 67 | |
| | Aluminum nose cone | 76 | |
| | Aluminum nose cone link | 34 | |
| | Small ears | 31 | |
| | Big ears | 73 | |
| | Hor. Eiffel Tower | 185 | |
| OT PP0-PP1 services | BTL PP0-PP1 Power | 430 | 1807 |
| | BTL PP0-PP1 OF | 12 | |
| | TBPS-TB2S PP0-PP1 Power | 710 | |
| | TBPS-TB2S PP0-PP1 OF | 51 | |
| | TEDD PP0-PP1 Power | 564 | |
| | TEDD PP0-PP1 OF | 40 | |
| TOTAL MASS | | | 6505 |
| TOTAL MASS, WITH 1.2 SAFETY FACTOR | | | 7805 |

(2021, phase-2 tracker estimate)

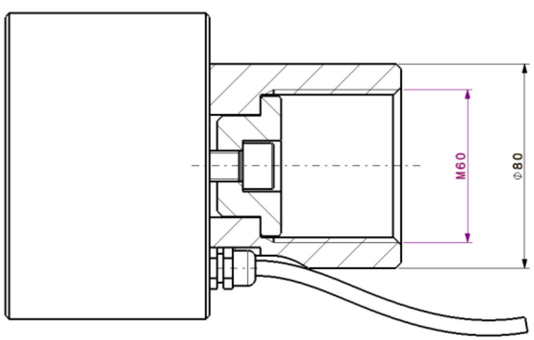
# New vertical eiffel tower

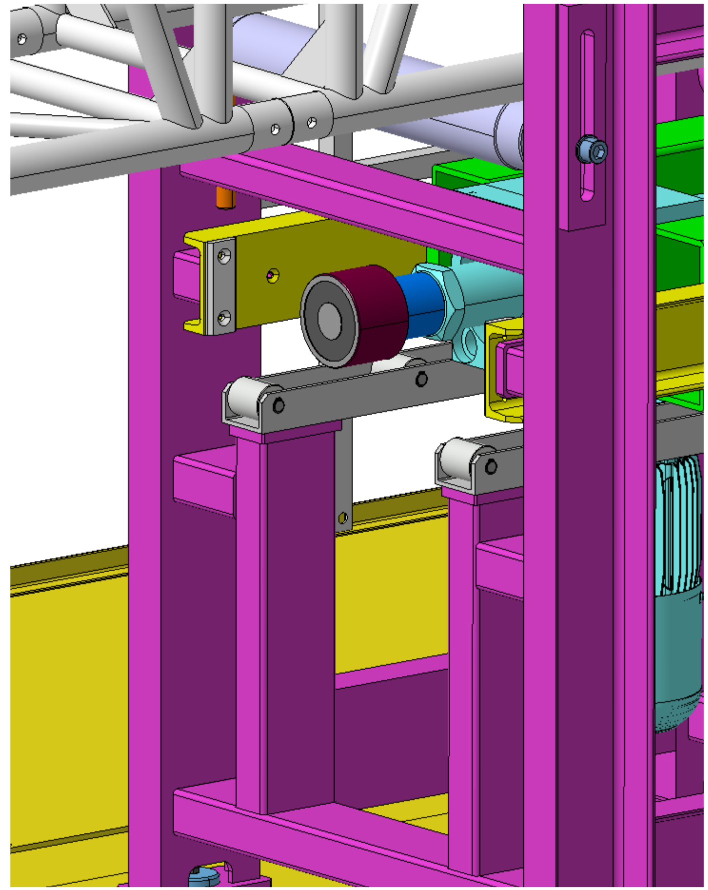


# New vertical eiffel tower

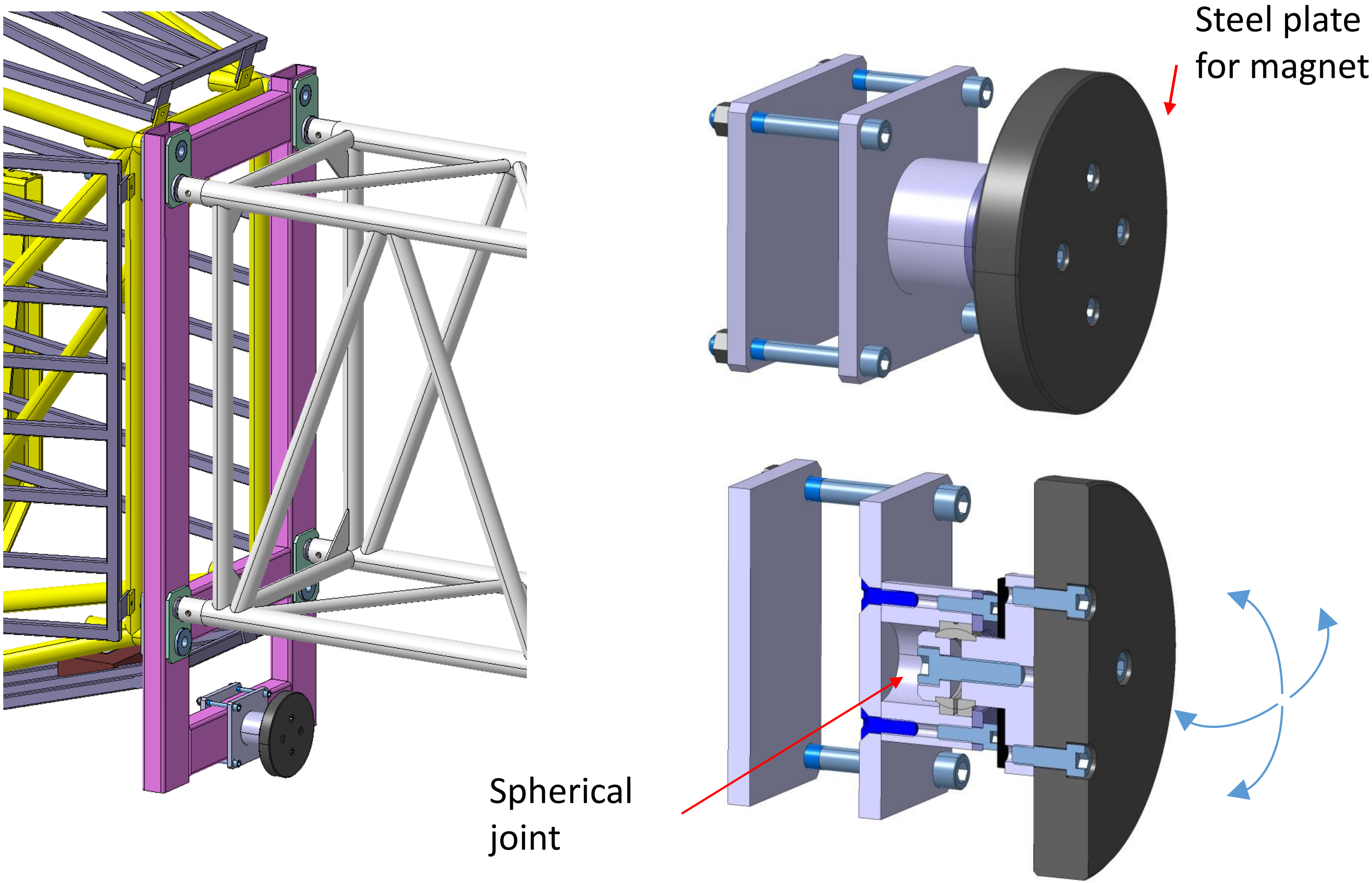


# New vertical eiffel tower



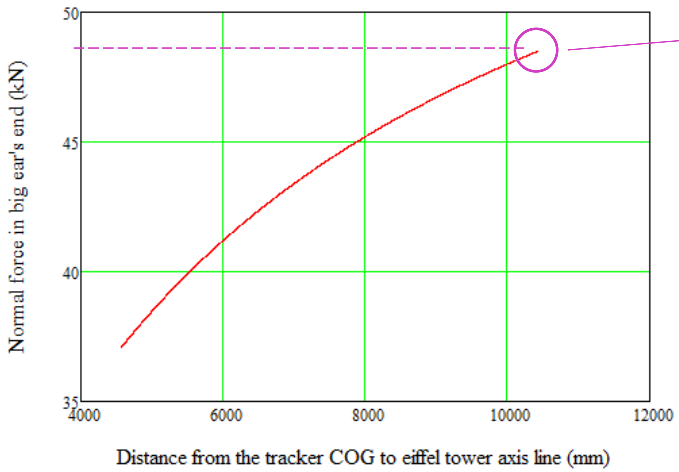



# New vertical eiffel tower



# Beginning of installation

*Reaction load on the BE-end*




*N.BE.fully_out.nominal = 48.5kN*

m = 6505kg

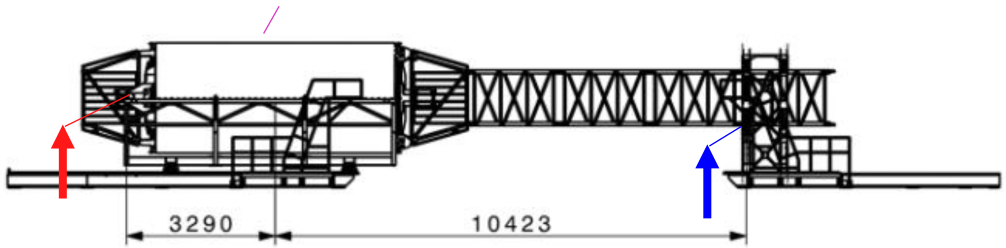
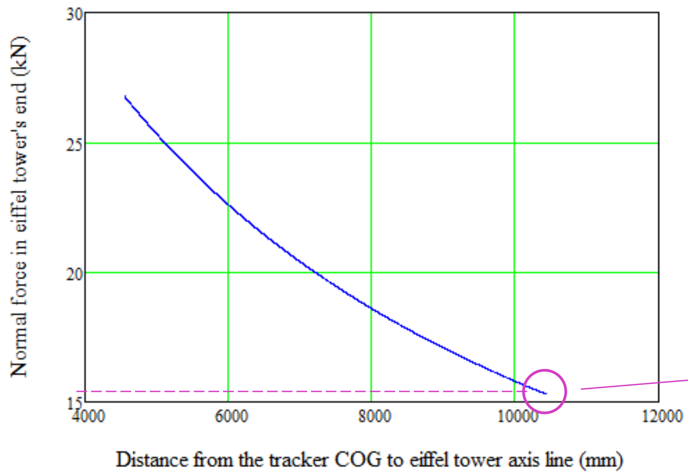



*Figure 1 Beginning of installation, distances from tracker COG to rolling axles*

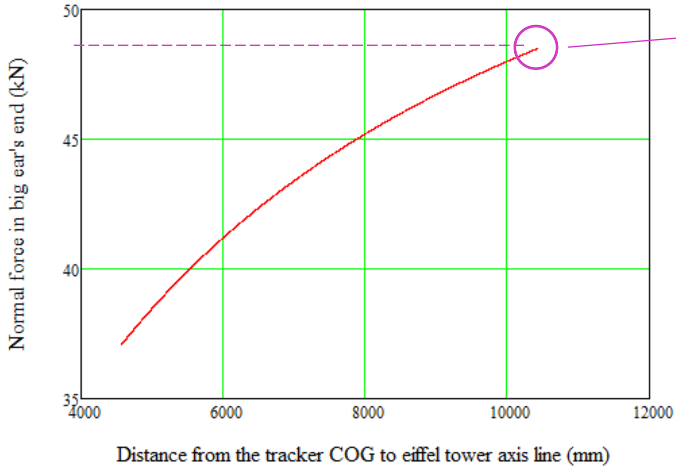
*Reaction load on the ET-end*




*N.ET.fully_out.nominal = 15.3kN*

# Beginning of installation

*Reaction load on the BE-end*




*N.BE.fully_out.nominal = 48.5kN*

m = 6505kg

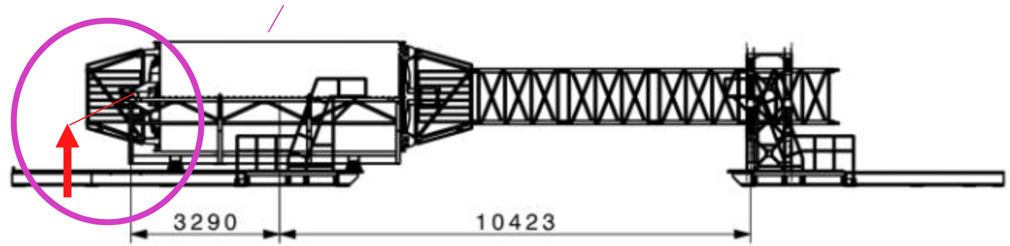
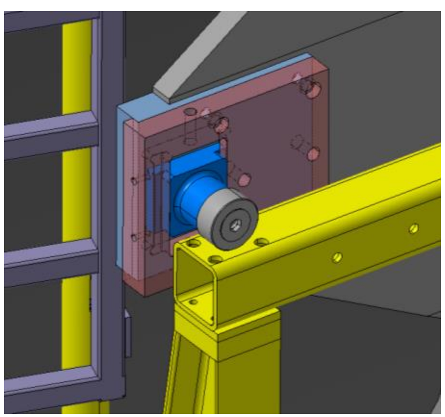



*Figure 1 Beginning of installation, distances from tracker COG to rolling axles*

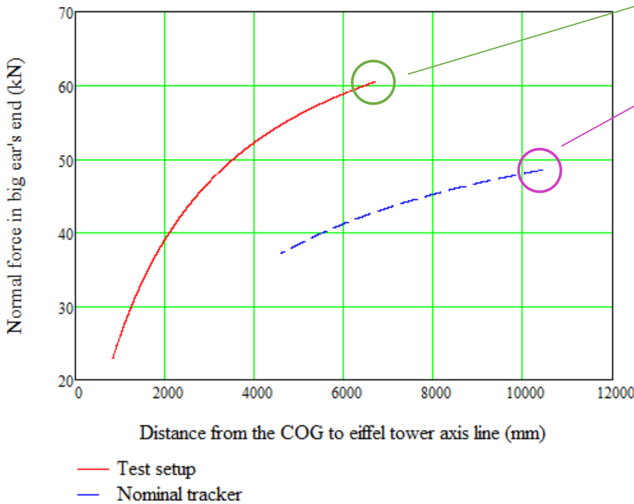
*Reaction load on the ET-end*



- The beginning of installation is:
  - Worst case for the BE-mechanism
  - Heaviest loading for the cradle

# Beginning of installation (scenario #2)

*Reaction load on the BE-end*




*N.BE.fully_out.test = 60.5kN*

*N.BE.fully_out.nominal = 48.5kN*

+24.4%

m = 6505kg

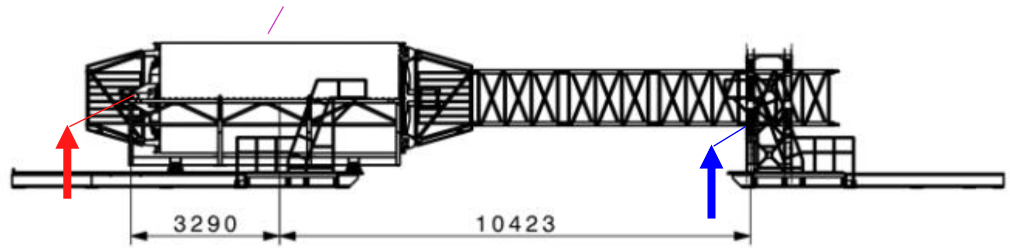
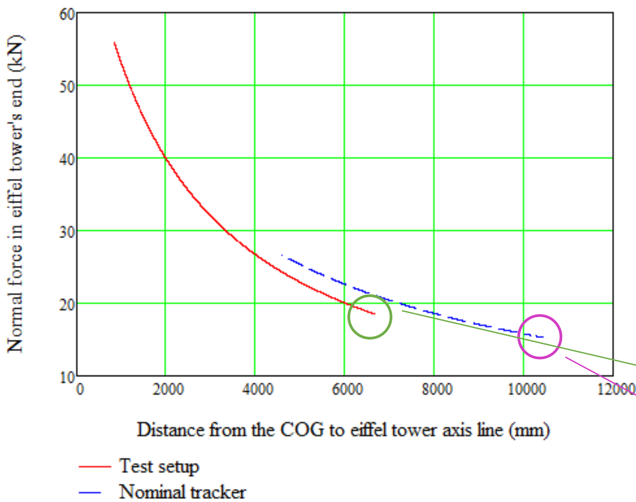
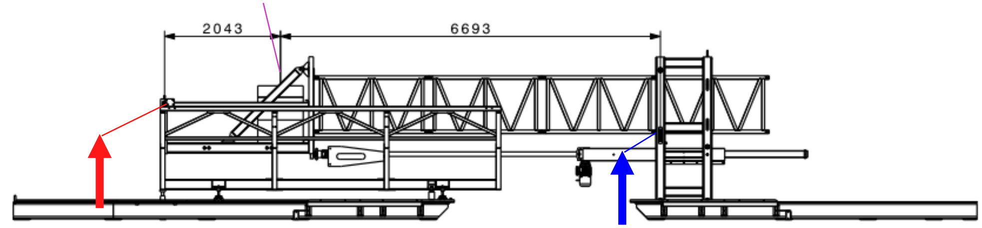



*Figure 1 Beginning of installation, distances from tracker COG to rolling axles*

*Reaction load on the ET-end*




m = 7000kg



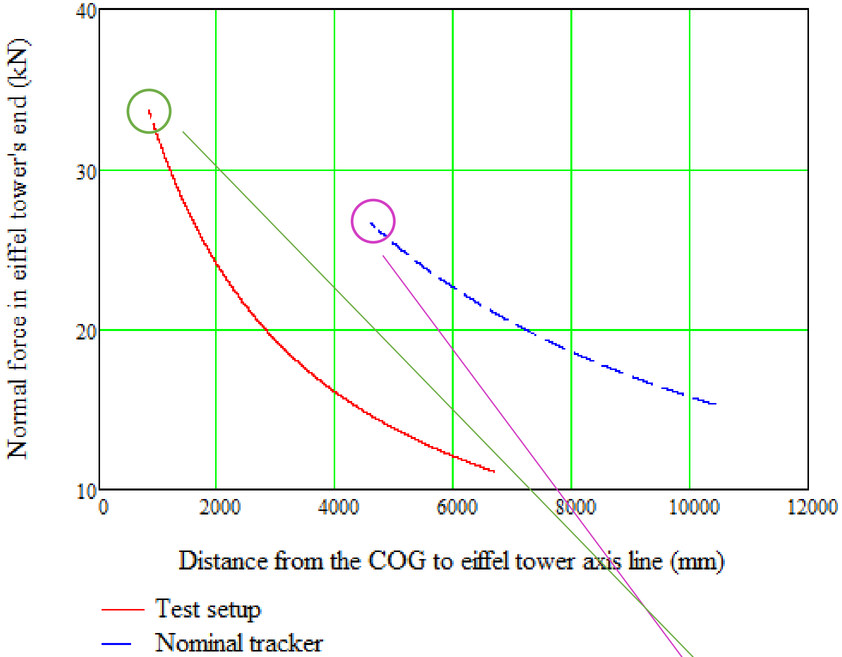

*N.ET.fully_out.test = 18.5kN*

*N.ET.fully_out.nominal = 15.3kN*

+21.6%


# End of installation (scenario #1)

*Reaction load on the ET-end*




m = 6505kg

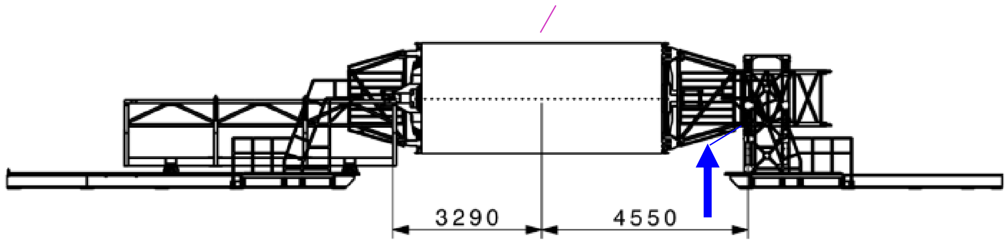
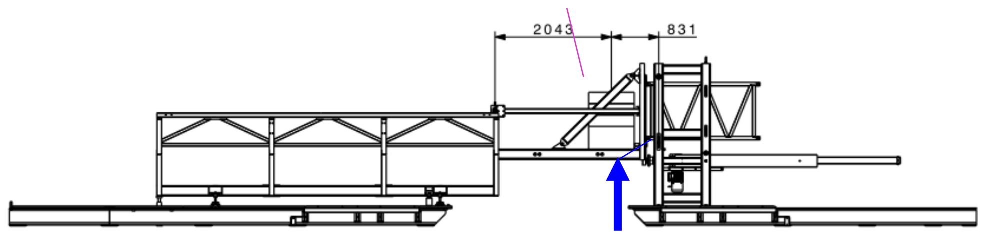



*Figure 2 End of installation, distances from tracker COG to rolling axles*

m = 4000kg



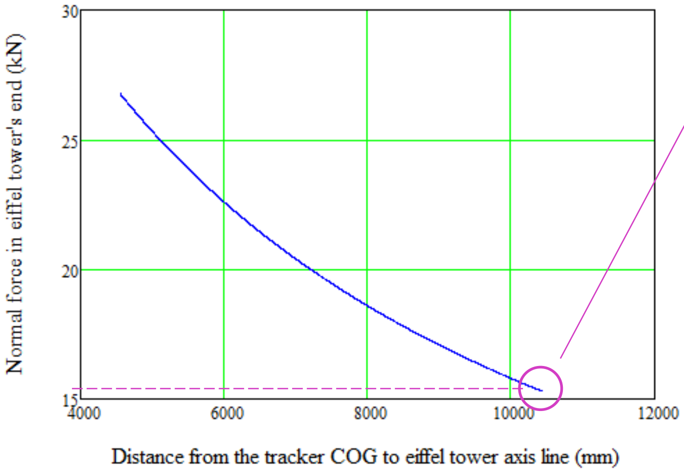

*N.ET.fully_in.test = 33.6kN*

*N.ET.fully_in.nominal = 26.7kN*

+20.5%

# Beginning of installation

*Reaction load on the ET-end*




*N.ET.fully_out.nominal = 15.3kN*

m = 6505kg

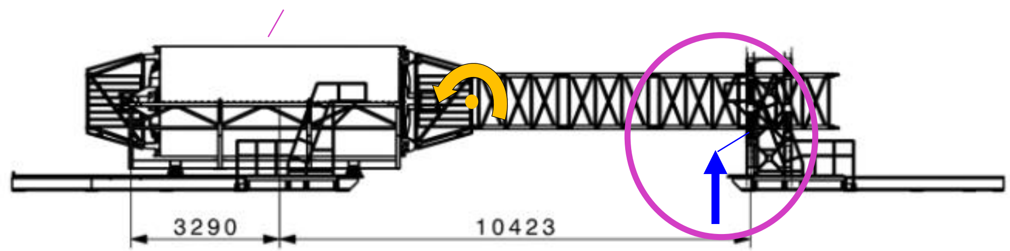
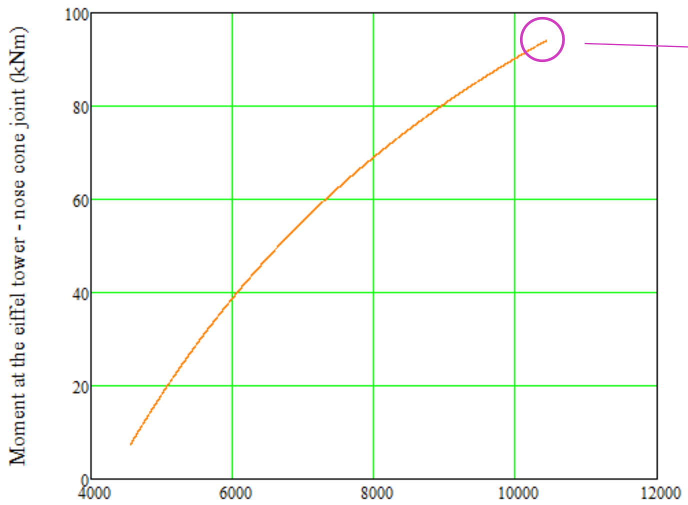


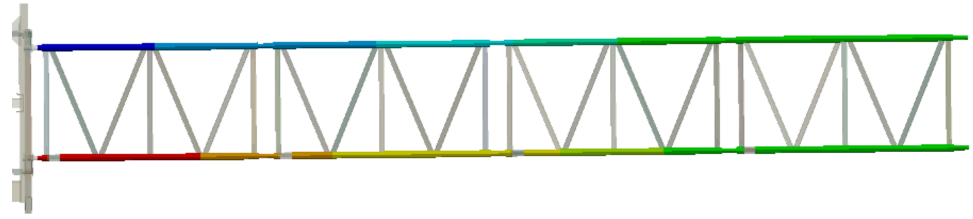

*Figure 1 Beginning of installation, distances from tracker COG to rolling axles*

*Reaction moment on the ET-NS-joint*



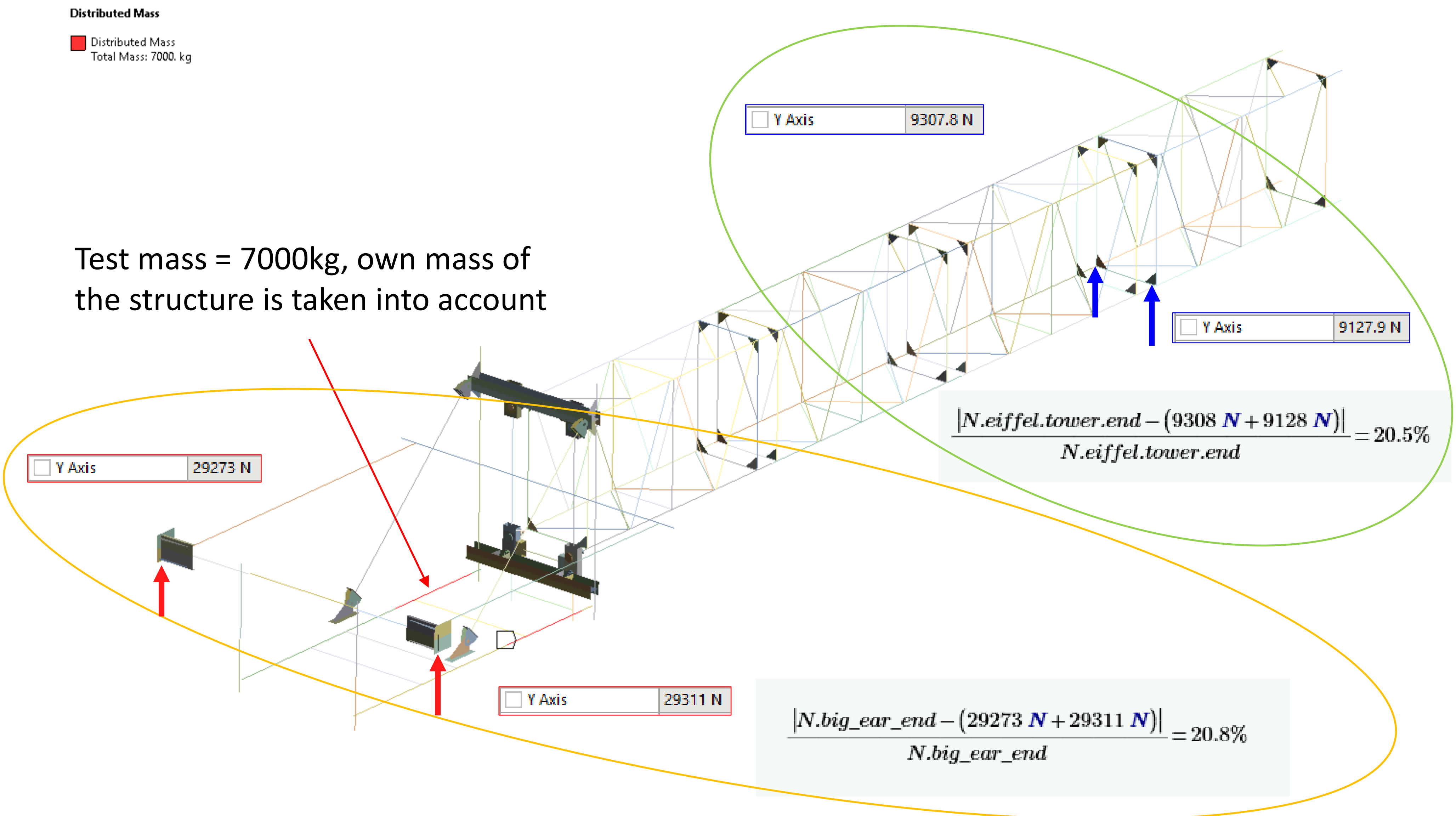

*M.ET.fully_out.nominal = 94.0kNm*

- The beginning of installation is:
  - Worst case for the horizontal Eiffel tower in stress and in deflection



# Test scenario #2, fully extended

Test mass = 7000kg, own mass of the structure is taken into account

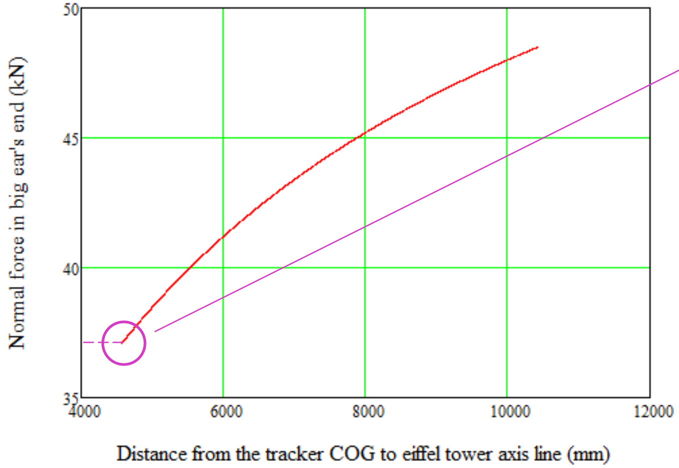



$$\frac{\left|N.eiffel.tower.end-\left(9308\ \boldsymbol{N}+9128\ \boldsymbol{N}\right)\right|}{N.eiffel.tower.end}=20.5\%$$

$$\frac{\left|N.big\_ear\_end-\left(29273\ \boldsymbol{N}+29311\ \boldsymbol{N}\right)\right|}{N.big\_ear\_end}=20.8\%$$

# End of installation

*Reaction load on the BE-end*




*N.BE.fully_in.nominal = 37.0kN*

m = 6505kg

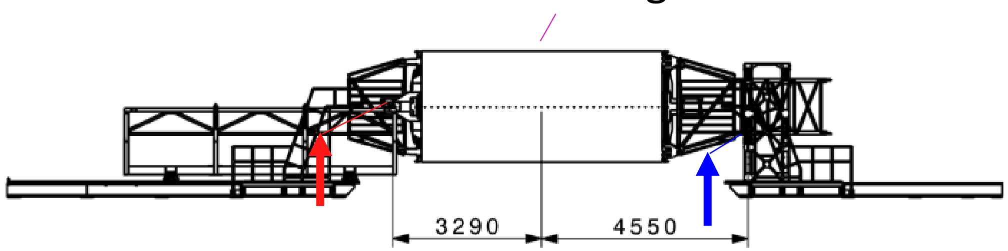
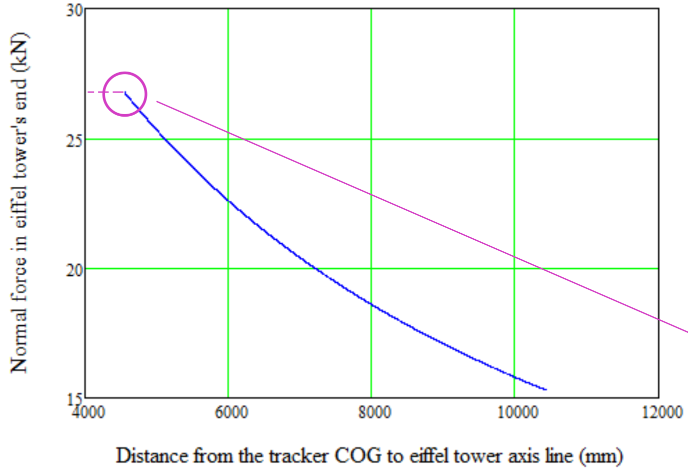



*Figure 2 End of installation, distances from tracker COG to rolling axles*

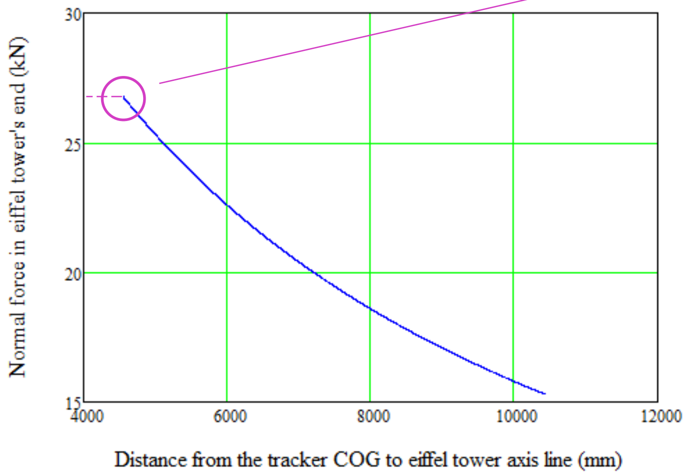
*Reaction load on the ET-end*




*N.ET.fully_in.nominal = 26.8kN*

# End of installation

*Reaction load on the ET-end* — *N.ET.fully_in.nominal = 26.8kN*



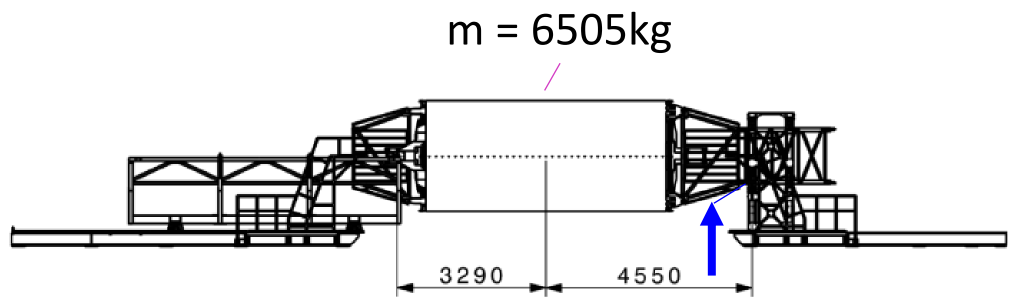
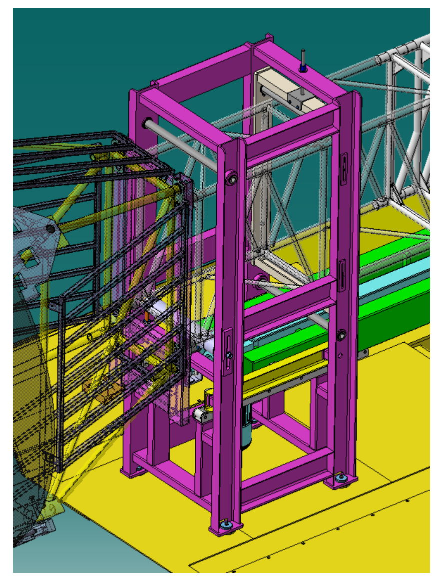



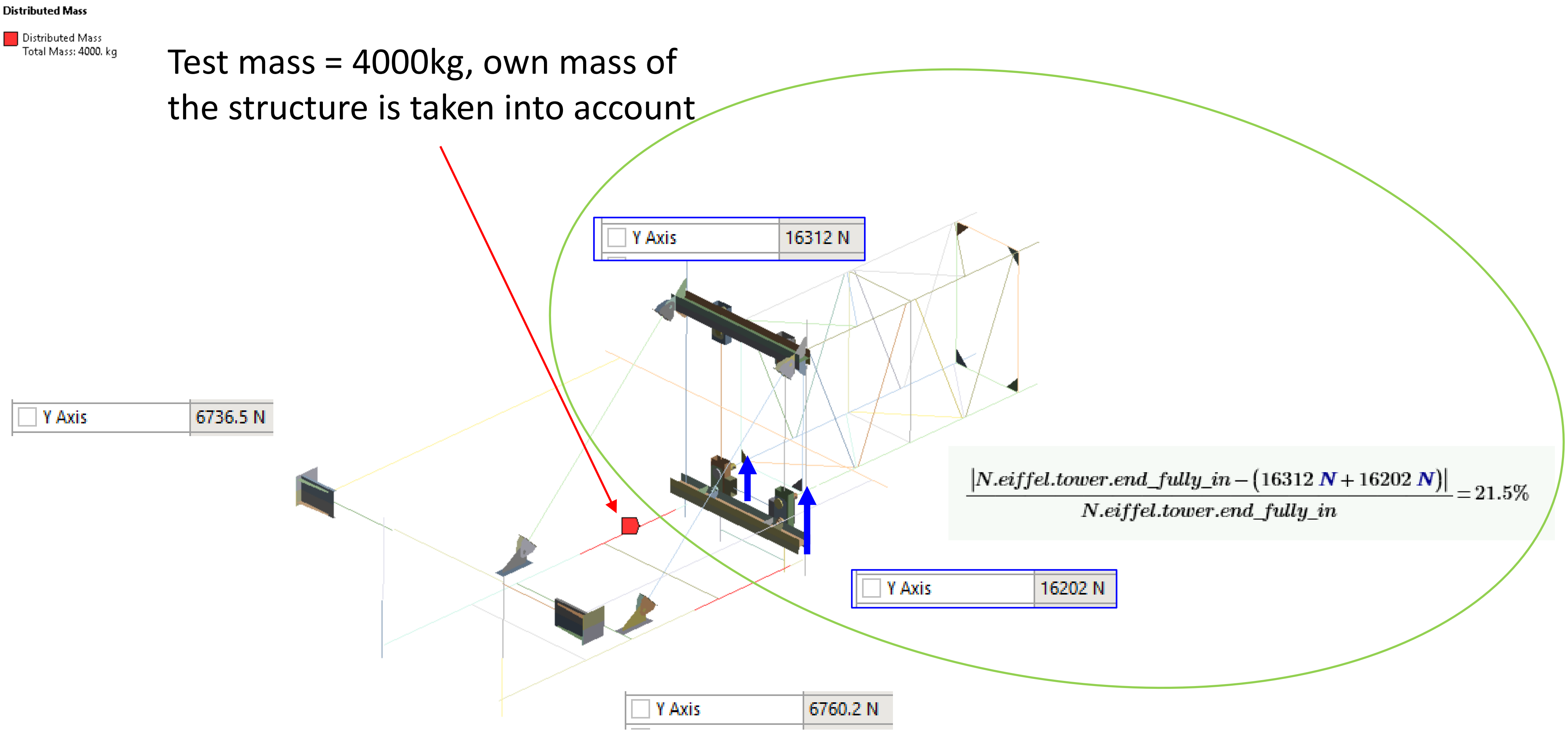

*Figure 2 End of installation, distances from tracker COG to rolling axles*

- The end of installation is:
  - Worst case for the vertical Eiffel tower structure, and its height adjustment mechanism



# Test scenario #1, fully in

Test mass = 4000kg, own mass of the structure is taken into account




$$\frac{\left|N.eiffel.tower.end\_fully\_in - (16312\ \mathbf{N} + 16202\ \mathbf{N})\right|}{N.eiffel.tower.end\_fully\_in} = 21.5\%$$

# Test, scenario #1

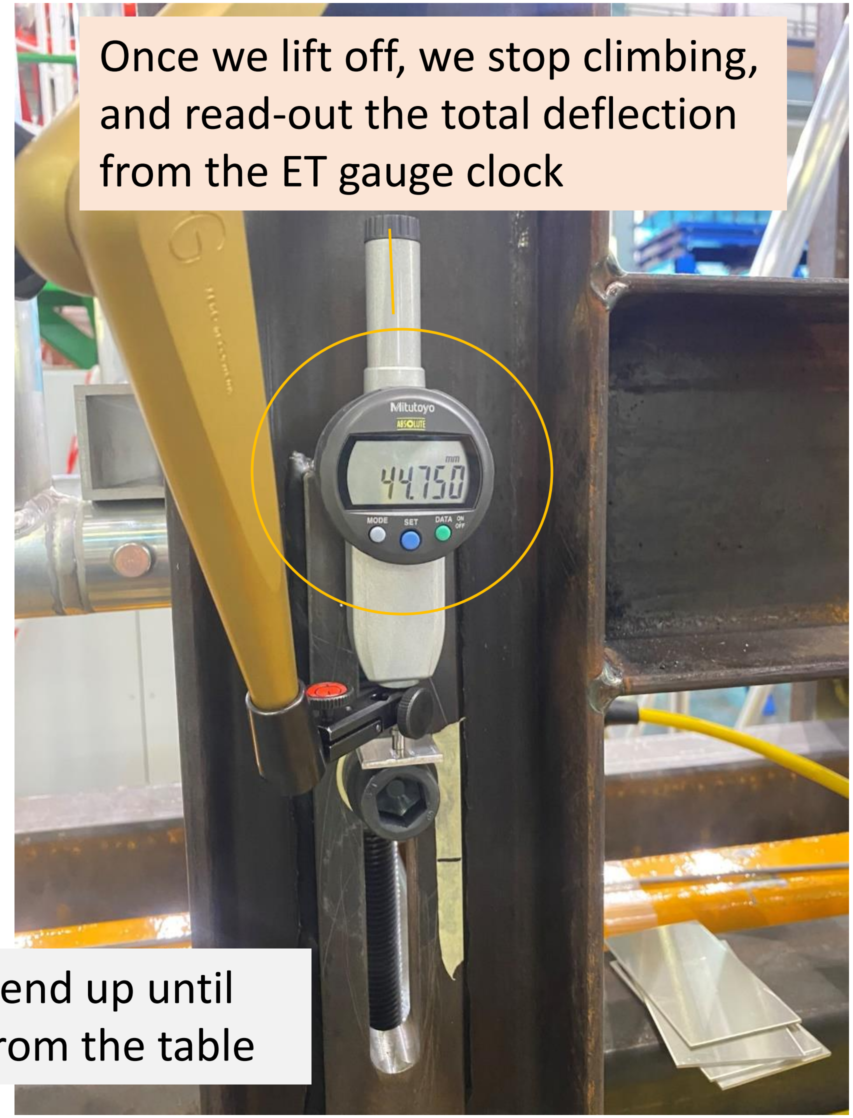
Step 0: Starting position, fully extended, resting on top of the "table"

# Test, scenario #1

# Test, scenario #1

Step 2: Jack the eiffel tower’s end up

# Test, scenario #1




Once we lift off, we stop climbing, and read-out the total deflection from the ET gauge clock

Step 2: Jack the ET-end up until the front end lifts from the table

# Test, scenario #1

Step 3: extending the actuator, connecting the magnet

# Test, scenario #1


Load cell in between to measure push/pull force

Step 3: extending the actuator, connecting the magnet

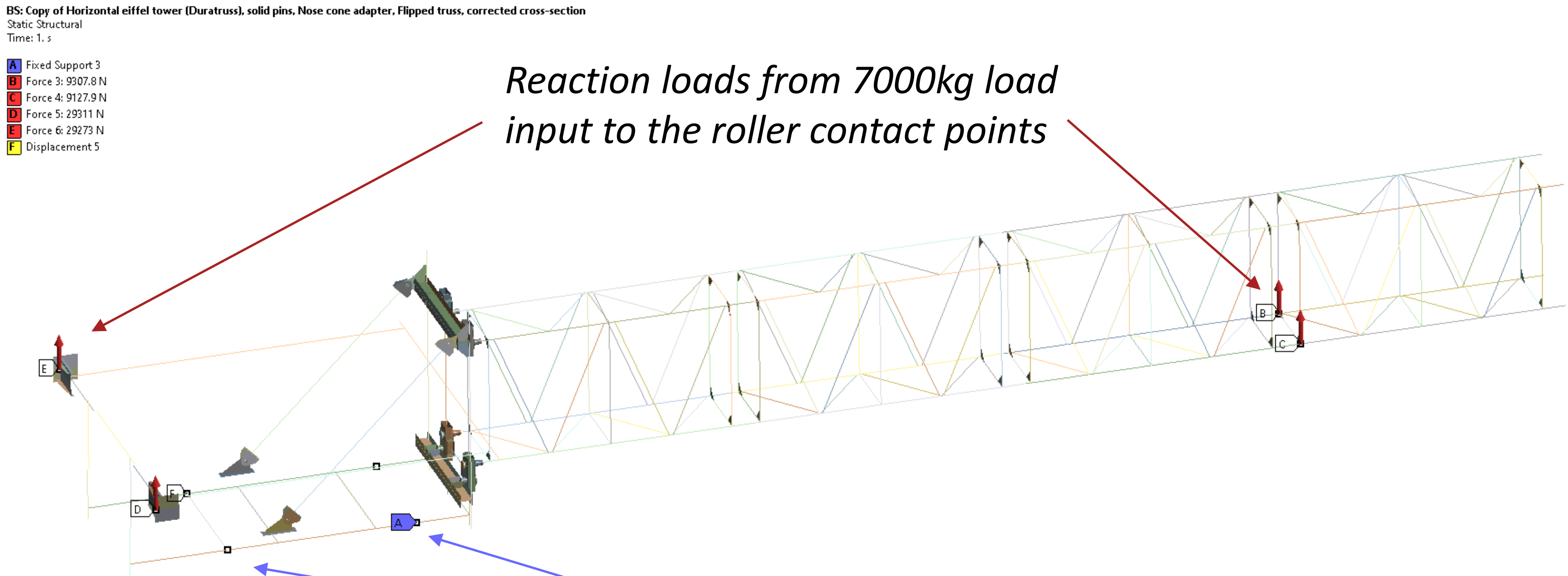
# Test, scenario #1

(video)

# Test, scenario #2

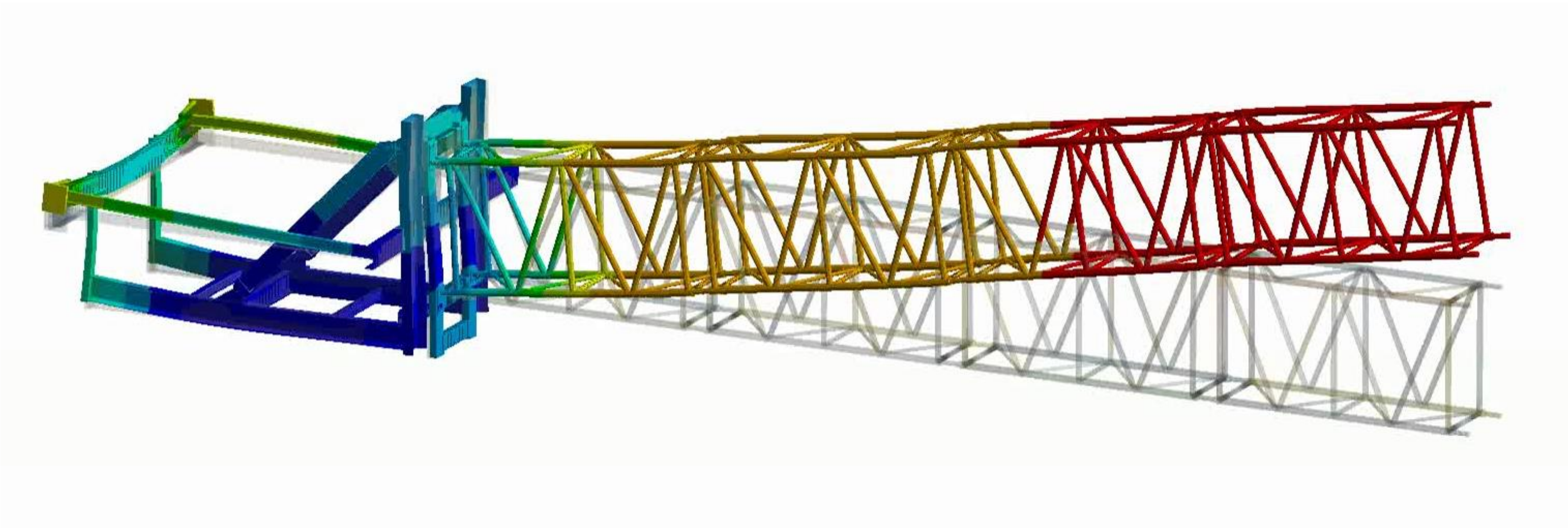
*“Inverse” boundary conditions:*

*Reaction loads from 7000kg load input to the roller contact points*




*Fixed displacements applied to the table contact points*

# Test, scenario #2



(video)

# Test, scenario #2

## Nominal phase-2, end of installation scenario

$m_{nom} := 6505kg$

$a := 3290mm$ — distance from COG to heavy end wheel axis

$b := 10423mm, 10422mm .. 4550mm$ — distance from COG to light end wheel axis

$$N_{light\_end.defined} := \frac{m_{nom} \cdot g \cdot a}{a + 4550mm} = 26.77\,kN$$

Normal force in eiffel tower's end, end of installation

$$N_{test\_target} := N_{light\_end.defined} \cdot 1.2 = \underline{32.124\,kN}$$

Target normal force in test, +20%

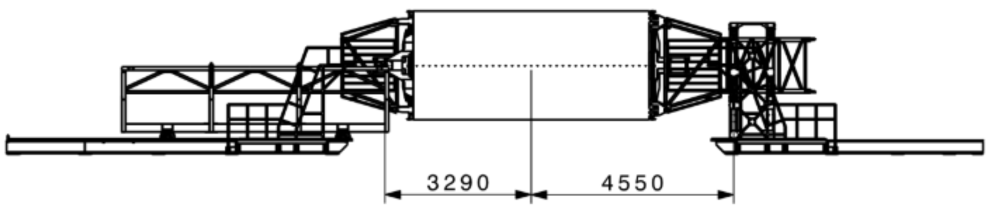



*Figure 2 End of installation, distances from tracker COG to rolling axles*

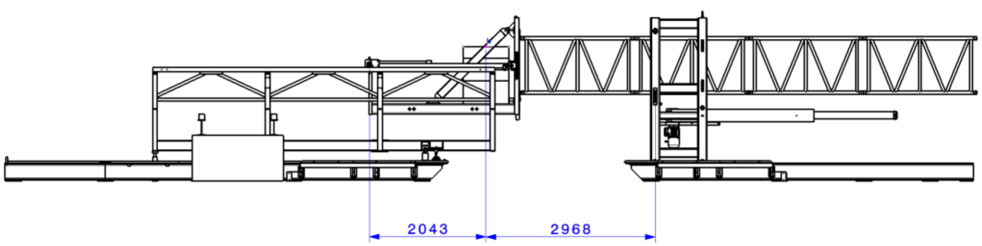
## Scenario #2, searching for equal reaction

$m_{test} := 8047kg$

$a_{test} := 2043mm$ — distance from COG to heavy end wheel axis

$b_{test} := 2968mm$ — distance from COG to light end wheel axis

$$N_{light\_end\_test\_defined} := \frac{m_{test} \cdot g \cdot a_{test}}{a_{test} + b_{test}} = \underline{32.174\,kN}$$




Test cage, Scenario #2 furthest point in