

a Geometric-based Method for the Perceptive Design of Hyperstatic Rigid Frames

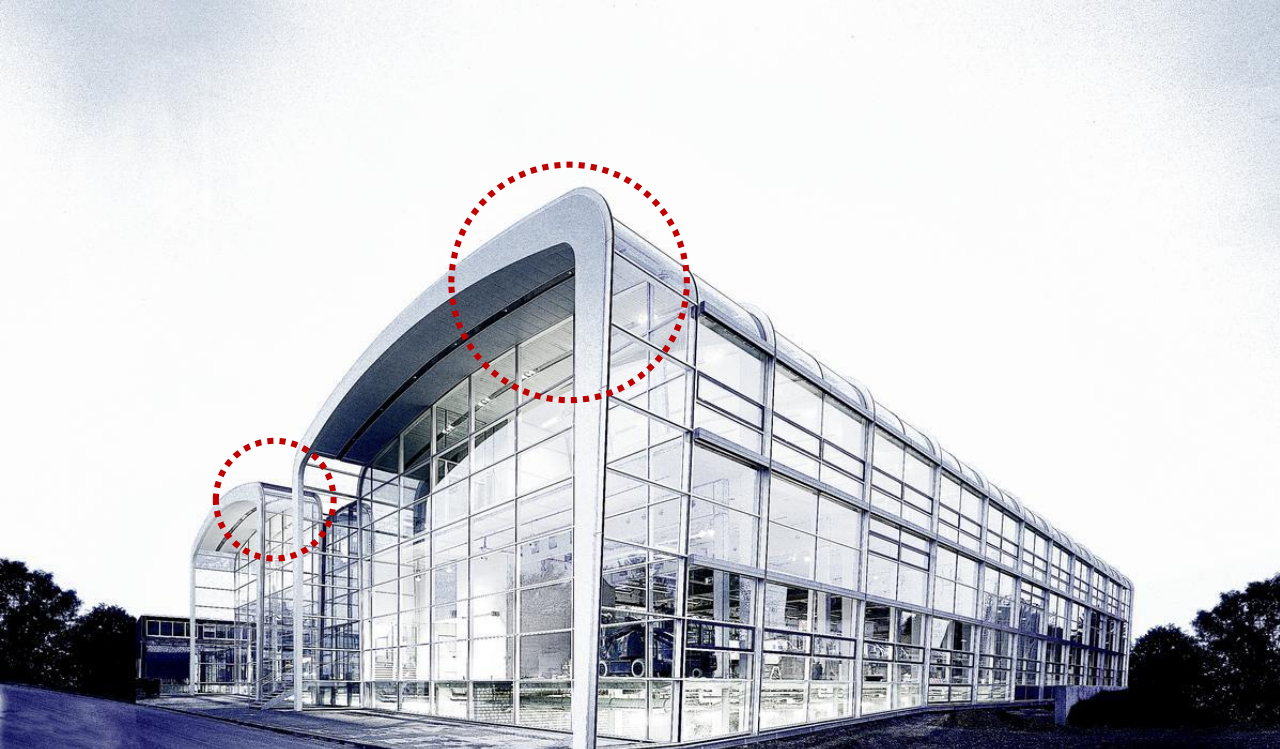
Thesis registered in 2018

Shuyuan Han, Denis Zastavini (supervisor)- Structures & Technologies LAB,
Faculté d'architecture, d'ingénierie architecturale, d'urbanisme - LOCI
Université catholique de Louvain

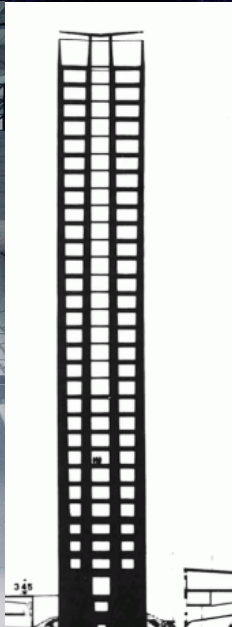


How to design hyperstatic rigid frames insightfully
with graphic statics ?

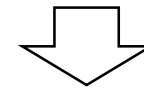
How to design hyperstatic rigid frames insightfully
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GIRA Production Hall
(Ingenhoven Architects,
source: [GIRA Giersiepen
GmbH & Co. KG](#))



Key feature:
Rigid/moment-resisting
connections and members



statically indeterminacy/
hyperstatic

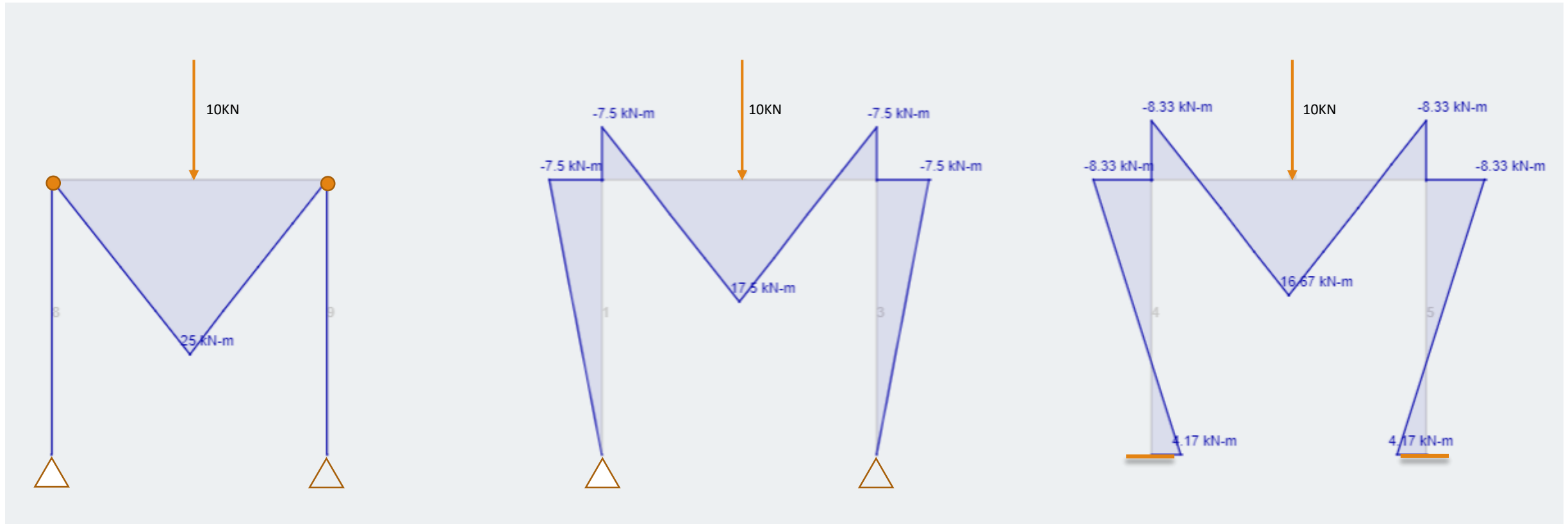
Pirelli Tower ([source:BMS](#))

The structural relevance of statically indeterminacy

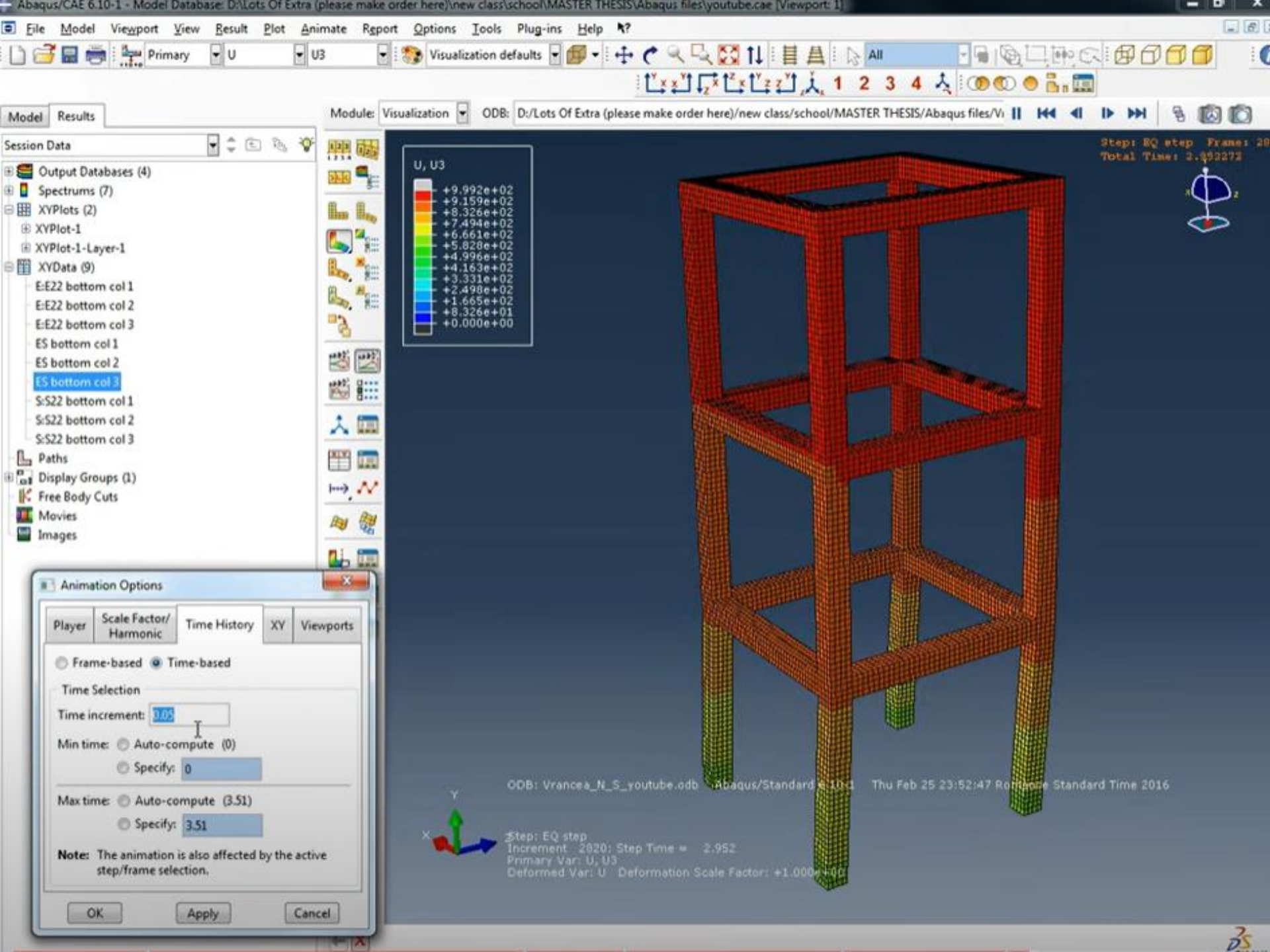
- Structural efficiency through hyperstability
- Structural redundancy

The structural relevance of rigid frames

- Geometrical relevance
- Lateral resistance capacity
- Constructability

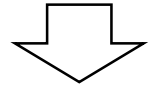


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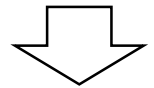


The current design practices

- Not insightful into the relation between form and forces.
- One-way approach: results are also not interactive
- Demanding of mathematics knowledge



- “Black-box” tools
- Trial-and-error approach
- Architects are deterred from in-depth form-finding of frames

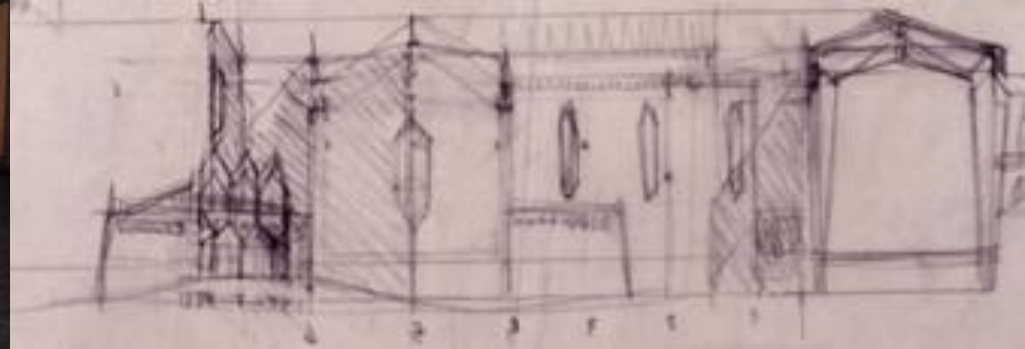


- Often materially-inefficient
- Aesthetic value is often unexploited

- Materially-efficient: varying sections according to bending moment
- Aesthetic value: an integrated element for architectural richness and elegance



Church of Saint Francis of Assisi al Foppino
Milano, Italy, 1964 (completed)
Architect: Gio Ponti
Engineer: Antonio Fornaroli (to be confirmed)
source: [Hidden Architecture](#)



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with graphic statics ?

Insight into the relation between form and forces

-44] EXAMPLES OF FRAME- AND STRESS- DIAGRAMS. 157

metrical to the triangle 1, 17, 18; the rectangle 8, 45, 43, 42 to the rectangle 2, 17, 19, 20: and so on.

All the upper bars are in compression, and all the lower ones are in tension.

The diagonals and contra-diagonals are all in compression; finally two of the verticals 23, 39 are in tension, and all the rest in compression.

44. Figure 9a* represents one half of a locomotive shed. The external forces are the weights 1, 2, 3, 4, 5 applied at

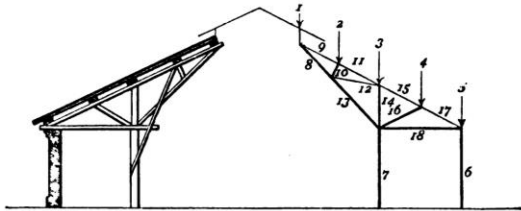


Fig. 9a.

the upper joints of the frame, and the reactions 6 and 7 of the wall and column. Again, all the external forces are parallel, and consequently the polygon of forces reduces, in diagram *b*, to one straight line. The force 6 (taken in the opposite sense to that in which it really acts) is equal to a certain part of the weight 5; by adding the difference to the other weights we get the magnitude of the force 7.

In the diagram *b* the direction of the lines 8 and 13 coincide; the first is a part of the second. Here then we have for the polygon corresponding to the joint (8, 10, 12, 13) one of those degenerate forms about which we spoke in Art. 33; the polygon is in fact a quadrilateral 8, 10, 12, 13, having three of its vertices (13, 8), (8, 10), (12, 13) in one straight line.

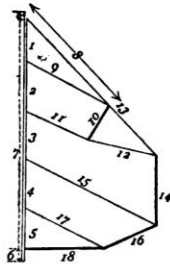
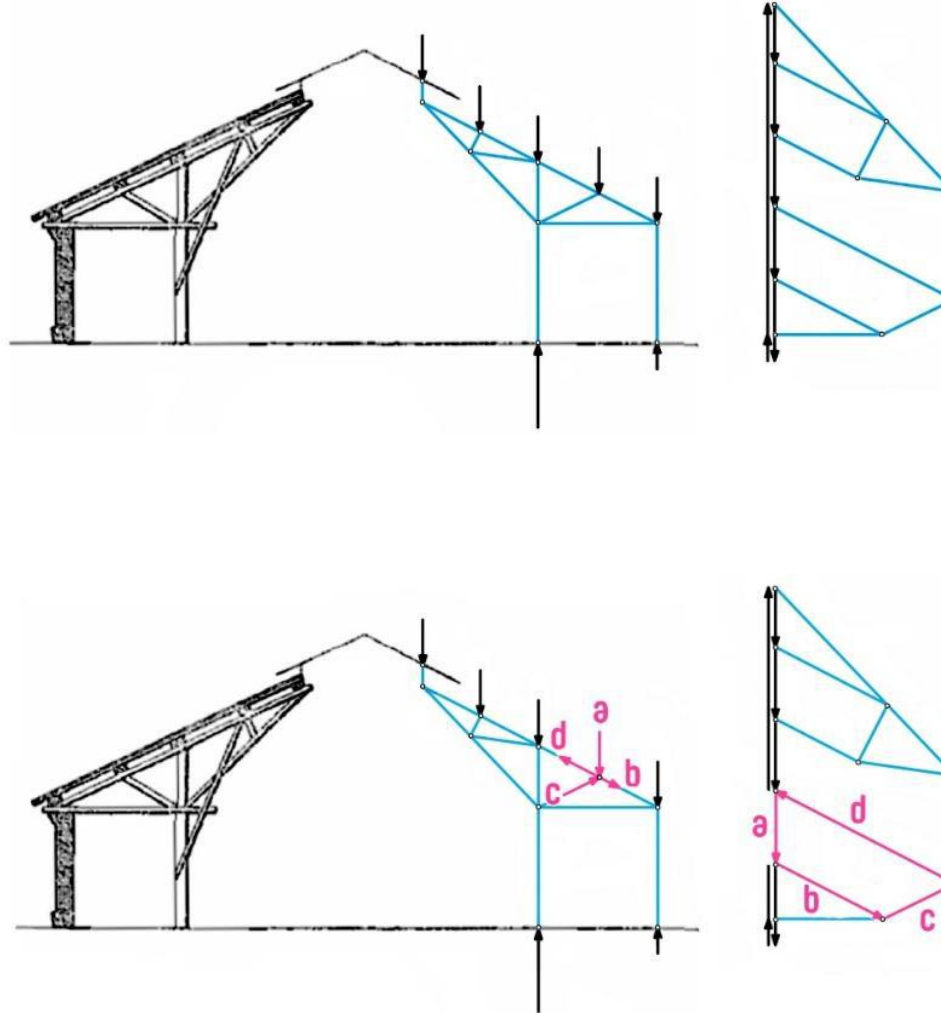


Fig. 9b.

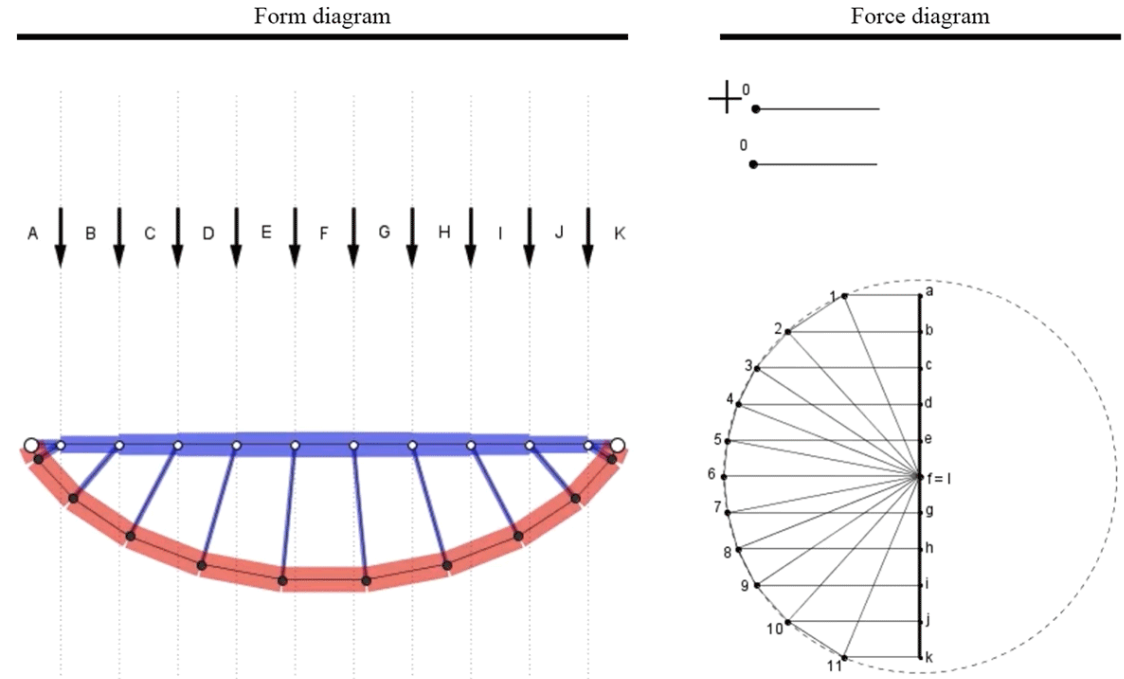
The polygon 5, 17, 18, 6, corresponding to the point where

* This example is taken from Pl. xix. of the atlas of *Graphische Statik* of CULMANN, 1st edition. As previously stated, the two diagrams are not rigorously reciprocal.



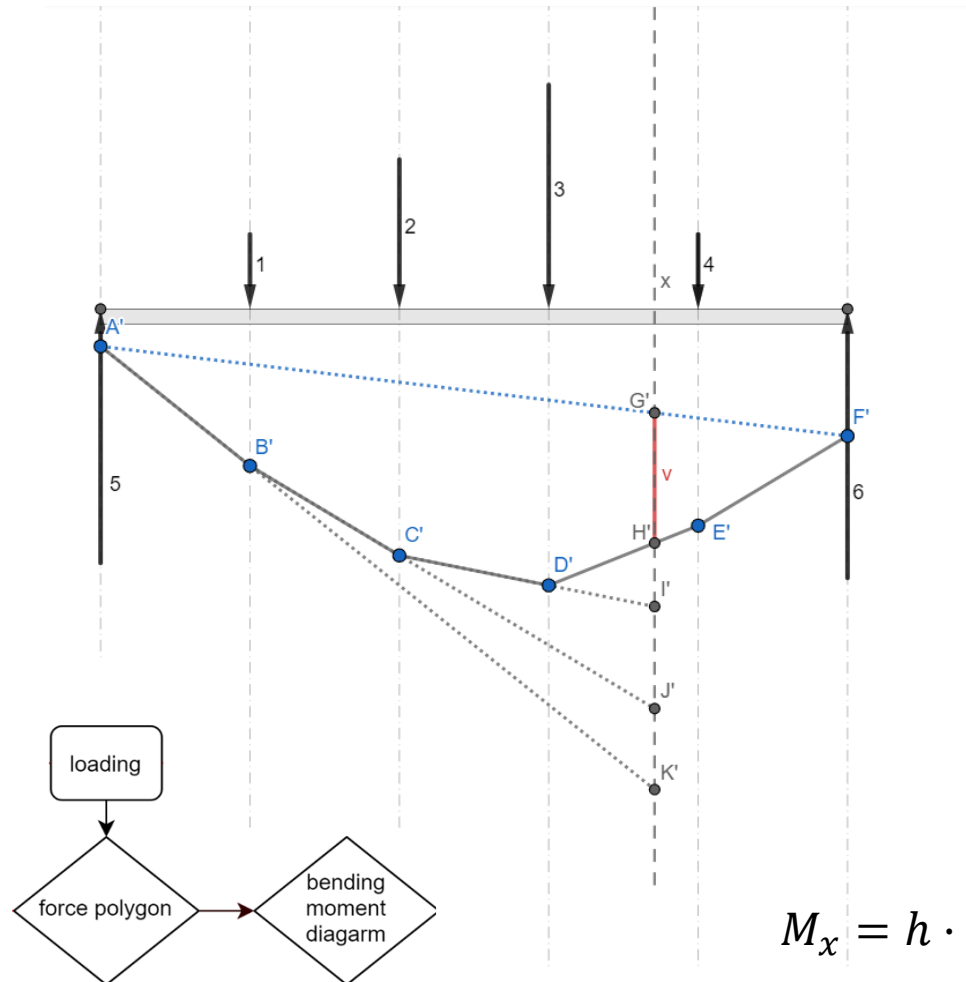
Advantages:

- insightful into the relation between form and forces.
- Two-way approach
- Less demanding of mathematics knowledge

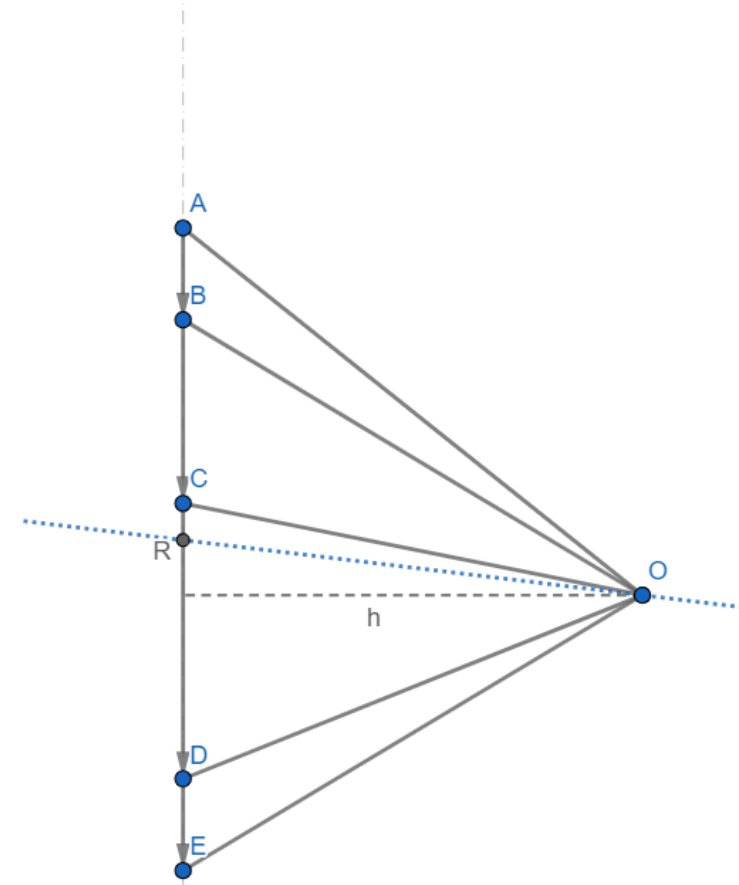


Source: Block's research group

The analysis of the bending moment of a beam with graphic statics



$$M_x = h \cdot G'K' - h \cdot J'K' - h \cdot I'J' - h \cdot H'I' = h \cdot G'H'$$

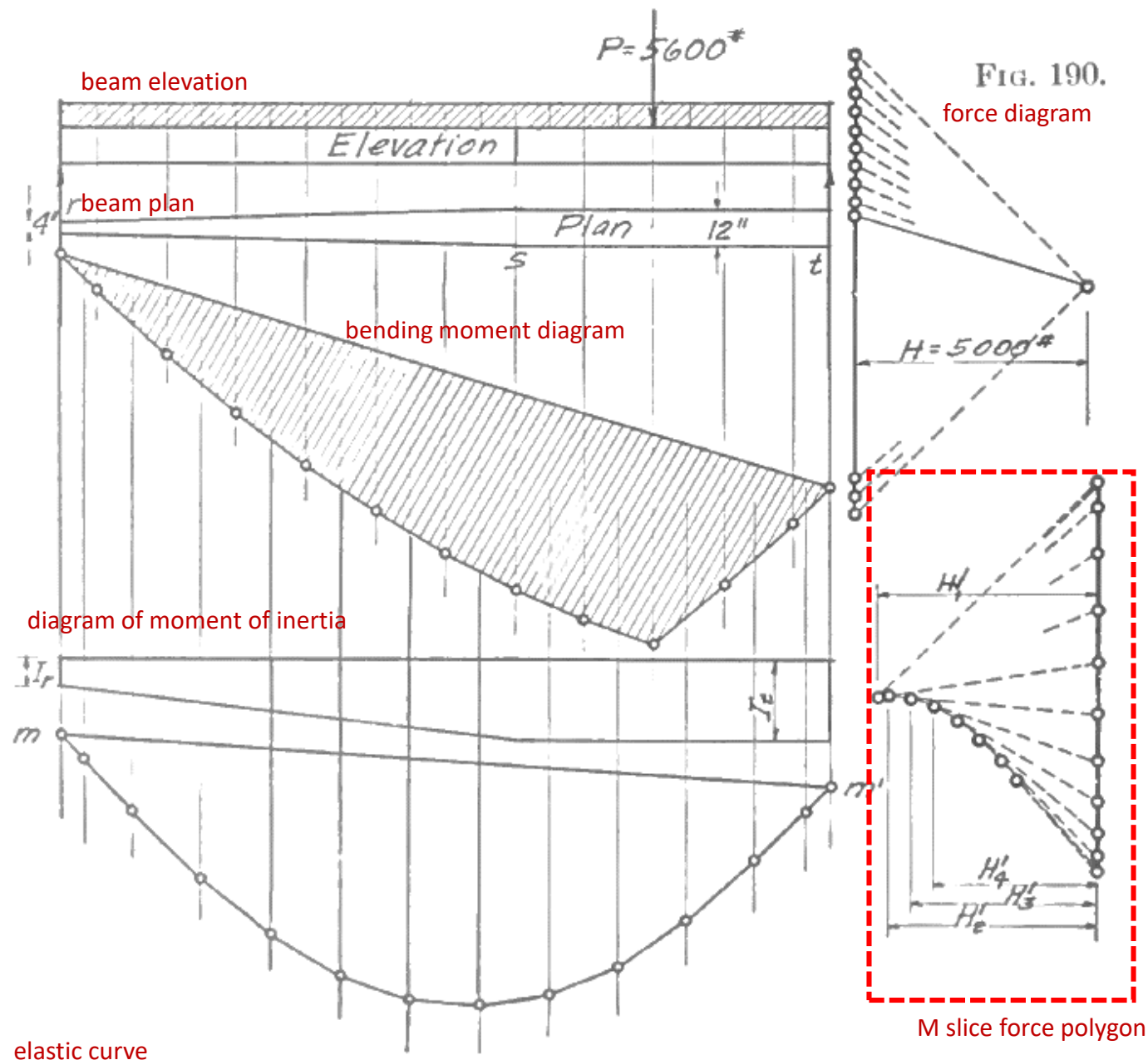
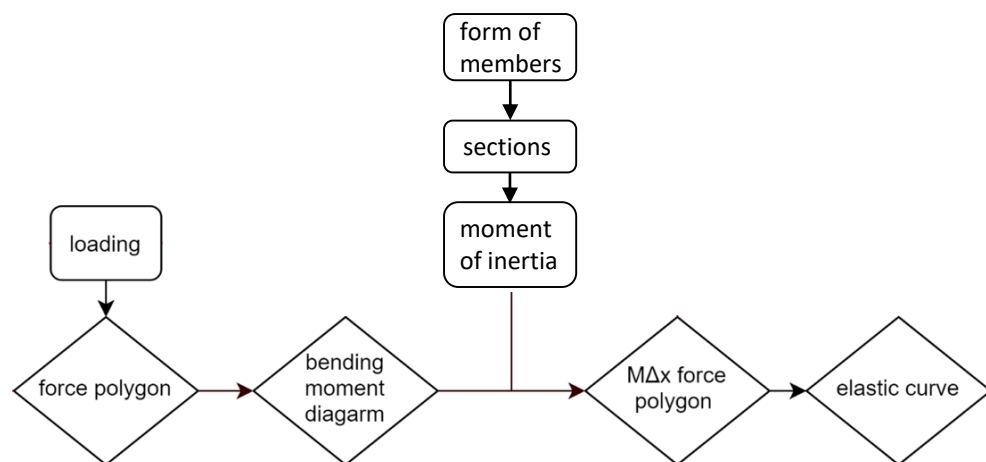


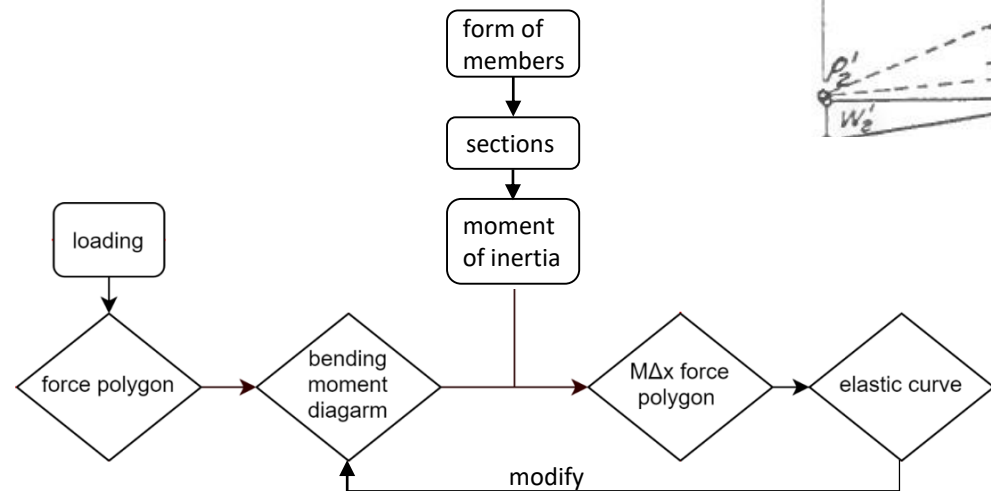
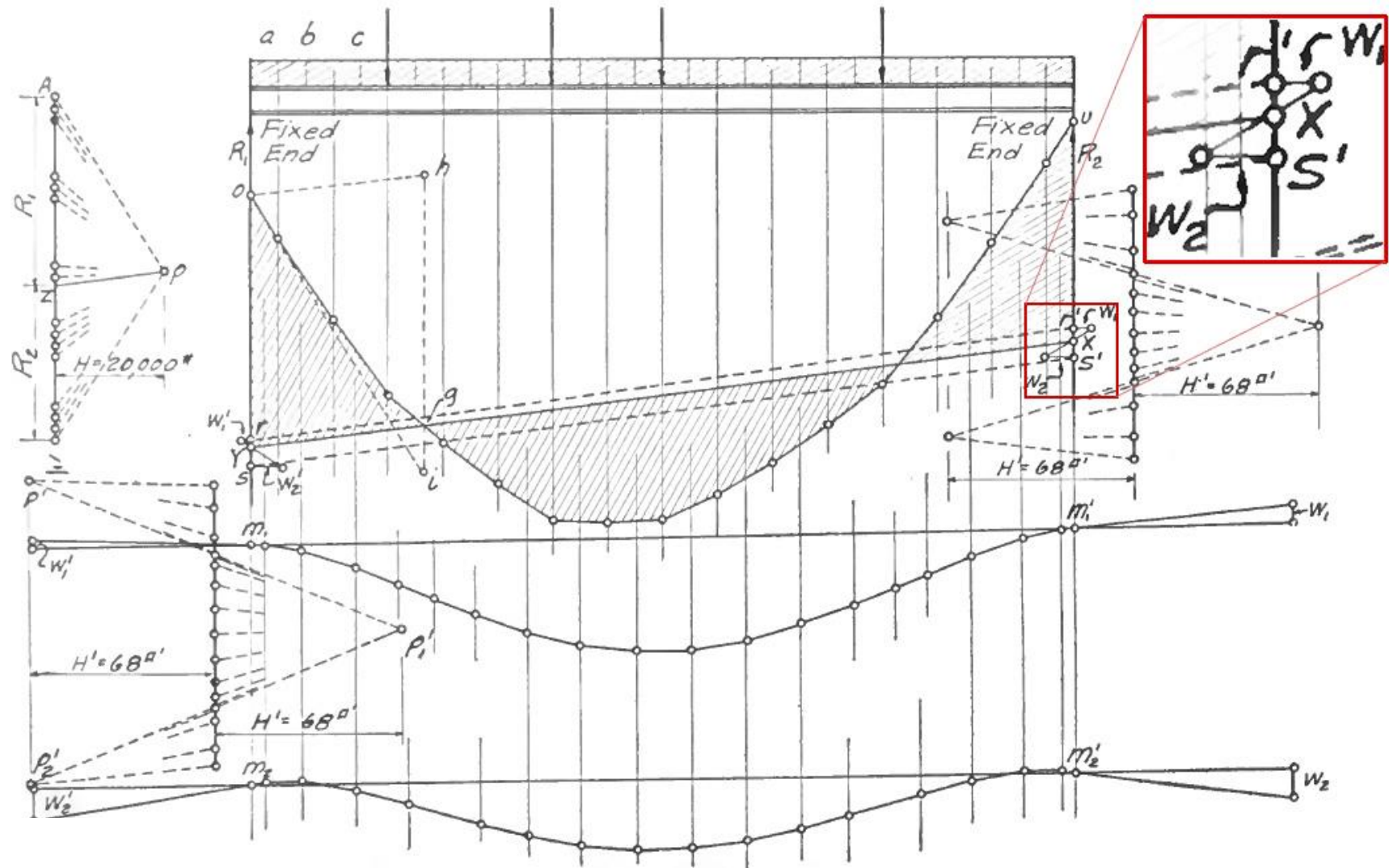
force polygon

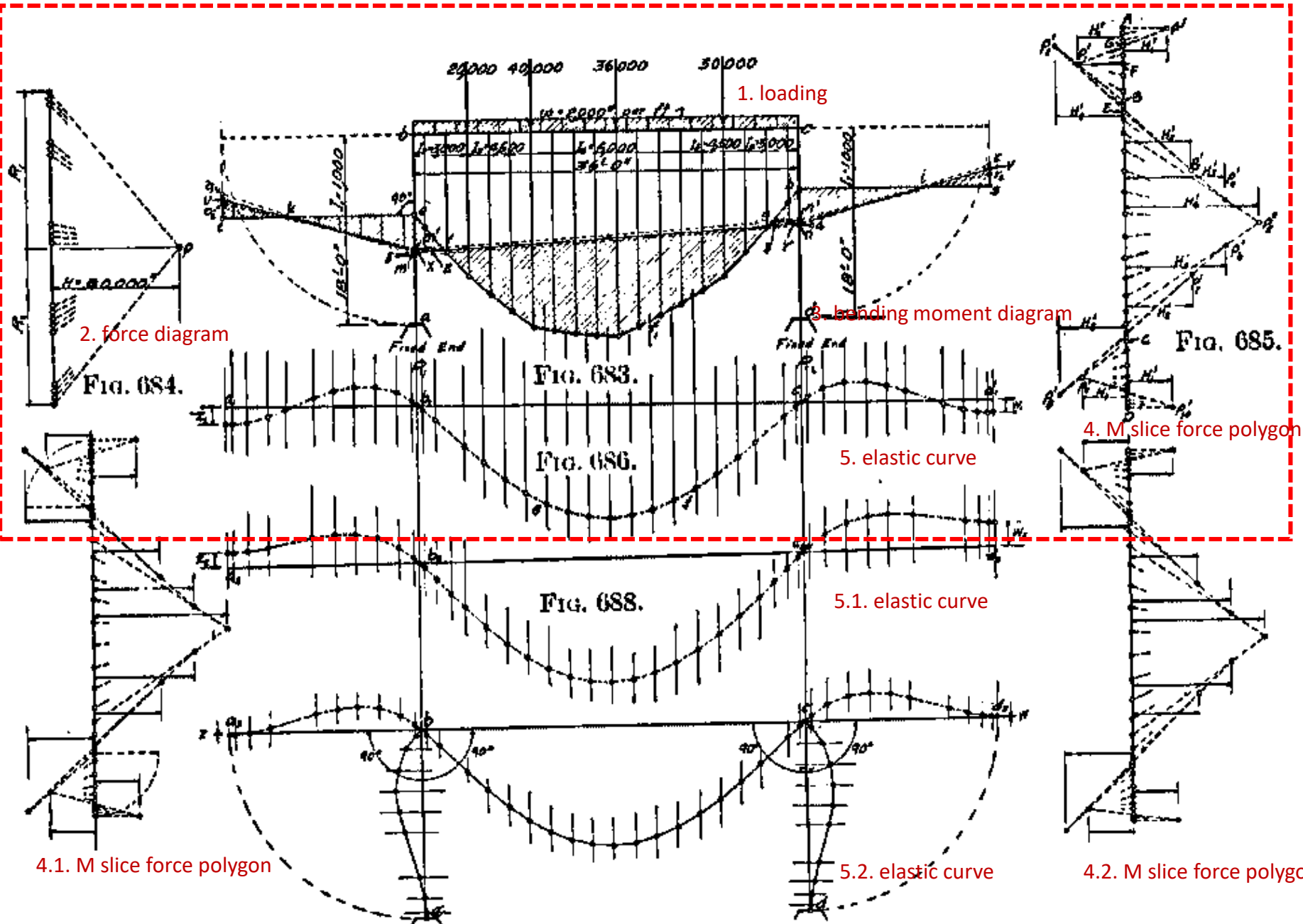
First funicular polygon/bending moment diagram

Beams with varying moment of inertia

- the pole distance for each segment is proportional to its corresponding inertia and equals $\frac{EI}{n \cdot H}$,
- Each ray intersects the previous one or its extension on the pole.







Key techniques for hyperstatic rigid frames:

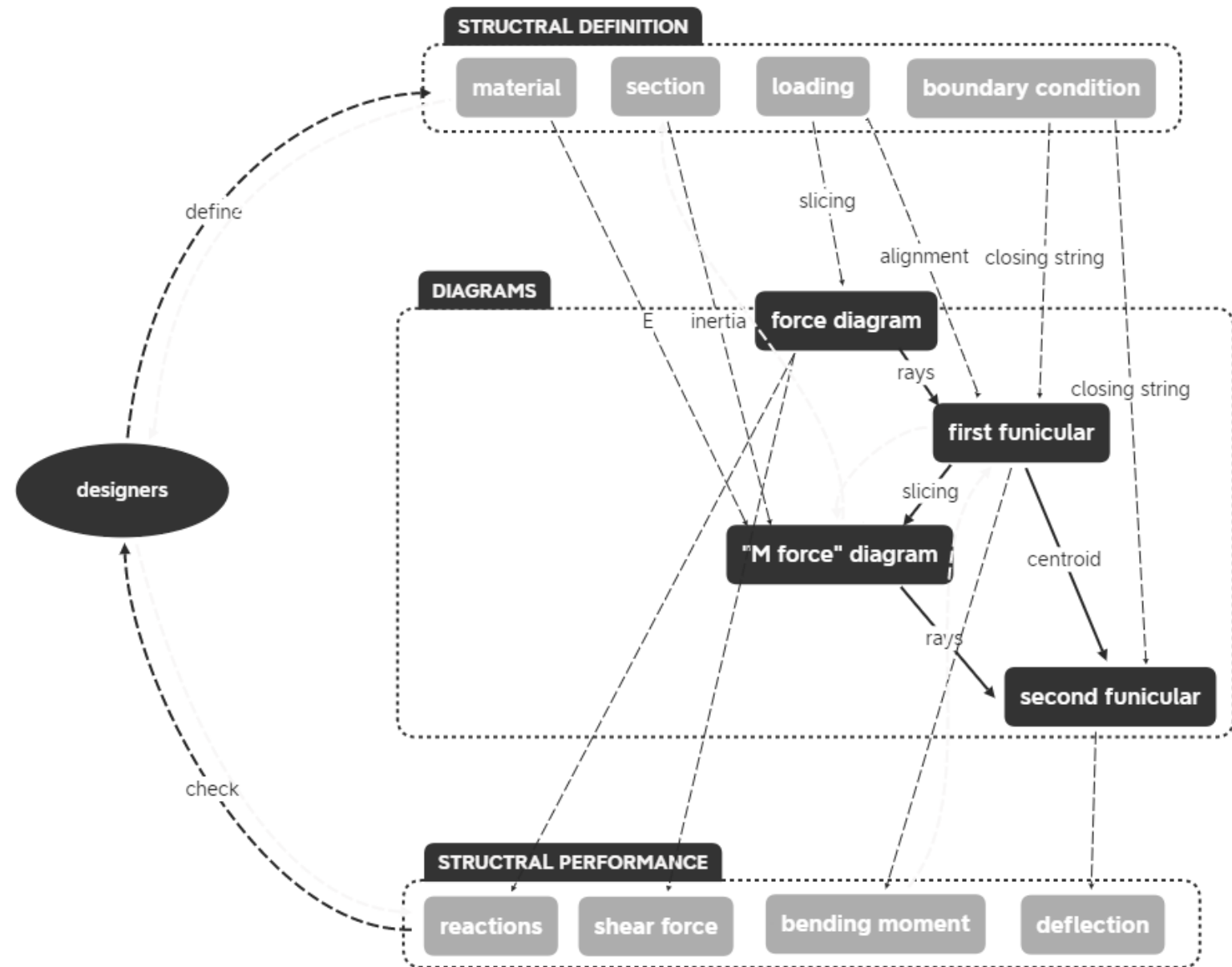
1. Frames are rotated into continuous beams
2. Using trial bending moment diagrams for hyperstaticity
3. Using elastic curves to check and adjust

Limitations:

1. limited to orthogonal portal frames under vertical loading
2. Slow and cumbersome with hand-drawing
3. imprecise for frames with static indeterminacy more than one degree

(Wolfe 1921)

Intuitive and insightful,
But still only a analyzing method,
And an incomplete one...



How to design hyperstatic rigid frames insightfully
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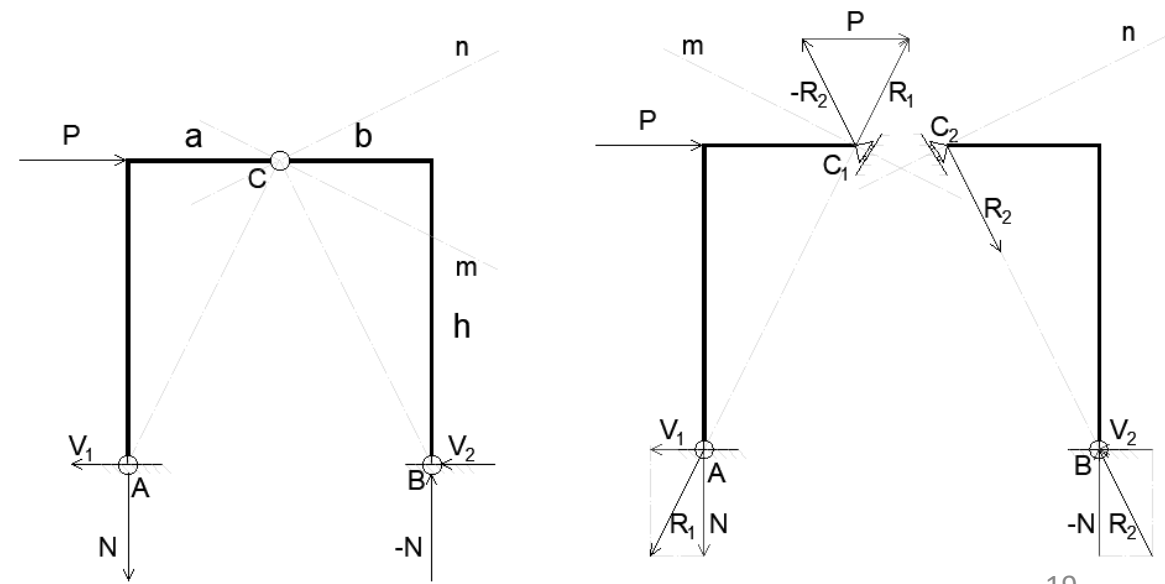
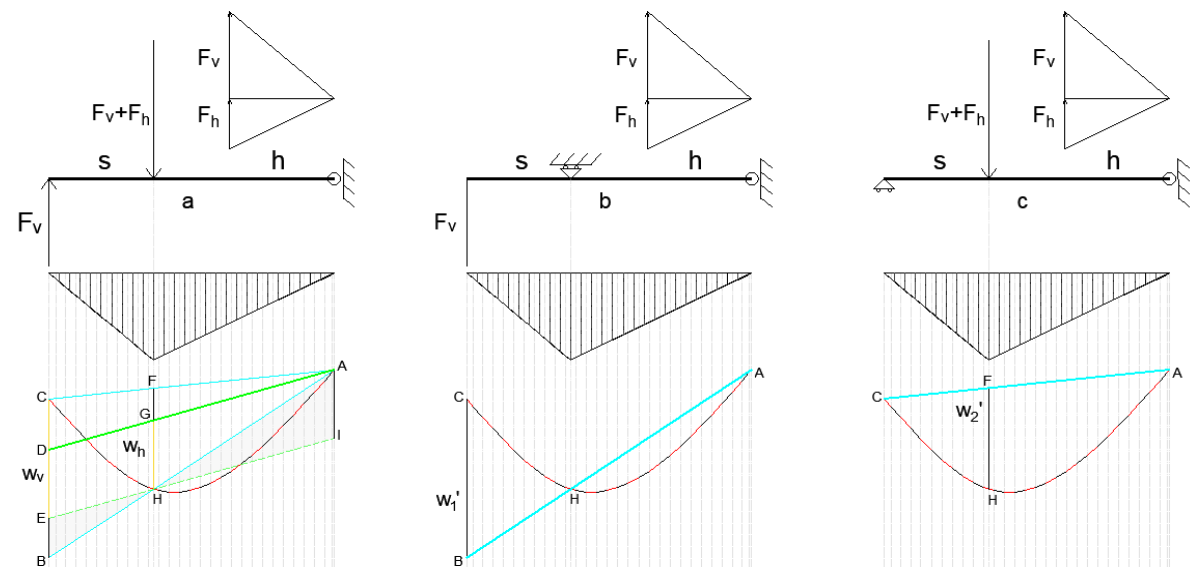
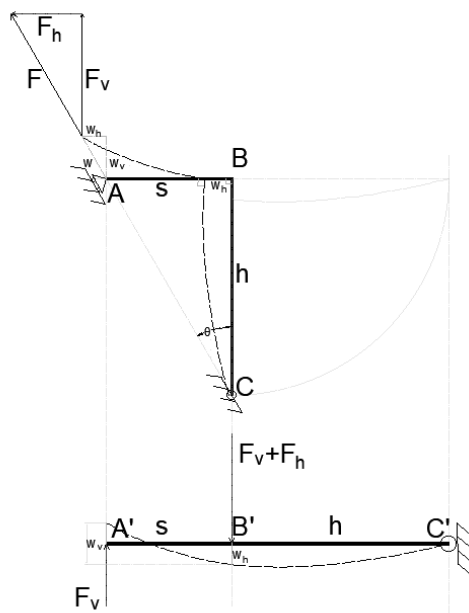
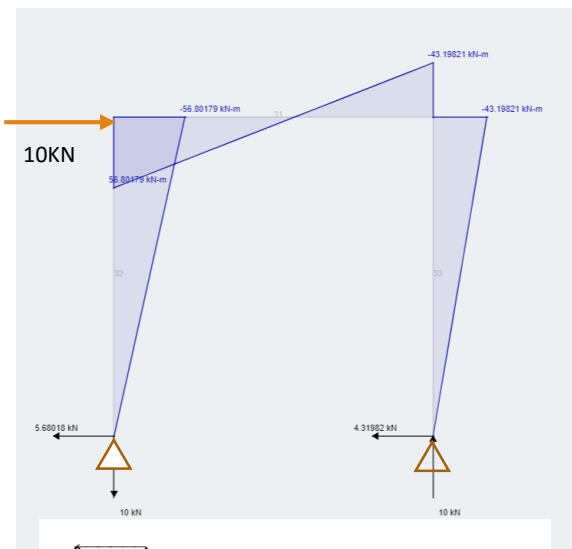
LIMITATIONS:

1. Limited to orthogonal portal frames under vertical loading
2. Slow and cumbersome with hand-drawing
3. Difficult to modify

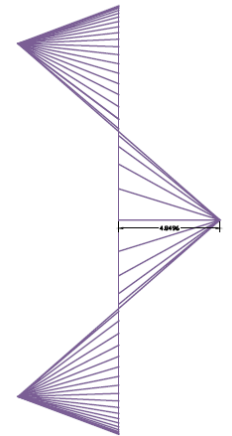
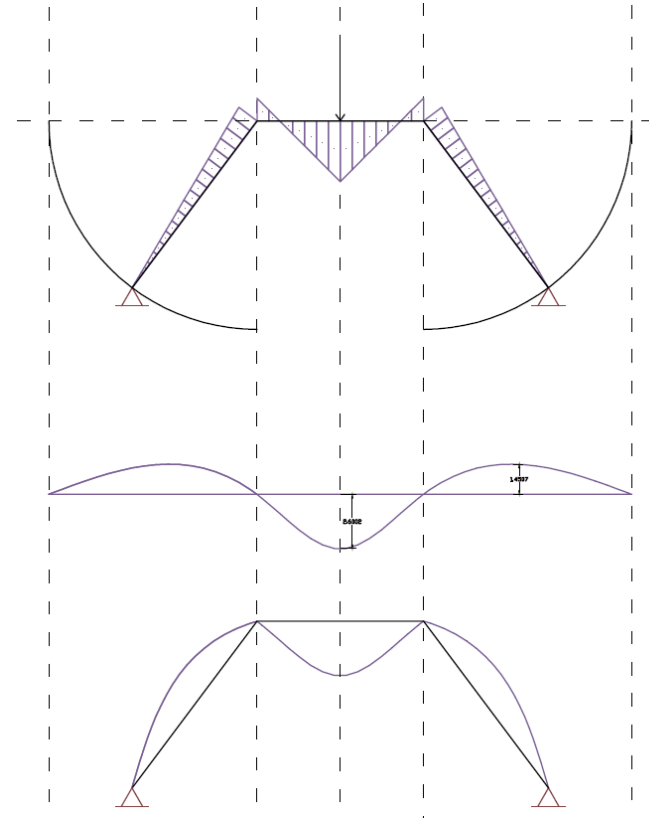
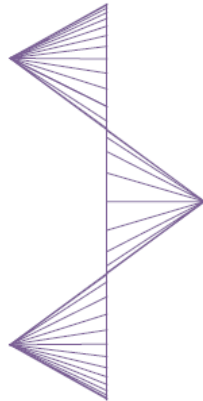
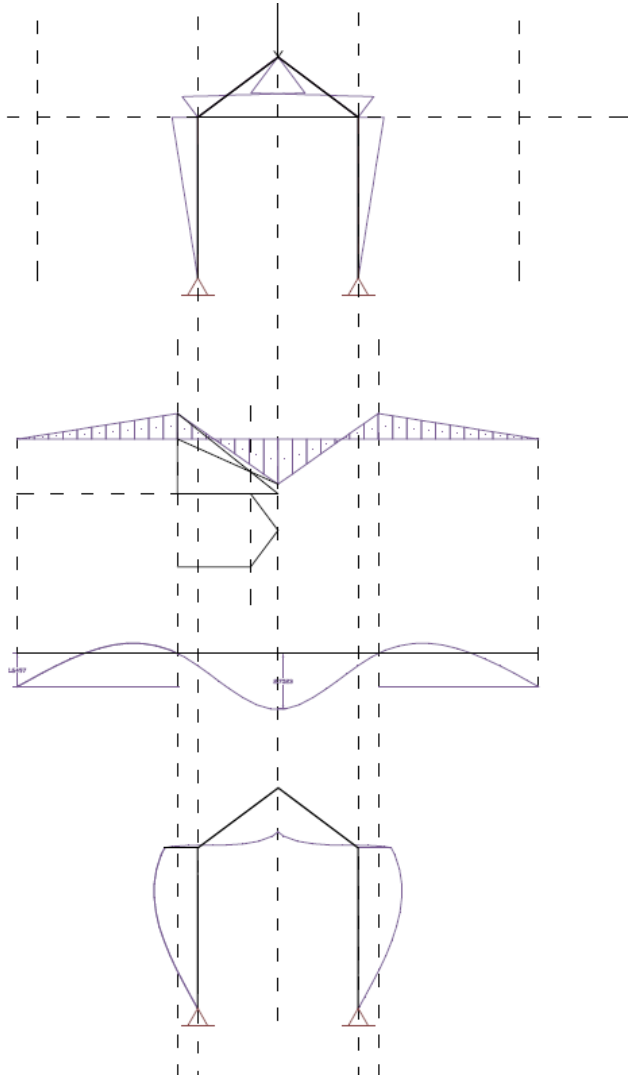
DEVELOPMENT TO BECOME A DESIGN TOOL

1. Portal frames under horizontal loading
2. The portal frames with oblique members
3. Multi-story and multi-span frames
4. Computerization and parameterization

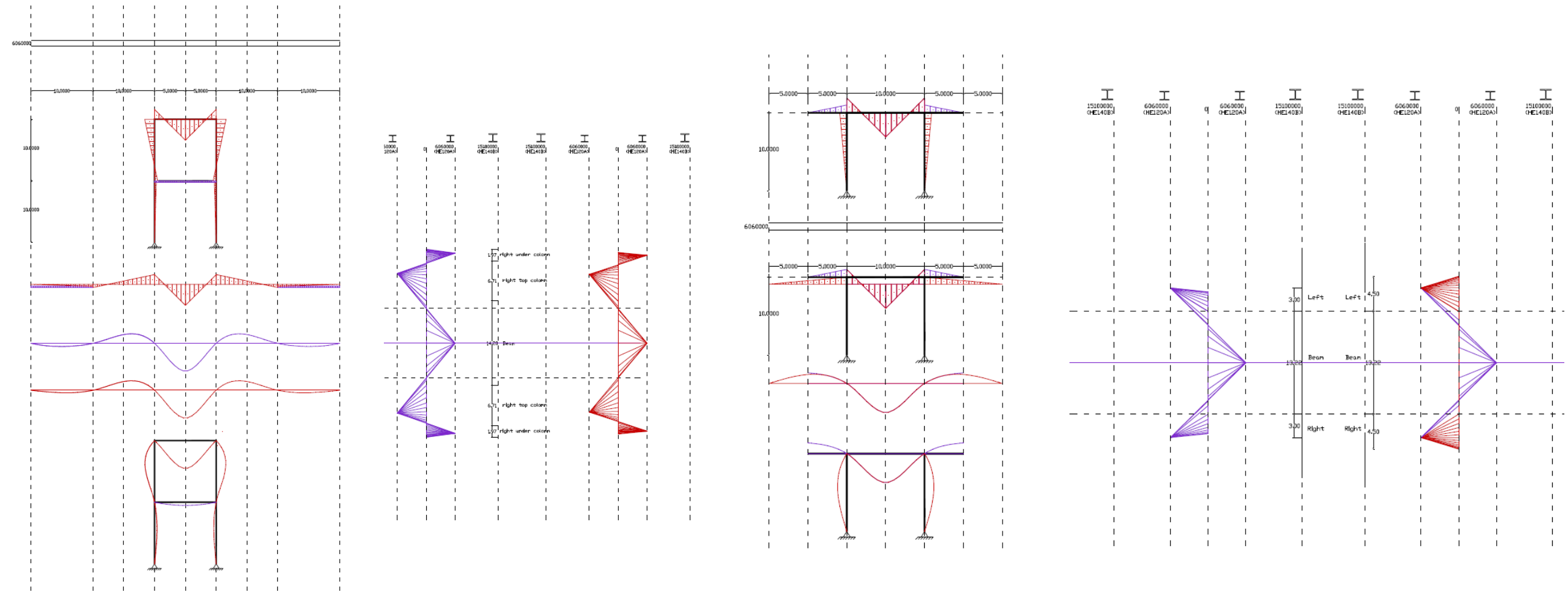
1. Portal frames under horizontal loading



2. Portal frames with oblique members

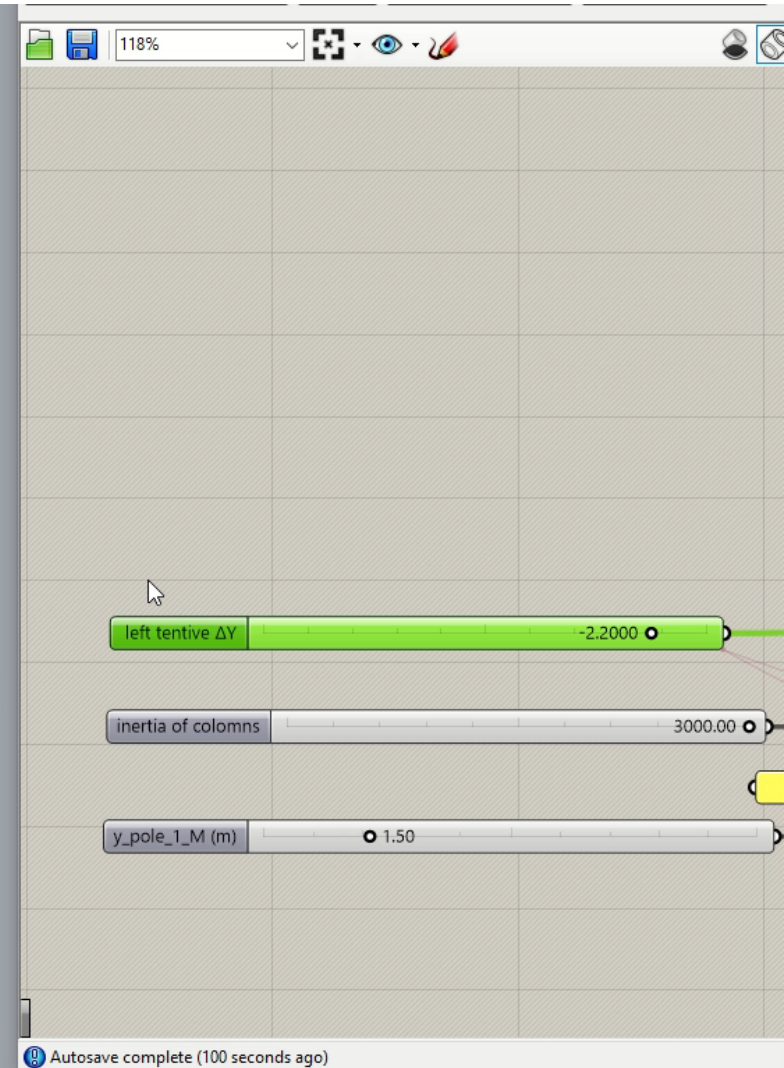
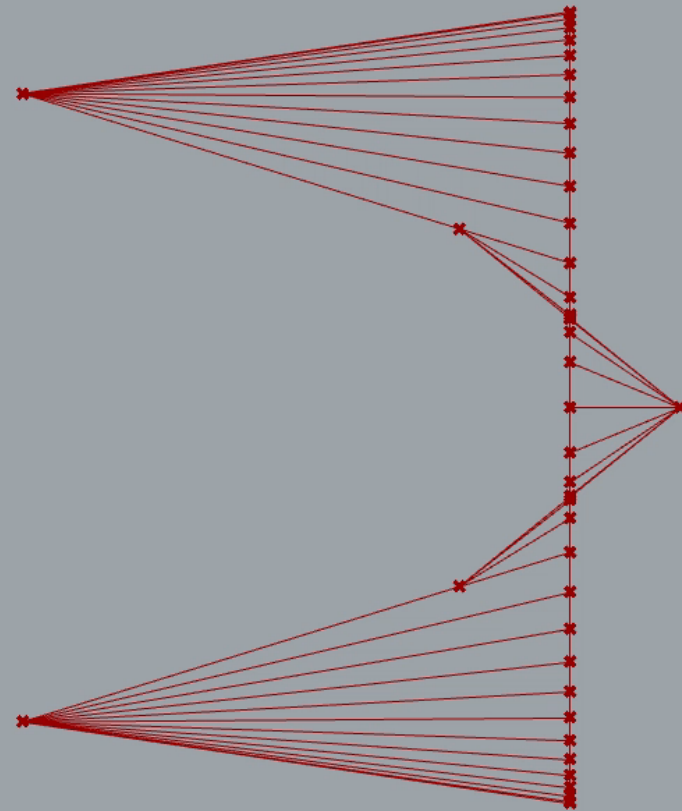
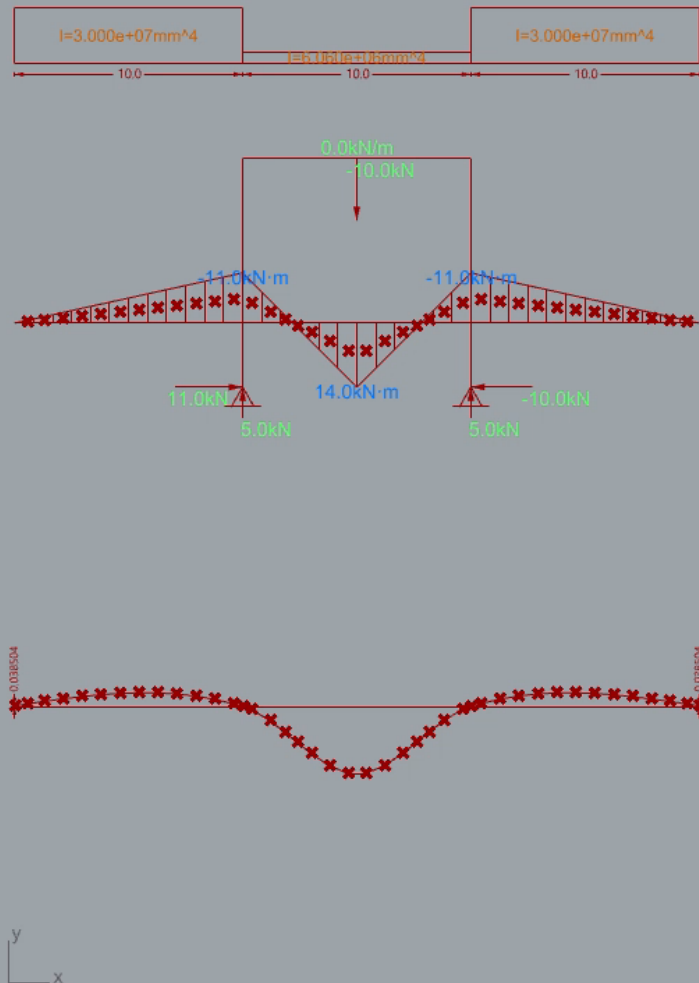


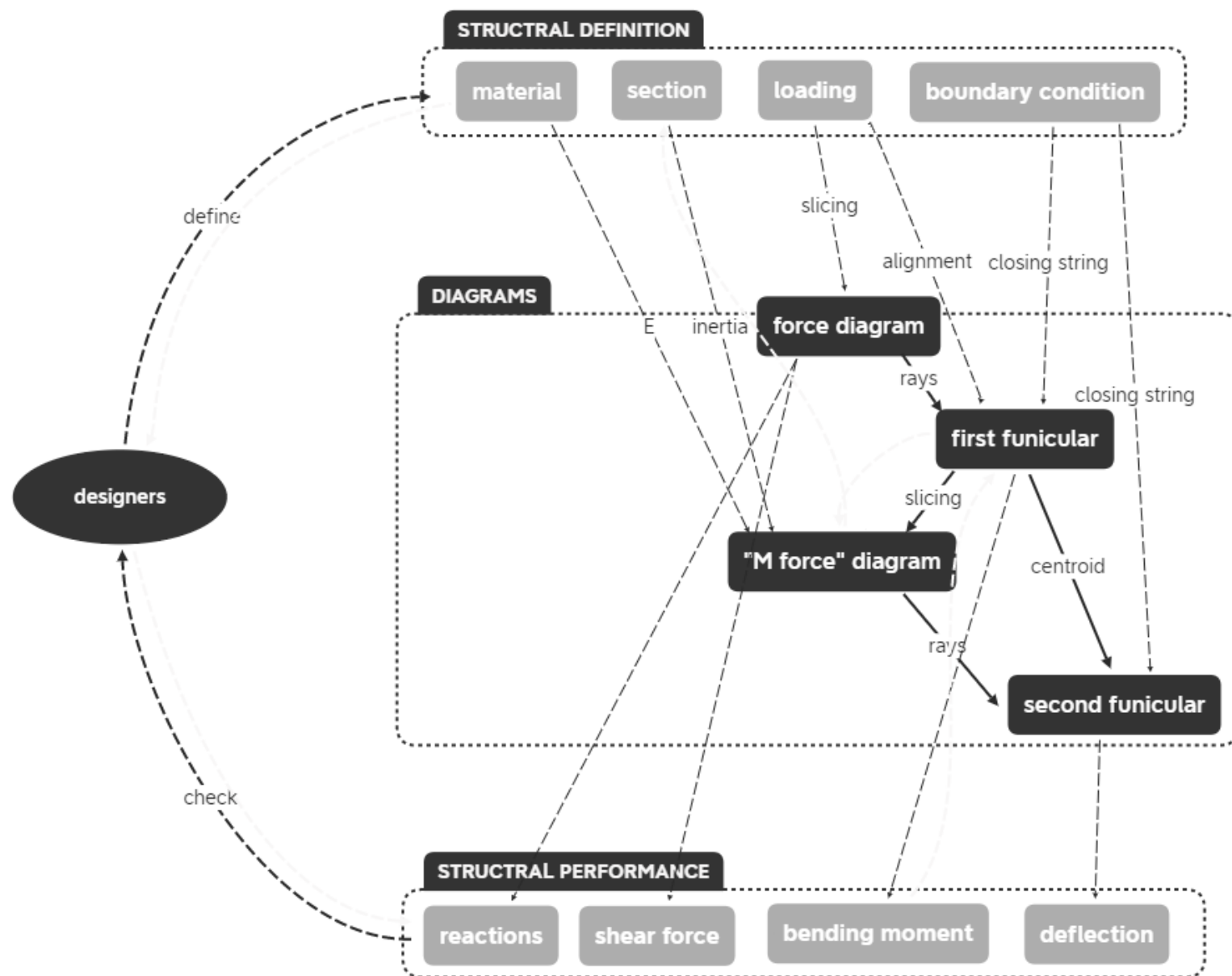
3. Multi-story and multi-span frames

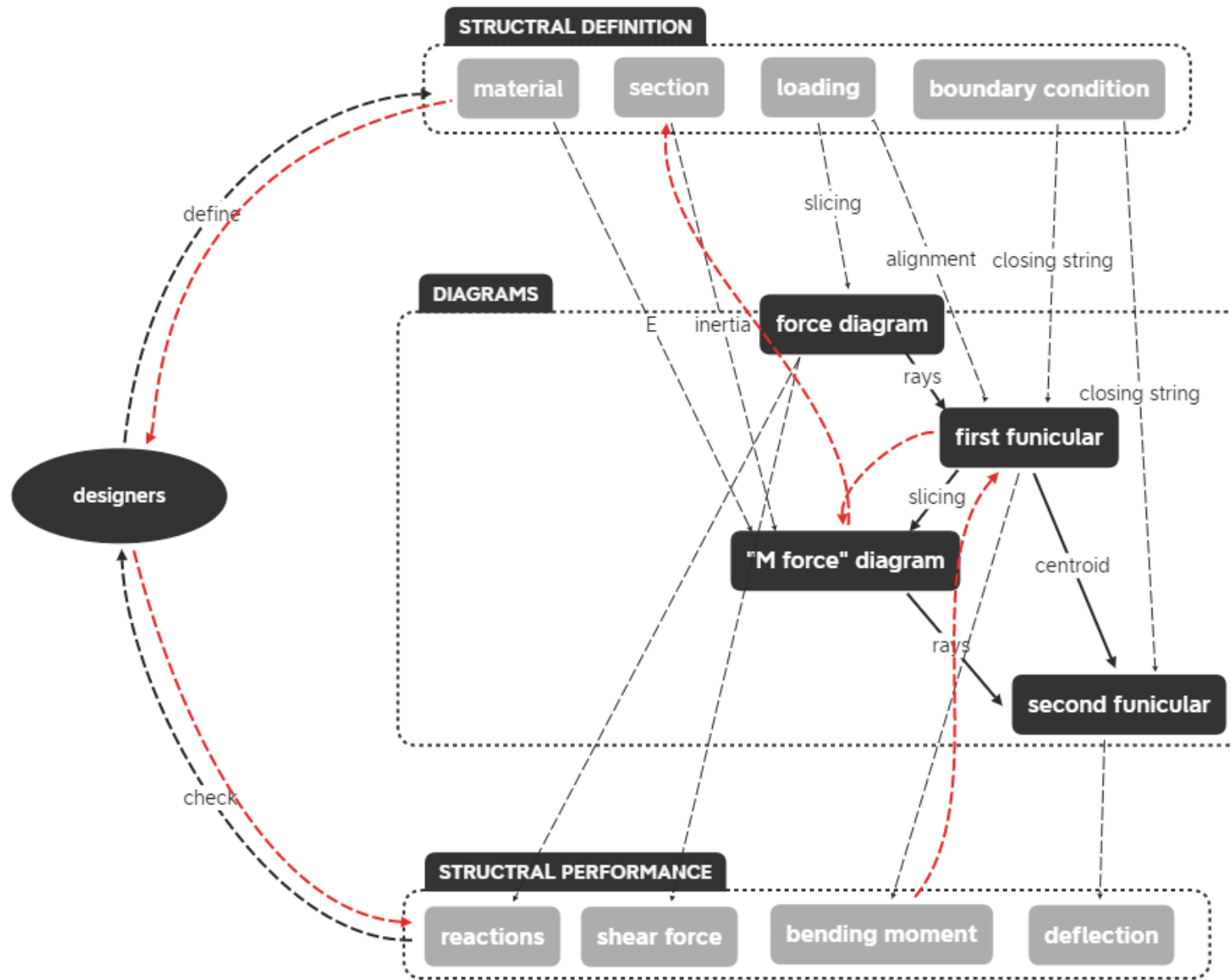


4. Computerization and parameterization

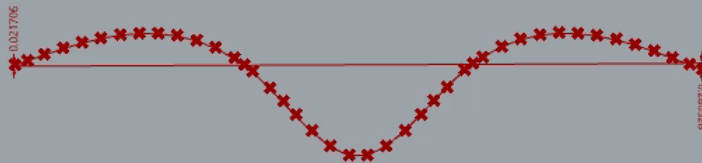
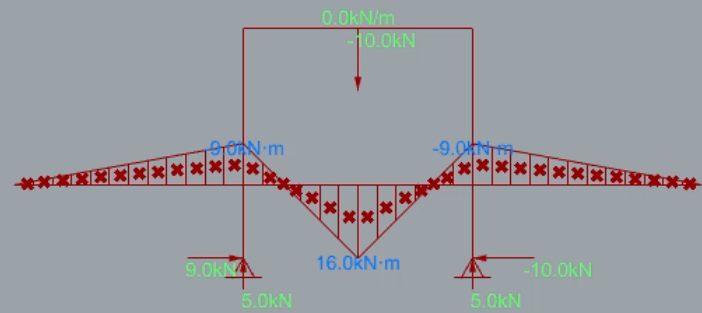
Top







Top ▾



118% ▾

left tentative ΔY -1.8000

inertia of columns

y_pole_1_M (m)

Number Slider (left tentative ΔY)
Numeric slider for single values
Floating point accuracy
Lower limit: -5.0000
Upper limit: -1.8000
Value: -1.8000
Factor: 100%

Autosave complete (52 seconds ago)

TO BE CONTINUED...

5. DISCUSSION

- **Advantages**

- Insightful
- Chronology-free
- Less demanding for mathematics

- **Limitation**

- The relation between form(member section) and moment of inertia is still to be worked on.
- Difficulty with high degree of indeterminacy
- Interactivity is still limited

THANK YOU !