Graphic statics in arches and beams

1e mentor - Andrew Borgart

2e mentor - Thijs Welman

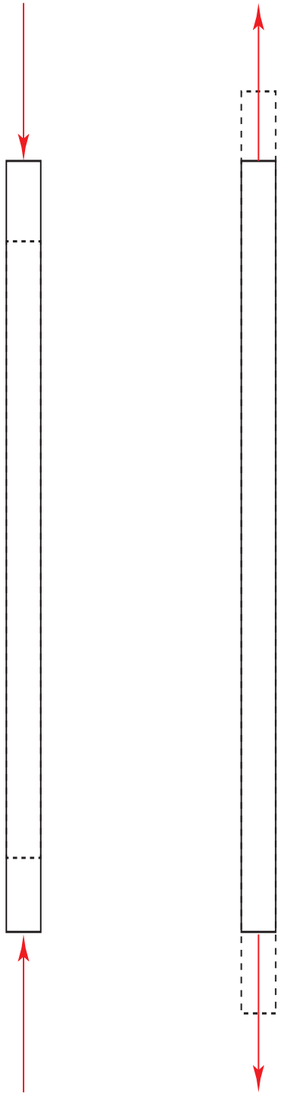
31-01-2014

Infinity bridge door Expedition Engineering, Stockton-on-Tees

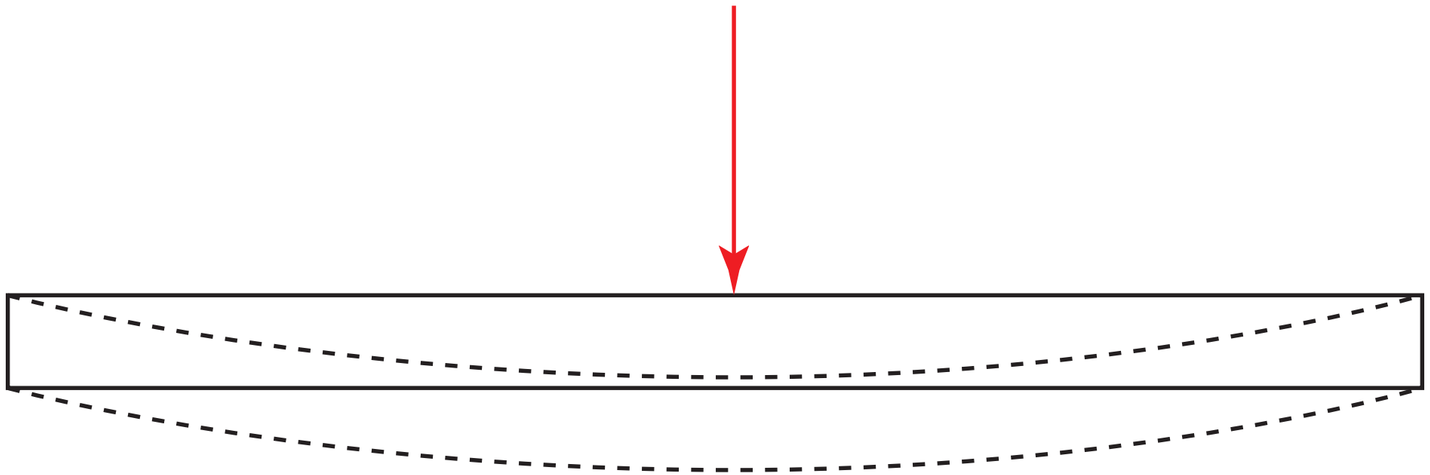
Krachtswerking

Krachtswerking

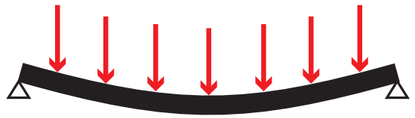
Normaalkrachten

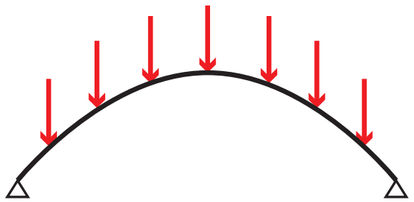


Buigend moment



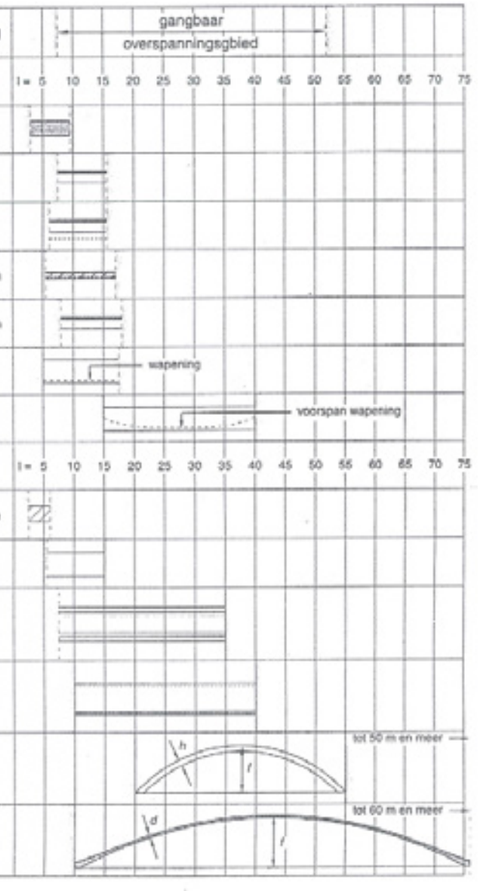
Dimensionering





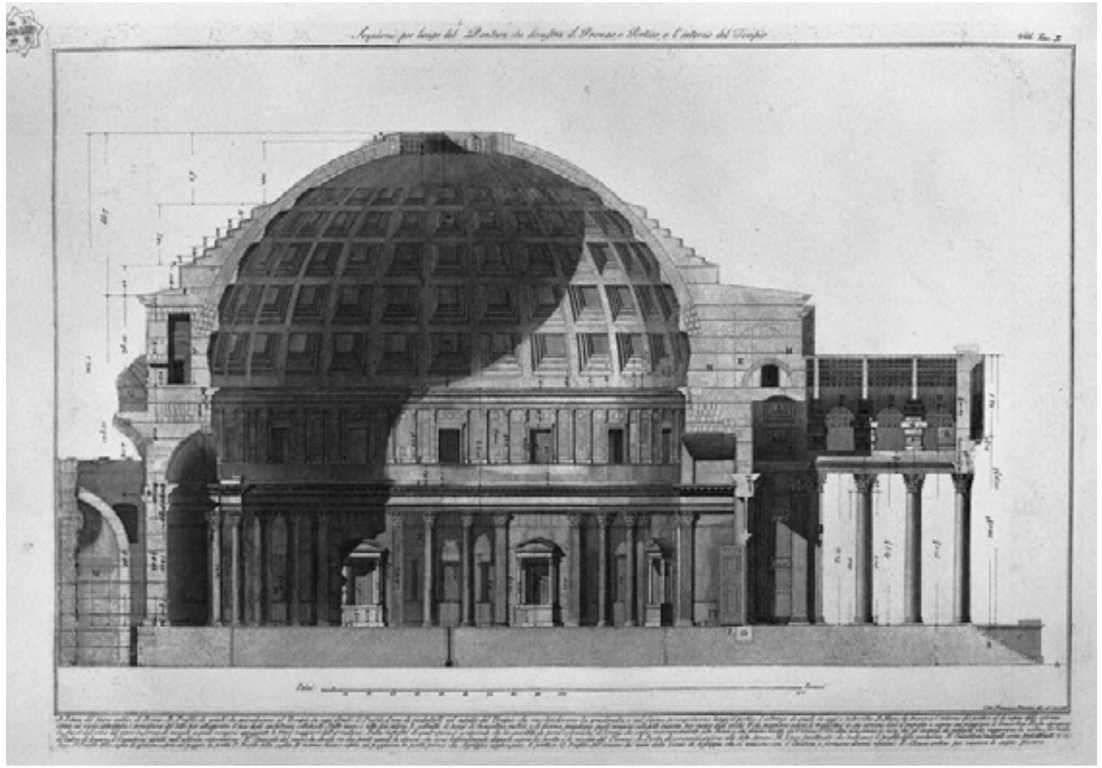
Tabel 3.3 **Schattingsregels overspanningsconstructies in beton**

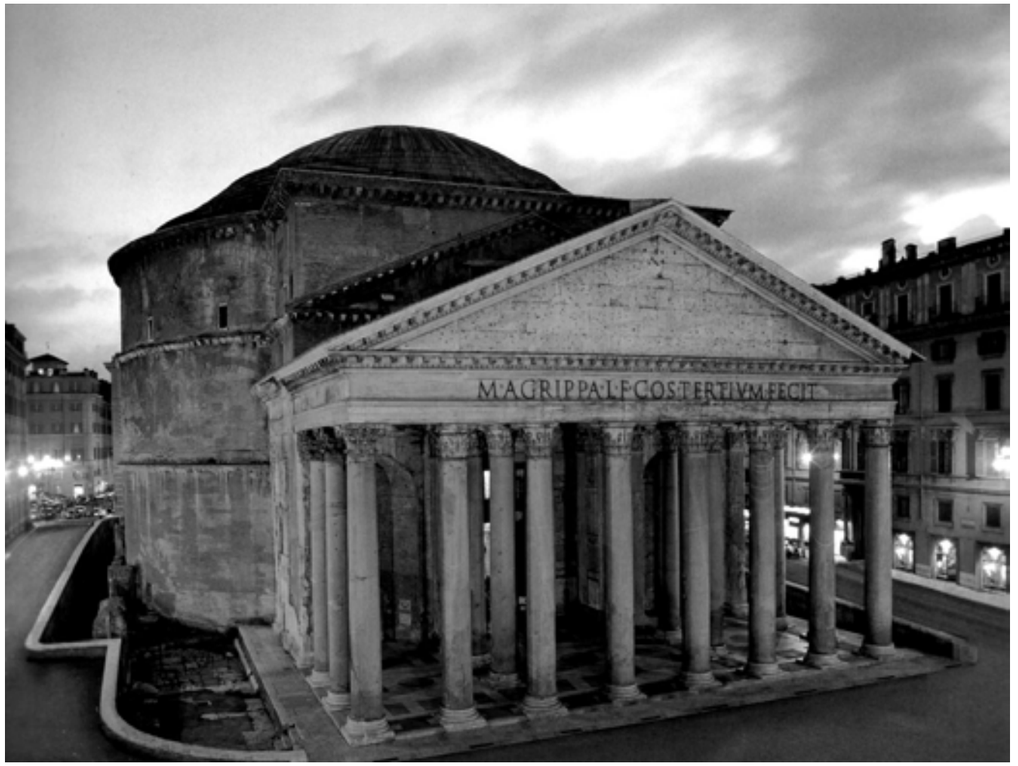
benaming	doorsnede	h	opmerking
VLOERCONSTRUCTIES			
vlakkeplaatvloeren		$\frac{1}{25} - \frac{1}{30}\,l$	
ribben- en cassettevloeren		$\frac{1}{20} - \frac{1}{25}\,l$	
balkenvloeren		$\frac{1}{10} - \frac{1}{20}\,l$	
kanaalplaatvloeren		$\frac{1}{35} - \frac{1}{40}\,l$	$b = 1200$ mm
TT - plaatvloeren		$\pm \frac{1}{25}\,l$	$b = 2400$ mm
gewapende balken ter plaatse gestort		$\frac{1}{10} - \frac{1}{12}\,l$	$b = \frac{1}{2}\,h$
voorgespannen - balken ter plaatse gestort		$\frac{1}{15} - \frac{1}{20}\,l$	$b = \frac{1}{2}\,h$
DAKCONSTRUCTIES			
cellenbeton dakplaten		$\pm \frac{1}{30}\,l$	$b = 600$ mm
voorgespannen rechthoekige balken		$\pm \frac{1}{20}\,l$	$b = \frac{1}{3}\,h$
voorgespannen I-balken		$\frac{1}{15} - \frac{1}{20}\,l$	$b = \frac{2}{7}\,h$
vouwdaken		$\frac{1}{8} - \frac{1}{15}\,l$	
boogspanten		$\frac{1}{30} - \frac{1}{40}\,l$	$f = \frac{1}{6}\,l$ $b = \frac{1}{3}\,h$
koepelschalen		$l = \frac{1}{4}$ à $\frac{1}{8}\,l$	$d \geq 80$ mm



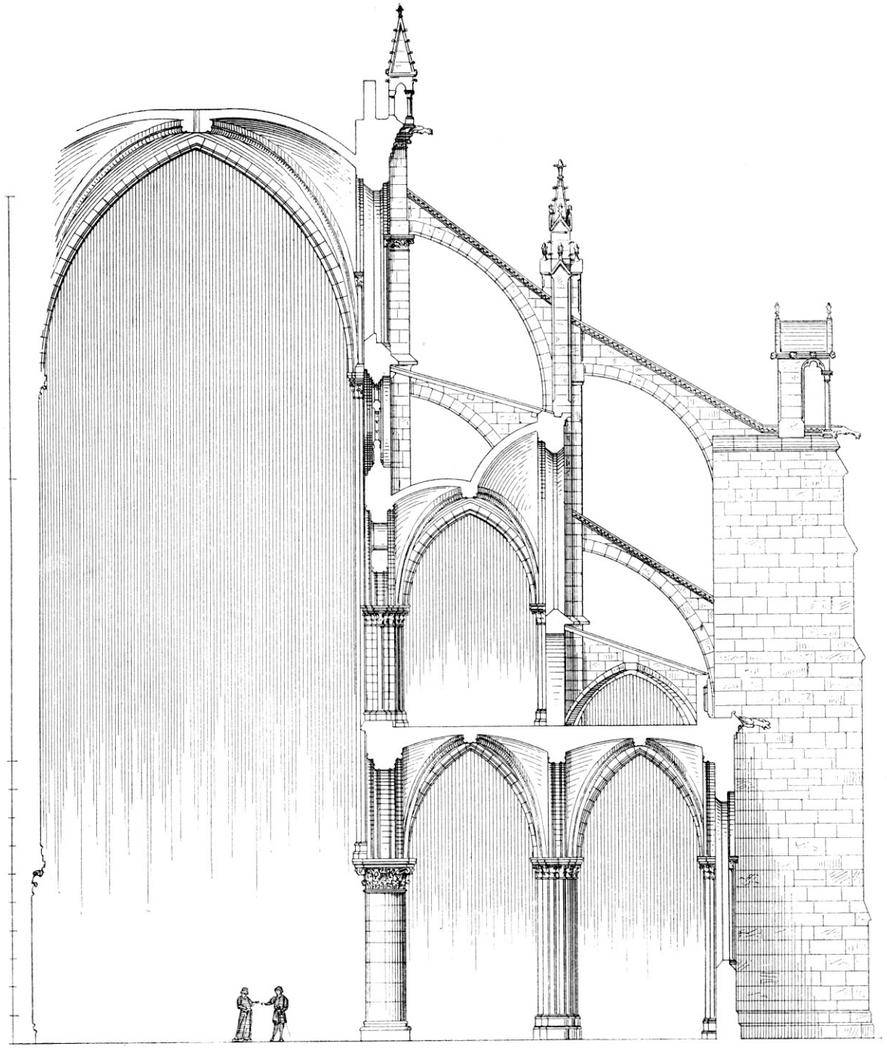
Pont du gard, Frankrijk

Pantheon, Rome





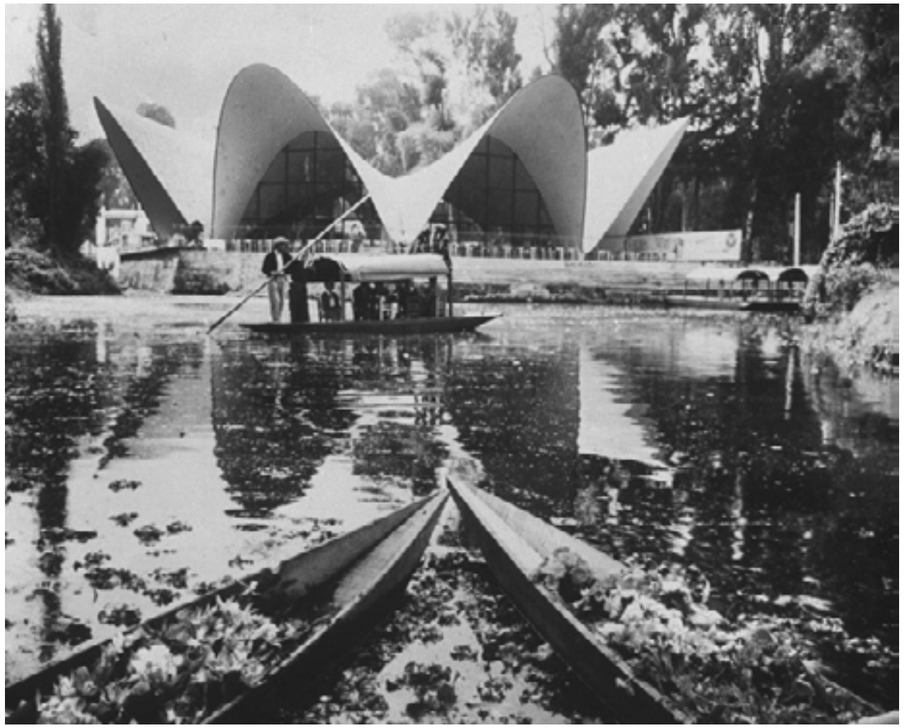
Notre Dame, Parijs

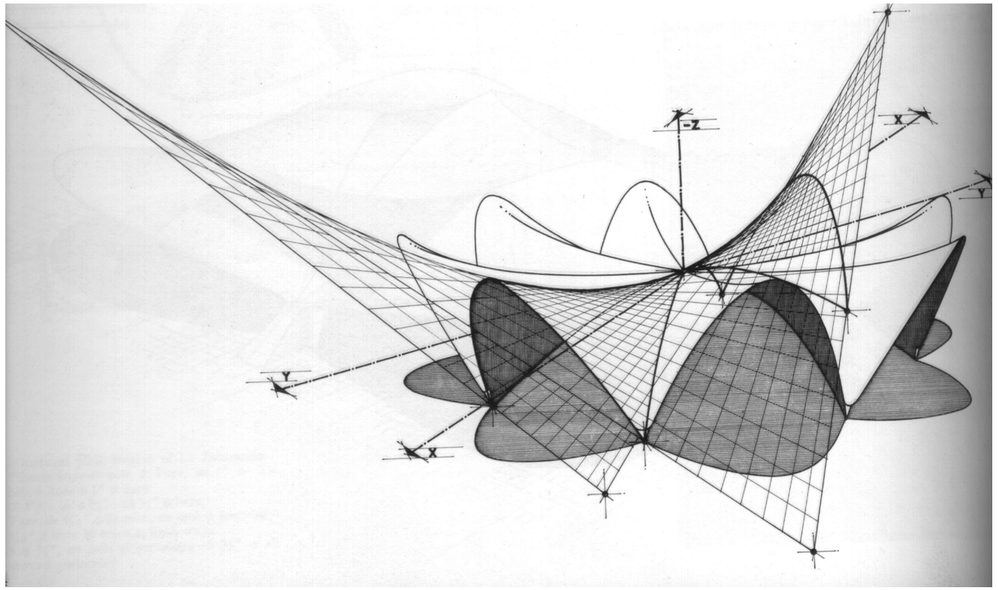


PARIS: NOTRE DAME

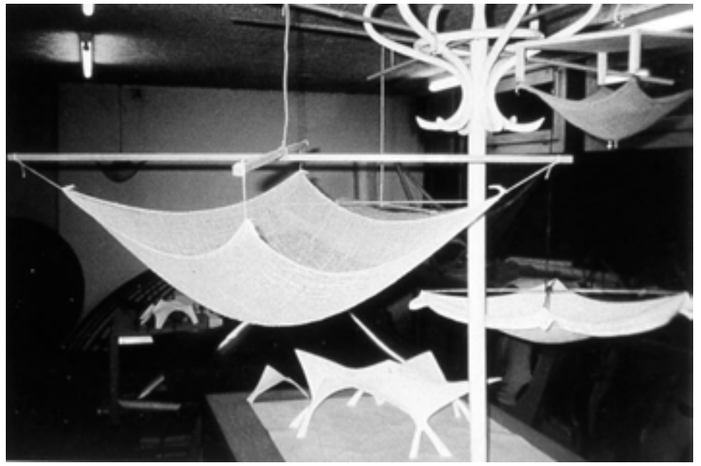
Sagrada Familia van Gaudi, Barcelona

Manantiales restaurant van Candela, Xocholmico

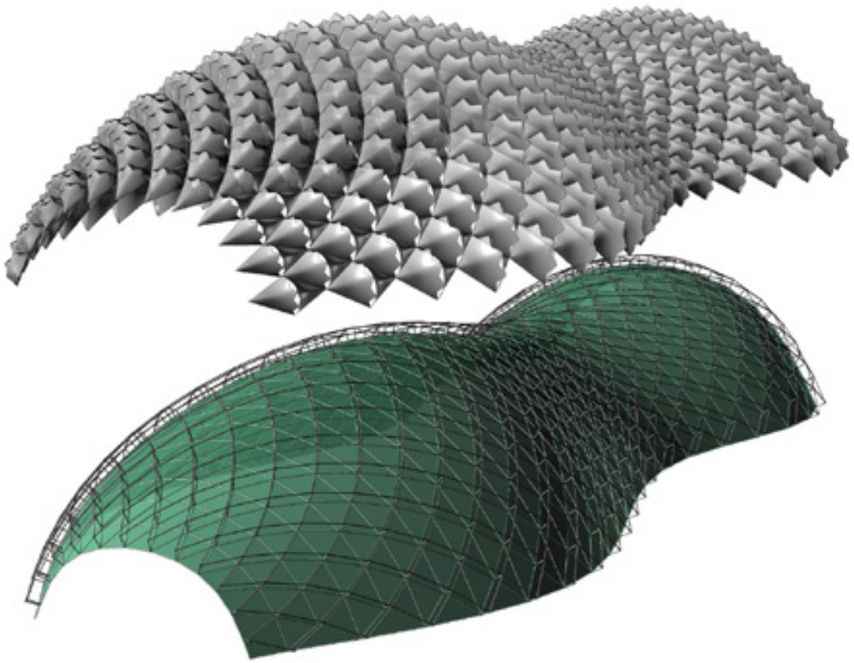


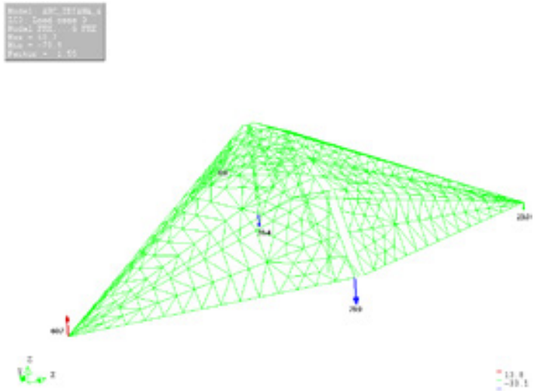


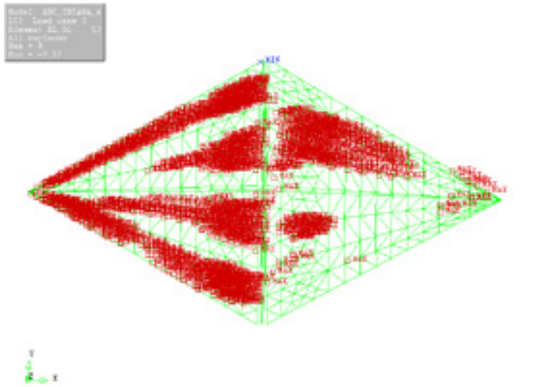
Tankstation van Isler, Deitingen

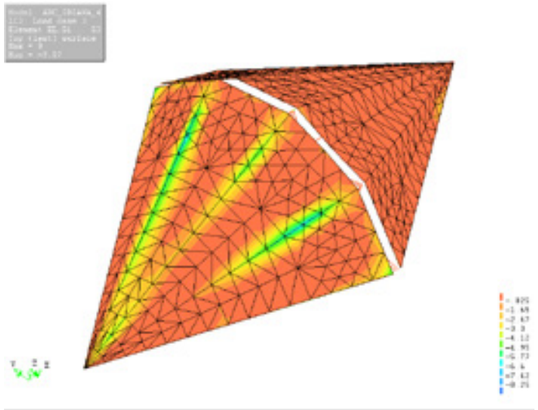


Sidney Opera van Utzon, Sidney







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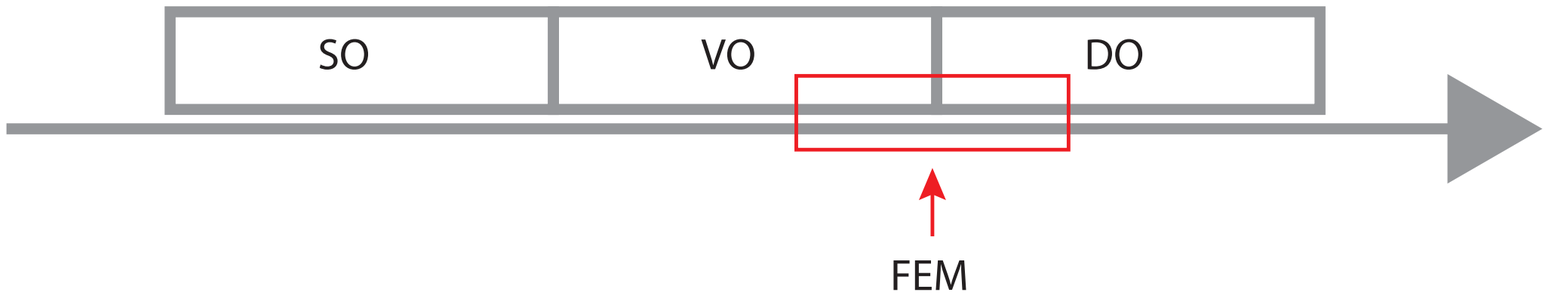
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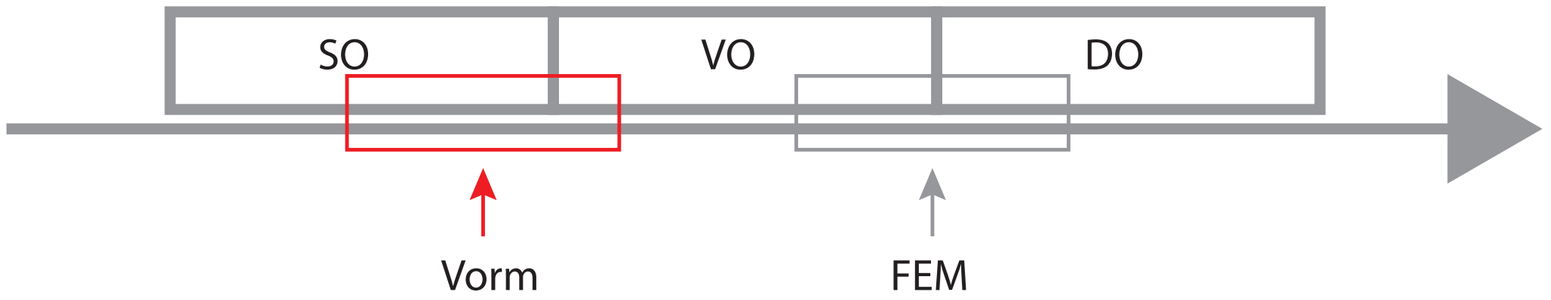
SO
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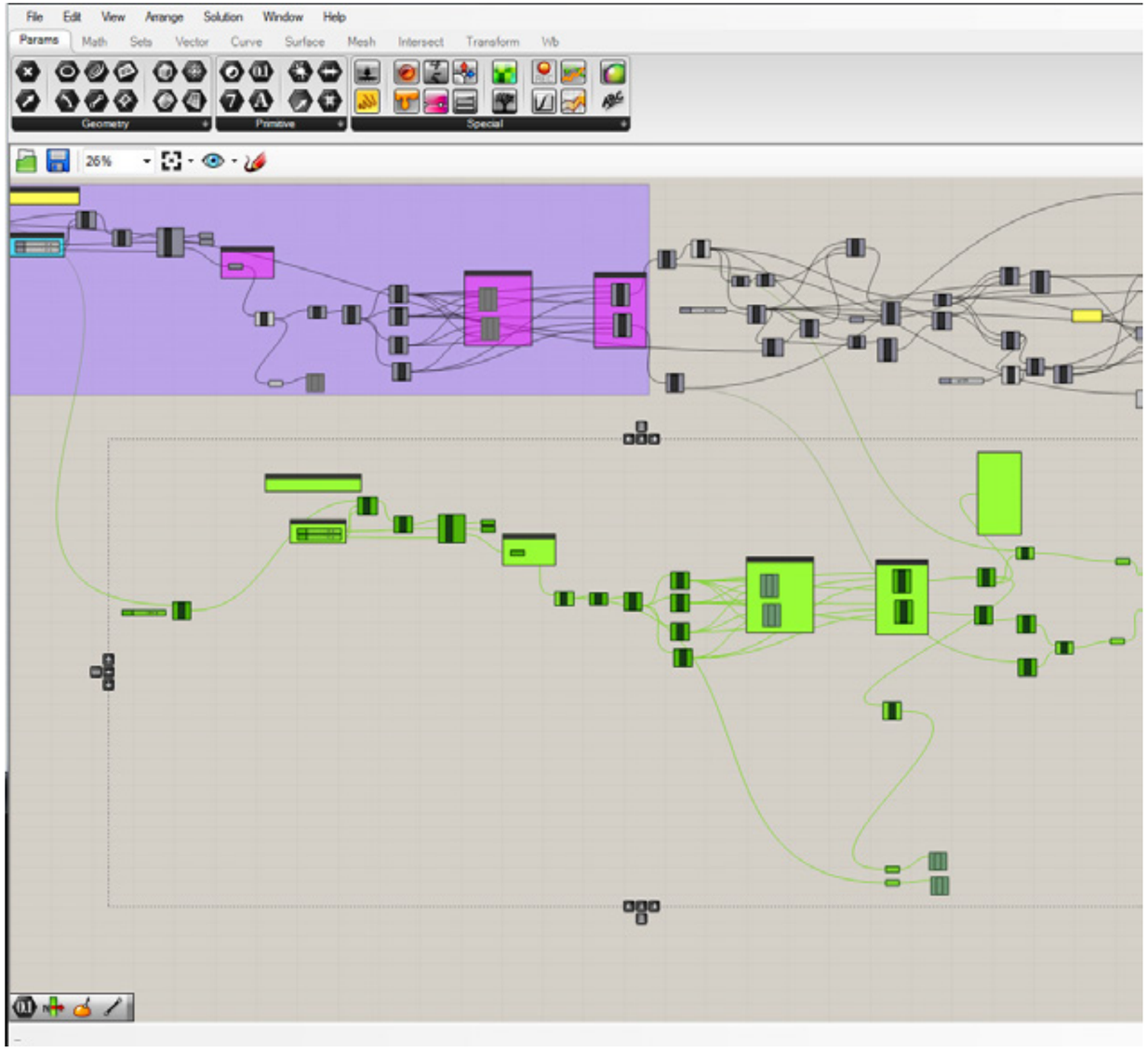
FILMPJE, te groot voor upload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Geometry
Primitive
Special
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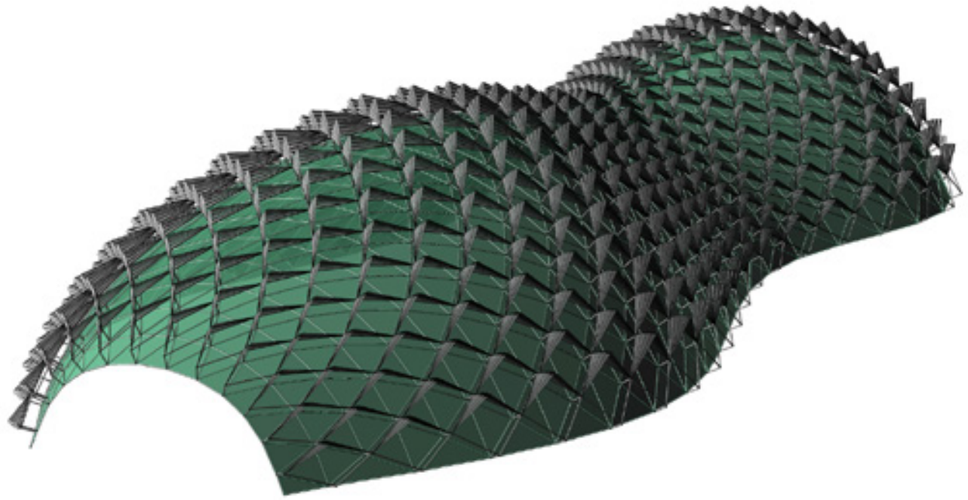
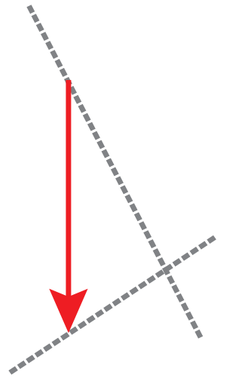
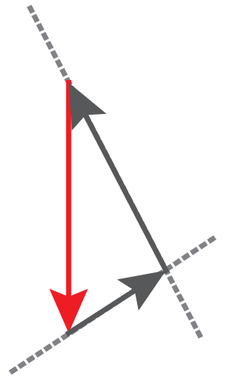


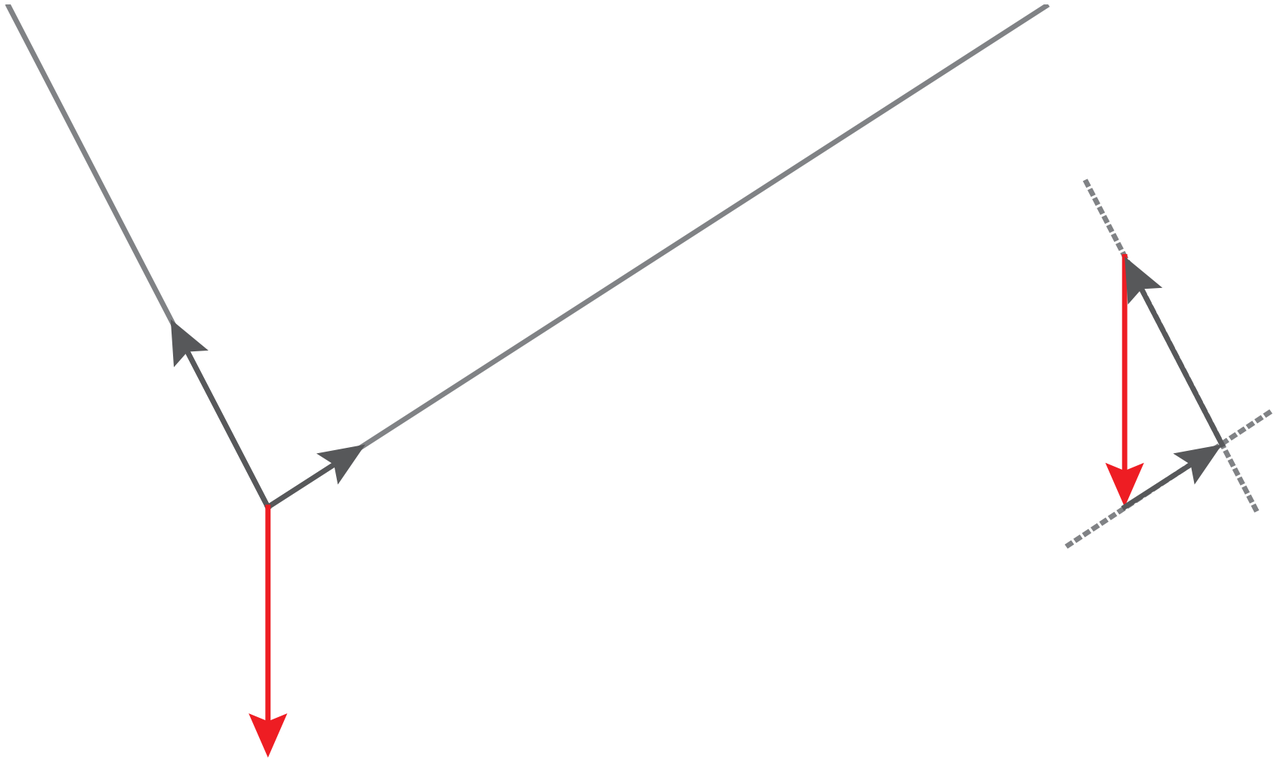
“How can analytical relations and structural analogies be used to create a parametric calculation tool, tu be used to calculate and design shells and thin plate structures?”

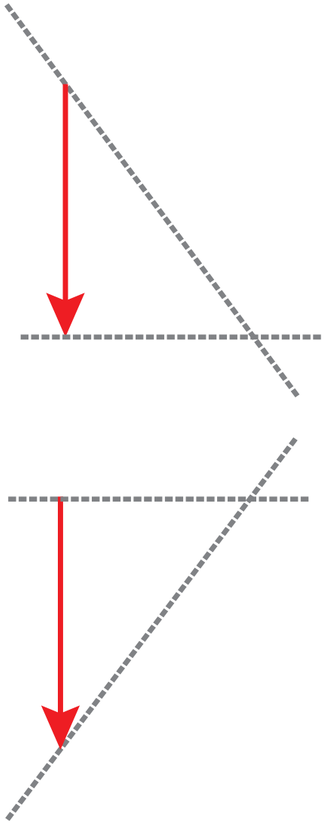
Concreet; wat is de verhouding tussen normaalkrachten en buigende momenten in gebogen balken en boogconstructies?

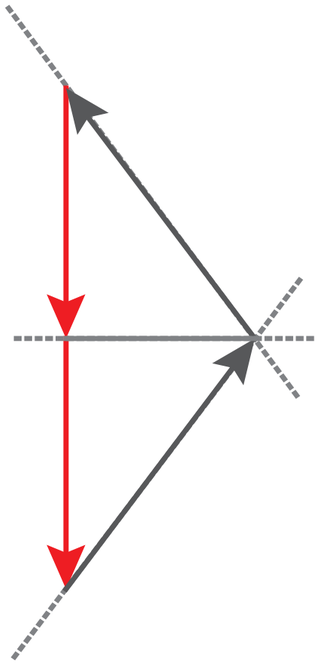
Analogie met kettingen

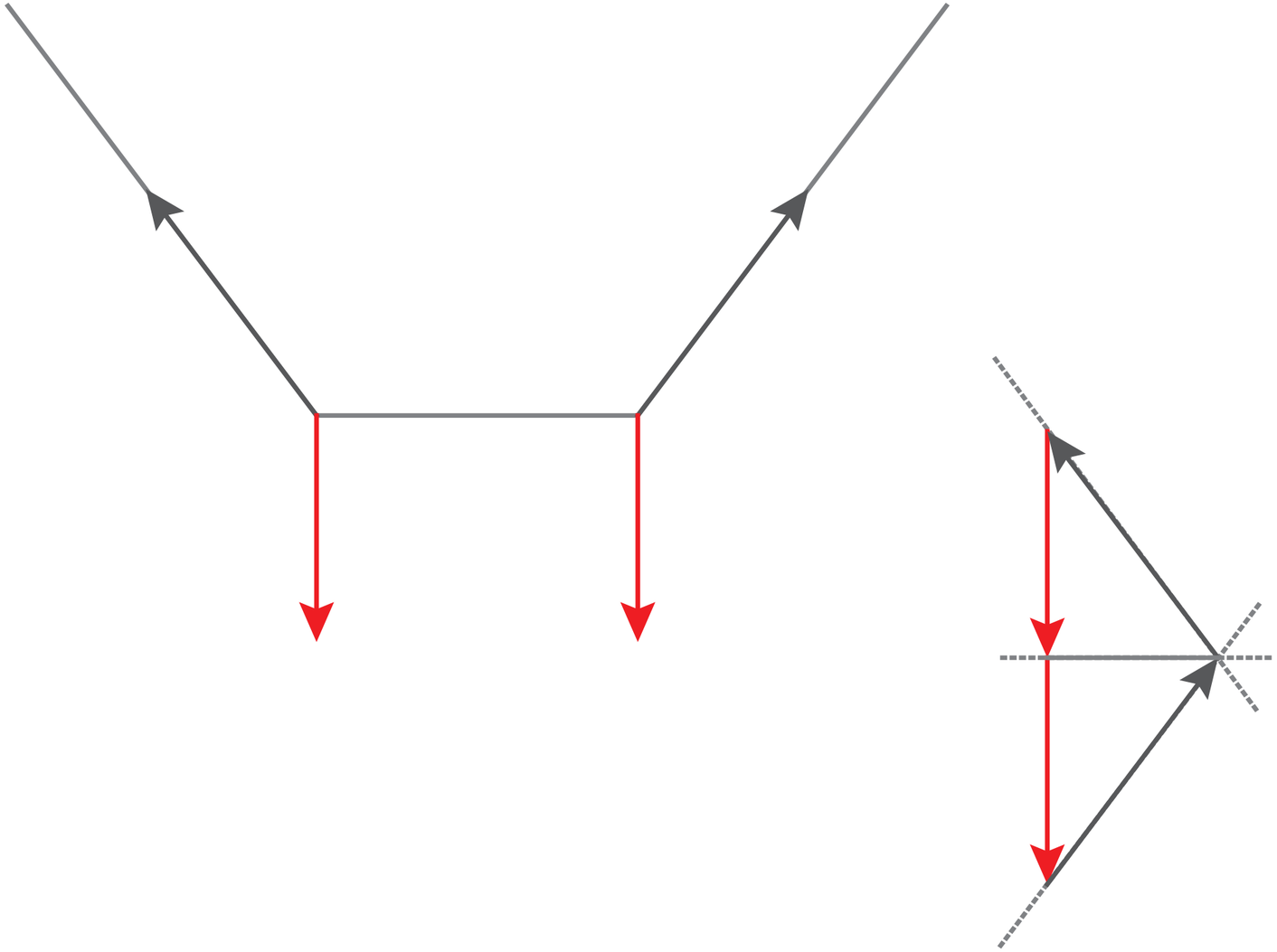


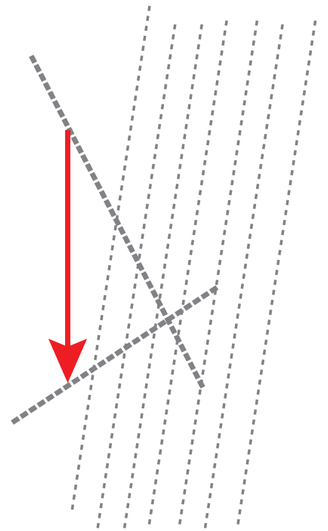


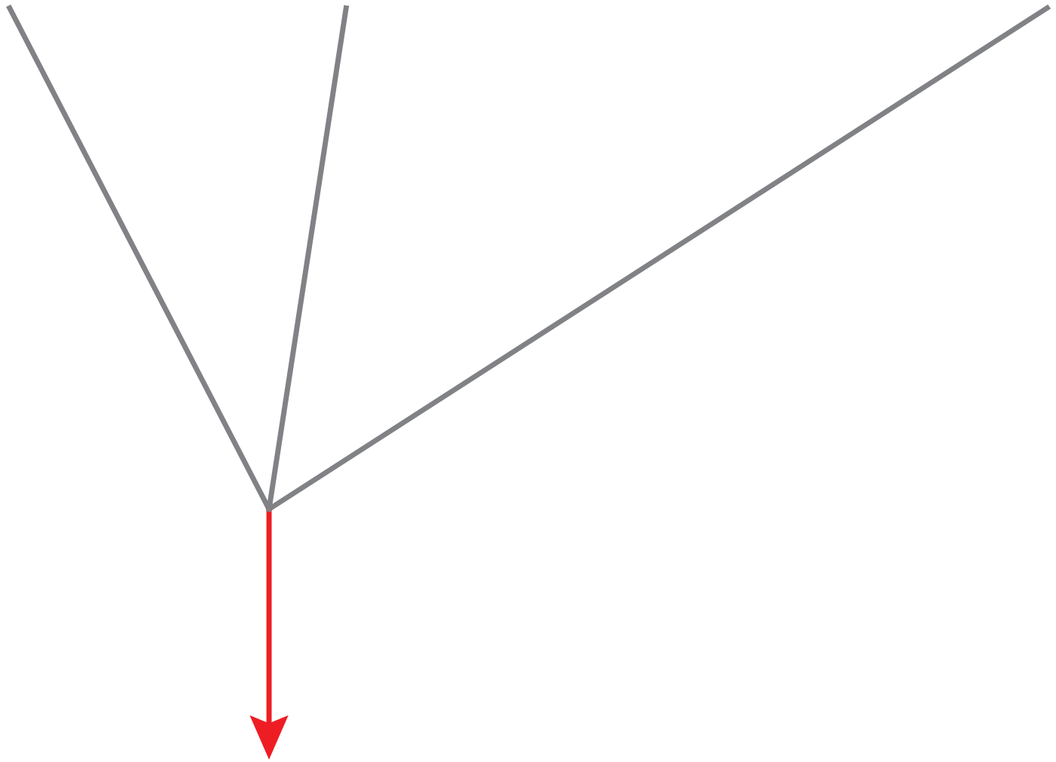


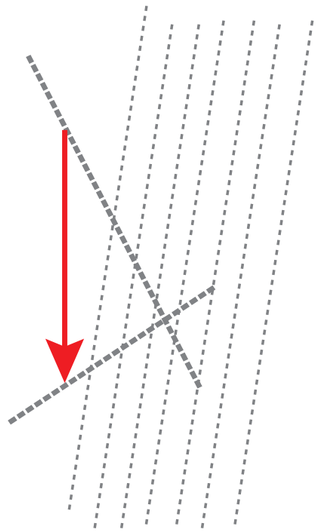










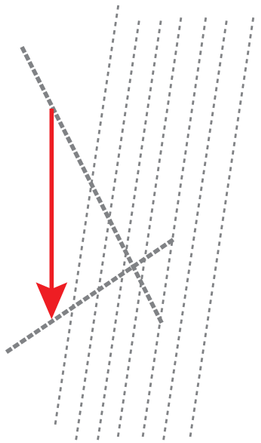


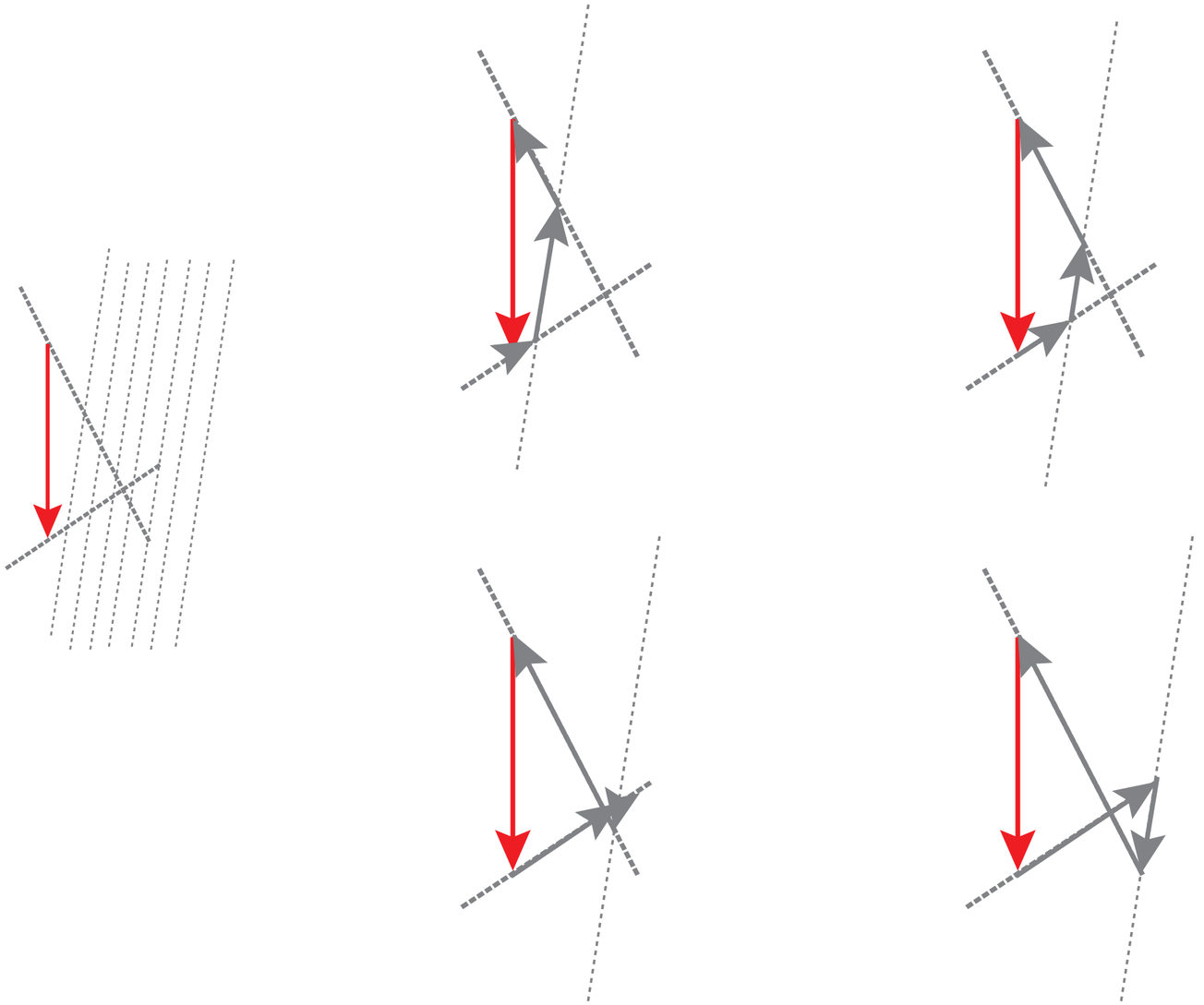
- Pierre-Louis Moreau de Maupertius (1698-1759)

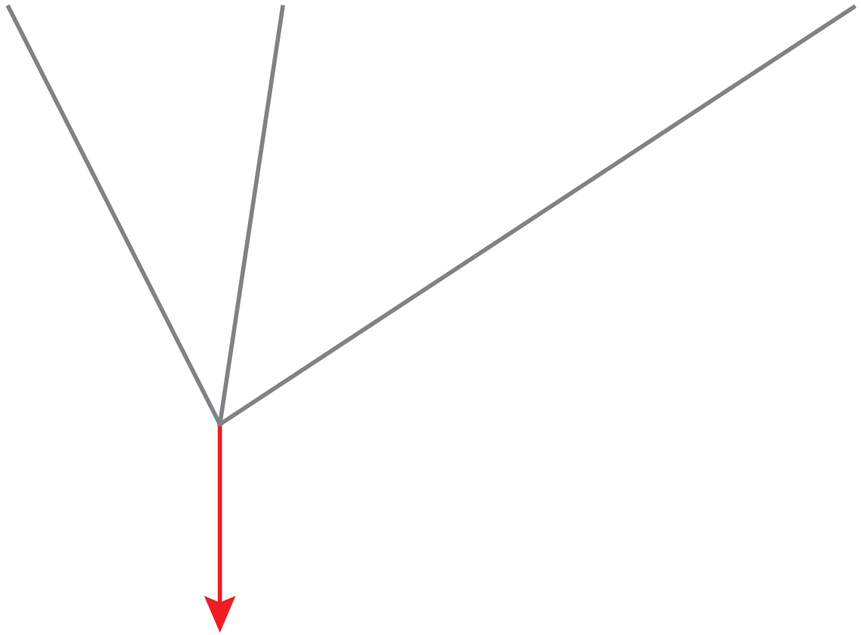
- Principe van minste energie

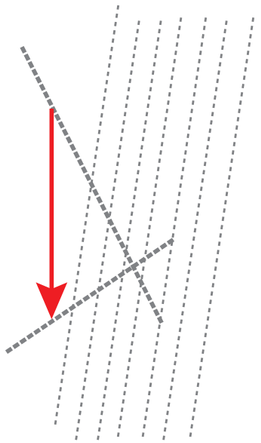
“Nature is thrifty in all its actions”

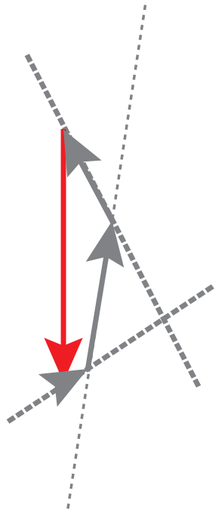
- Krachten + eigenschappen van de balk

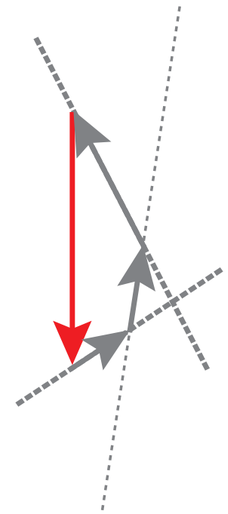


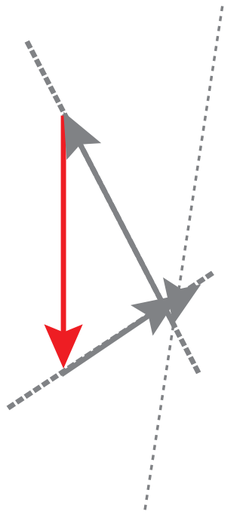


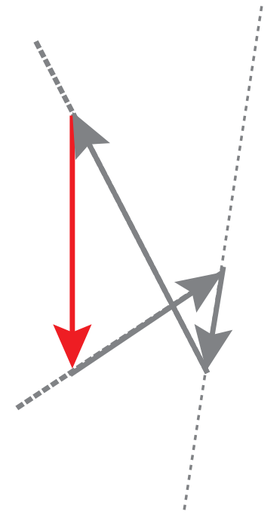


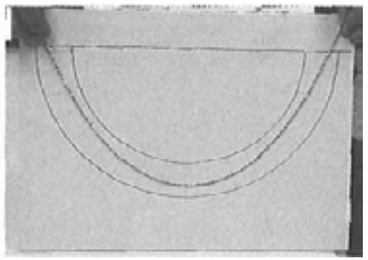


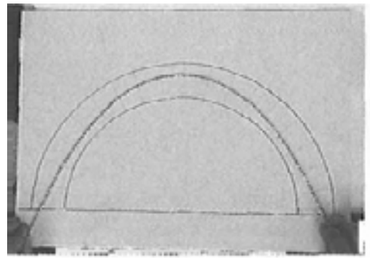


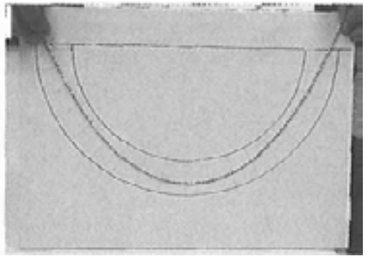


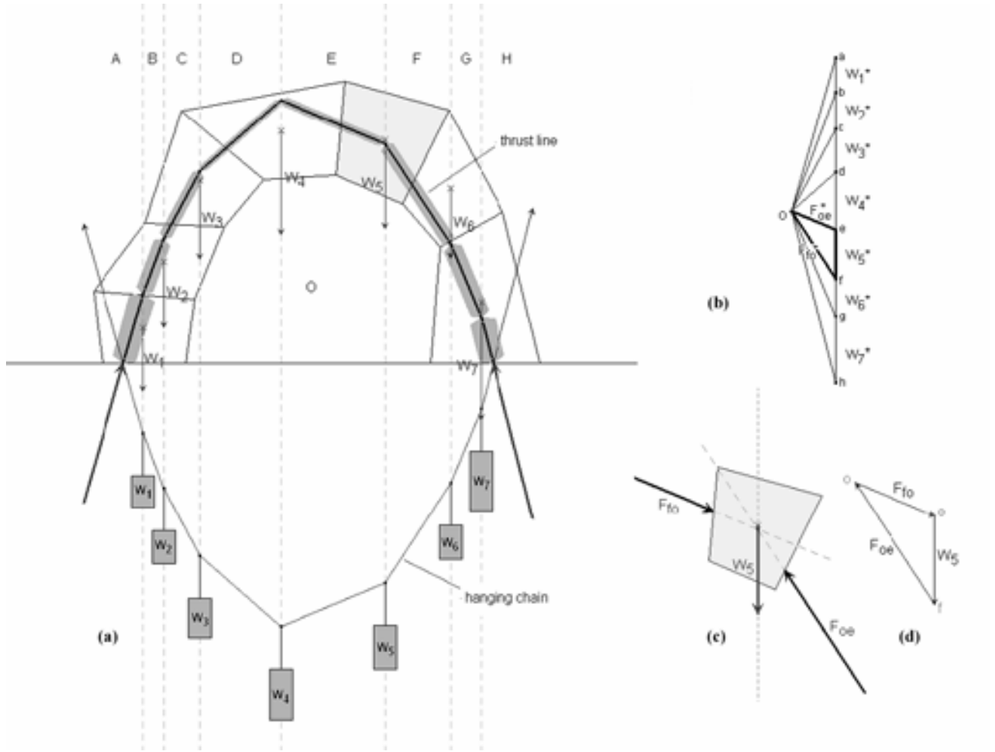


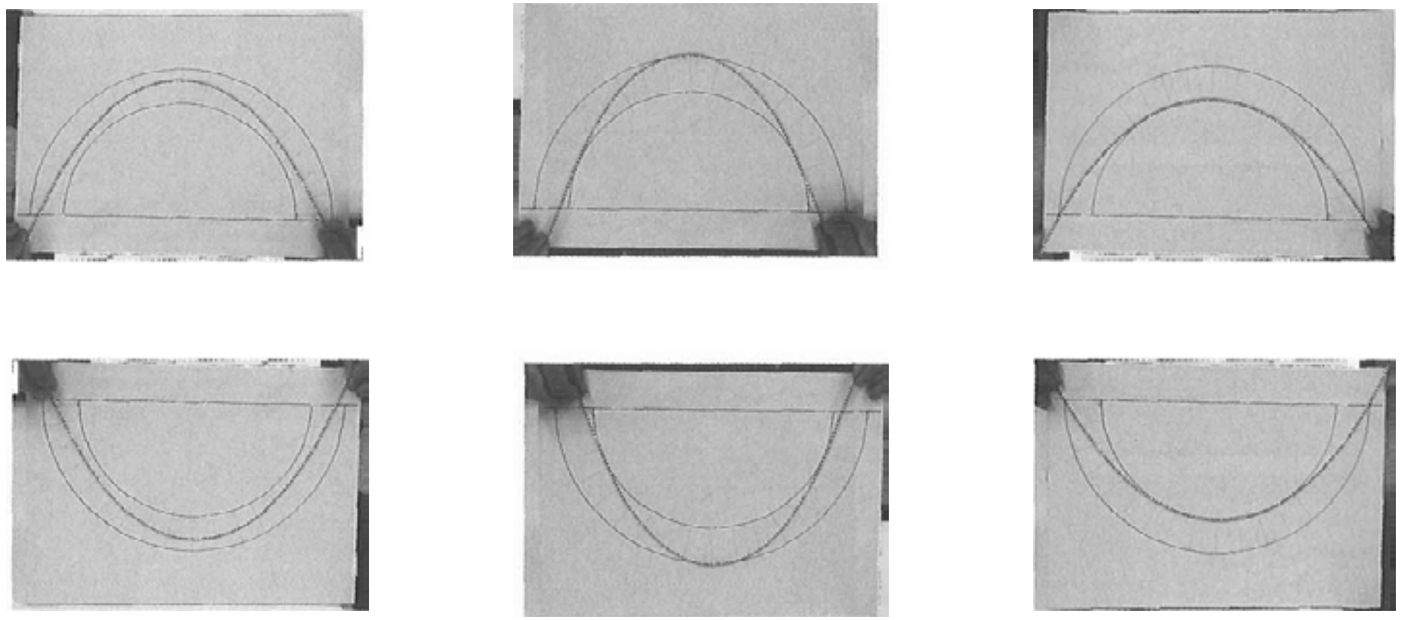


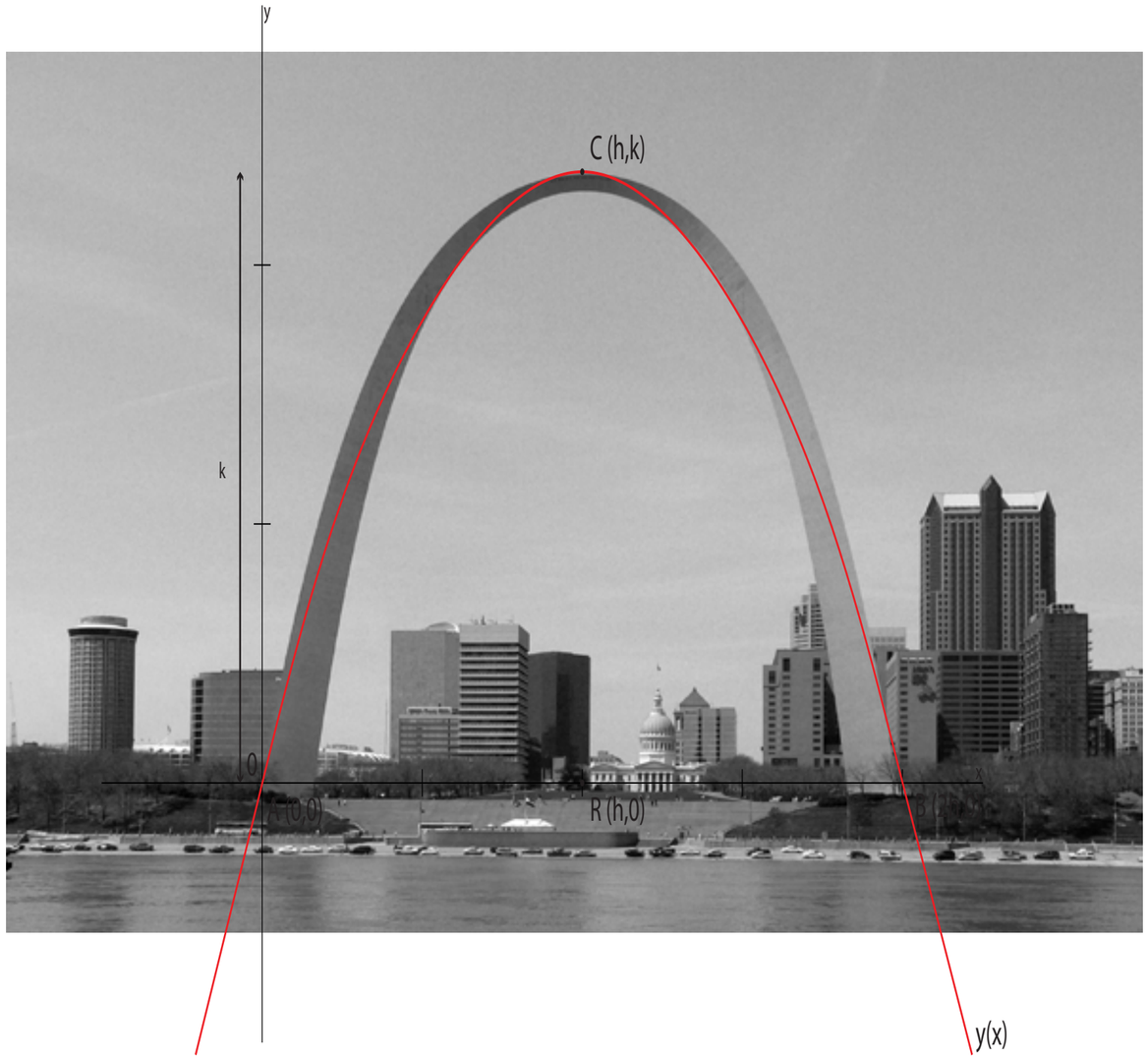




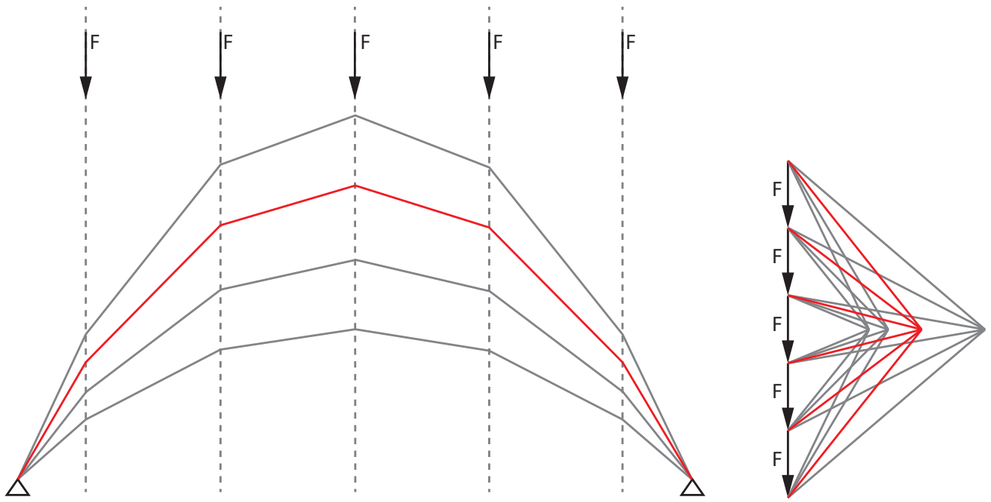



A B C D E F G H
thrust line
W1
W2
W3
W4
W5
W6
W7
O
hanging chain
(a)
(b)
(c)
(d)
Fto
Foe

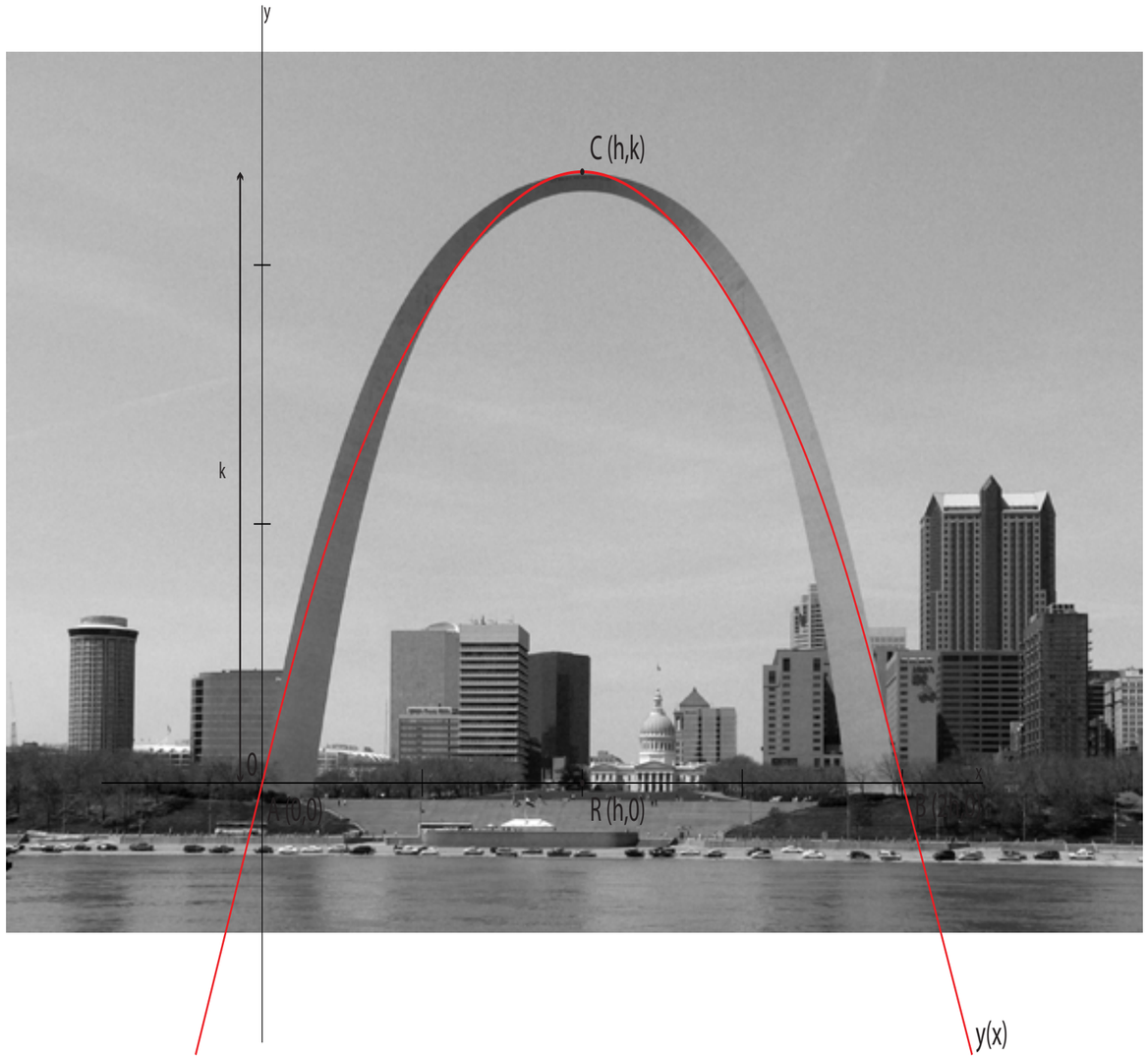



y
C (h,k)
k
0
L (0,0)
R (h,0)
y(x)

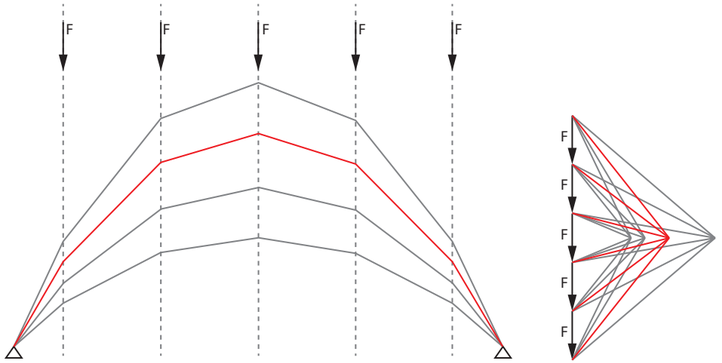
$$gg(x) = f - \frac{f(x-r)^2}{r^2}$$



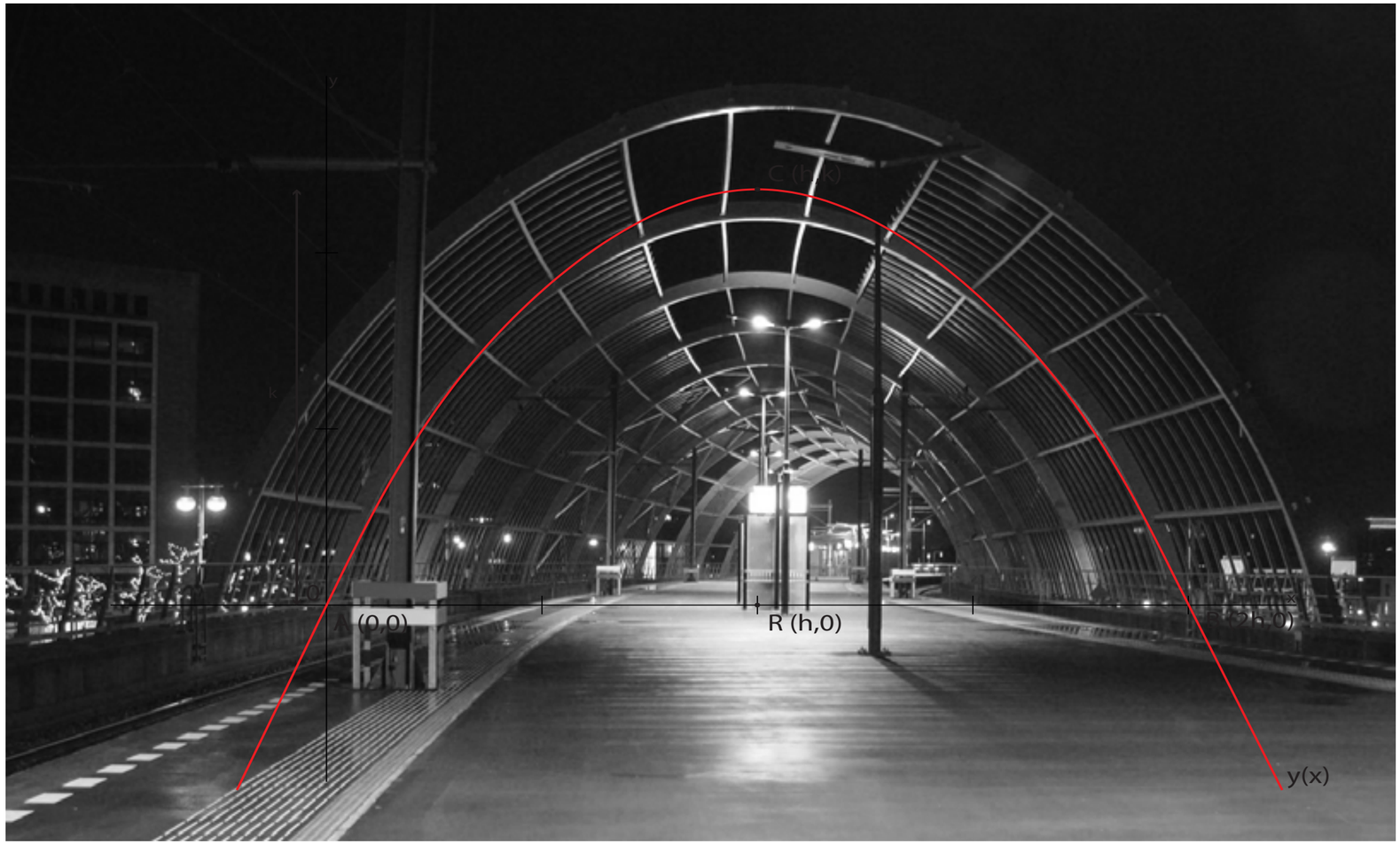
Minste energie -> goede evenwicht



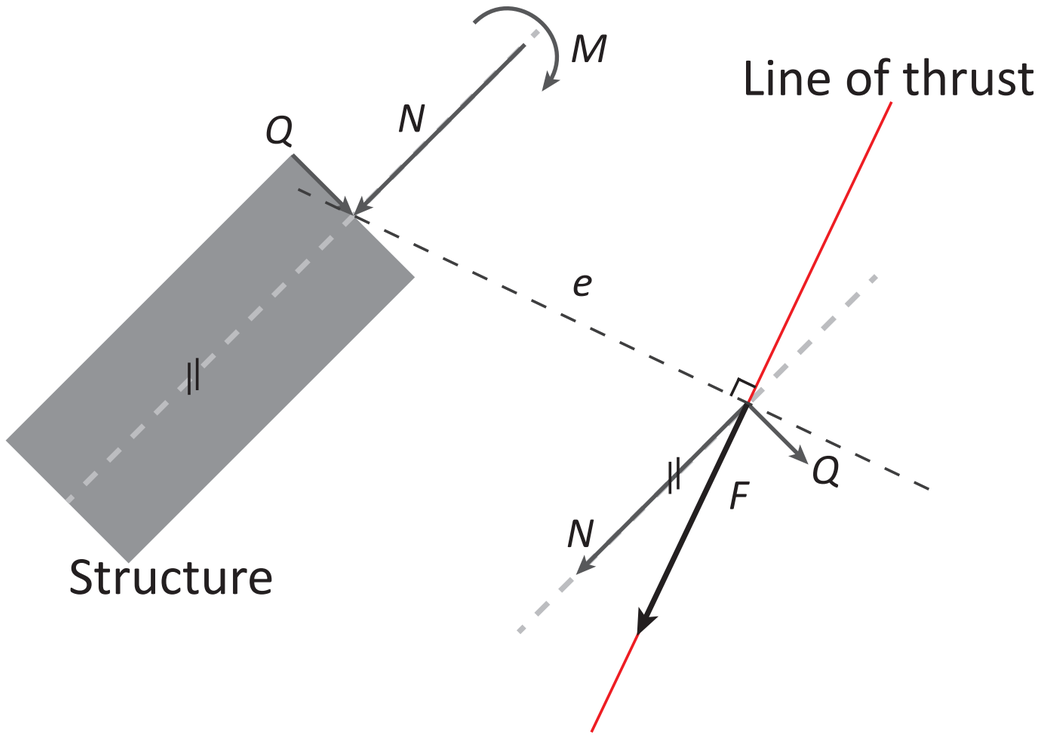
$$gg(x) = f - \frac{f(x-r)^2}{r^2}$$



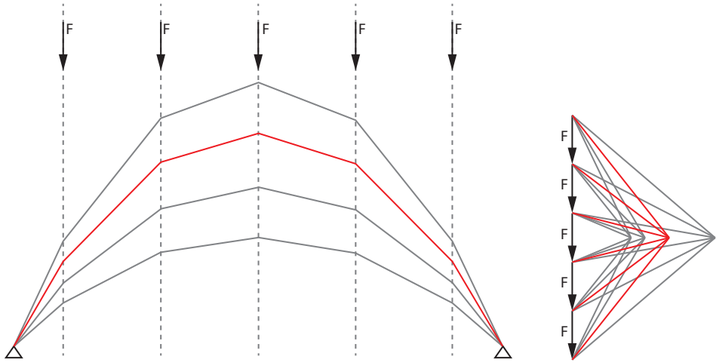
Minste energie -> niet goede evenwicht

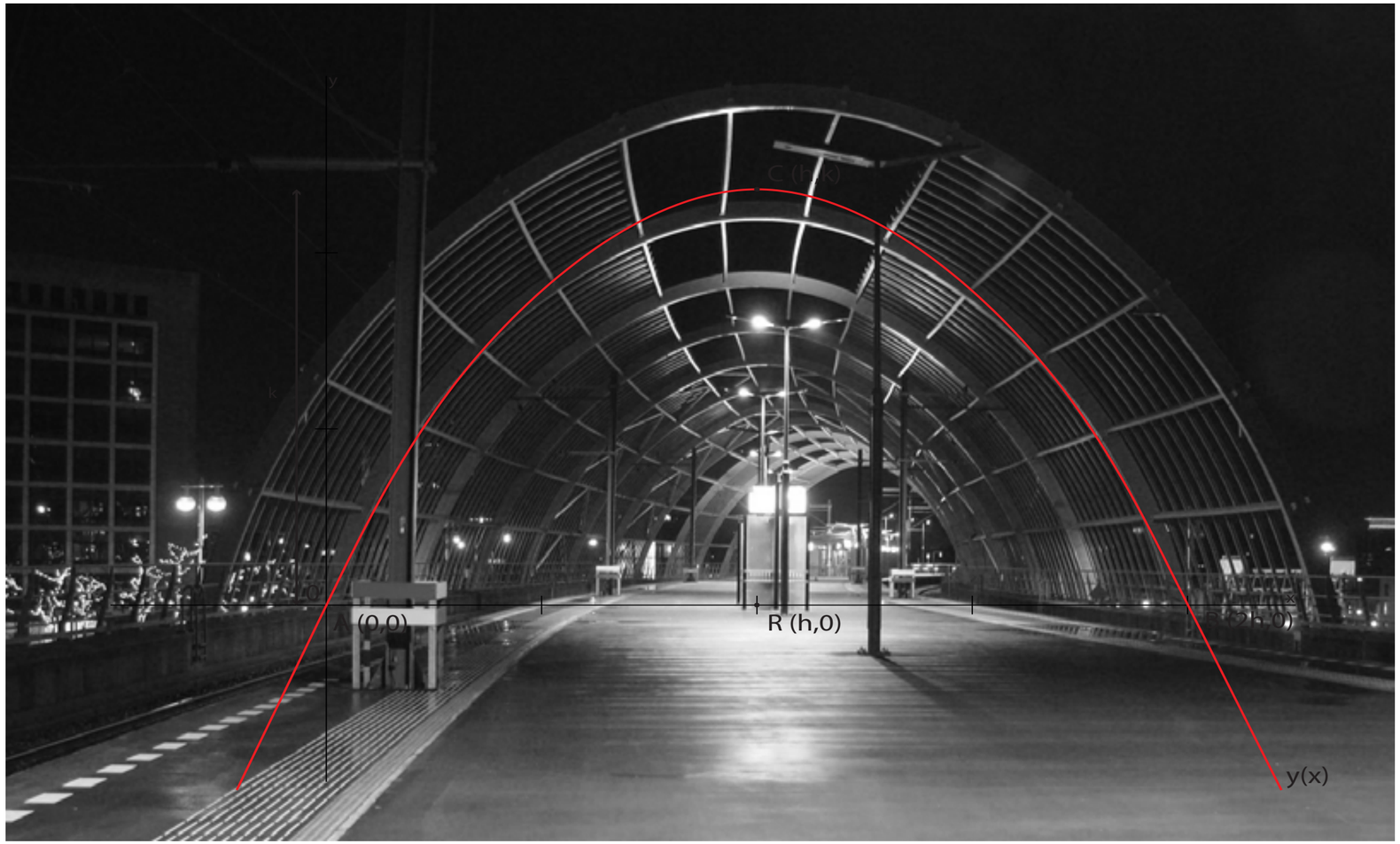


Krachten relateren

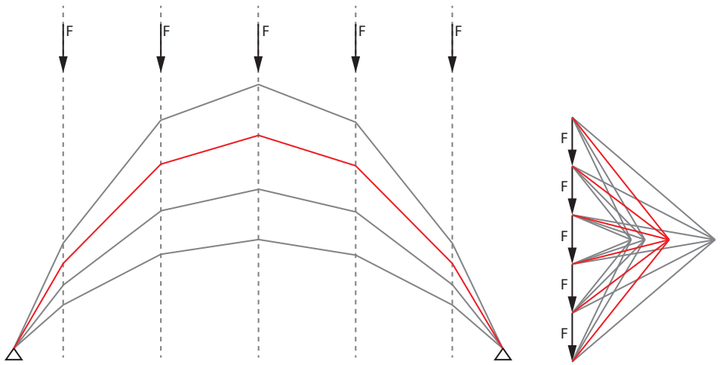


$$gg(x) = f - \frac{f(x-r)^2}{r^2}$$

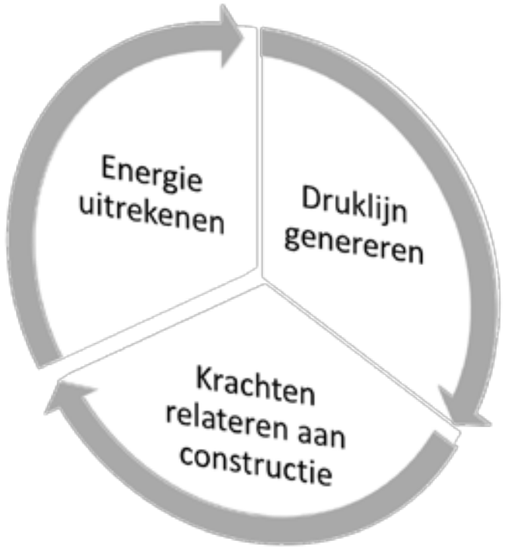


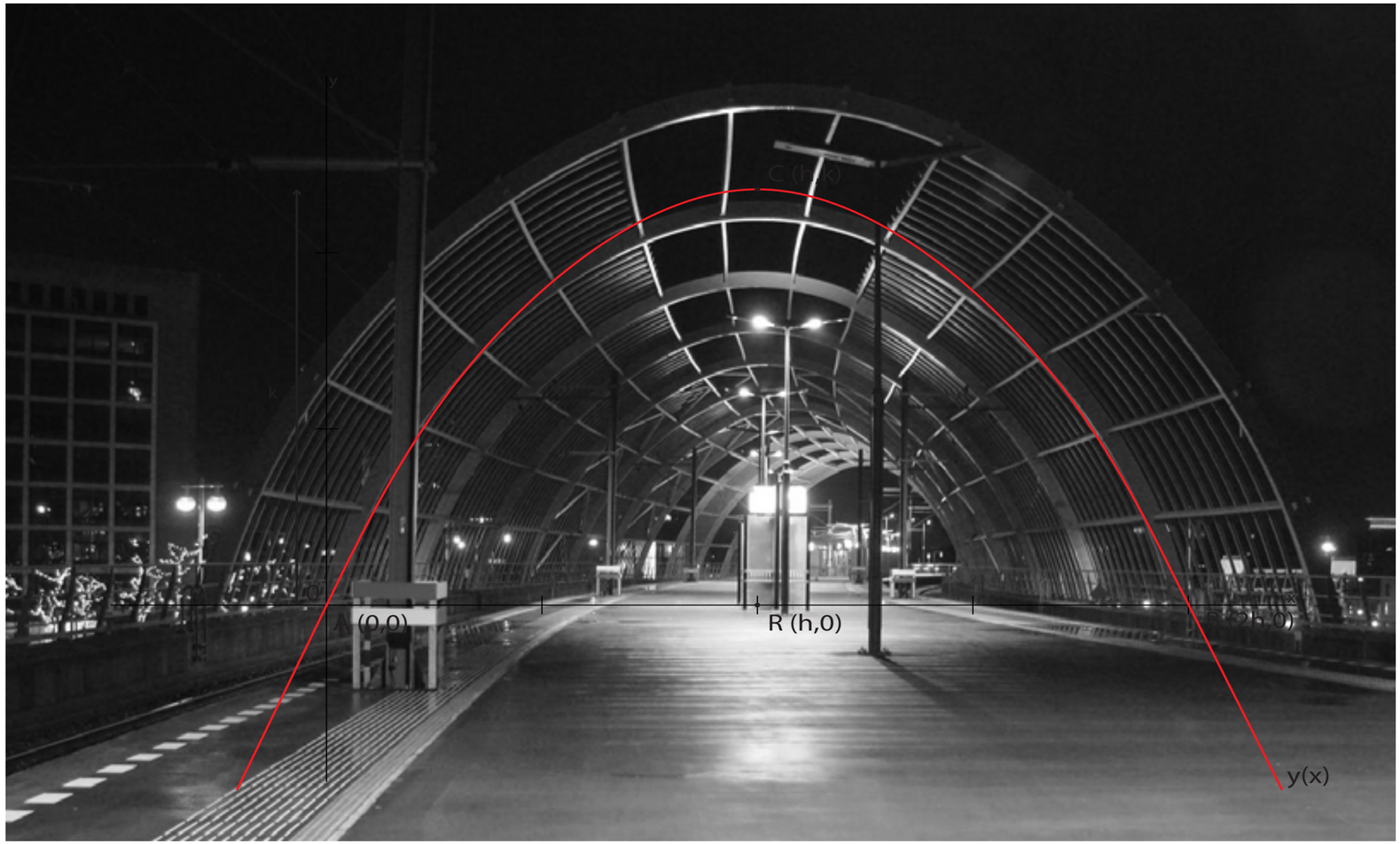


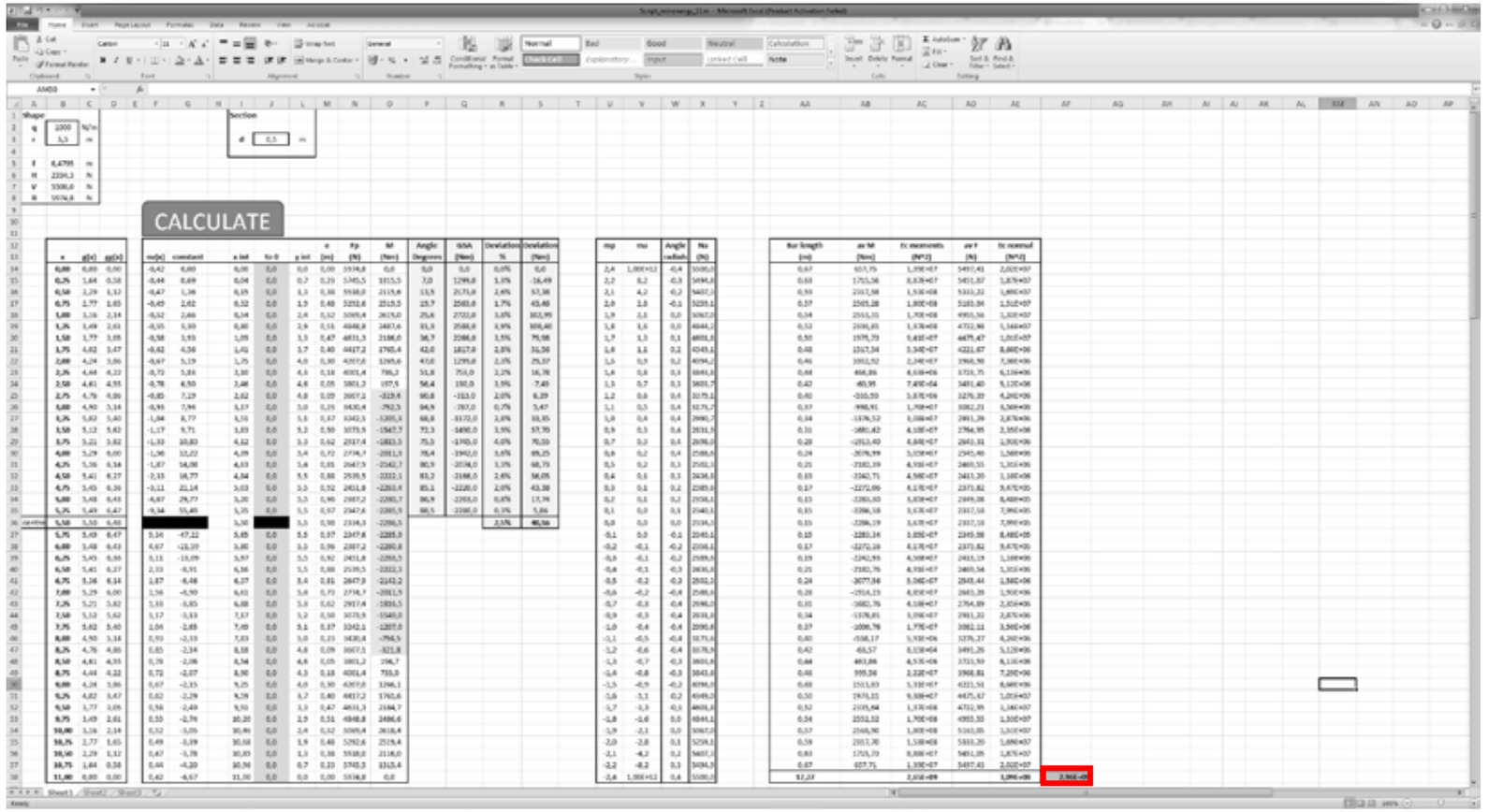
$$gg(x) = f - \frac{f(x-r)^2}{r^2}$$



Minste energie -> goede evenwicht

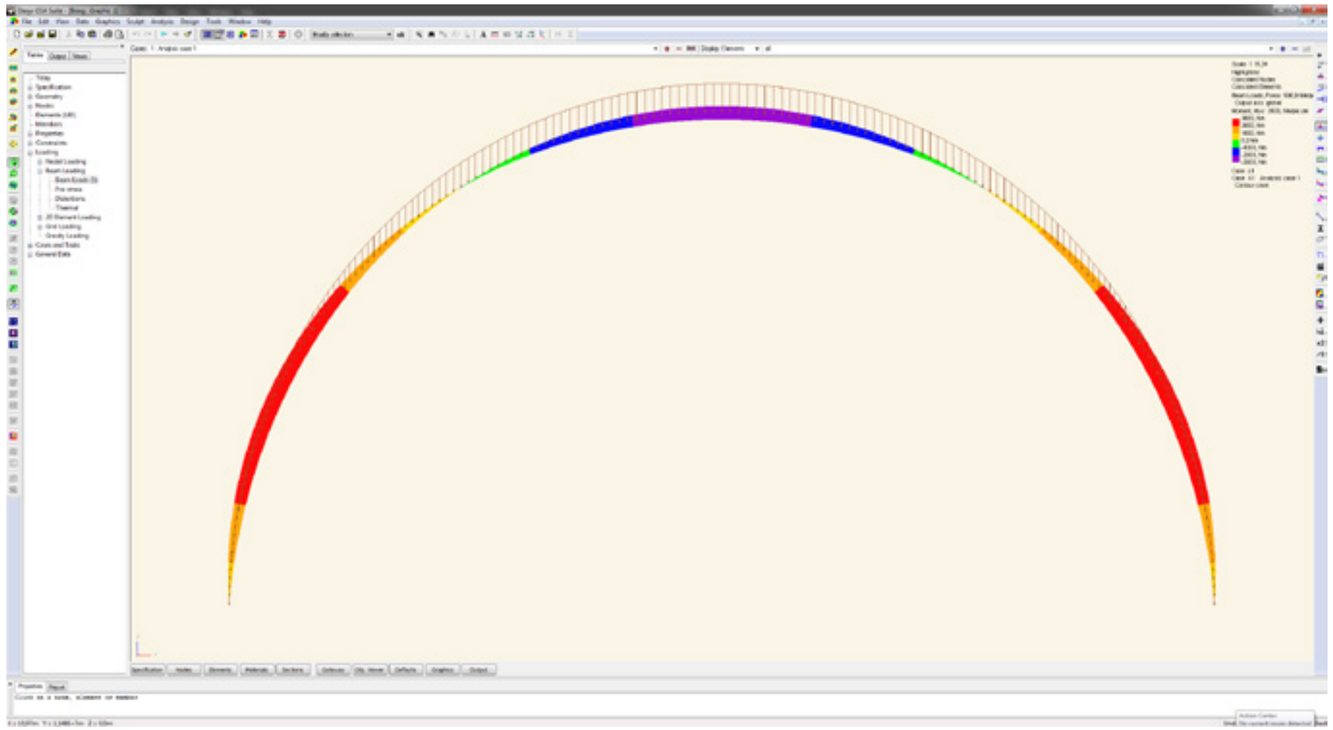


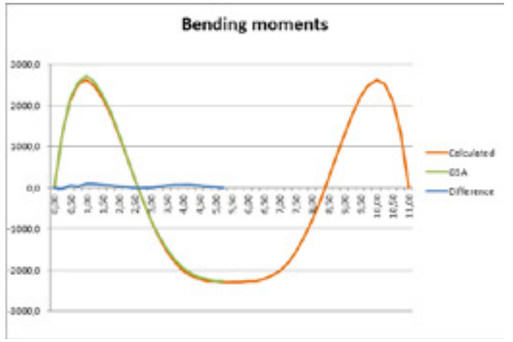




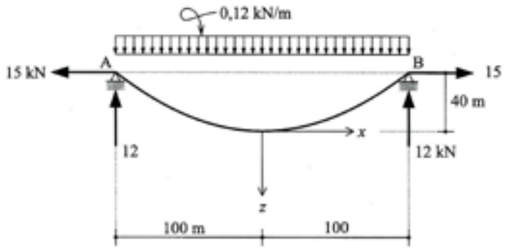
$f\ [m]$	$E_{c,M}\ [N^2]$	$E_{c,N}\ [N^2]$	$\sum E_{c,N} + E_{c,M}\ [N^2]$
6,2	6,77E+08	3,13E+08	9,91E+08
6,3	6,63E+08	3,12E+08	9,74E+08
6,4	**6,58E+08**	**3,10E+08**	**9,69E+08**
6,5	6,63E+08	3,09E+08	9,72E+08
6,6	6,77E+08	3,08E+08	9,85E+08

Valideren antwoorden



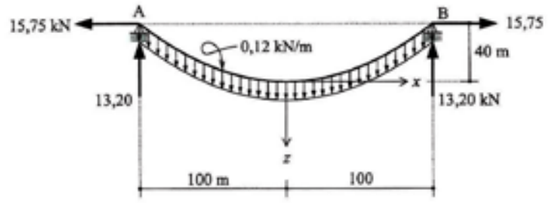


Geprojecteerde belasting



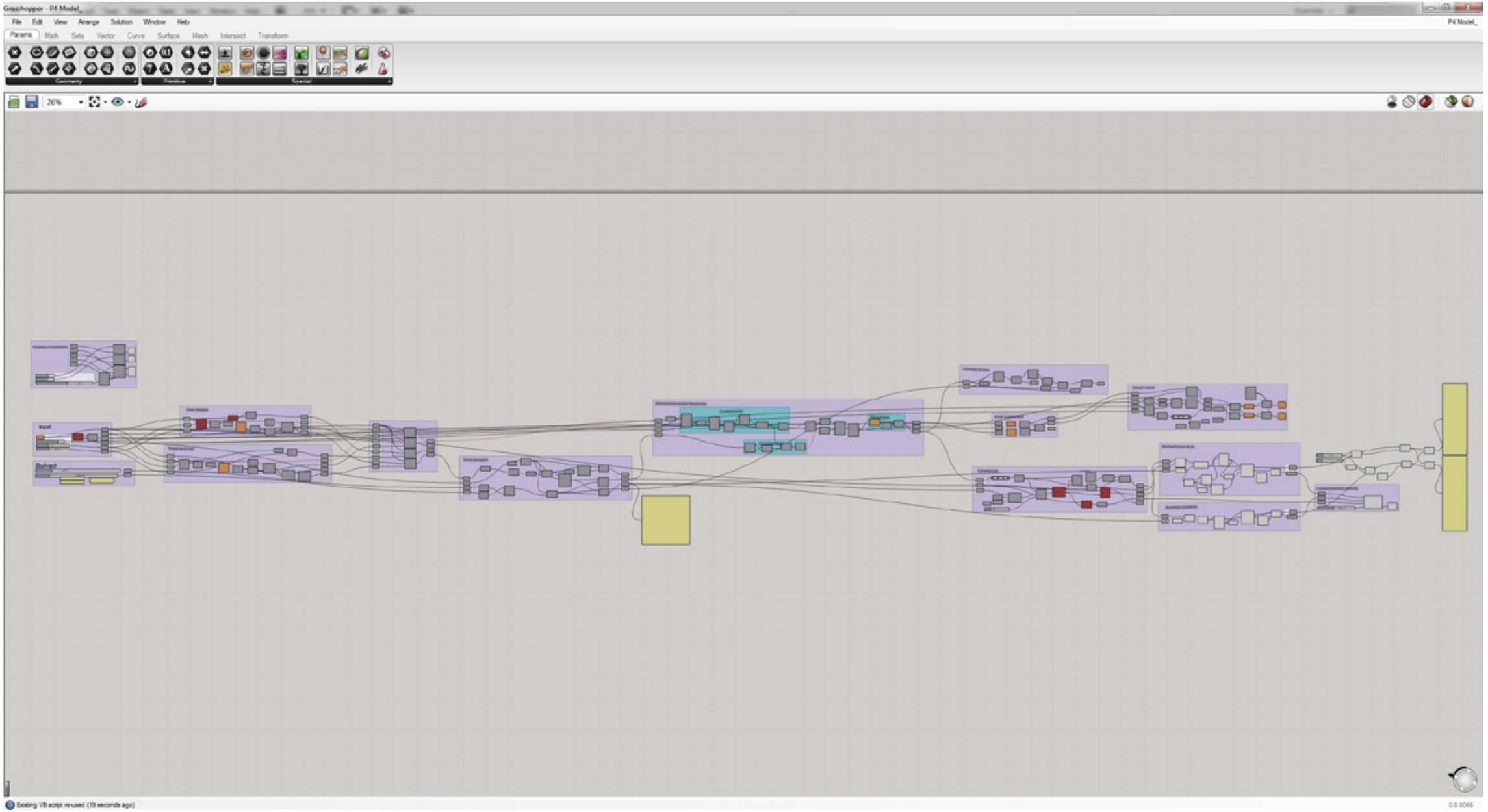
$$gg(x) = f - \frac{f(x-r)^2}{r^2}$$

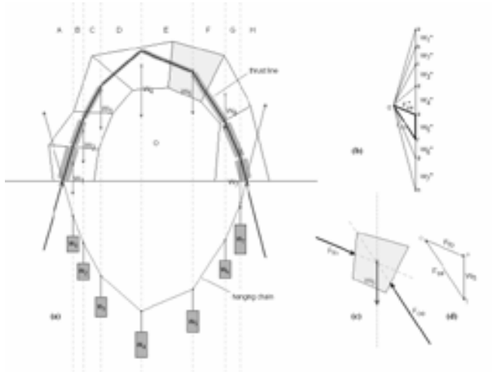
Eigen gewicht

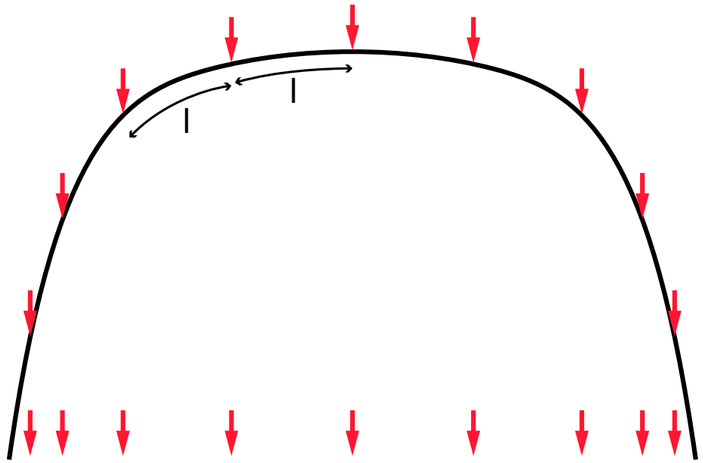


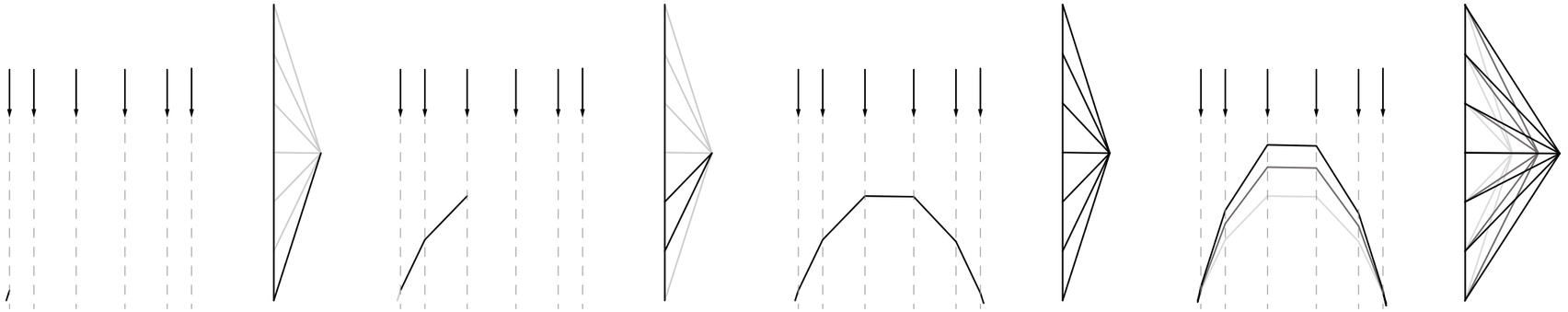
$$gg_{catenary}(x) = -\frac{H}{g}(\cosh\frac{gx}{H} - 1)$$

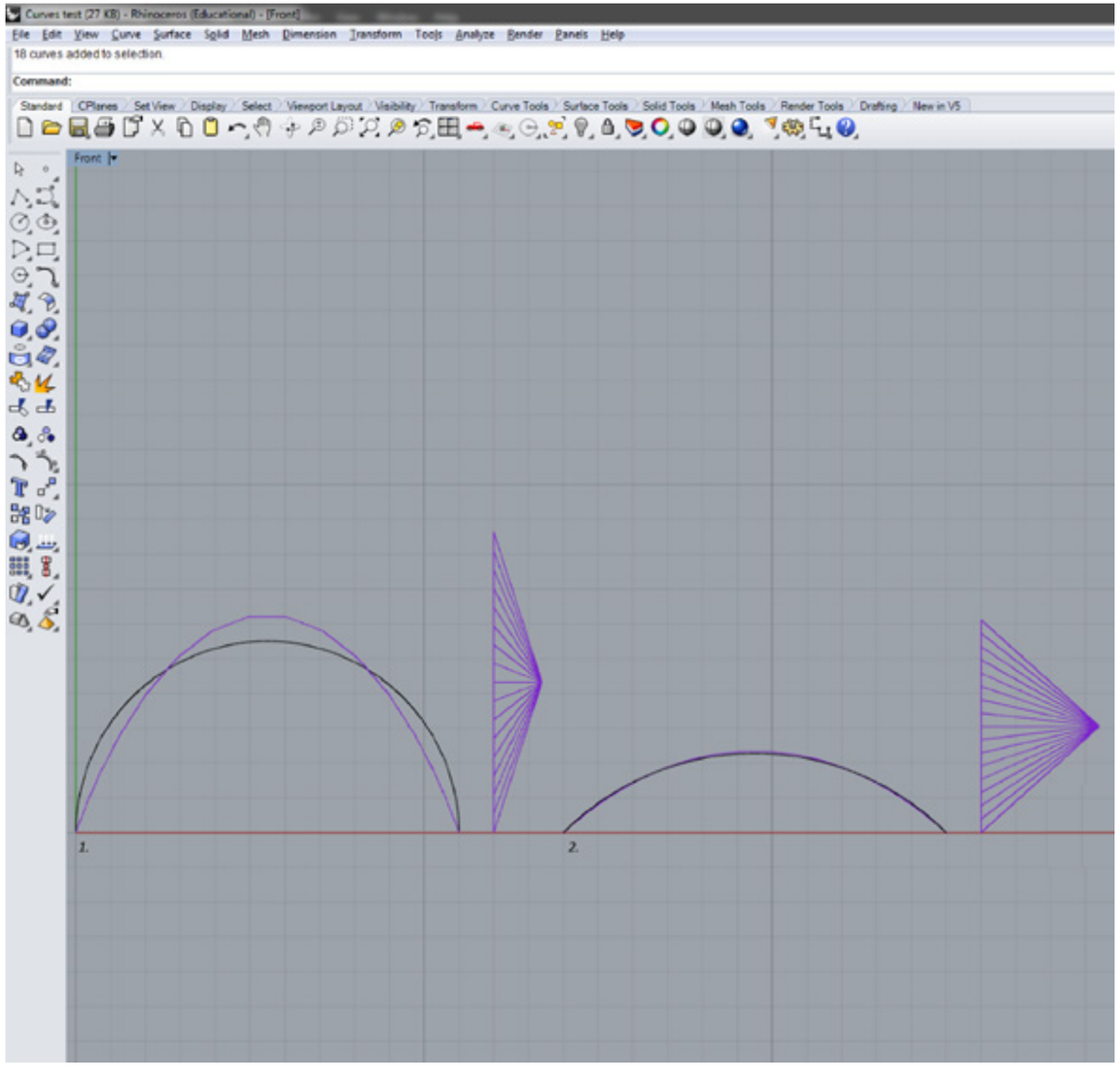
krachten in kN	parabool	kettinglijn
H	15	15,75
V_{max}	12	13,20
N_{max}	19,2	20,55

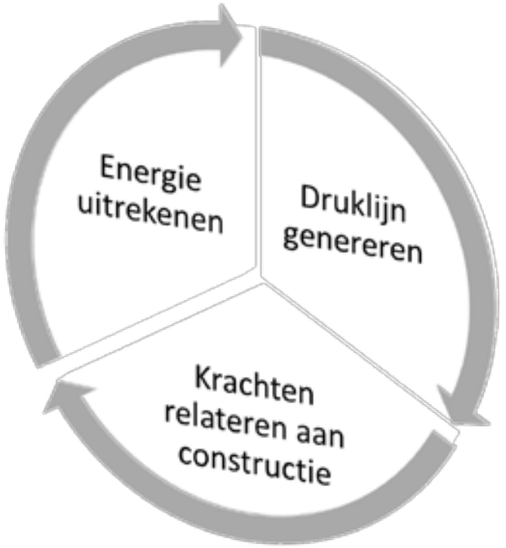

Grasshopper - P4 Model_
File Edit View Arrange Solution Window Help
Params Math Sets Vector Curve Surface Mesh Intersect Transform
P4 Model_
Geometry
Primitive
Special
26%
Input
Output
Existing VB script re-used (19 seconds ago)

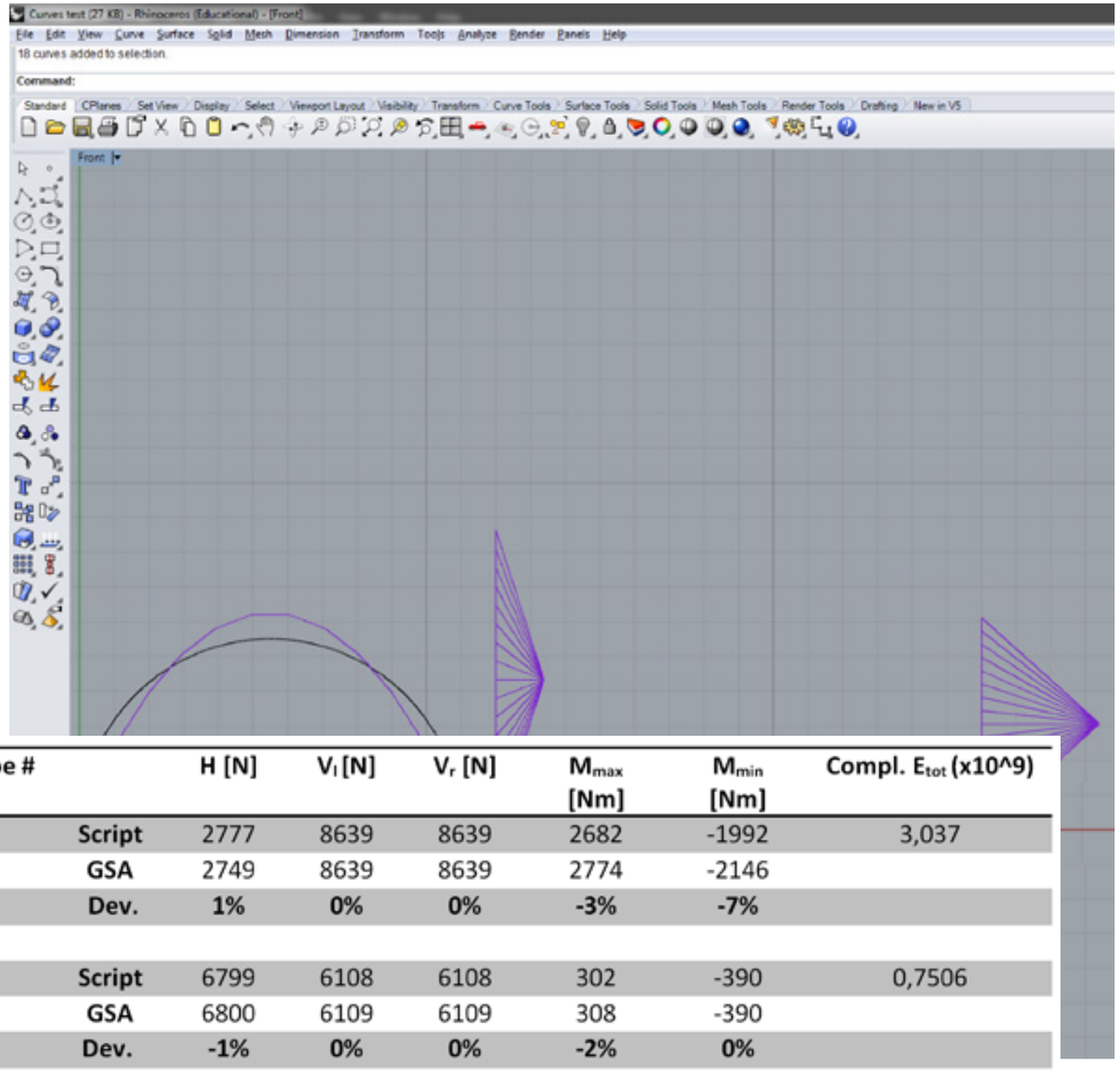







Curves test (27 KB) - Rhinoceros (Educational) - [Front]
File Edit View Curve Surface Solid Mesh Dimension Transform Tools Analyze Render Panels Help
18 curves added to selection
Command:
Standard CPlanes Set View Display Select Viewport Layout Visibility Transform Curve Tools Surface Tools Solid Tools Mesh Tools Render Tools Drafting New in V5
Front
1.
2.



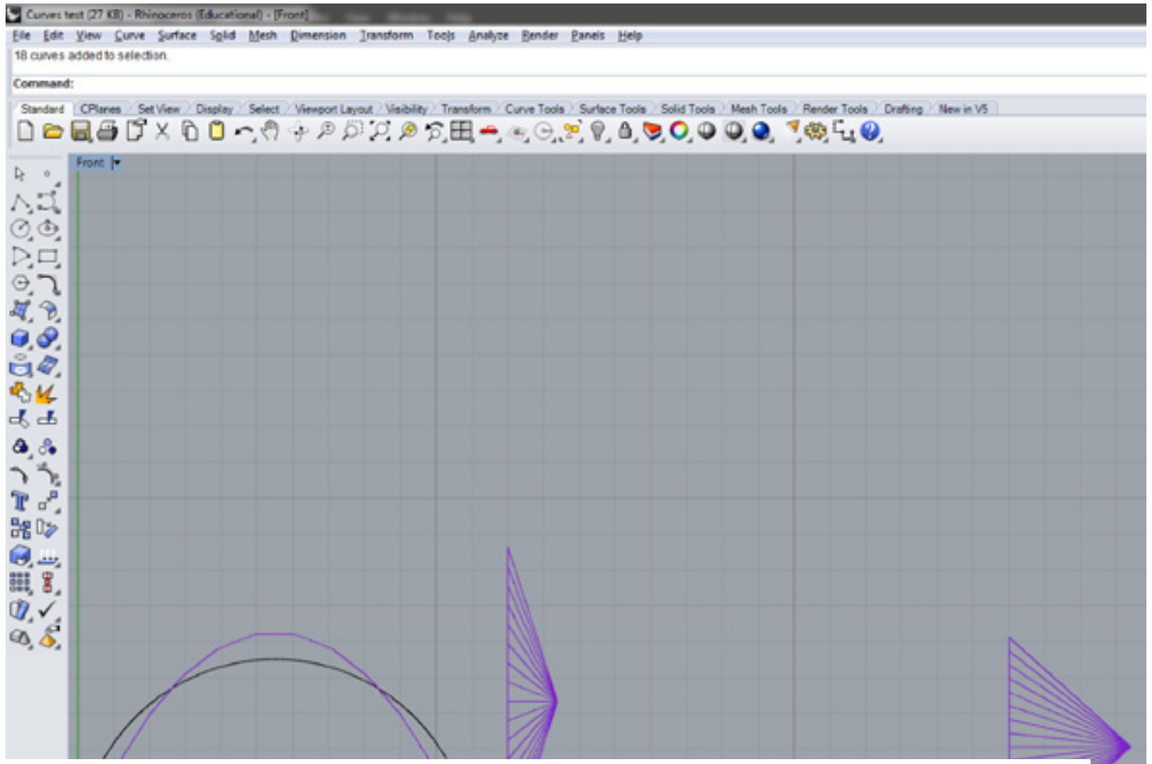


Shape #		H [N]	V_l [N]	V_r [N]	M_{max} [Nm]	M_{min} [Nm]	Compl. E_{tot} (x10^9)
1	Script	2777	8639	8639	2682	-1992	3,037
	GSA	2749	8639	8639	2774	-2146	
	Dev.	1%	0%	0%	-3%	-7%	
2	Script	6799	6108	6108	302	-390	0,7506
	GSA	6800	6109	6109	308	-390	
	Dev.	-1%	0%	0%	-2%	0%	

- Afrondingsfouten

- Discrete belasting

- Gemiddelde krachten over de boog



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	GSA	6800	6109	6109	308	-390	
	Dev.	-1%	0%	0%	-2%	0%	

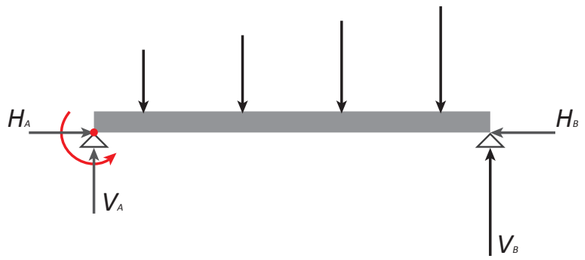
- Symetrische constructies

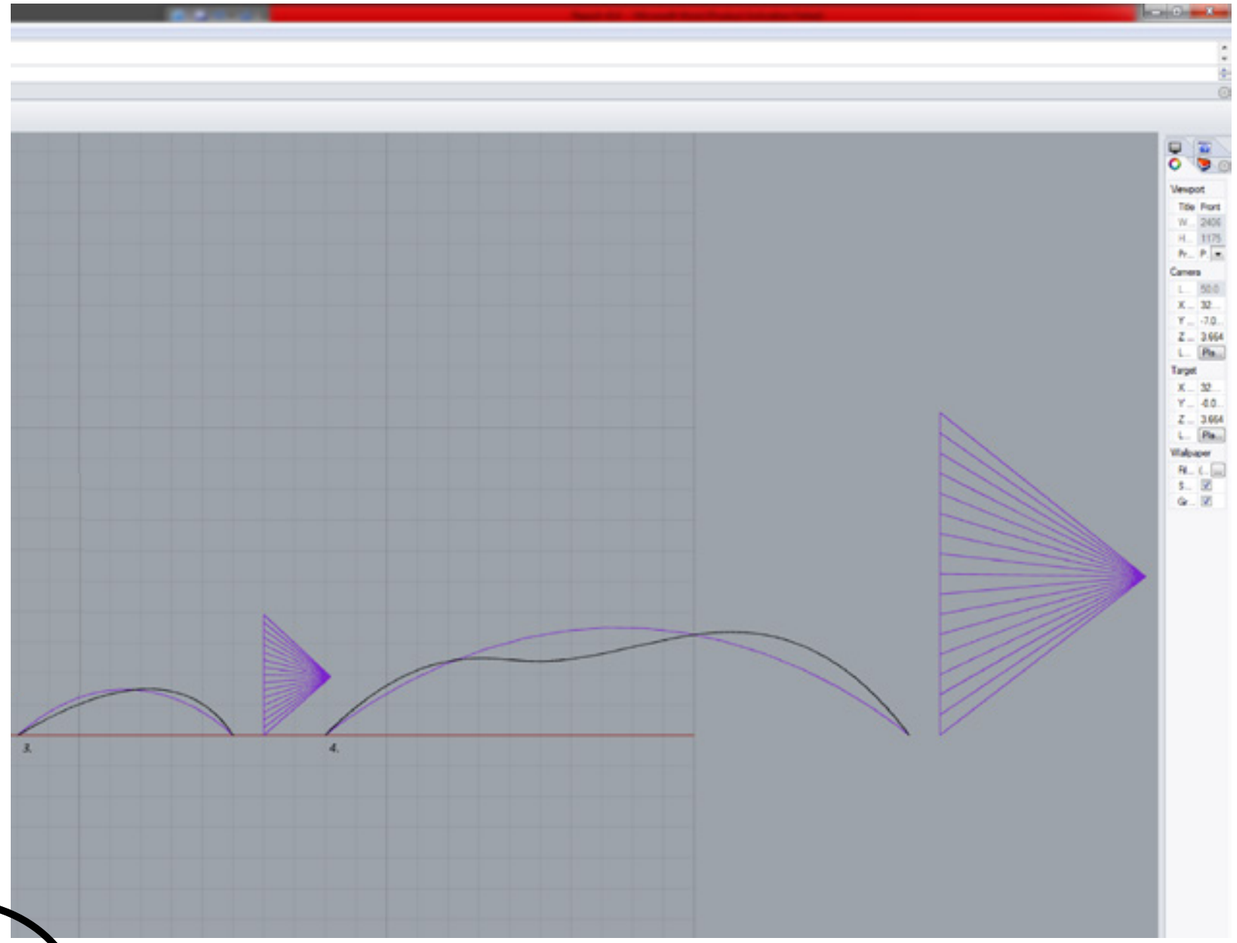
- Oplegging op een lijn

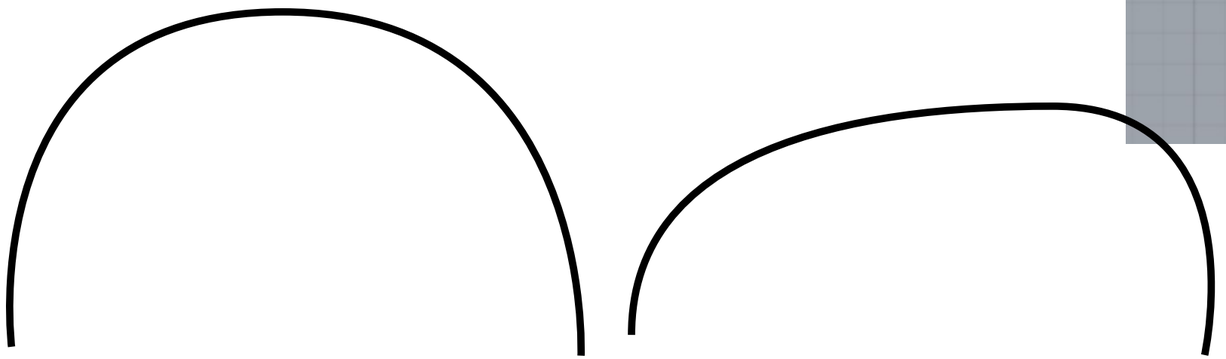
- Met de hand antwoord zoeken

- Verschillende modellen

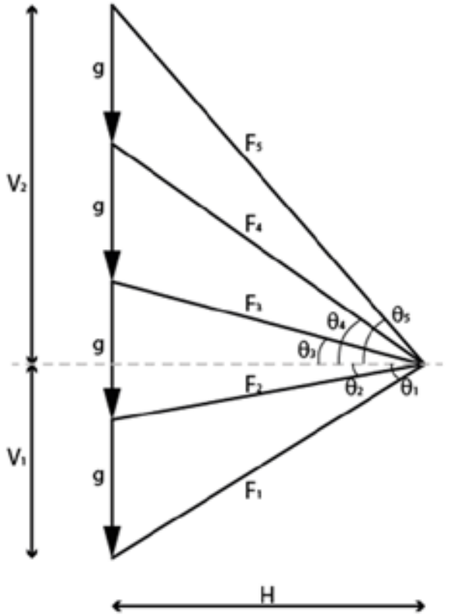
Asymetrische constructies





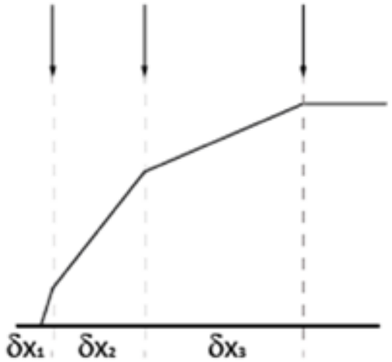


Wiskundige oplossing

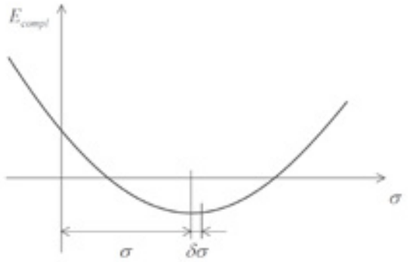


$$F_1 = \sqrt{(H^2 + {V_1}^2)}$$
$$F_2 = \sqrt{(H^2 + (V_1 - g)^2)}$$
$$F_3 = \sqrt{(H^2 + (V_1 - 2 * g)^2)}$$
$$F_4 = \sqrt{(H^2 + (V_1 - 3 * g)^2)}$$
$$F_5 = \sqrt{(H^2 + (V_1 - 4 * g)^2)}$$

$$F_i = \sqrt{(H^2 + (V_1 - (i-1) * g)^2)}$$

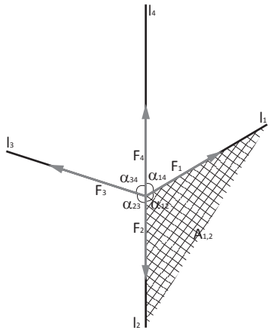


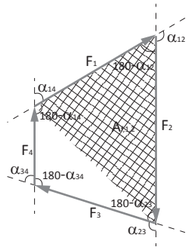
$$\tan\theta_1 = \frac{V_1}{H}$$
$$\tan\theta_2 = \frac{V_1 - g}{H}$$
$$\tan\theta_3 = \frac{V_1 - (2 * g)}{H}$$
$$\tan\theta_4 = \frac{V_1 - (3 * g)}{H}$$
$$\tan\theta_5 = \frac{V_1 - (4 * g)}{H}$$
$$\tan\theta_i = \frac{V_1 - ((i-1) * g)}{H}$$

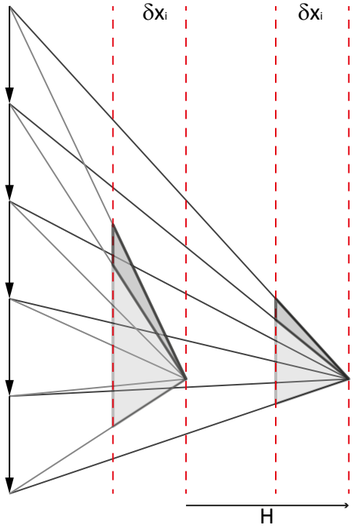


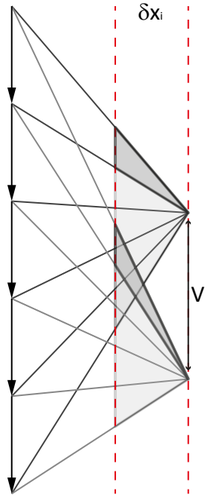
$$\sum E'_{c,N} = \sum \delta x_i * \sqrt{(\frac{V_1 - ((i-1)*g)}{H})^2 + 1} * (H^2 + (V_1 - \big((i-1) * g\big))^2)$$

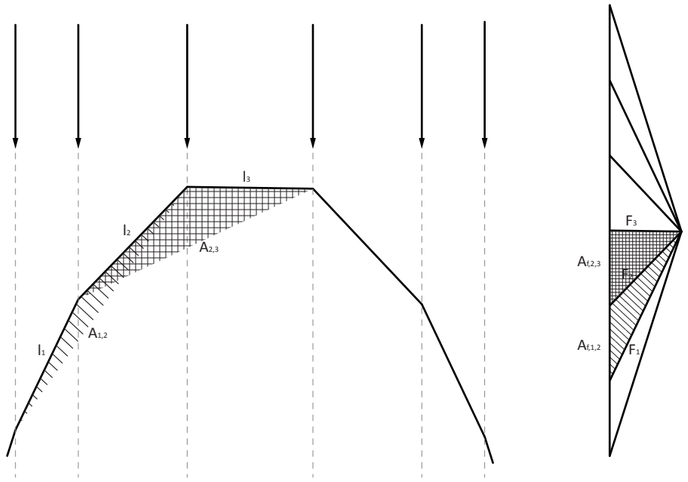
Oplossing in tekeningen

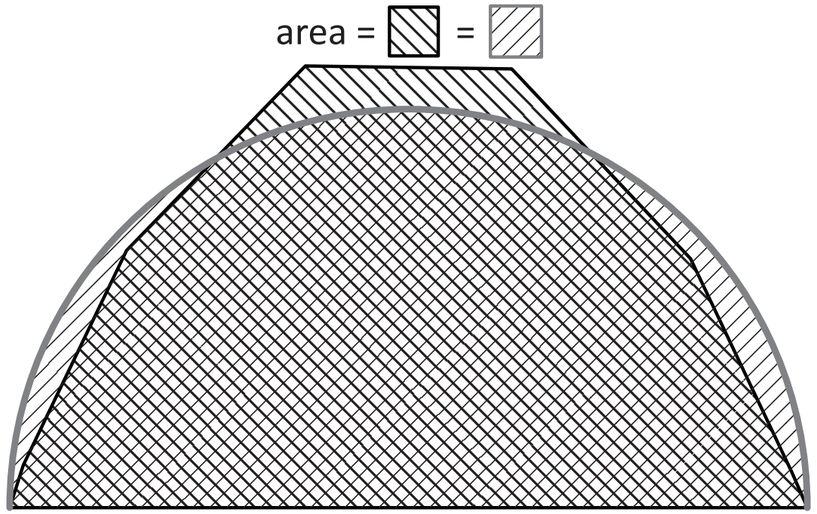




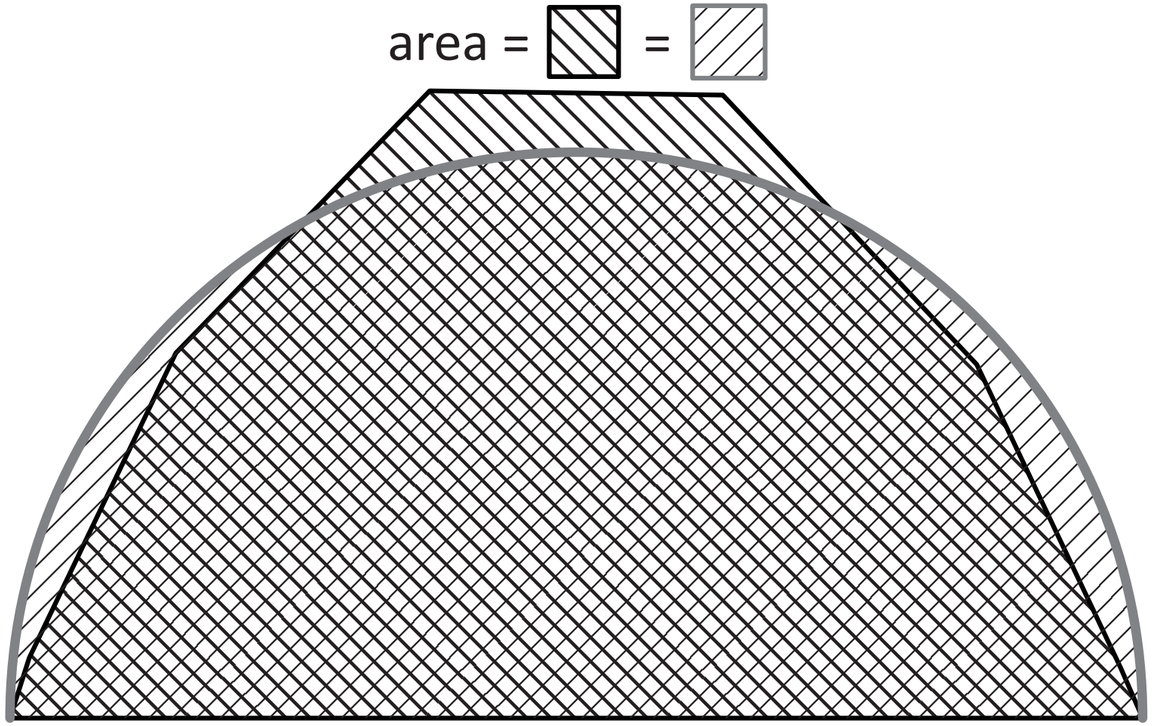


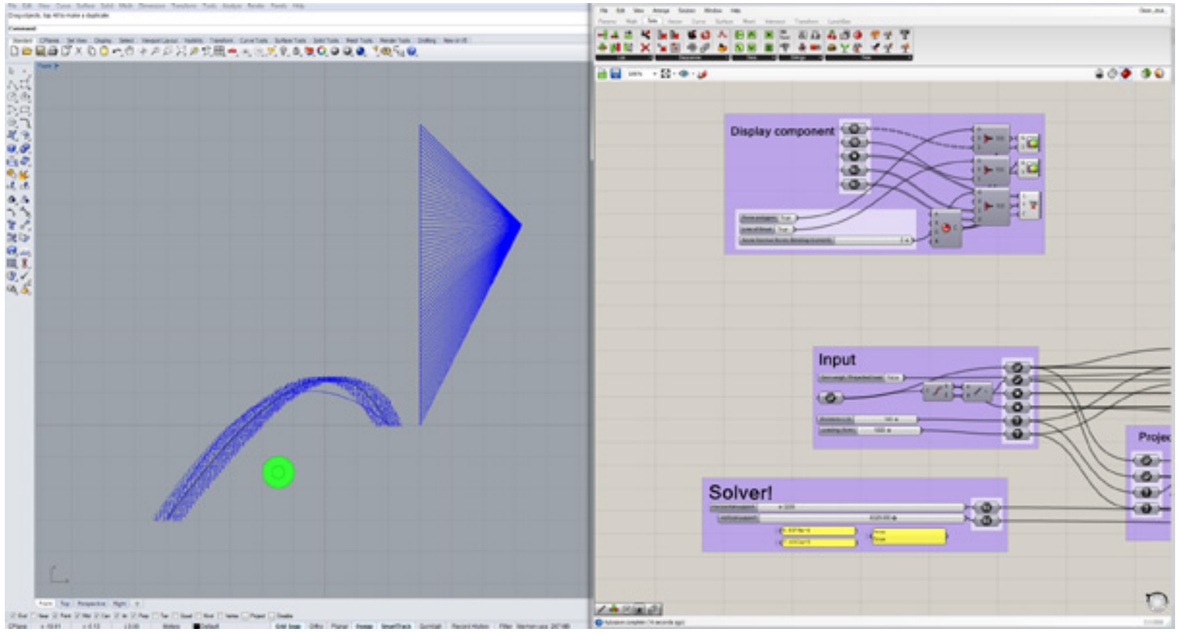




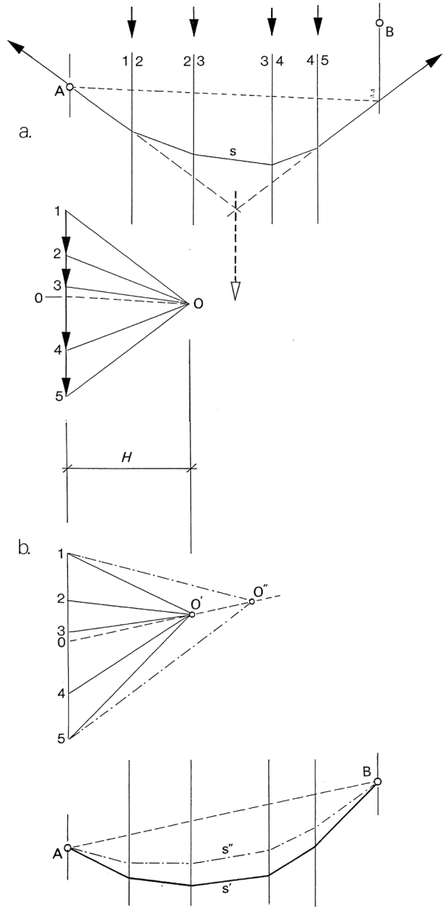


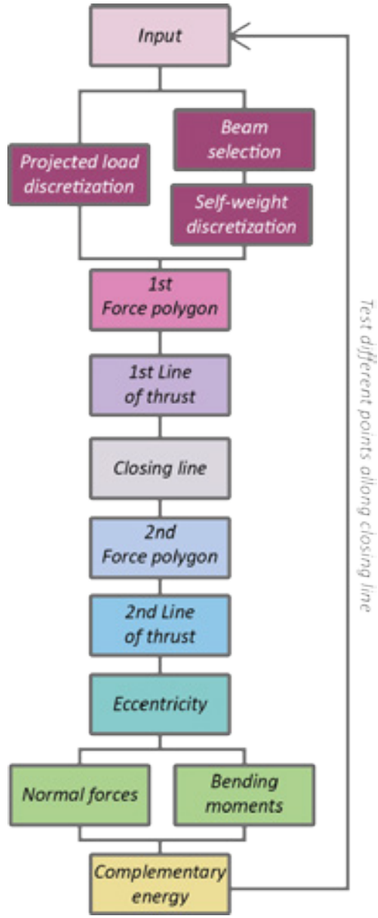
Twee variabelen

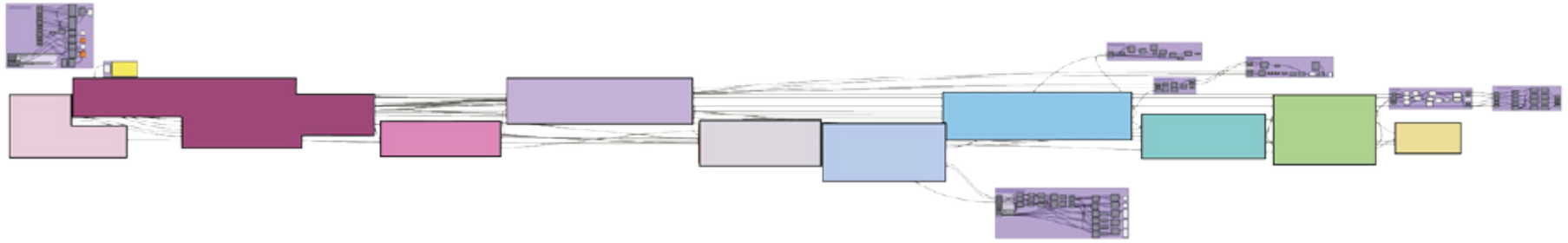




Een variabele

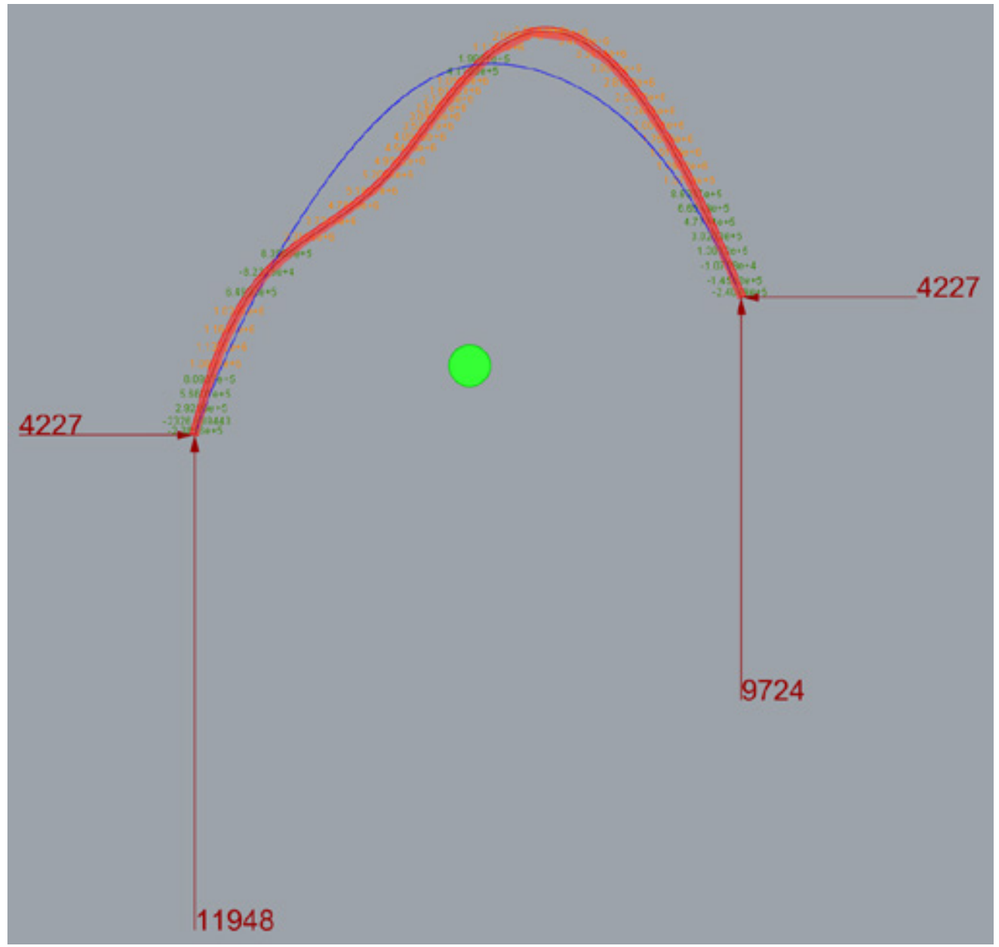






- Snel inzicht krijgen in krachten in constructies

- Snel feedback op je vorm



FILMPJE, te groot voor upload

- Visueel EN numeriek feedback

- Snel en flexibel

- Oppervlaktes in plaats van energie

- Toevoegen van vervormingen

- Flexibiliteit vergroten

- Stap naar schalen maken