ARUP

Voor en door Staalconstructeurs 2018

3D-geprinte brug MX3D

Stijn Joosten


crew

Voor en door staalconstructeurs – 21 nov 2018

ARUP

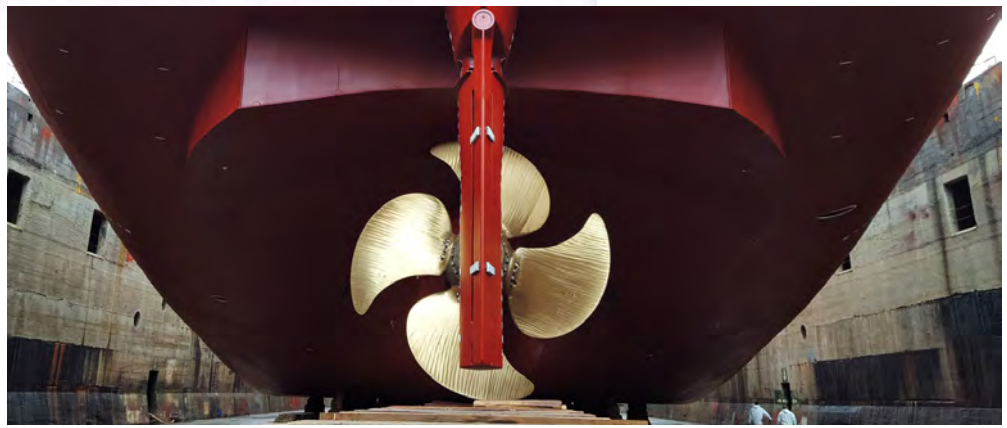
// Achtergrond
// Ontwerp
// Uitdagingen
// Testen
// Constructieve analyse
// Sensors & monitoring

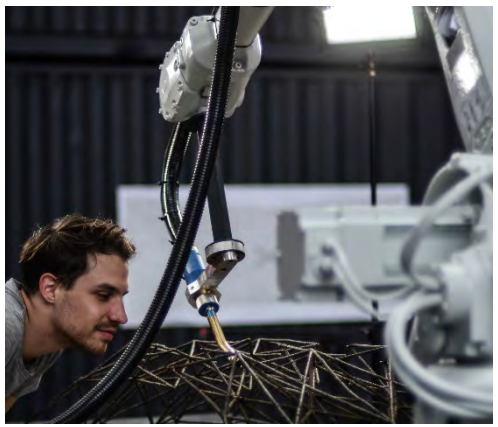
Achtergrond
Joris Laarman Lab – MX3D

- (Industrieel) ontwerp en design
  - Mooie dingen

- Nieuwe technieken
  - Rol van fabricageproces
  - Hoe maak je het?

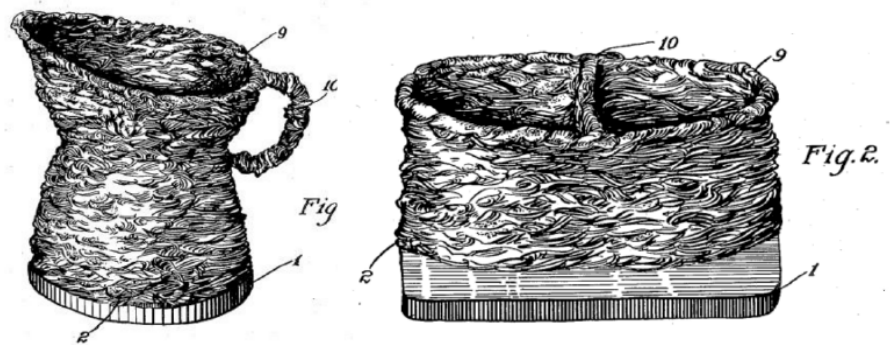
JORIS LAARMAN LAB



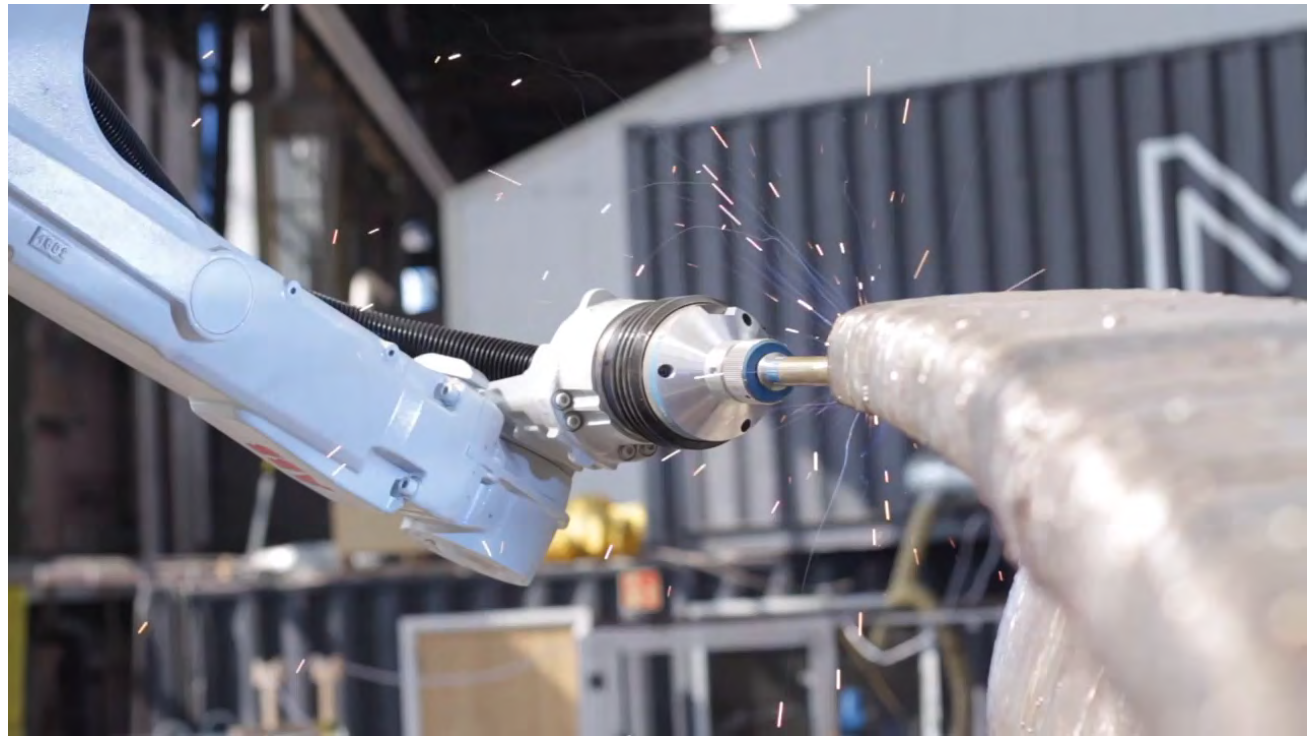


Achtergrond
Van 3D-printen naar digitale fabricage

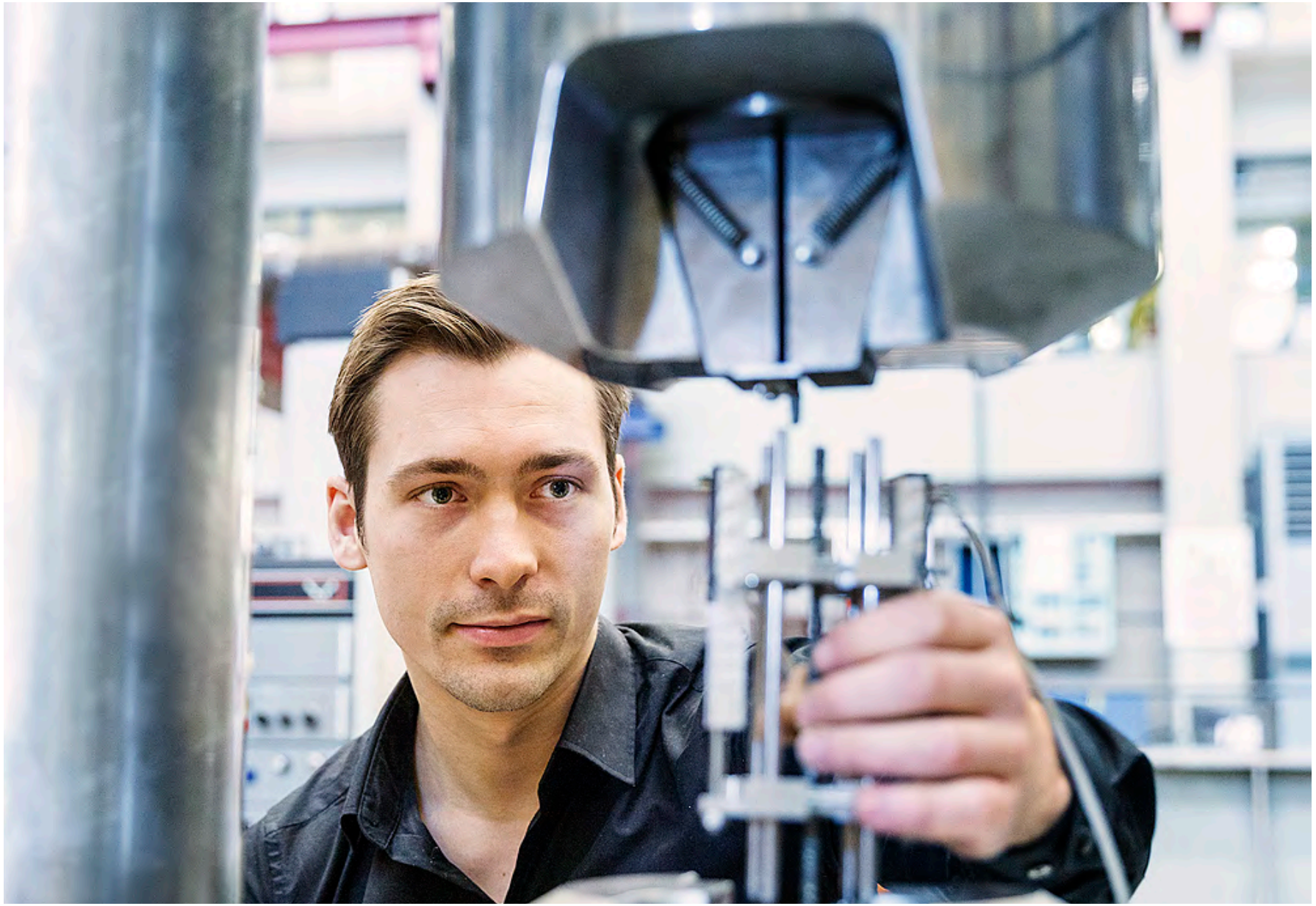
- Patent (1926): “the use of an electric arc as a heat source to generate 3D objects depositing molten metal in superimposed layers”



- Mx3D
  - + Lasapparaat
  - + Robot
  - + Software
  - + Engineer/designer
  - = Nieuwe constructiemethode




PIPSLAB
TOOLS
TORCH



Stijn Joosten

Structural Engineer

2008-2011

TU Delft BSc Architectuur

2012-2015

TU Delft MSc Structural Engineering

2014-2015

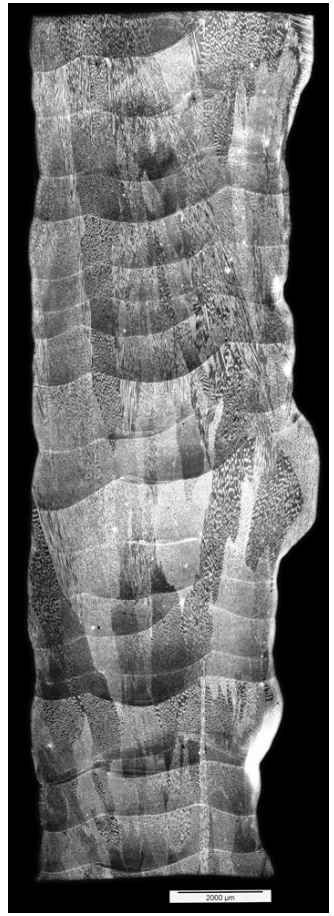
MSc Thesis ‘Printing a Stainless Steel Bridge’

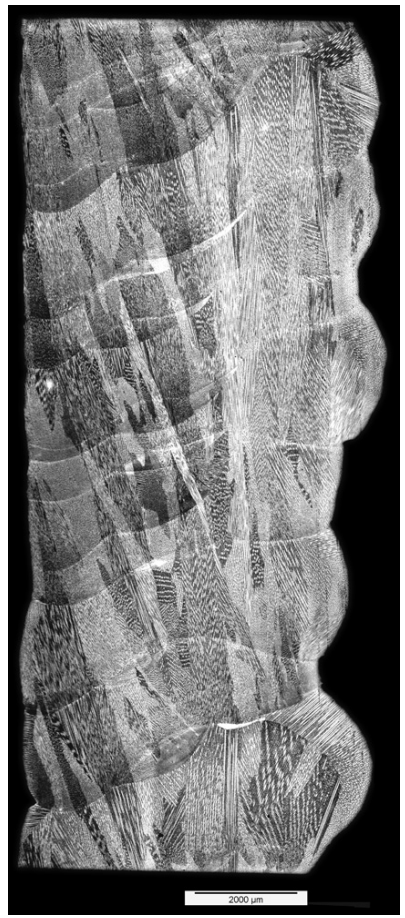
2015-heden

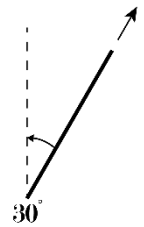
Arup Amsterdam Infrastructure

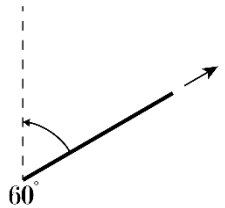
Eerste conclusies

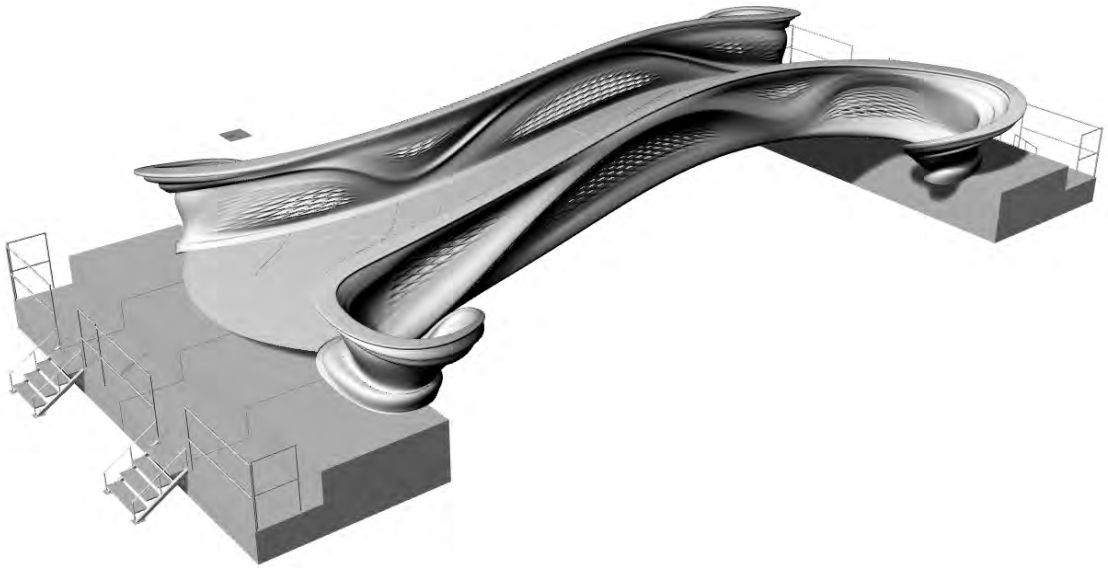
Het kan!



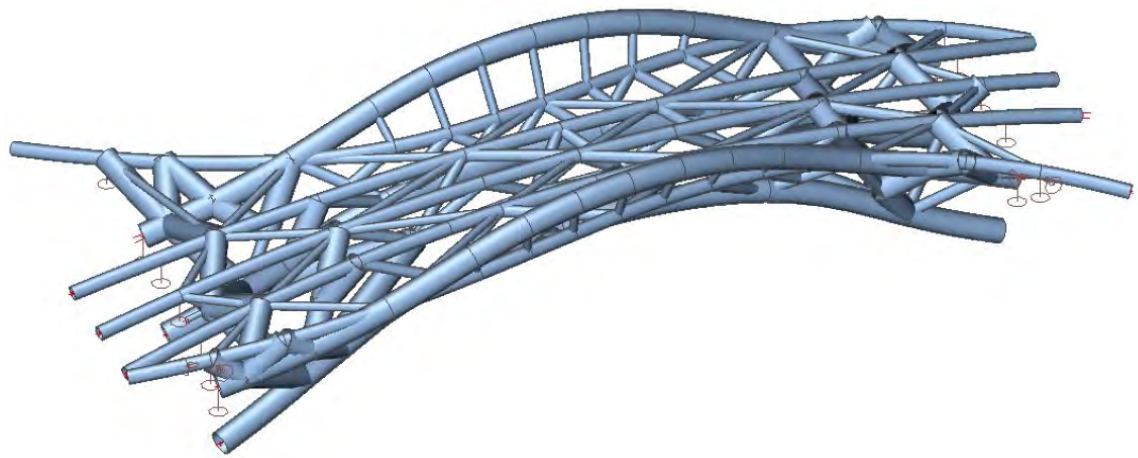




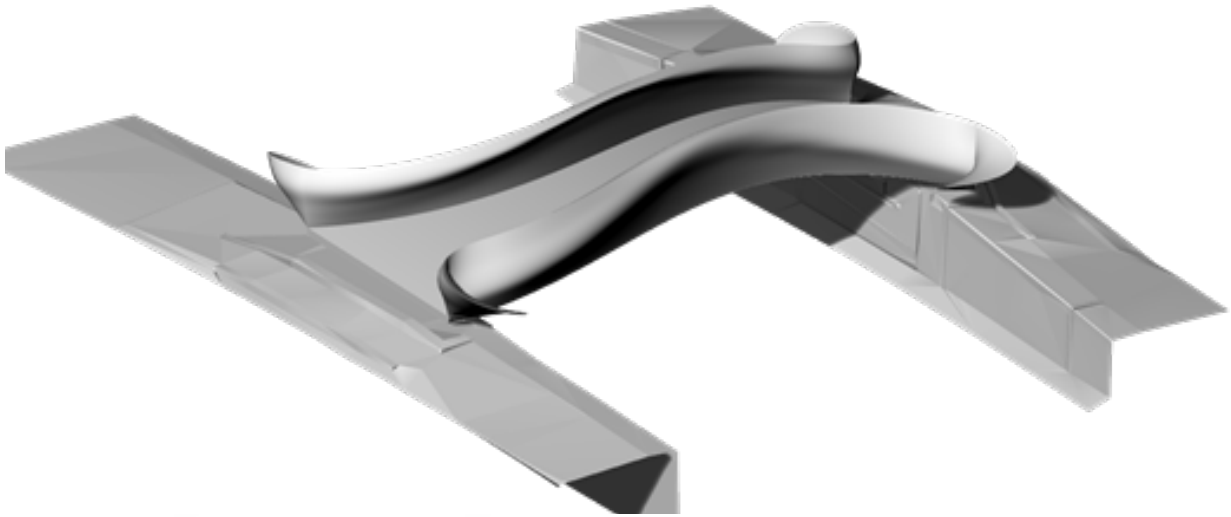


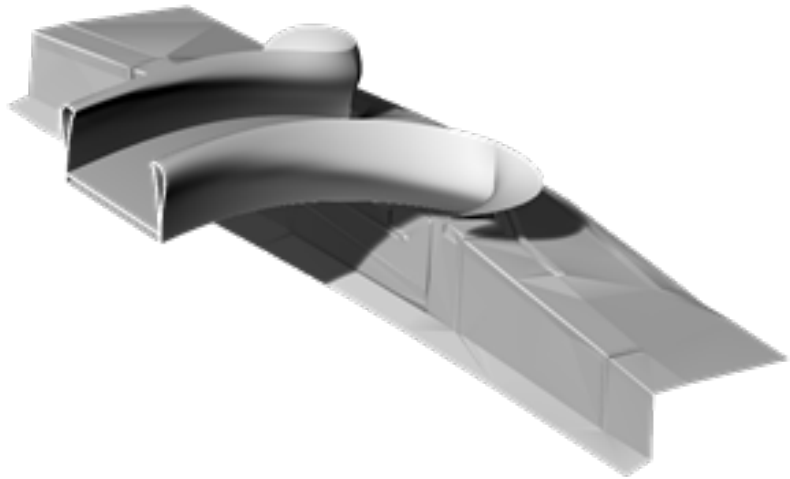


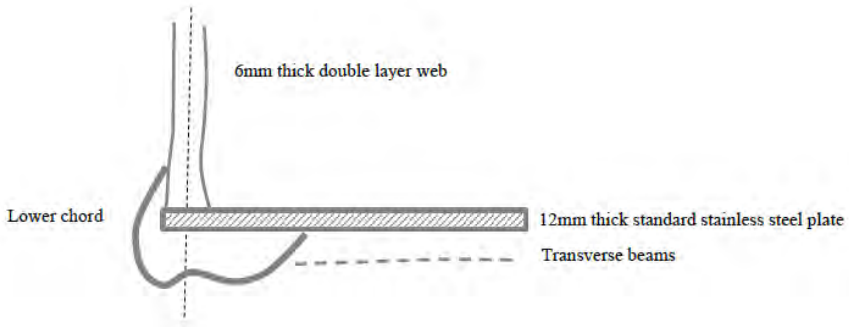
Ontwerp
Eerste versie MX3D



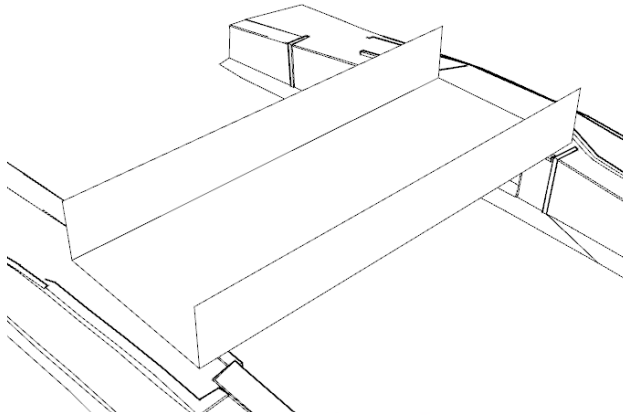
Ontwerp
Schetsontwerp

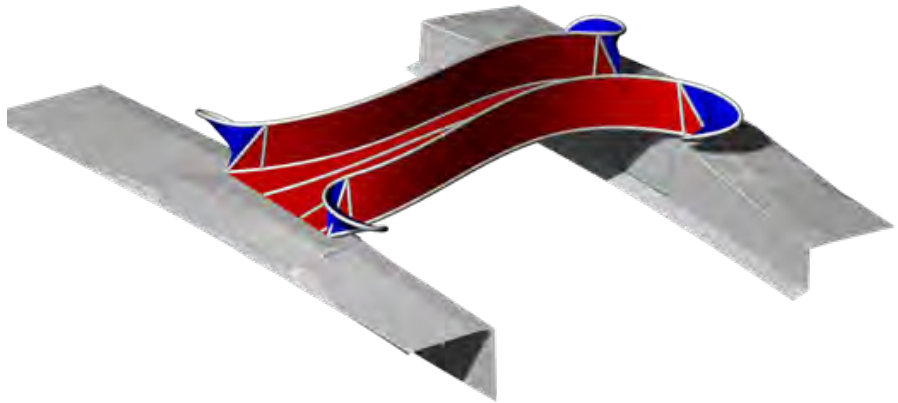


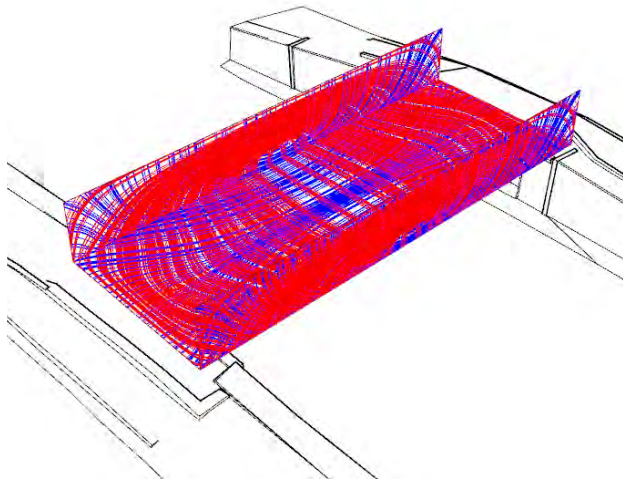


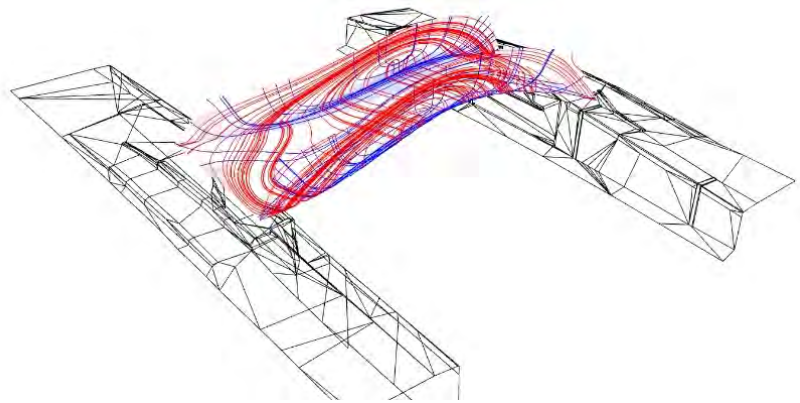


Ontwerp
Parametrisch ontwerp

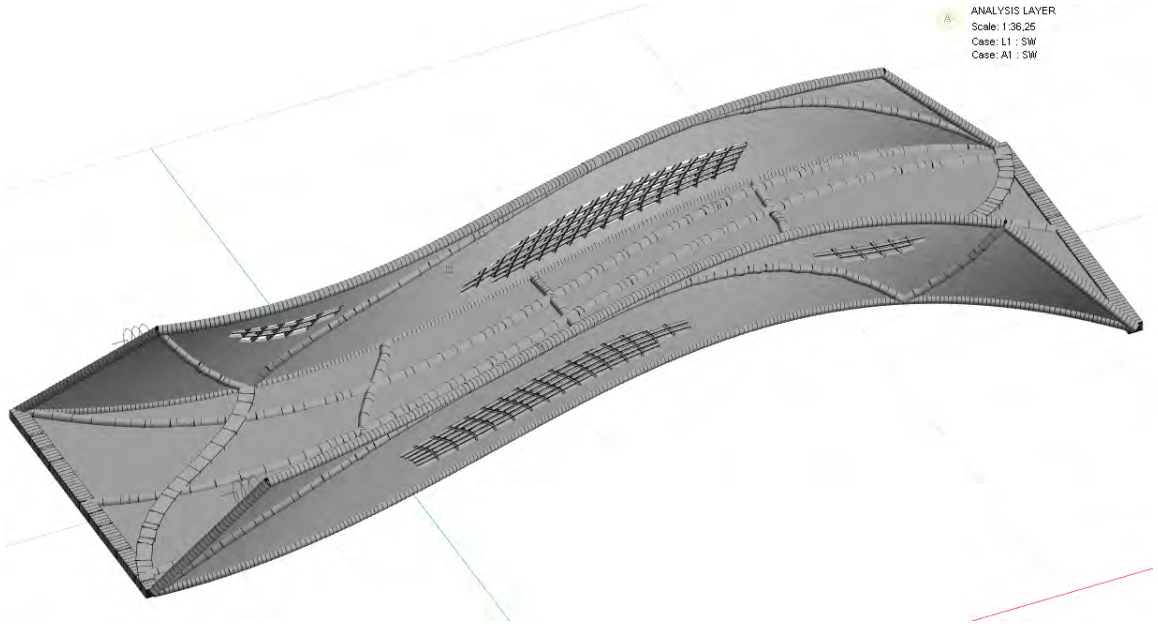






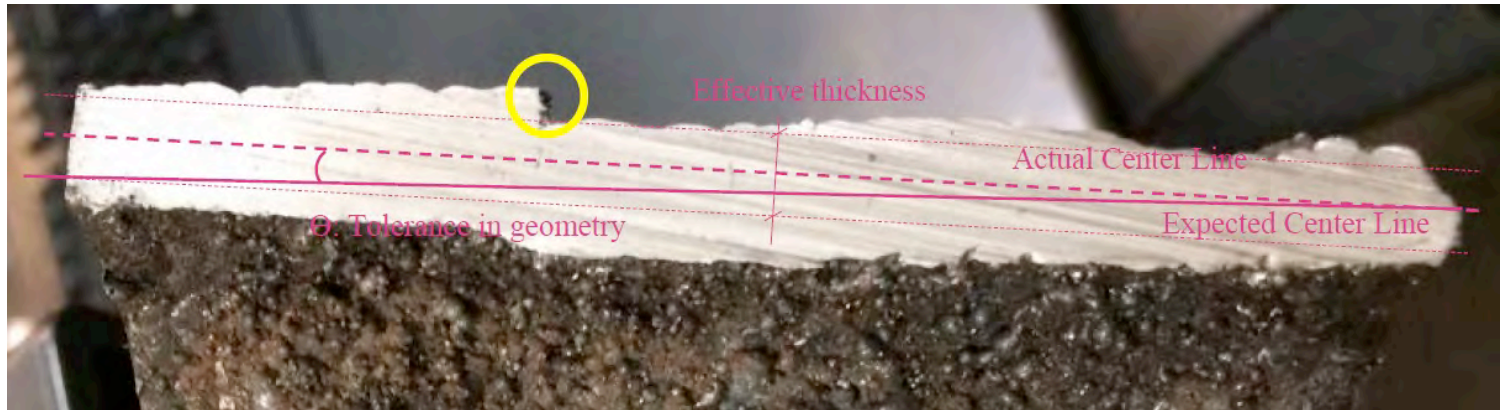


Ontwerp
VO

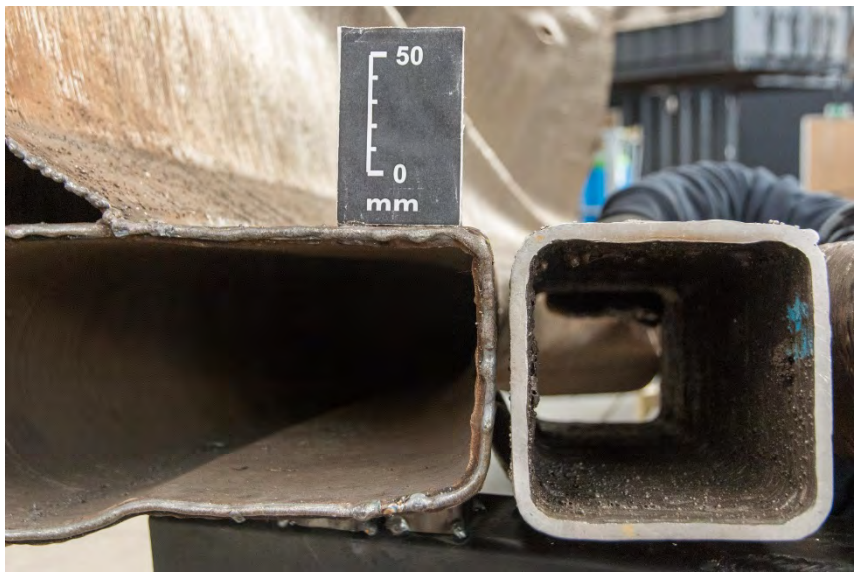


Uitdagingen
Geometrie

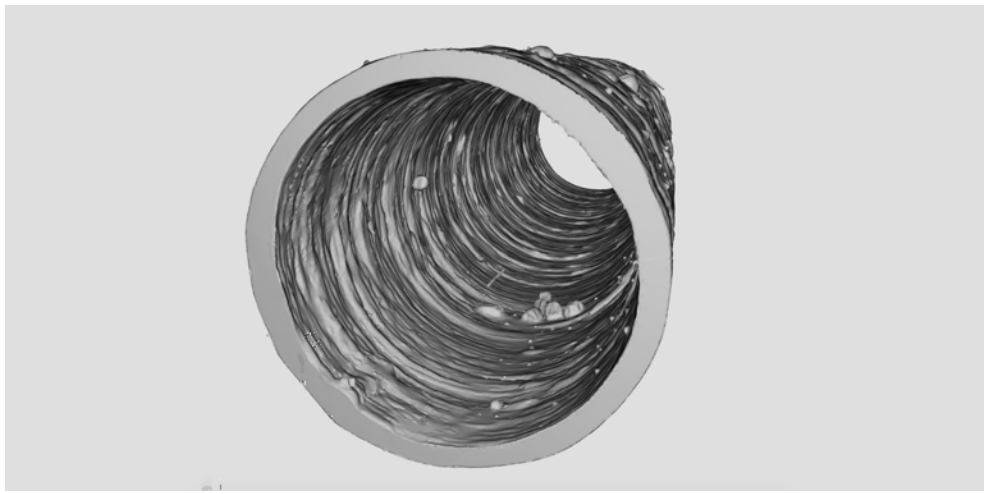
- Diktevariatie

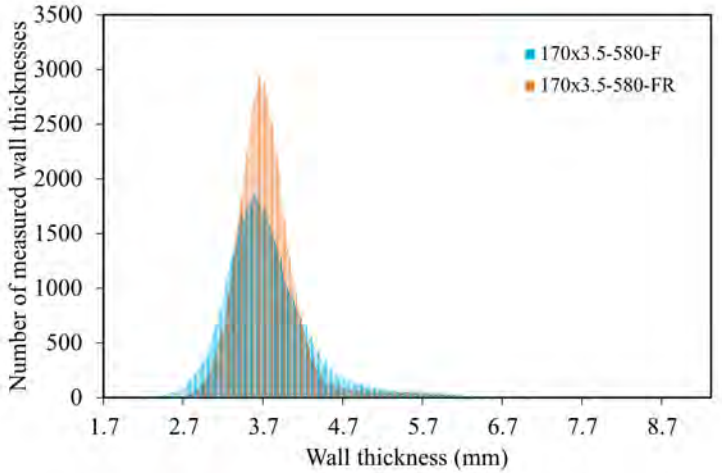


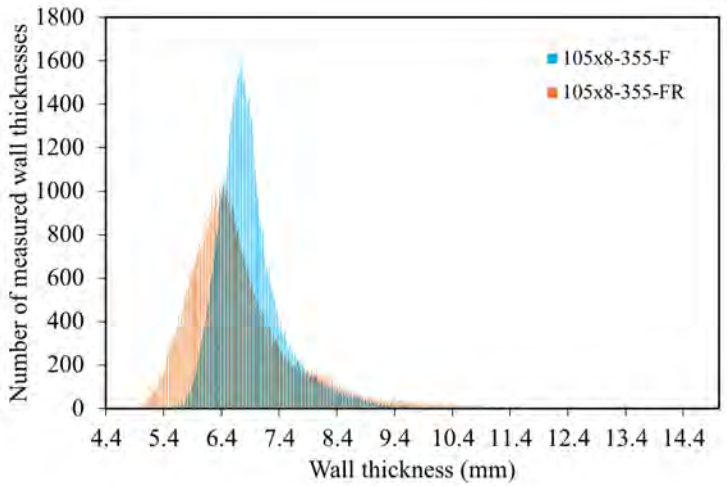
- Misalignments

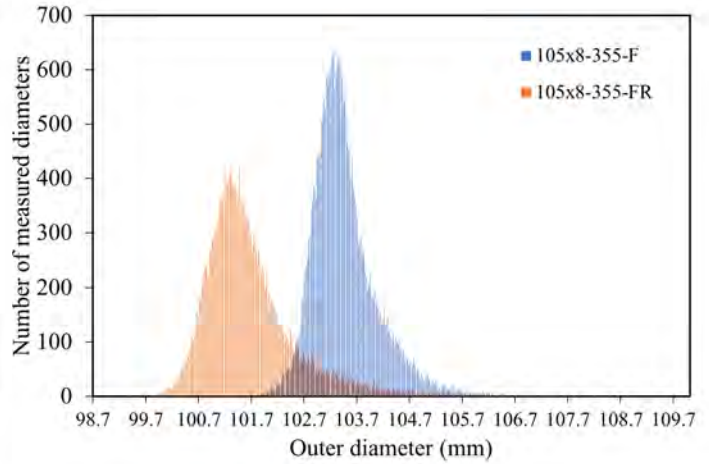


Uitdagingen
Geometrie





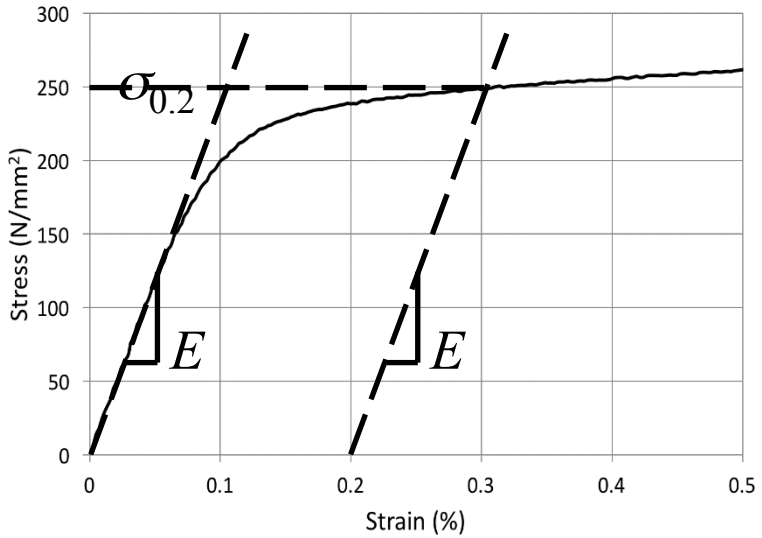


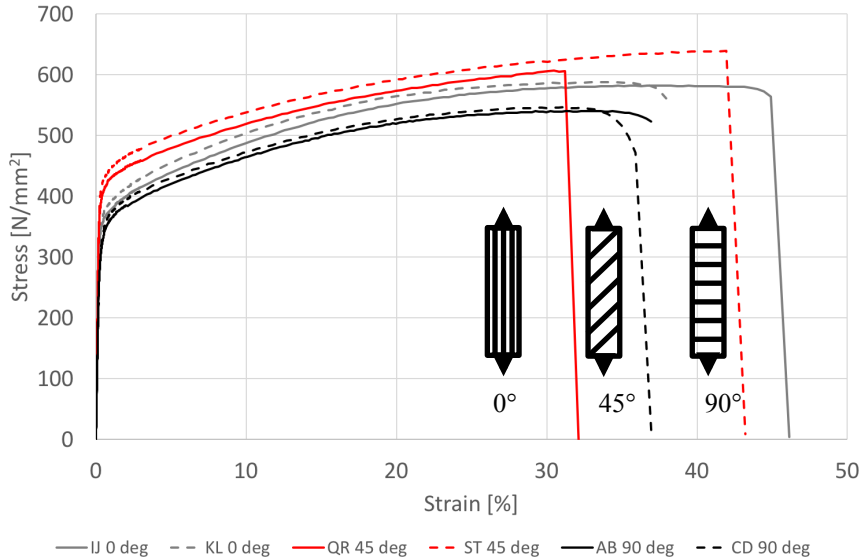


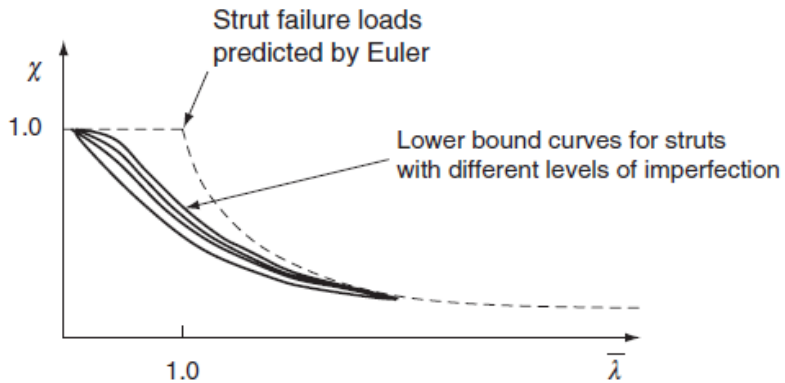
Uitdagingen

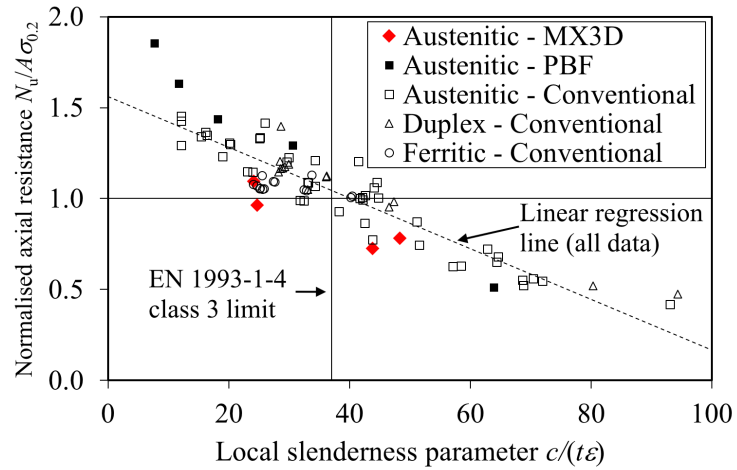
Materiaal – geen eurocode

- Materiaaleigenschappen
  - E
  - f_y ($\sigma_{0,2}$)
  - f_u
  - Ductiliteit
  - Taaiheid
- Stabiliteit
  - Doorsnedeklasse - lokaal
  - Knikkrommen - globaal









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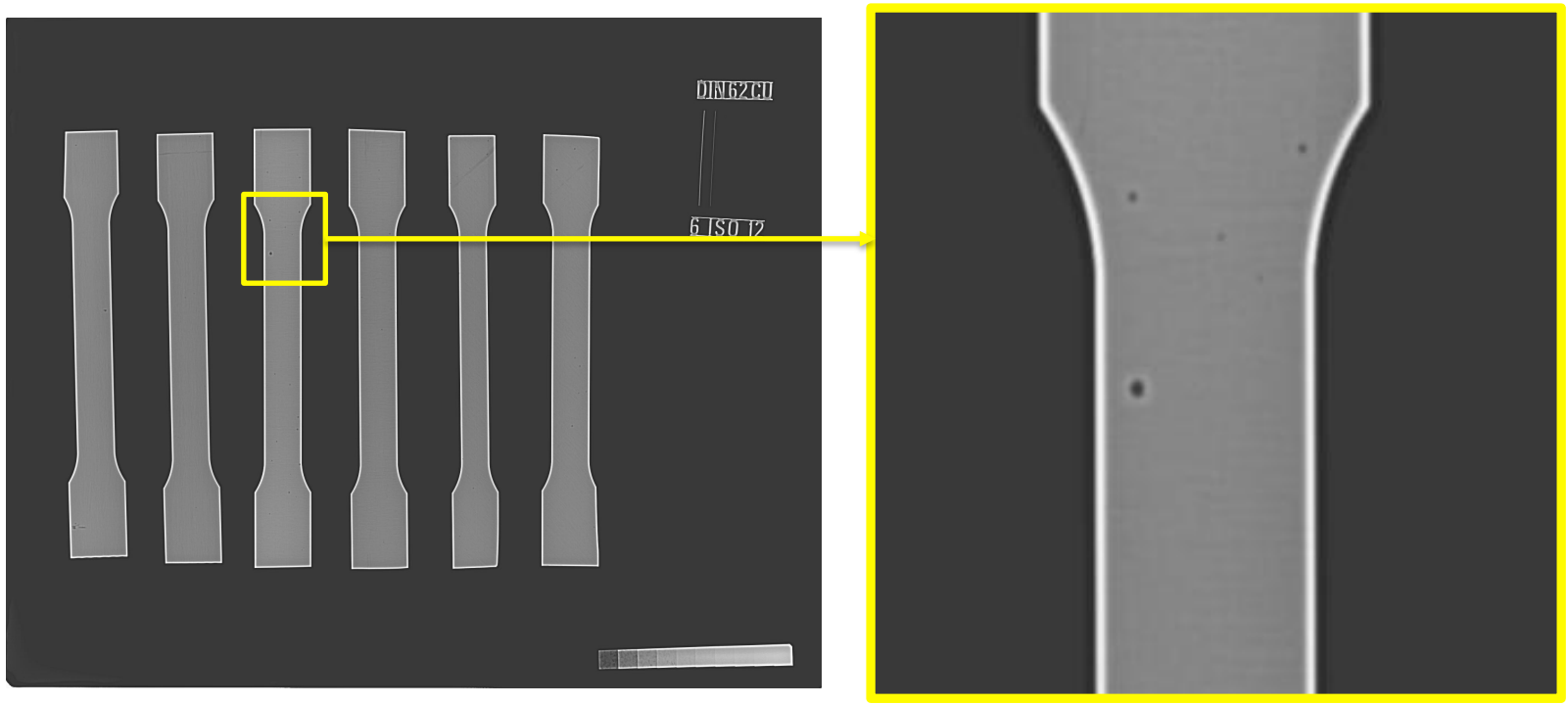
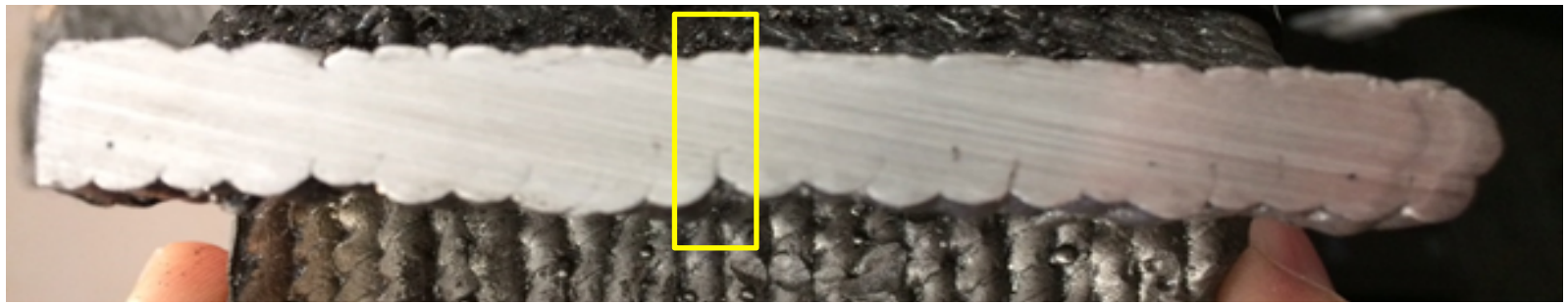
Uitdagingen
Lasfouten

- Insluitingen

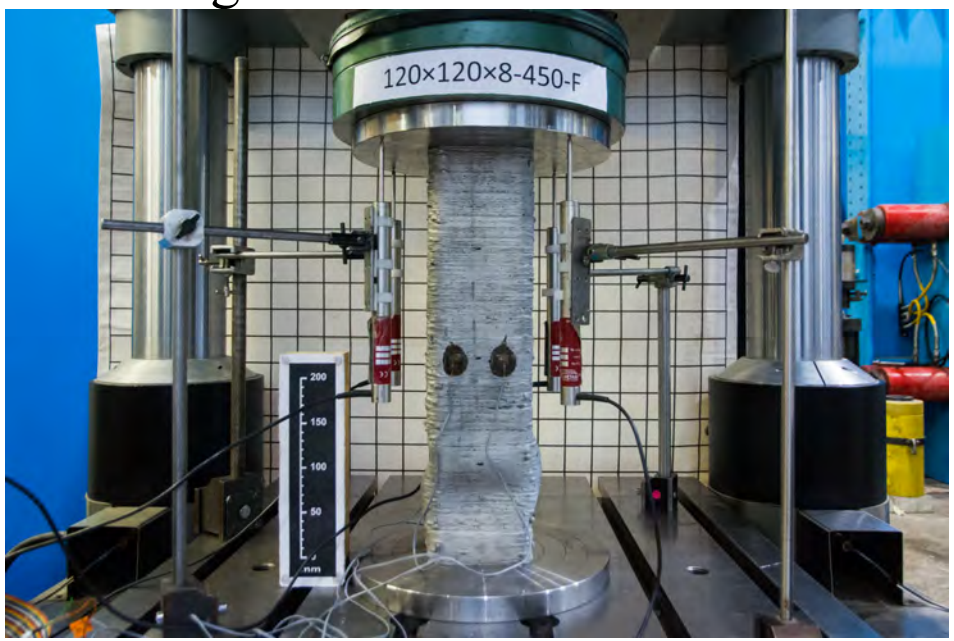


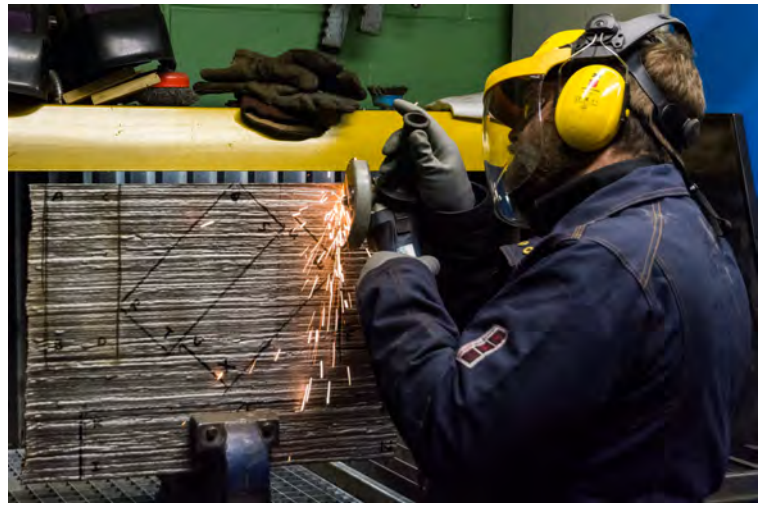
- Lack of fusion

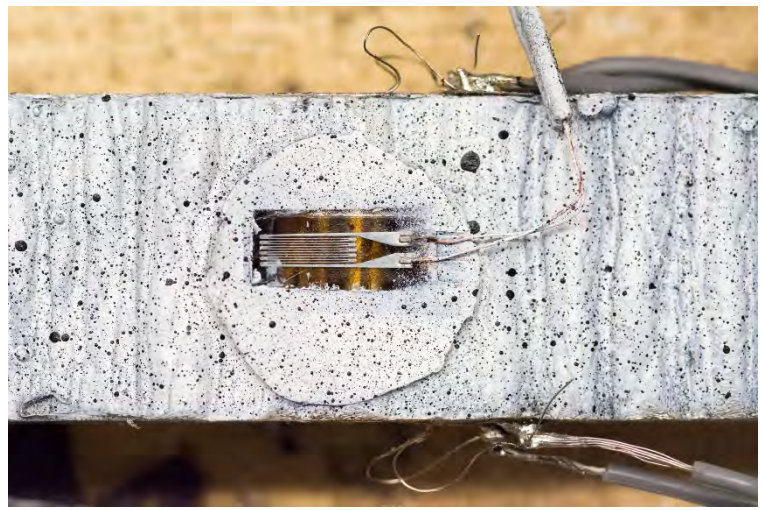


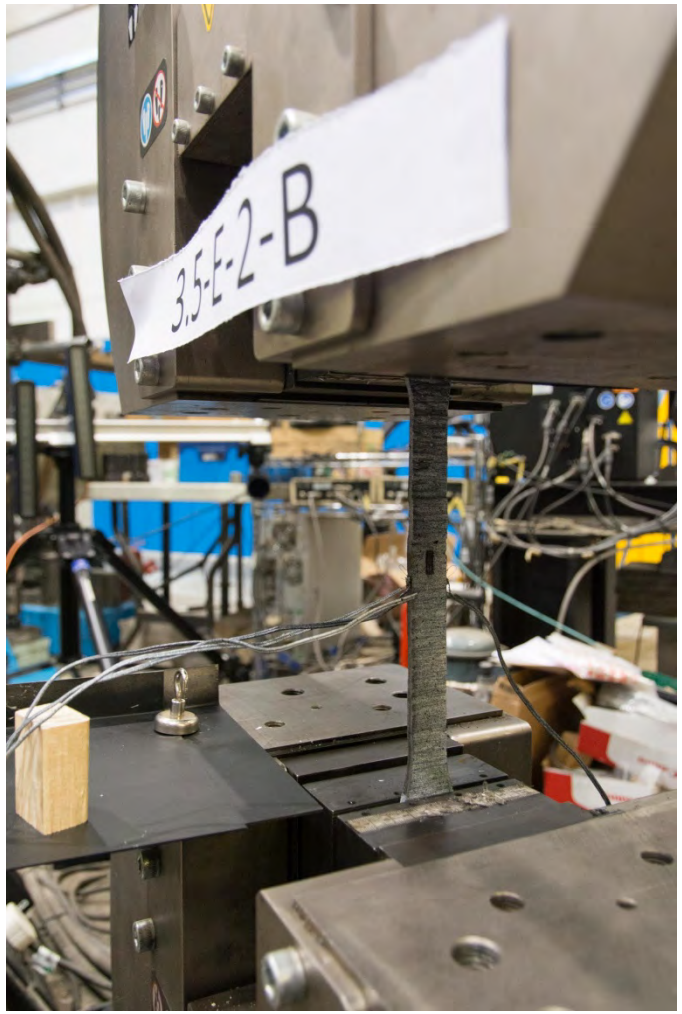
Testen
Laboratorium

- Material tests
- Coupons tests
- Column tests
- Bending tests









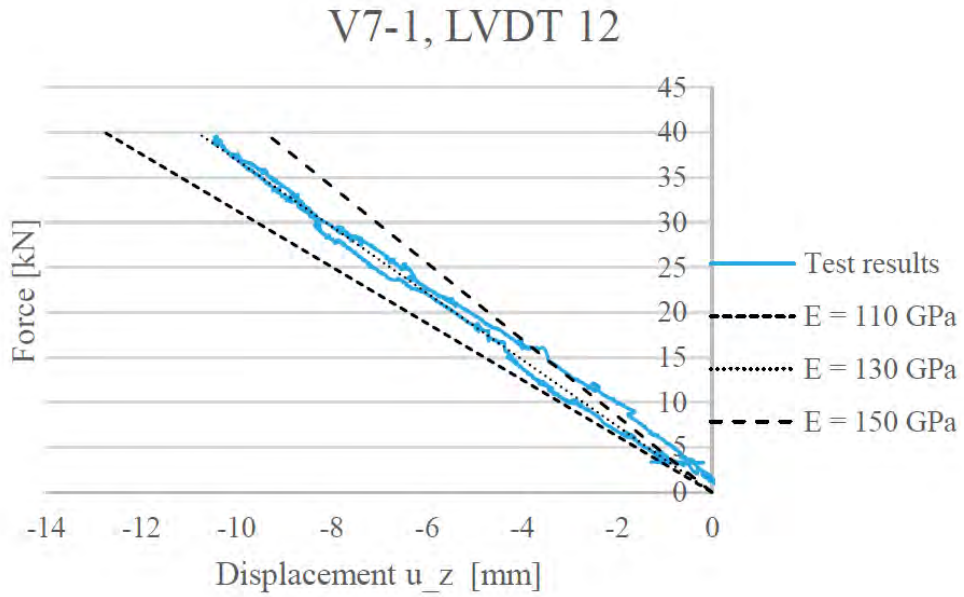
Testen
Full-scale

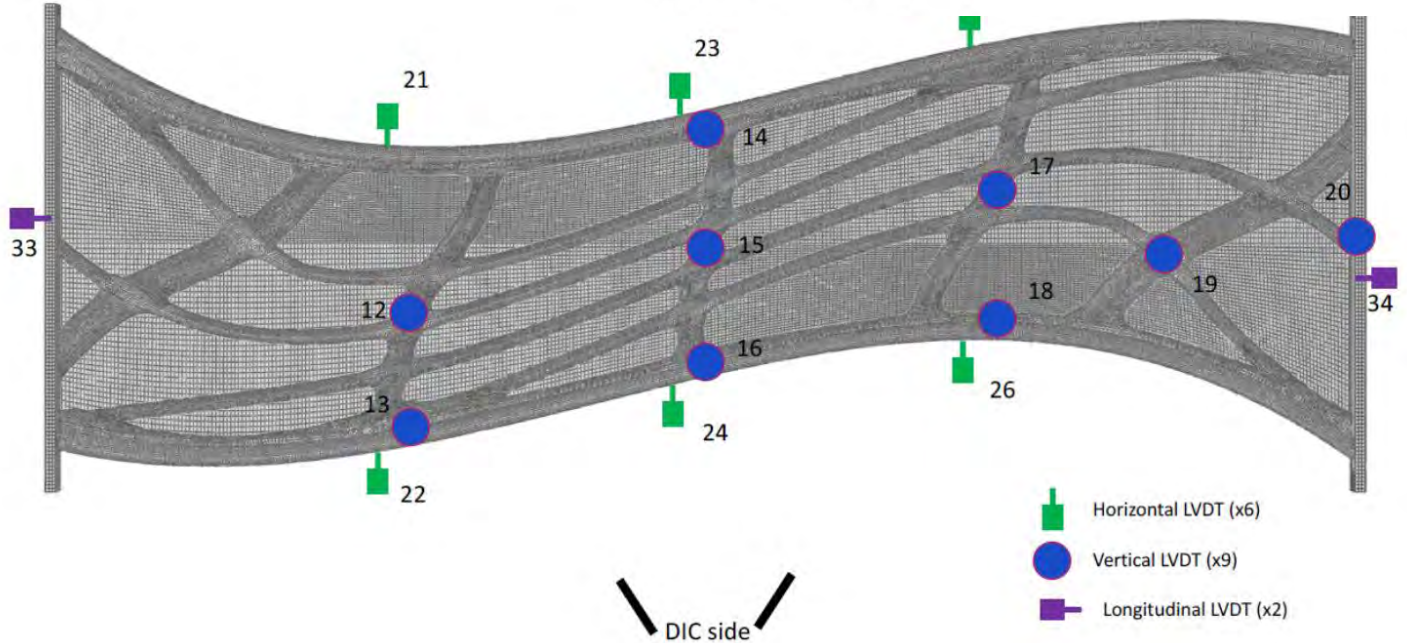
Verticaal: 115kN (ca. 4-5 kN/m2)

Horizontaal: 3 x 7,5 kN

Testen

Ontwerp op basis van experimenten





Constructieve analyse
Uitgangspunten

- Gevolgklasse 1 (CC1)
- Ontwerplevensduur 5 jaar (tijdelijk, 3 jaar)
- Ontwerpwaarden: NEN – EN1990 – Annex D

(1) The design value X_d for X should be found by using :

$$X_d = \eta_d m_X \{1 - k_{d,n} V_X\} \qquad (D.4)$$

In this case, η_d should cover all uncertainties not covered by the tests.

(2) $k_{d,n}$ should be obtained from table D2.

Table D2 - Values of $k_{d,n}$ for the ULS design value.

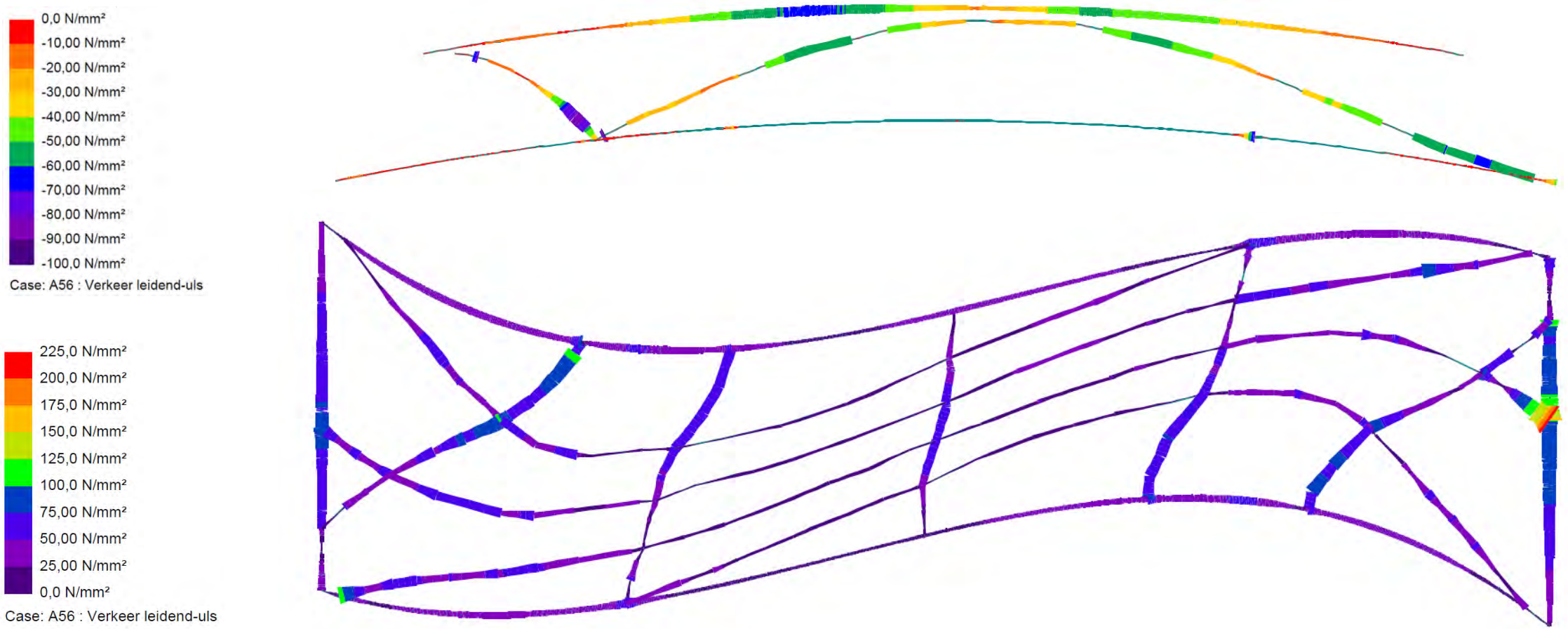
n	1	2	3	4	5	6	8	10	20	30	∞
V_X known	4,36	3,77	3,56	3,44	3,37	3,33	3,27	3,23	3,16	3,13	3,04
V_X unknown	-	-	-	11,40	7,85	6,36	5,07	4,51	3,64	3,44	3,04

Nominal	Average	Characteristic	Design
t= 3,5mm	3,57mm	3,14mm	**2,81mm**
t= 7mm	6,96mm	6,08mm	**5,41mm**
f_y= 240MPa	267MPa	235MPa	**202 MPa**
f_u= 585MPa	571MPa	518MPa	**462 MPa**

- Vermoeiingsmodel
  - 50 personen in één keer op en dan weer van de brug af;
  - Elke 10 min (250 000 herhalingen gedurende levensduur).

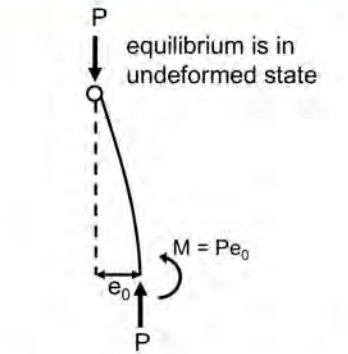
Constructieve analyse
Analyse

- Statische check (in elastisch gebied)

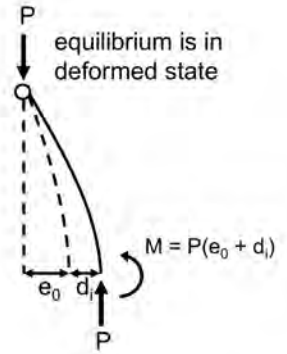


Constructieve analyse
Analysis

- Von-Misesspanningen
  - Reductie doorsnede door lokaal plooien
  - Diktevariaties meenemen
- Knikfactor >> 10
- Eigenfrequentie boven grenswaarde

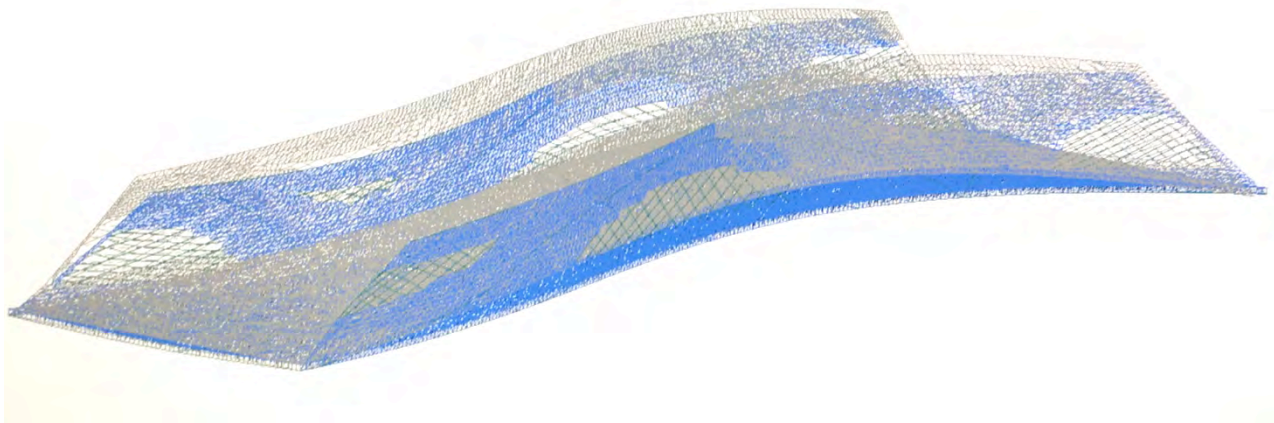


Linear geometry

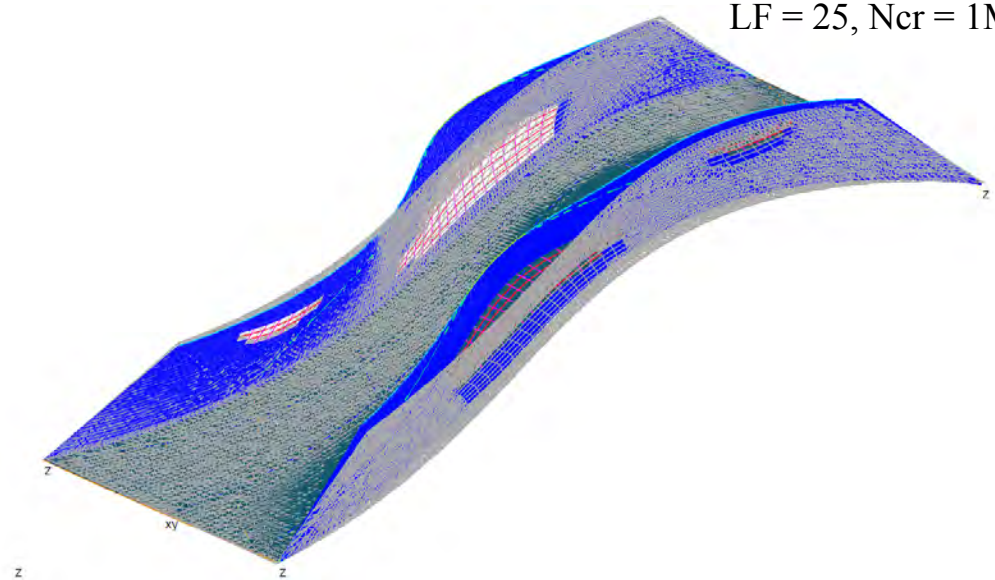


Nonlinear geometry

1st mode, f = 6,4 Hz



LF = 25, Ncr = 1MN



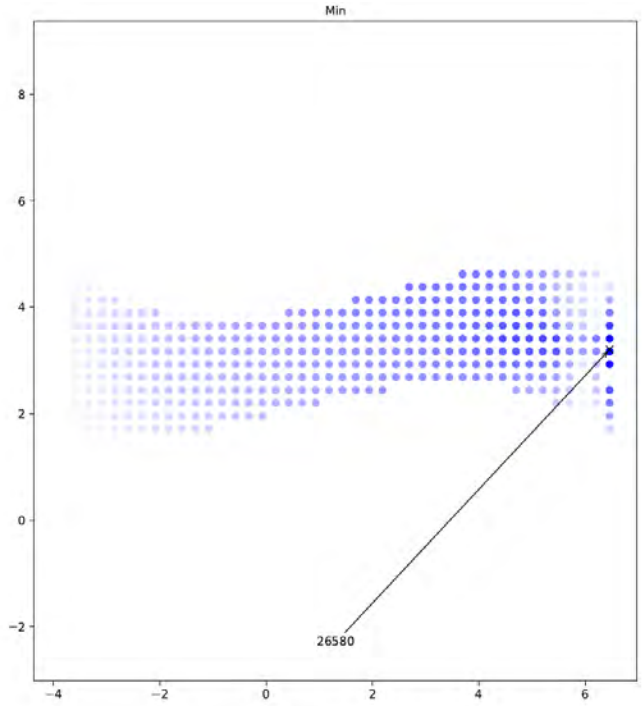
Constructieve analyse
Checks

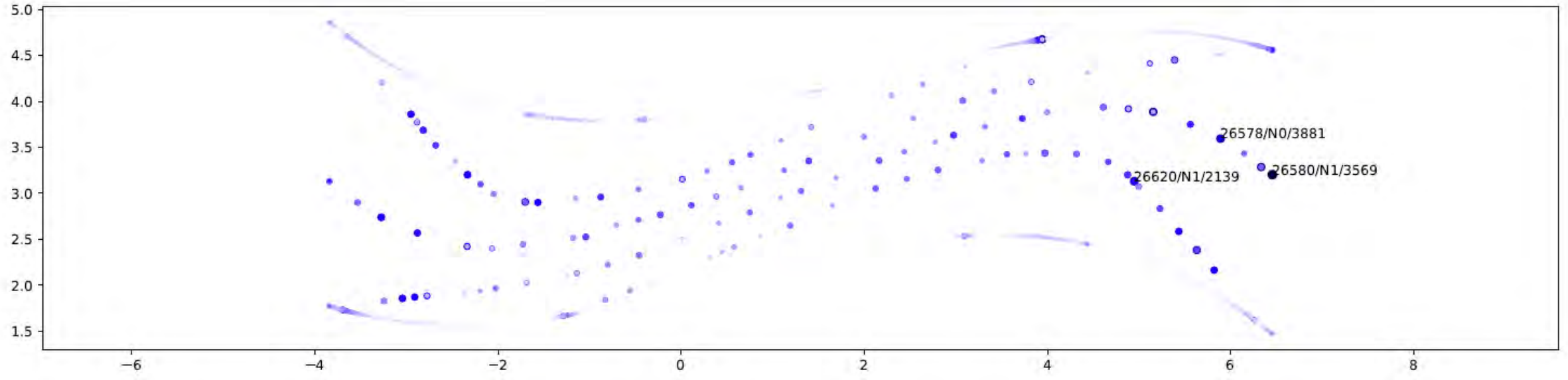
- Focus: plots bezwijken
  - (Globale) instabiliteit;
  - Scheurgroei.

- Andere bezwijkvormen waarschuwen:
  - Inspecties;
  - Live monitoring met sensors;
  - (Smarter bridge project)

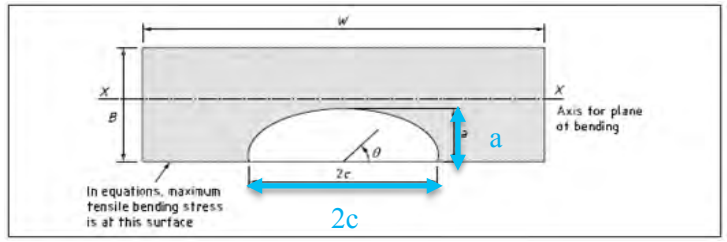
Constructieve analyse
Invloedsanalyse

- <u>Selectie kritische elementen;</u>
  - Zwaarst belast door voetgangersbelasting;
  - Belasting zo ongunstig mogelijk positioneren.





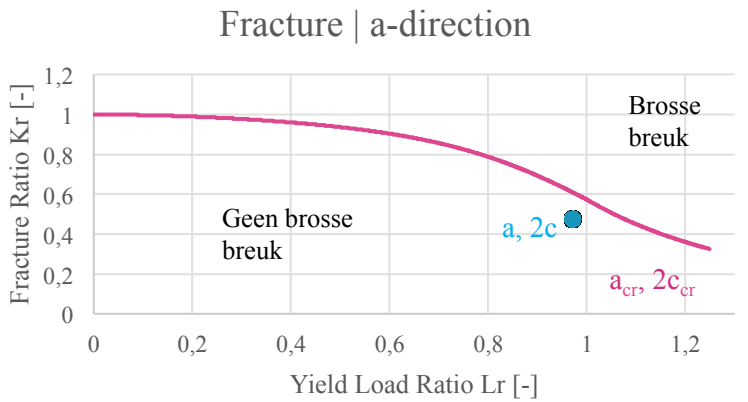
Constructieve analyse
Breukmechanica



- <u>Breukweerstand (statisch)</u>
  - Effect: Statische spanning bij ULS combinatie

$$E_d = 1{,}0E_T + 1{,}0G_k + 0{,}80Q_{ped} + 0{,}4Q_{PL}$$

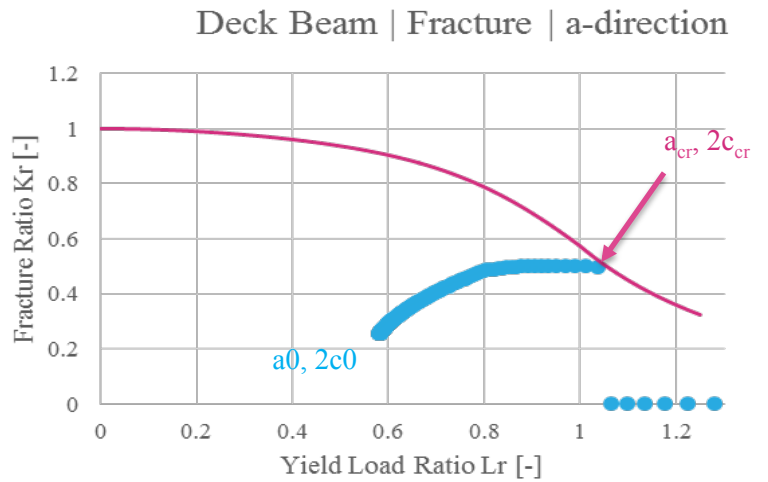
  - Weerstand: Bepaal grootte kritisch defect (a_{cr}, $2c_{cr}$)



- <u>Vermoeiingsweerstand (cyclisch)</u>
  - Effect: Vermoeiingsmodel; stress history [Δσ,N]

$$E_d = q_{50personen} + Q_{PL}$$

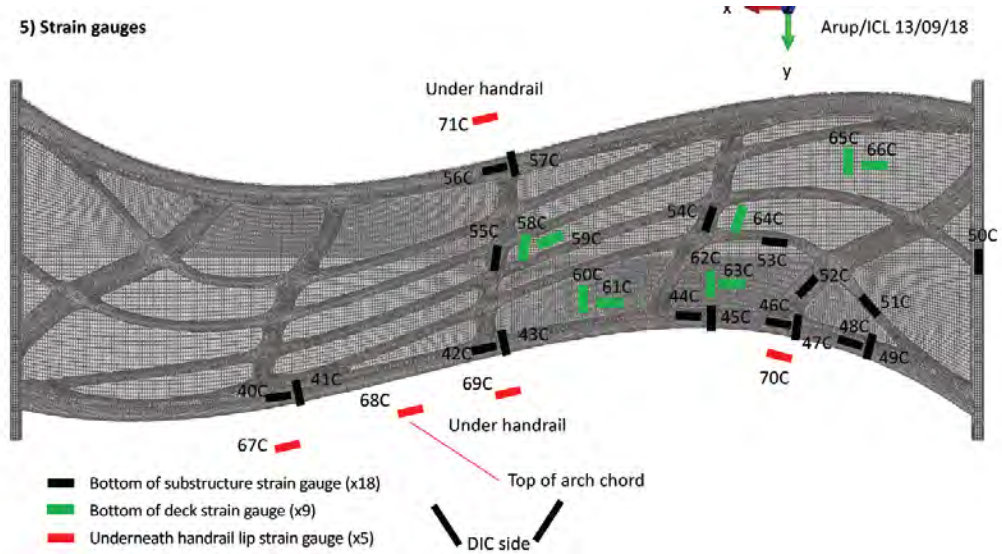
  - Weerstand: Bepaal maximale grootte initieel defect (a_0, $2c_0$) voor levensduur (5 jaar)



Sensors & monitoring

A smarter bridge project

- Sensoren geplaatst bij proefbelastingen
  - EEM kalibreren
  - Ontwerpwaarden definieren
- Sensorsysteem in gebruik
  - Monitoring van constructieve veiligheid, afwijkingen duiden op een mogelijk defect.
  - Bigger picture: Digital twin & Data mining
    - Analyse van voetgangersstromen, gedrag
    - Directe relatie omgeving en constructie
    - Informatie hoe de brug gebruikt wordt - belastingen
    - Internet of Things
    - …



Project Mx3D geprinte brug
Locatie Nederland
Klant Gemeente Amsterdam

Key facts

// *12,5m lang, 1,95 to 3 m breed*
// *10,3m span, 23,3m2,*
// *3D-geprint staal: 4500kg -1100km lasdraad*
// *Volledige EC proefbelasting: Q2-2019*
// *Plaatsing in Amsterdam: Q4-2019*

Arup Services

// *Lead Structural engineering*
// *Materiaalkunde – breukmechanica*
// *Testprogramma opstellen*
// *Mede-ontwerper sensorsysteem*
// *Onderdeel van het 'Smarter Bridge'-team*