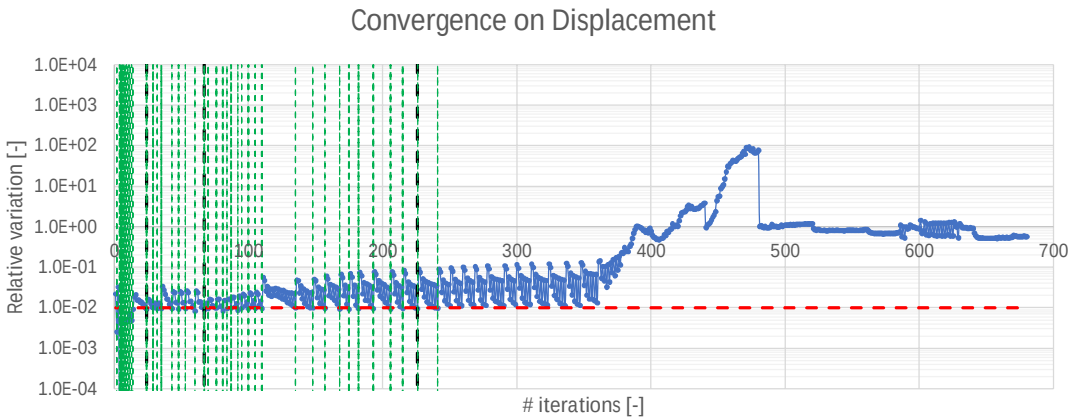
DIANA Users Association

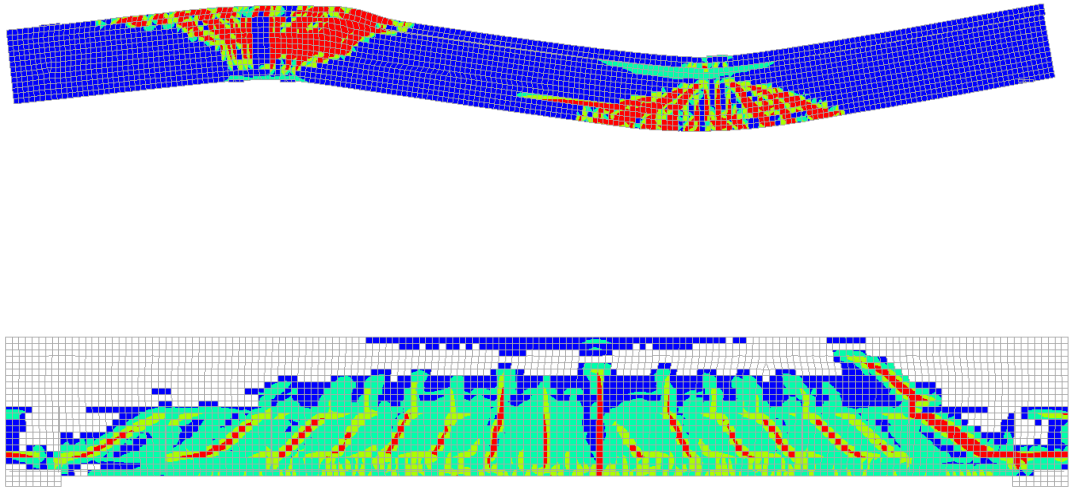
DIANA FEA

wagemaker

Existing bridge structures

Reassessment of existing shear-prone bridge structures using NLFEA



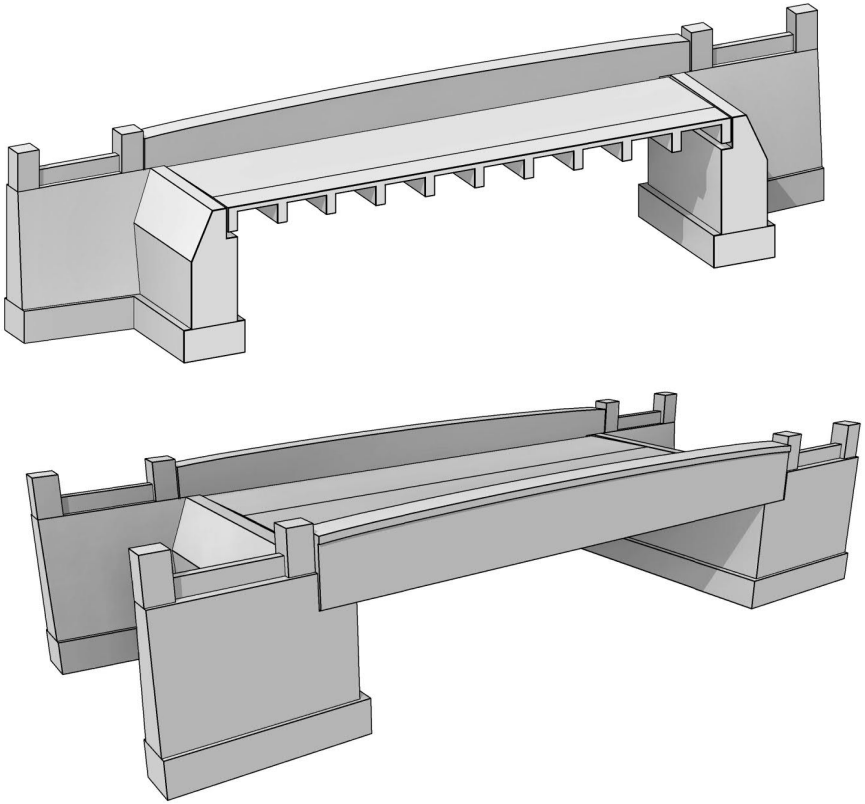




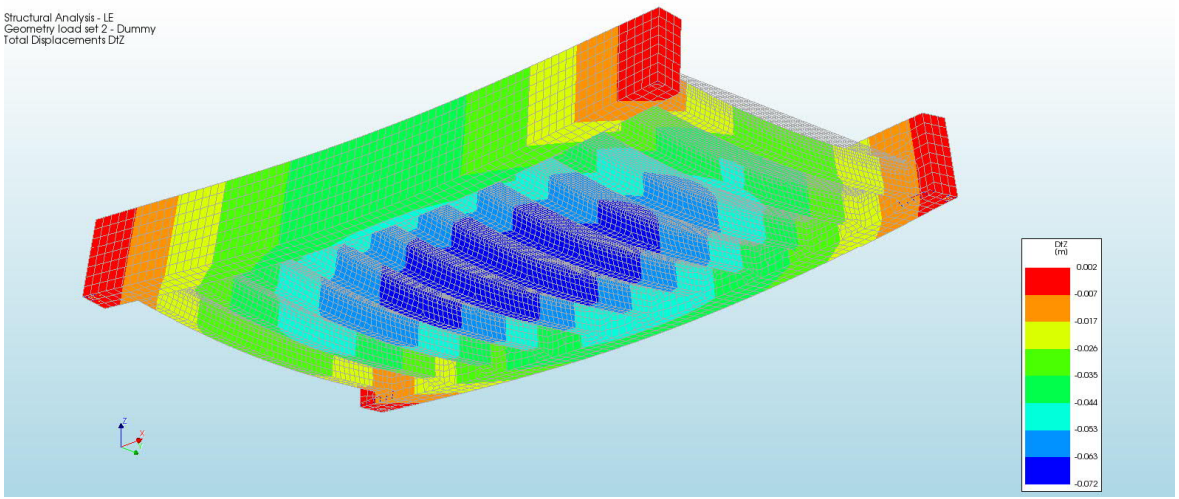
dr.ir. Dennis Schoenmakers

DOV - June 14th 2023
Amersfoort

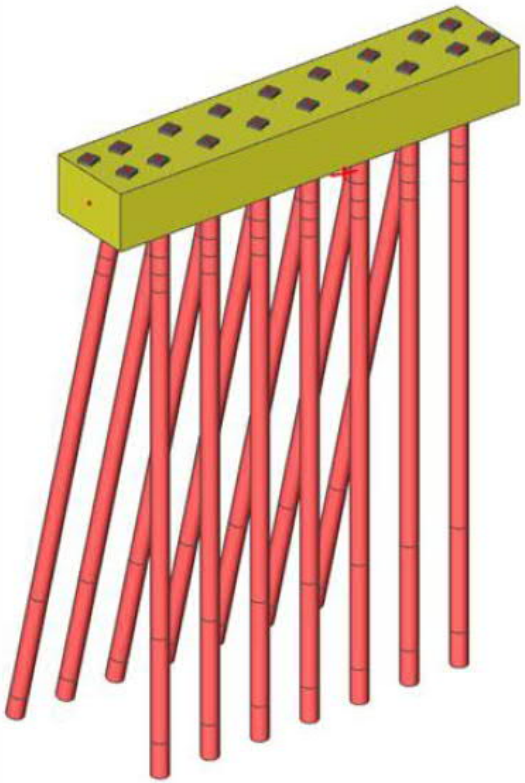
Dennis Schoenmakers

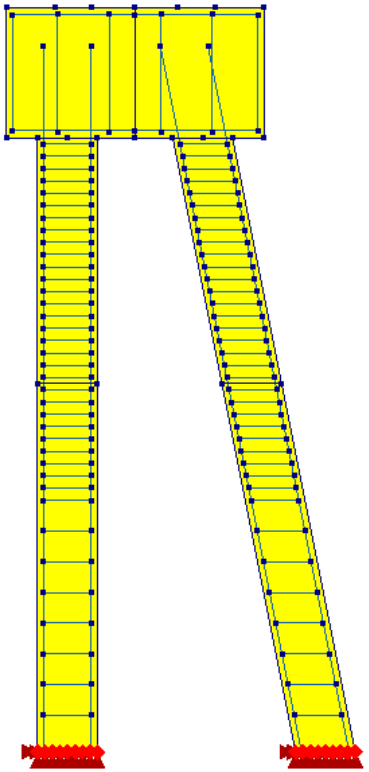


- DIANA FEA user since 2016 (release 10.0)

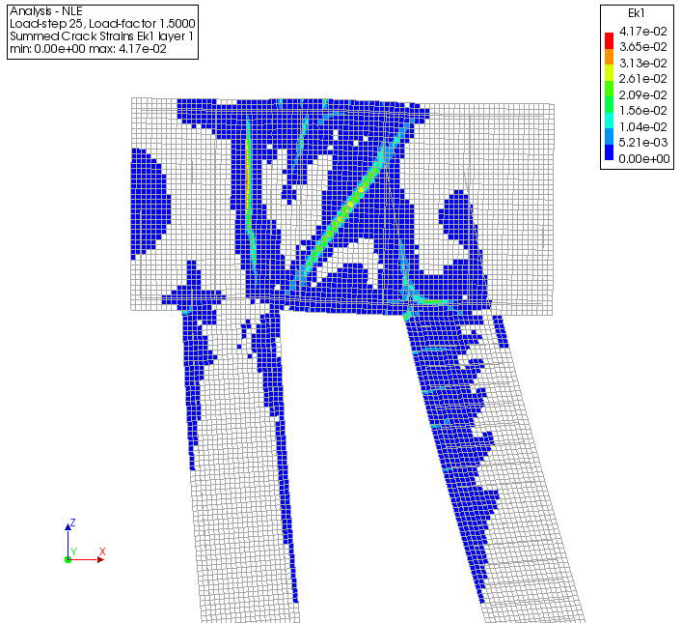


Dennis Schoenmakers



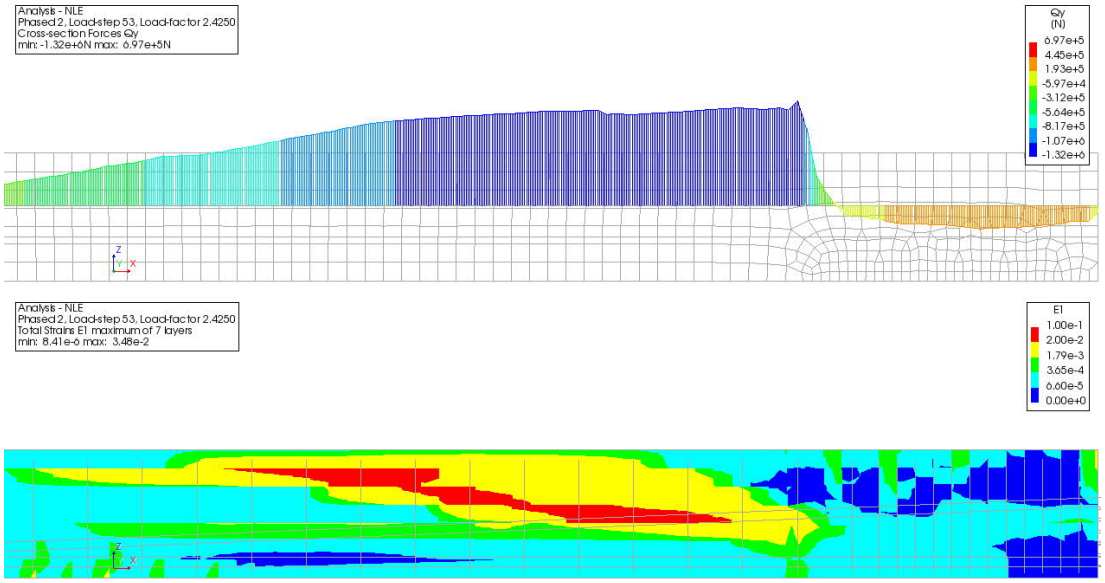


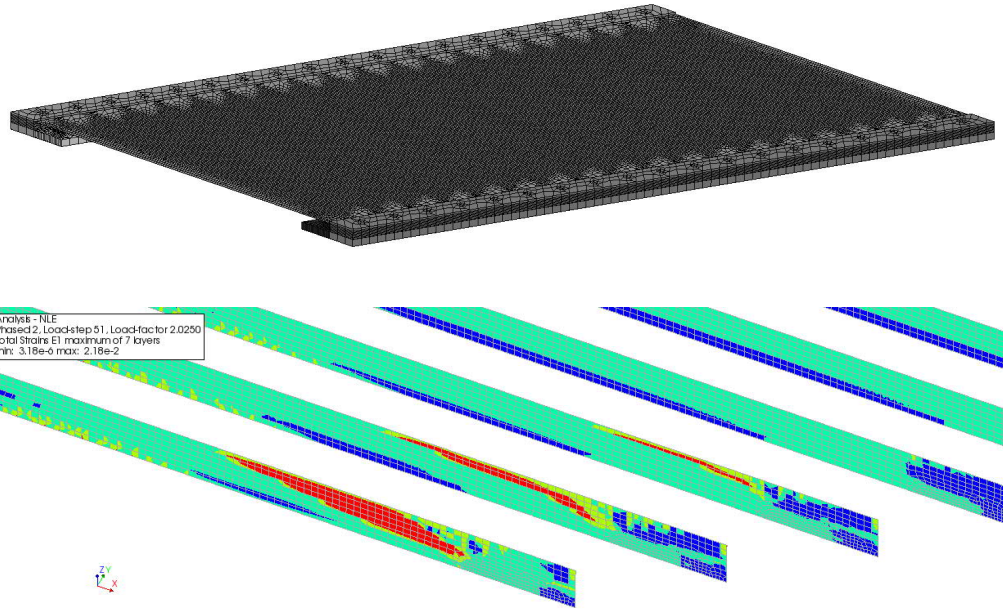
- DIANA FEA user 2021 (release 10.4)



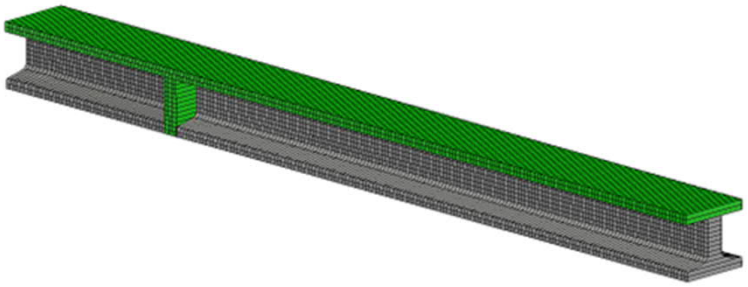
Dennis Schoenmakers

- DIANA FEA user 2021 (release 10.3)



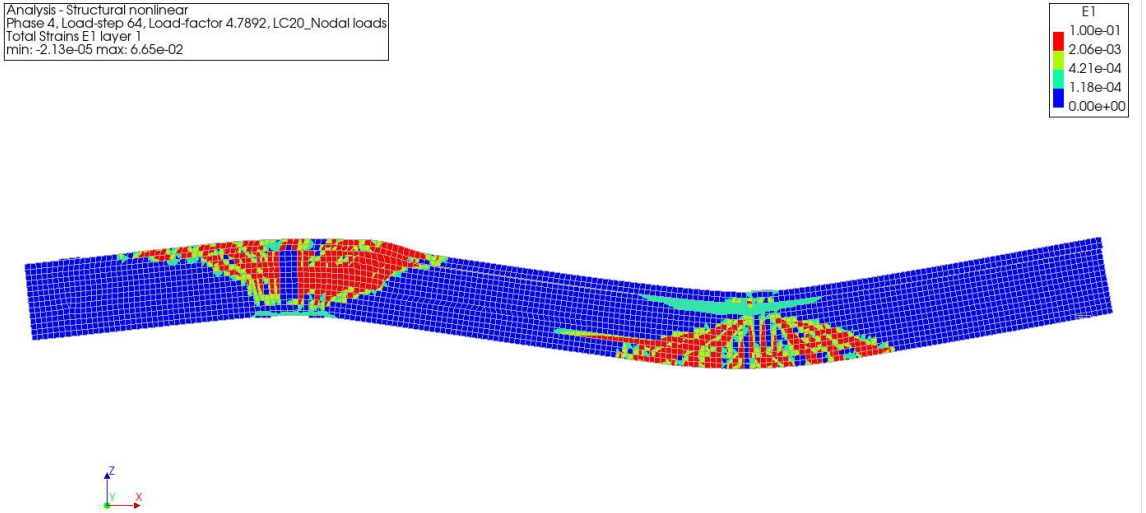


Dennis Schoenmakers

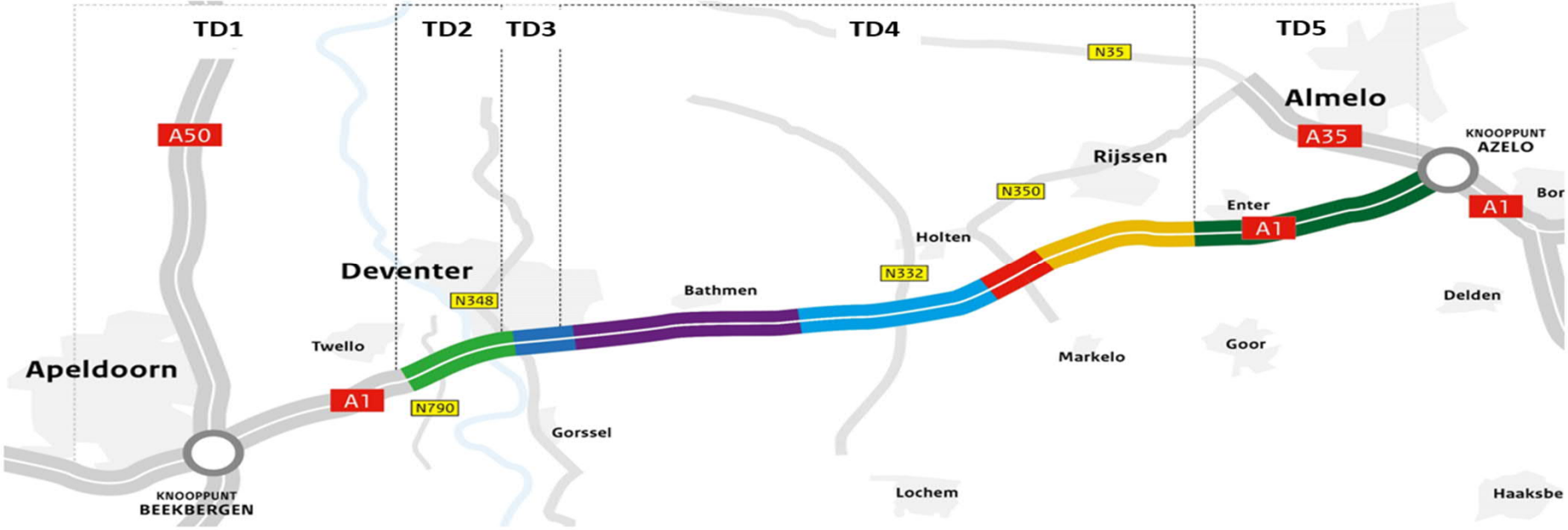


- DIANA FEA user 2023 (release 10.6)





Dutch Highway A1 Apeldoorn Azelo
Reassessment of existing shear-prone bridge structures using NLFEA



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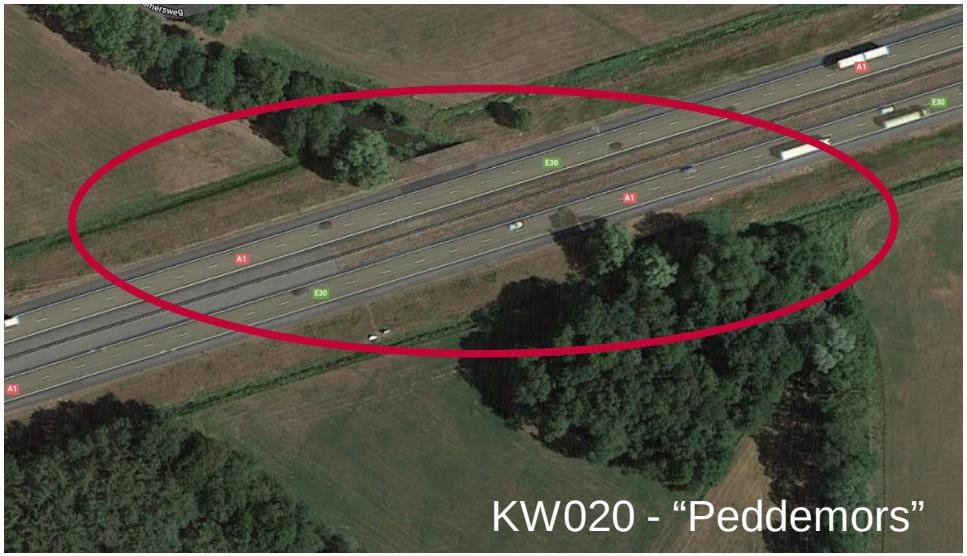
Introduction



- Widening of Dutch highway
- Shear force problem



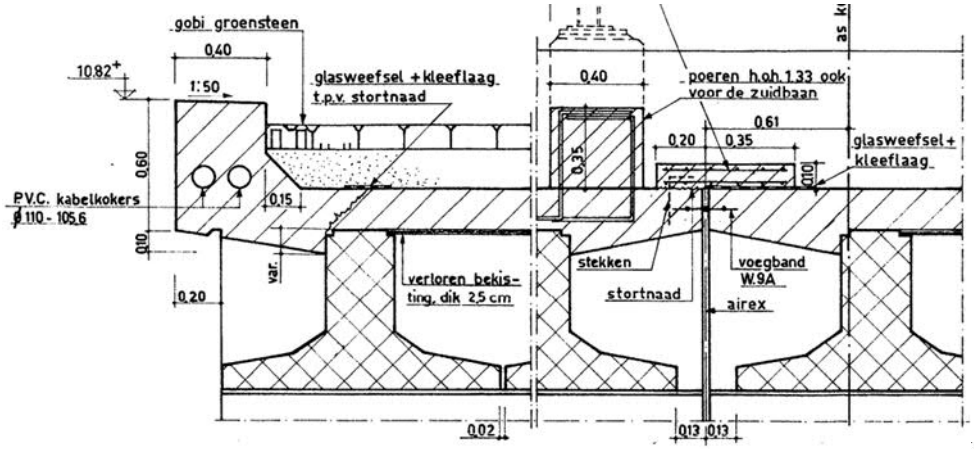
KW018 - “Binnenkraai”

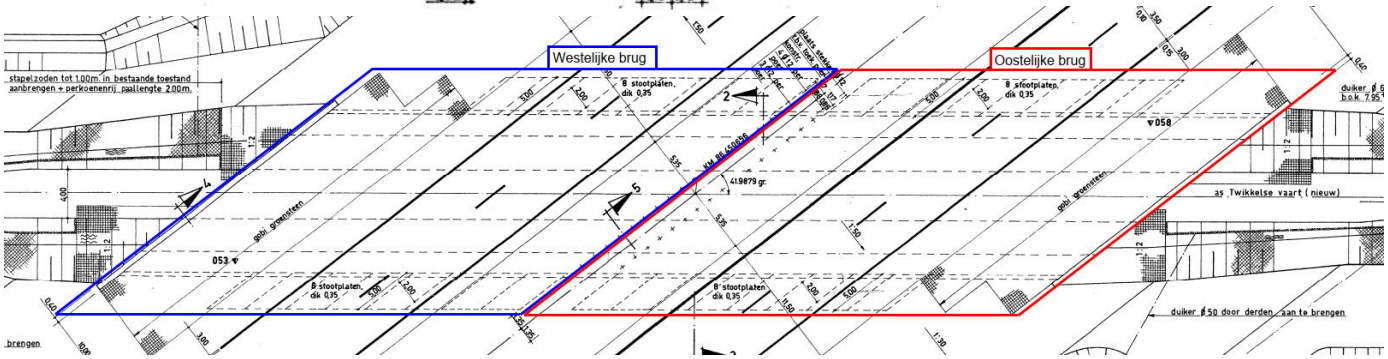


KW020 - “Peddemors”

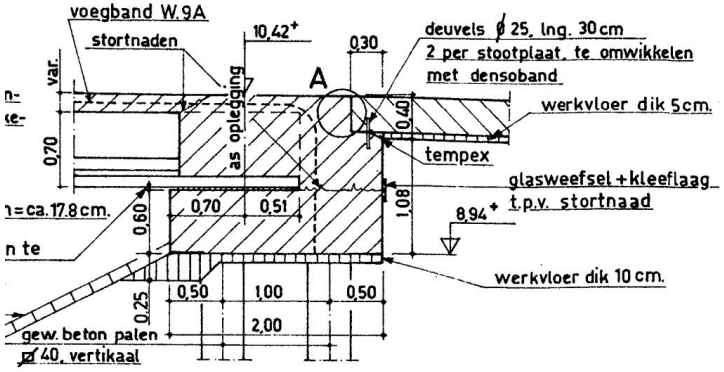
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Introduction





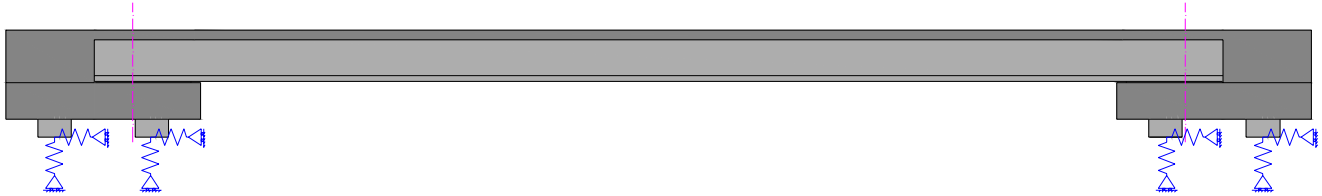
- Integral structure (monolithic jointed deck and abutments)
- Inverted T-girder + slab 700 + 160 mm
- Span: 17.6 m / Width 25.0 m



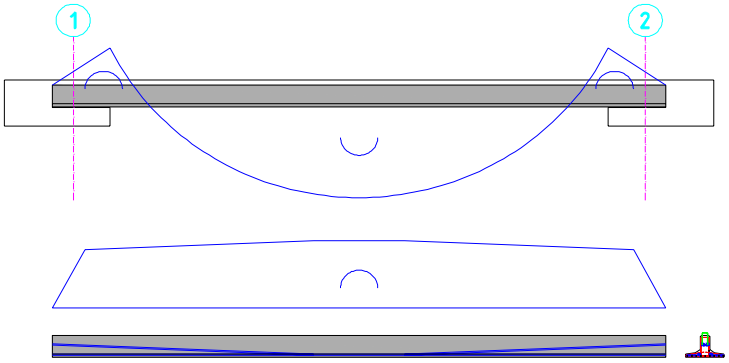
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Introduction

- Mechanical point of view



Bending moment external loading



Bending moment due to prestress

Introduction



- Reassessment based on LE-calculations

RTD1006 (RBK1.1)

(1) De rekenwaarde van de dwarskrachtweerstand $V_{Rd,c}$ is gegeven door:

$$V_{Rd,c} = [C_{Rd,c} k (100\, \rho_l f_{ck})^{1/3} + k_1\, \sigma_{cp}]\, b_w d$$

met een minimum van

$$V_{Rd,c} = (v_{min} + k_1 \sigma_{cp})\, b_w d$$

Shear strength was nearly sufficient

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“New” developments “shear knowledge”

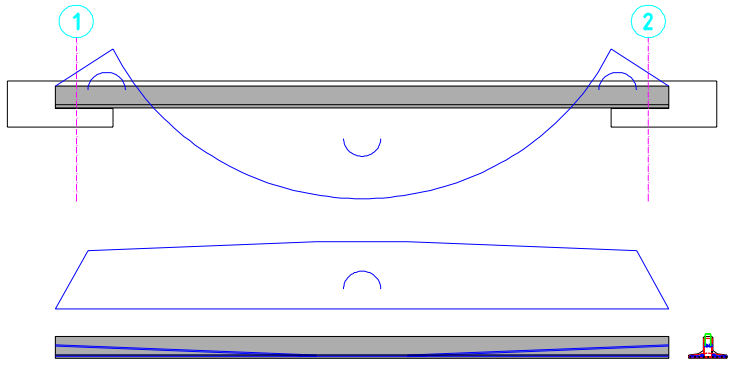
SYS-0824	6.2.2 (1)-NEN-EN 1992-1-1	Kunstwerk
Eistekst	De rekenwaarde van de dwarskrachtweerstand voor situaties waarbij de voorspanning gelegen is aan de gedrukte zijde van de constructie moet bepaald worden met $\sigma_{cp} = 0$.	
Toelichting	Dit artikel betreft bijvoorbeeld bruggen met statisch bepaalde liggers (trek aan de onderzijde) die met het storten van de druklaag worden samengevoegd tot een statisch onbepaald systeem (met trek aan de bovenzijde nabij de tussensteunpunten). Deze situatie waarbij de voorspanning zich bevindt aan de gedrukte zijde van de constructie, valt buiten het beoogde toepassingsgebied van dit artikel van NEN-EN 1992-1-1. Door in deze situatie uit te gaan van $\sigma_{cp} = 0$ zal een ondergrens gevonden worden voor het betonaandeel in de dwarskrachtcapaciteit van de te beschouwen doorsnede.	

N_{Ed} is de normaalkracht in het verificatievlak ten gevolge van belasting of voorspanning in [N] ($N_{Ed} > 0$ voor druk). De invloed van opgelegde vervormingen op N_{Ed} mag zijn verwaarloosd.
Bij statisch onbepaald gemaakte voorgespannen liggerviaducten met voorspanstaal mag de bijdrage van de voorspanning in N_{Ed} ter plaatse van de tussensteunpunten niet in rekening gebracht worden.

RTD1001 (ROK2.0)

Bending moment external loading

Bending moment due to prestress



RTD1006 (RBK1.2.1)

(1) De rekenwaarde van de dwarskrachtweerstand $V_{Rd,c}$ is gegeven door:

$$V_{Rd,c} = [C_{Rd,c} k (100\,\rho_l f_{ck})^{1/3} + k_1 \sigma_{cp}]\, b_w d$$

met een minimum van

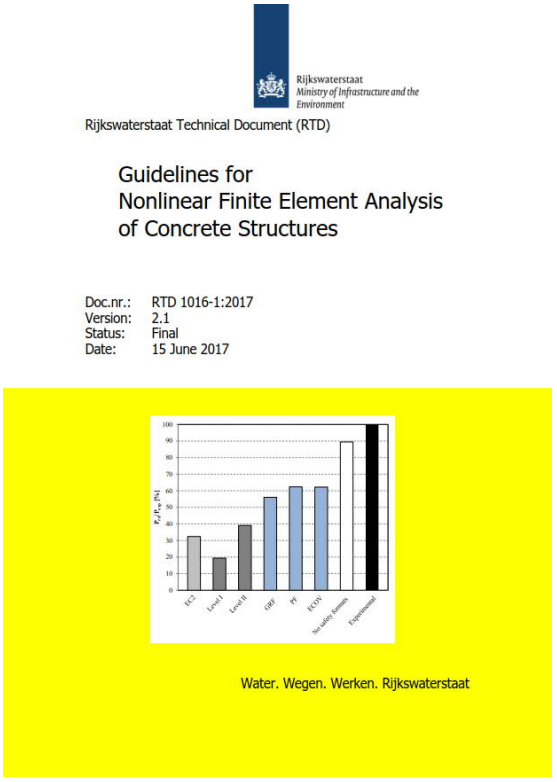
$$V_{Rd,c} = (v_{min} + k_1 \sigma_{cp})\, b_w d$$

i.e. $\sigma_{cp} = 0$ MPa

Shear strength was not sufficient (max. u.c. 2.19)

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Non Linear Finite Element Analysis



- Physical NLFEA
- DIANA FEA 10.3
- 3D-analysis necessary
- GRF-philosophy (ultimate load of the system)
- Simulation of shear failure

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

TNO innovation for life

TU Delft

DIANA FEA

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Modeling (I)

- Building sequence / history

Dead weight

+

Prestressing

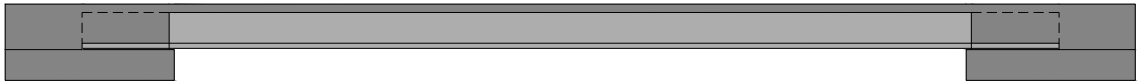




Mounting at abutments



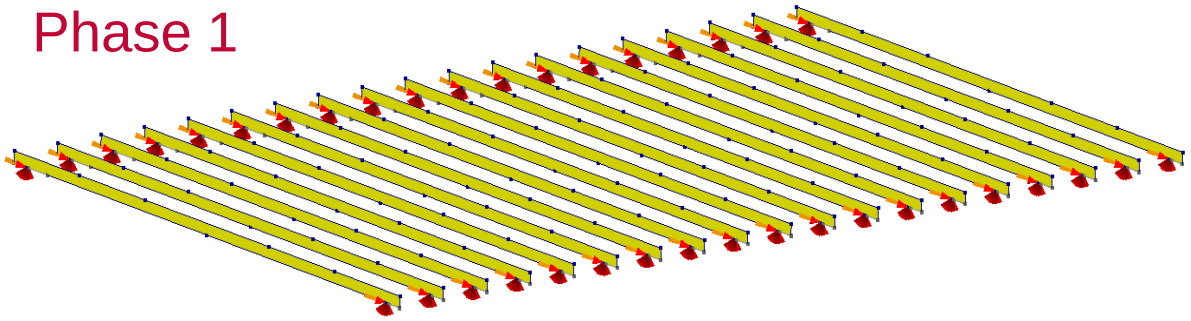
Monolithic jointed (hyperstatic)



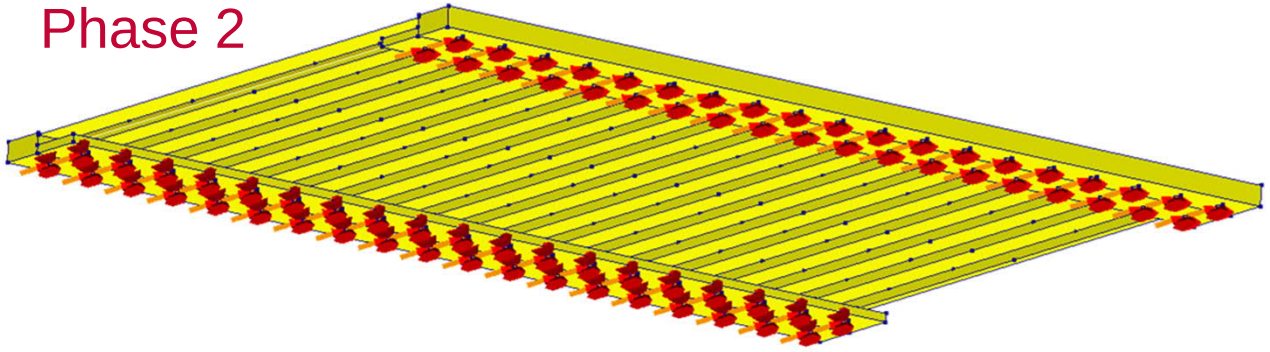
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Modeling (III)

Phase 1



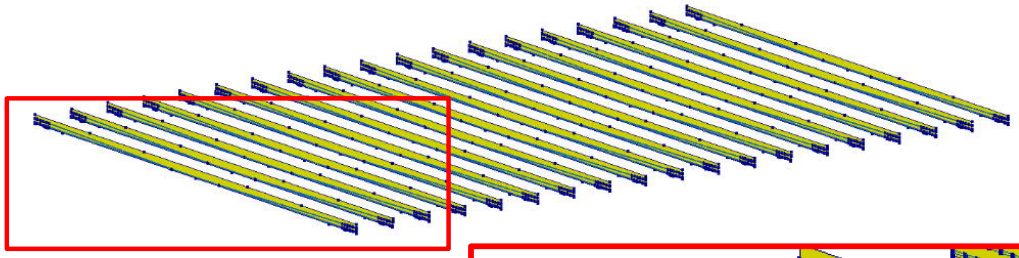
Phase 2



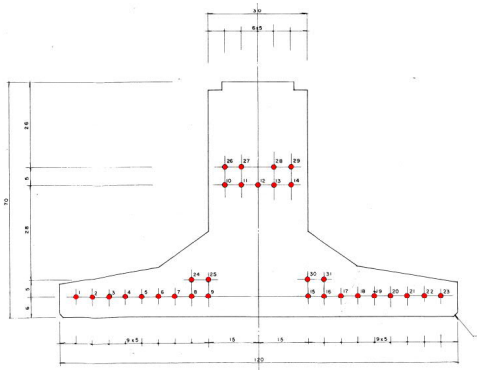
- DIANA FEA model in R3-world
- Phased analysis
  - Phase 1: Dead weight + Prestress + cast in-situ weight
  - Phase 2: Monolithic with additional loading P + Q

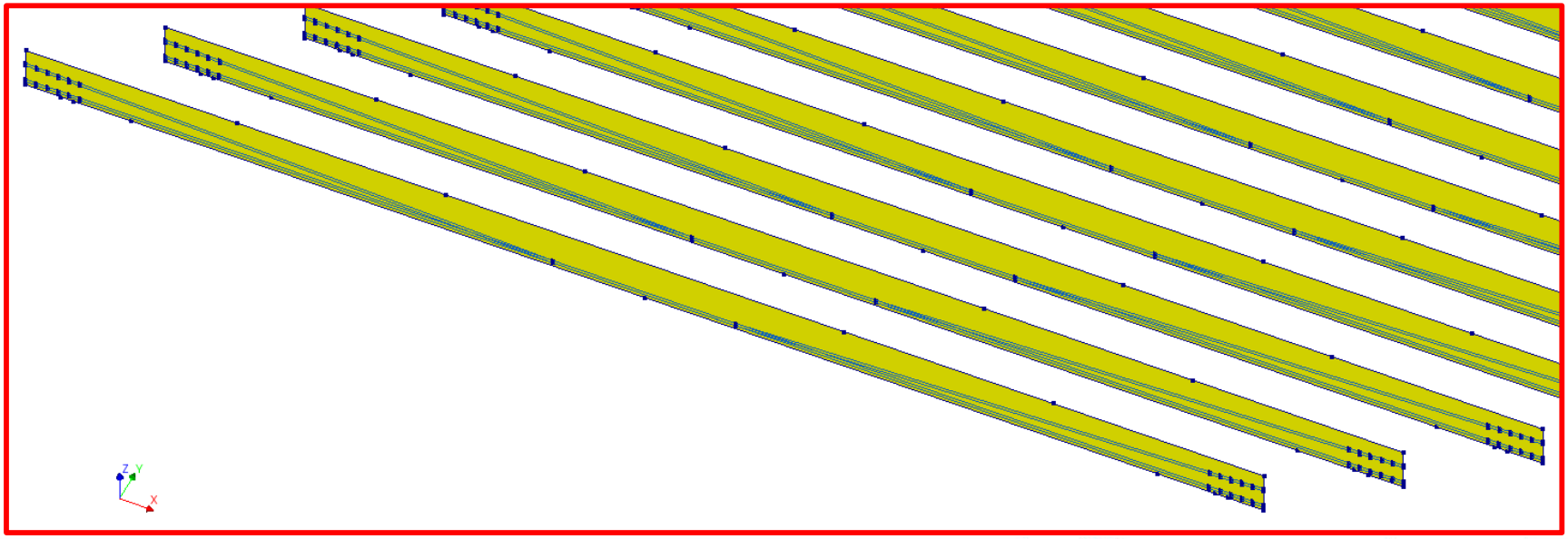
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Modeling (IV)



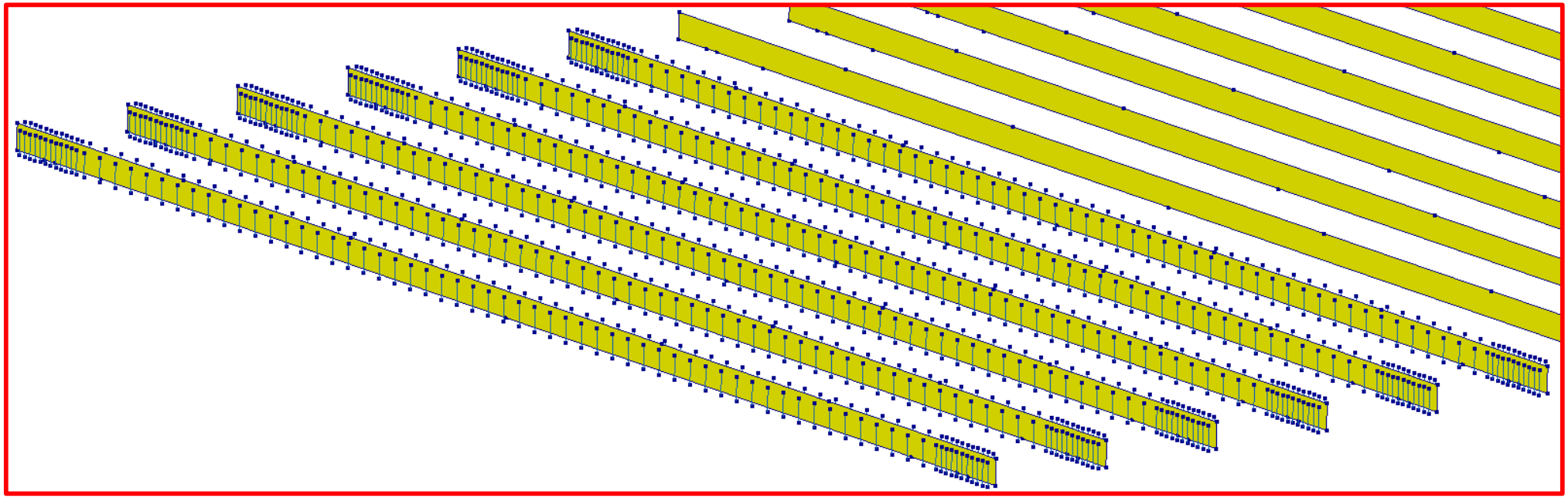
- Prestressing strands (4 groups)



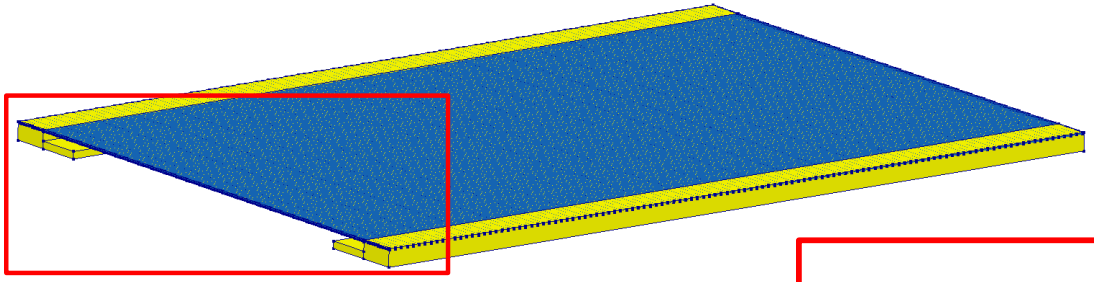


Modeling (V)

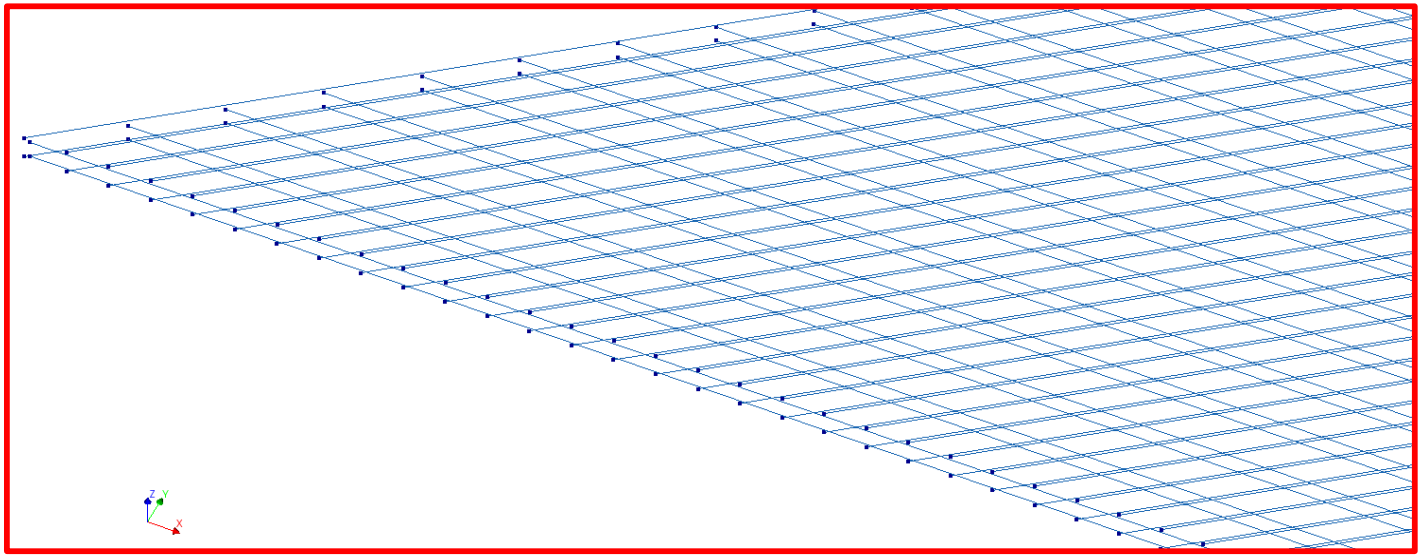
- Stirrup reinforcement beams



Modeling (VI)

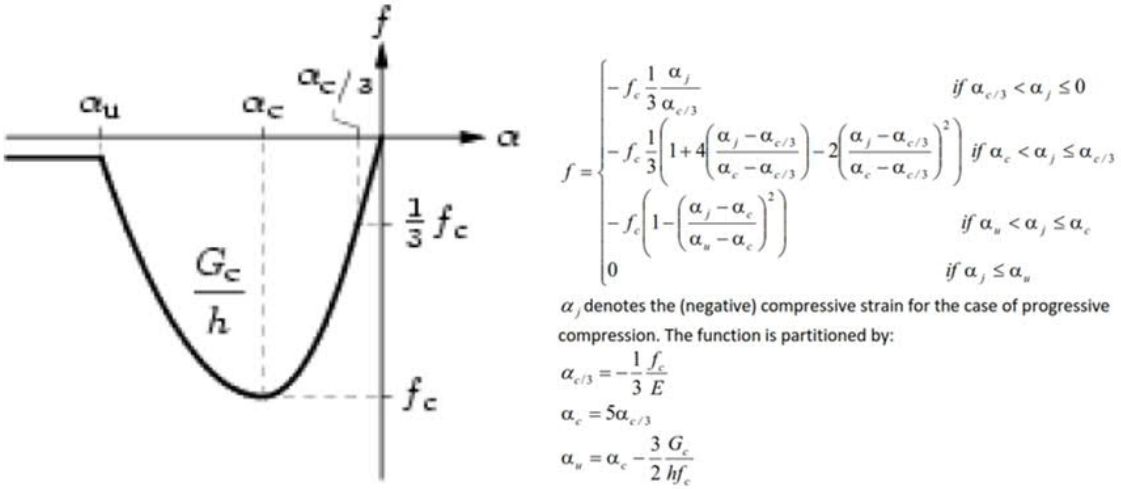


- Flexural reinforcement topping



Constitutive model concrete (I)

- Material models acc. RTD1016-1(2019)



$$f = \begin{cases} -f_c \frac{1}{3} \frac{\alpha_j}{\alpha_{c/3}} & \text{if } \alpha_{c/3} < \alpha_j \le 0 \\ -f_c \frac{1}{3}\left(1 + 4\left(\frac{\alpha_j - \alpha_{c/3}}{\alpha_c - \alpha_{c/3}}\right) - 2\left(\frac{\alpha_j - \alpha_{c/3}}{\alpha_c - \alpha_{c/3}}\right)^2\right) & \text{if } \alpha_c < \alpha_j \le \alpha_{c/3} \\ -f_c\left(1 - \left(\frac{\alpha_j - \alpha_c}{\alpha_u - \alpha_c}\right)^2\right) & \text{if } \alpha_u < \alpha_j \le \alpha_c \\ 0 & \text{if } \alpha_j \le \alpha_u \end{cases}$$

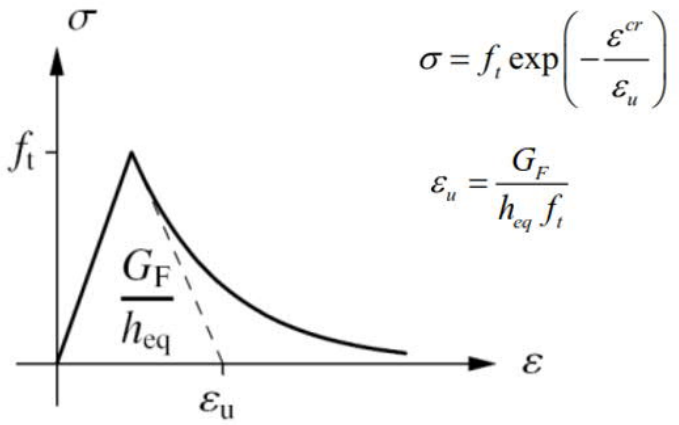
α_j denotes the (negative) compressive strain for the case of progressive compression. The function is partitioned by:

$$\alpha_{c/3} = -\frac{1}{3}\frac{f_c}{E}$$

$$\alpha_c = 5\alpha_{c/3}$$

$$\alpha_u = \alpha_c - \frac{3}{2}\frac{G_c}{h f_c}$$

Figuur 46: Spanning-rekrelatie beton onder druk

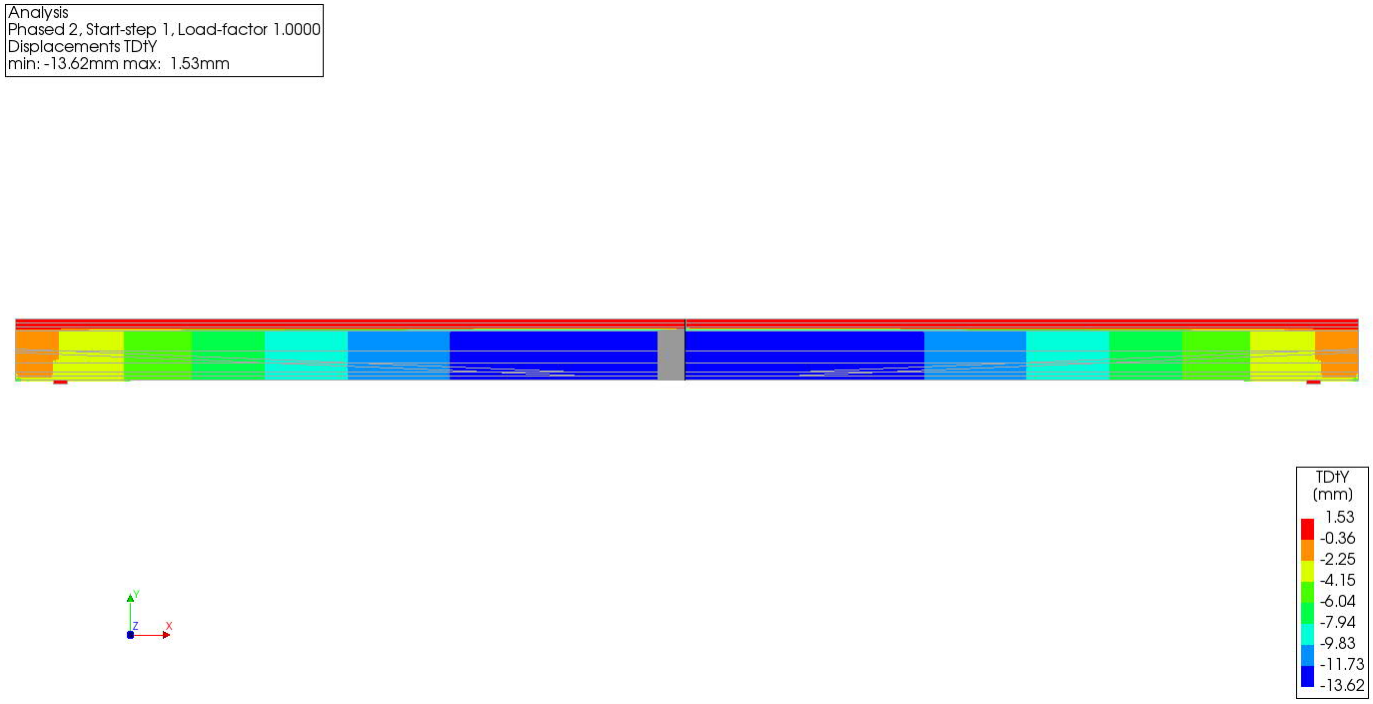


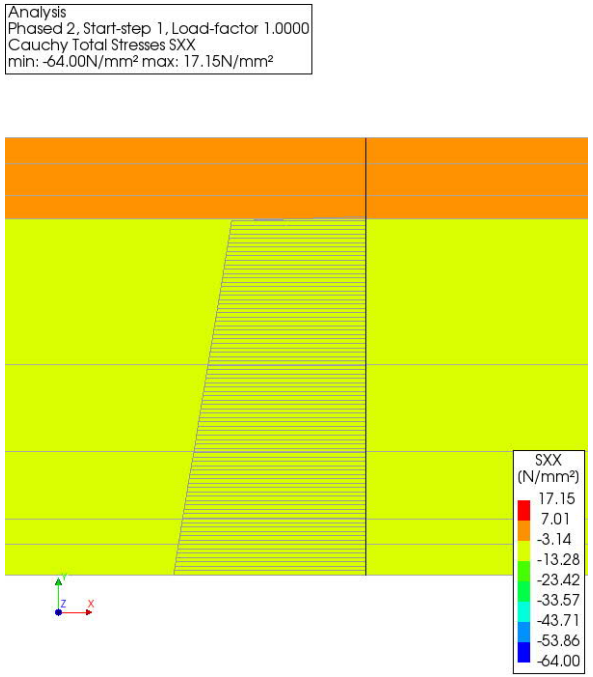
Figuur 47: Spanning-rekrelatie beton onder trek

wagemaker

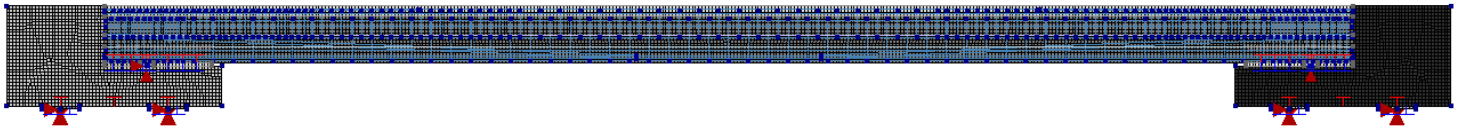
Model validation - result phased analysis

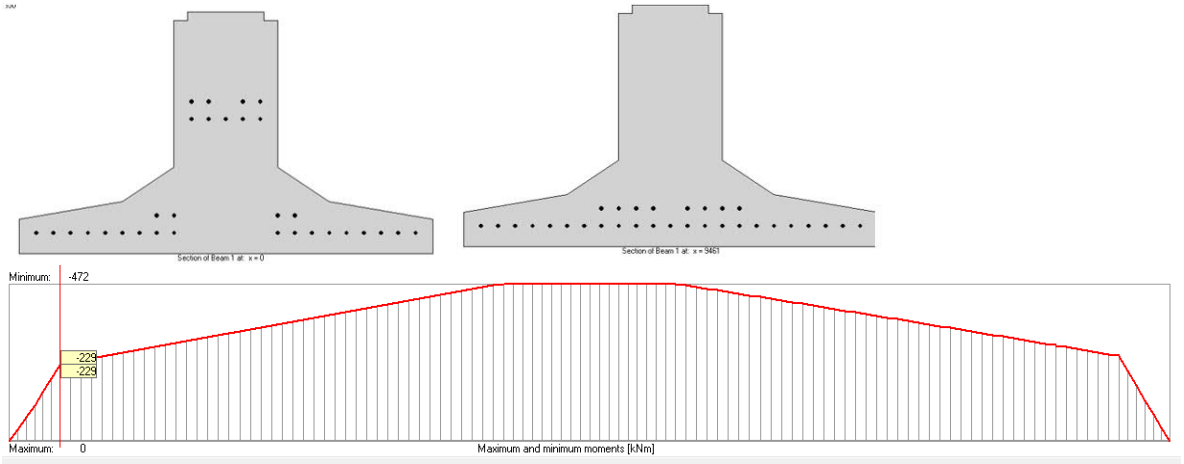
- Loading history (stressless slab)





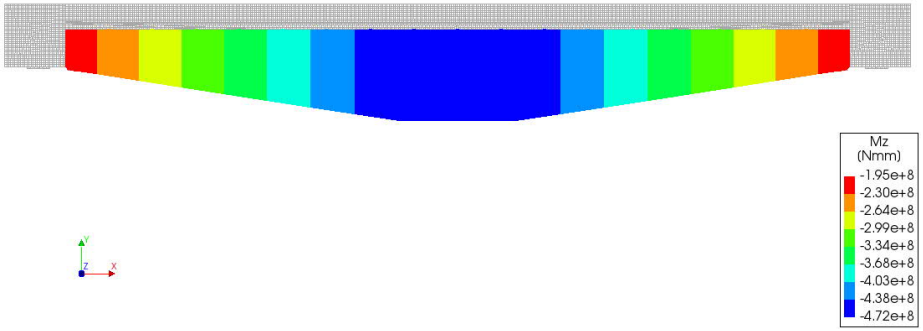
Model validation - Modeling prestress + rebar





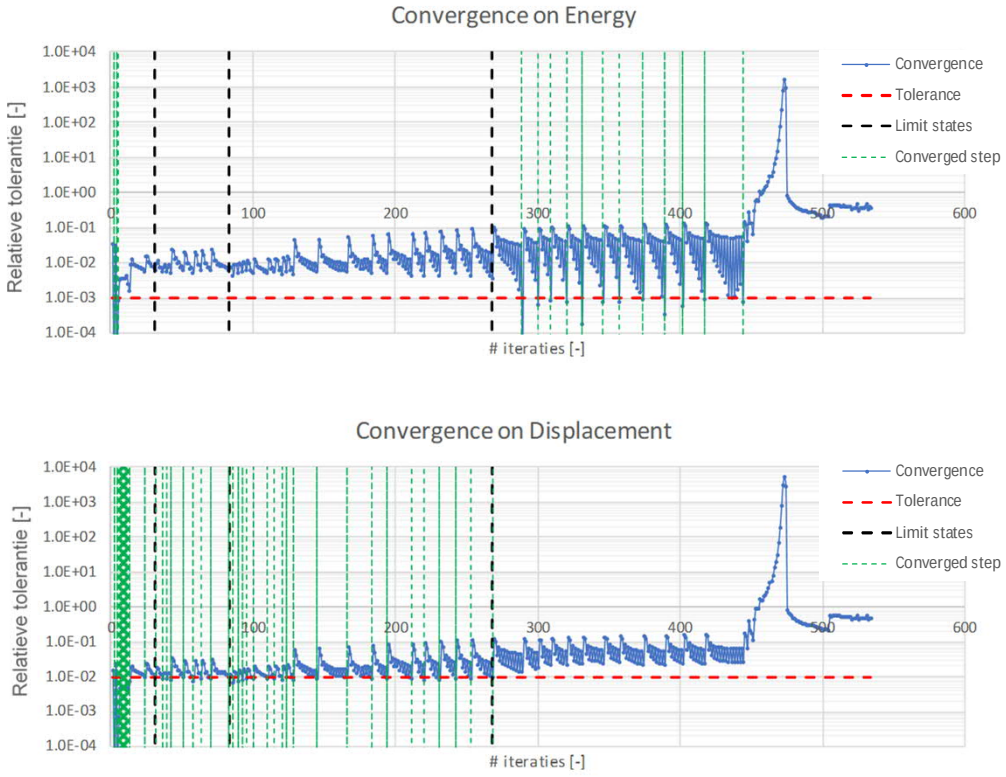
- Stress level σ_{pw} = 969 MPa (drawing)

- DIANA: σ_{pw} = 969 MPa, M_p = 472 kNm

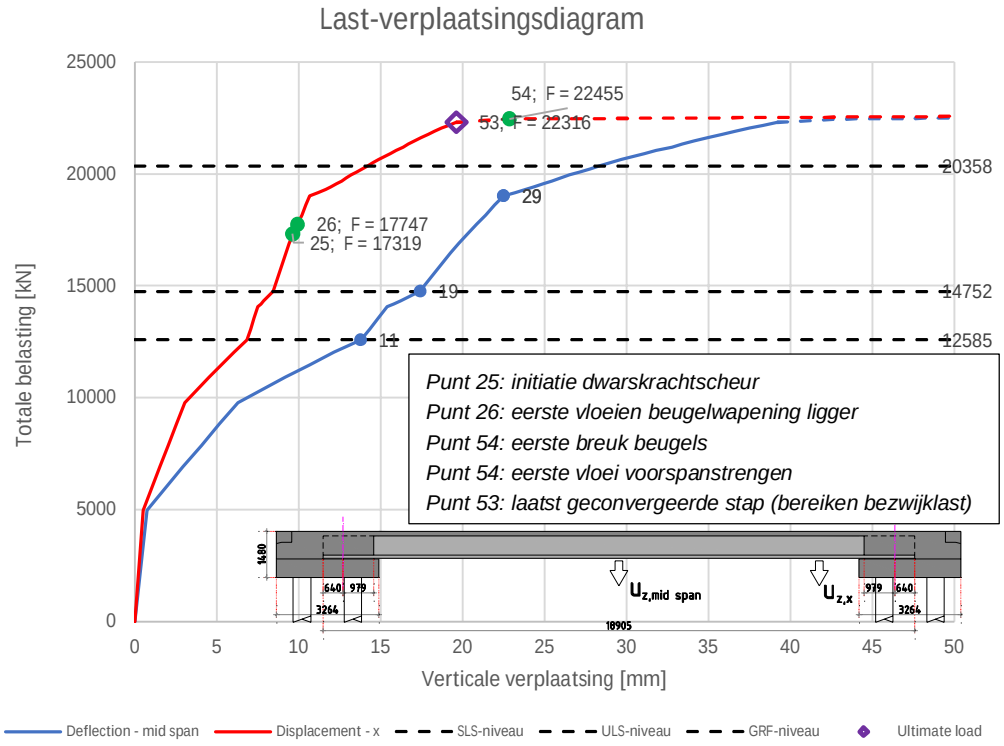


- ALP: σ_{pw} = 969 MPa, M_p = 472 kNm

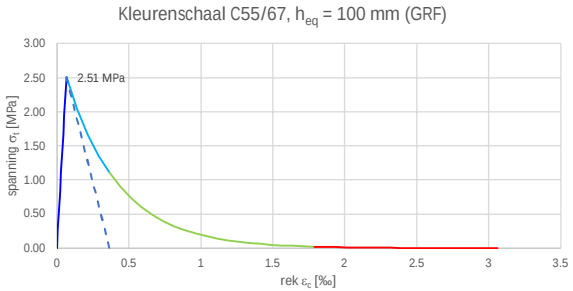
Results NLFEA (I) - Base analysis



- Convergence / load-displacement

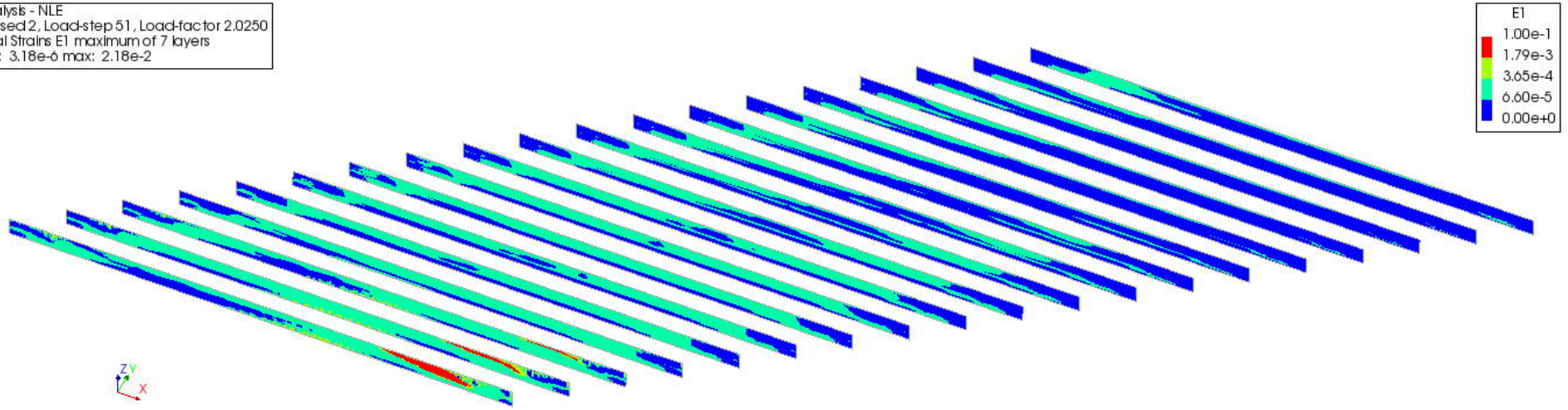


Results NLFEA (II) - Base analysis

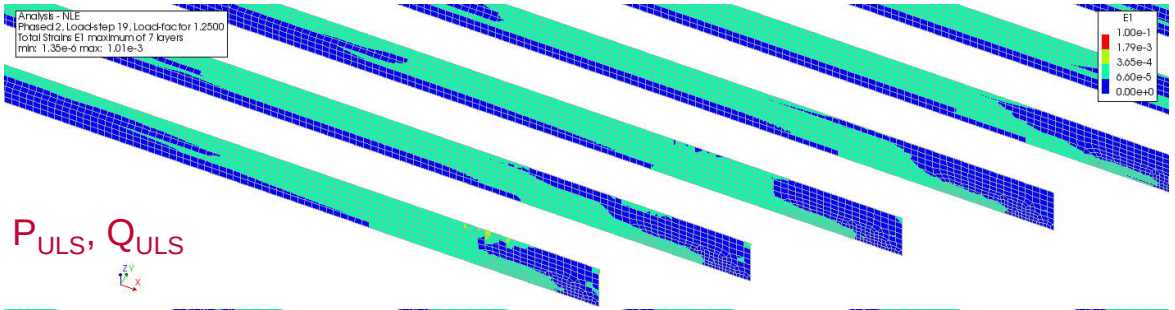


Analysis - NLE
Phased 2, Load-step 51, Load-factor 2.0250
Total Strains E1 maximum of 7 layers
min: 3.18e-6 max: 2.18e-2

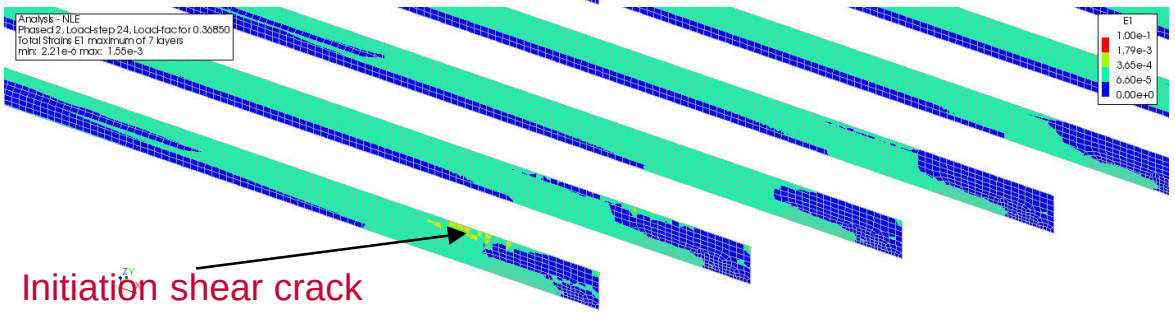
- Development fracture zones
- Last conv. step = > GRF (P_{GRF} + 2.025 Q)
- First principe strain



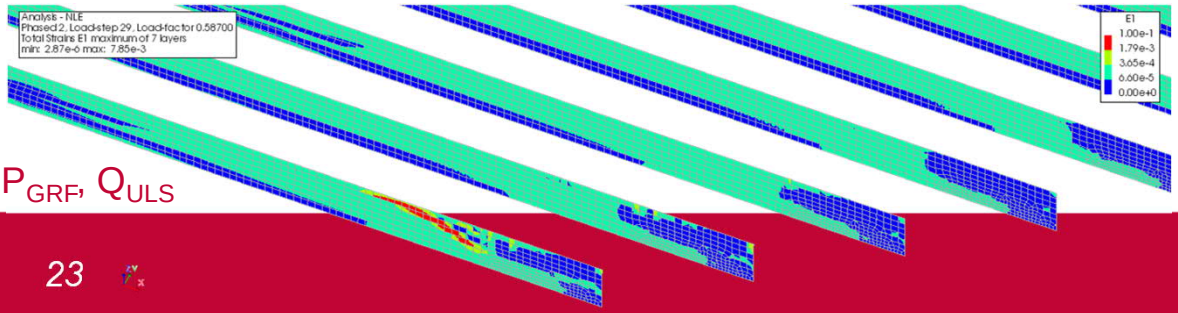
Results NLFEA (III) - Base analysis



P_{ULS}, Q_{ULS}

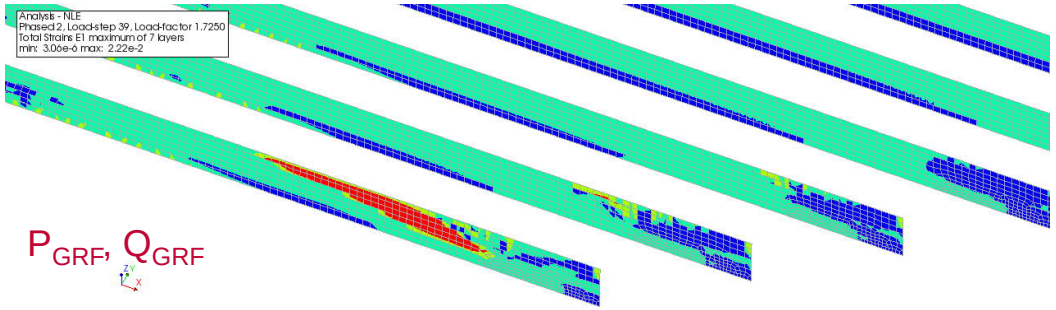


Initiation shear crack

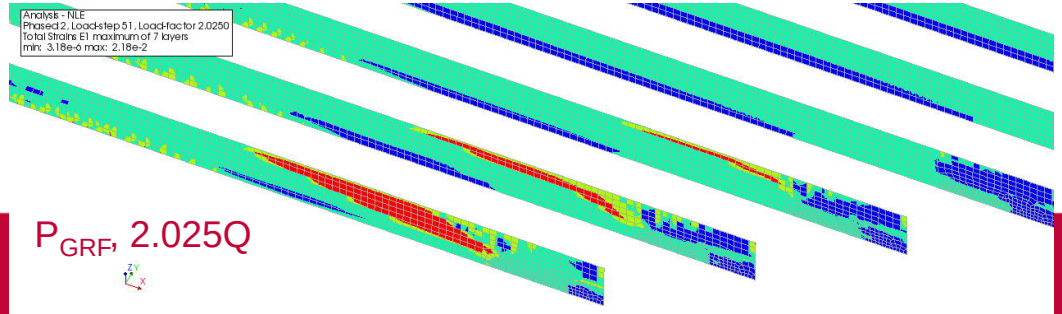


P_{GRF}, Q_{ULS}

- Development fracture zones
- Last conv. step = > GRF (P_{GRF} + 2.025 Q)
- First principe strain



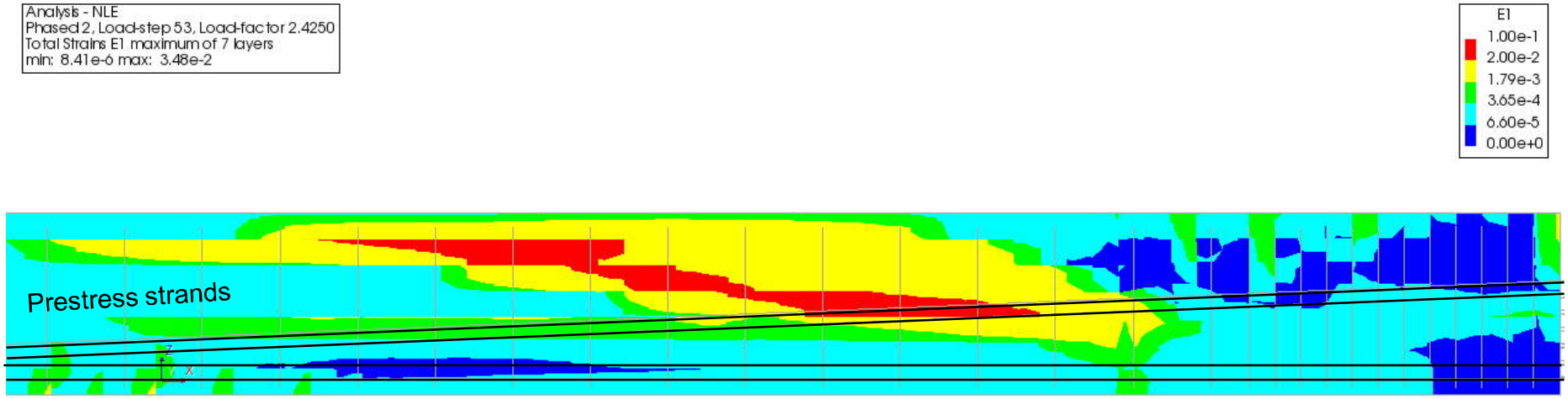
P_{GRF}, Q_{GRF}



P_{GRF}, 2.025Q

Results NLFEA (IV) - Base analysis

- Development fracture zones
- Last conv. step = > GRF (P_{GRF} + 2.025 Q)
- Shear crack arrested by bent strands?!

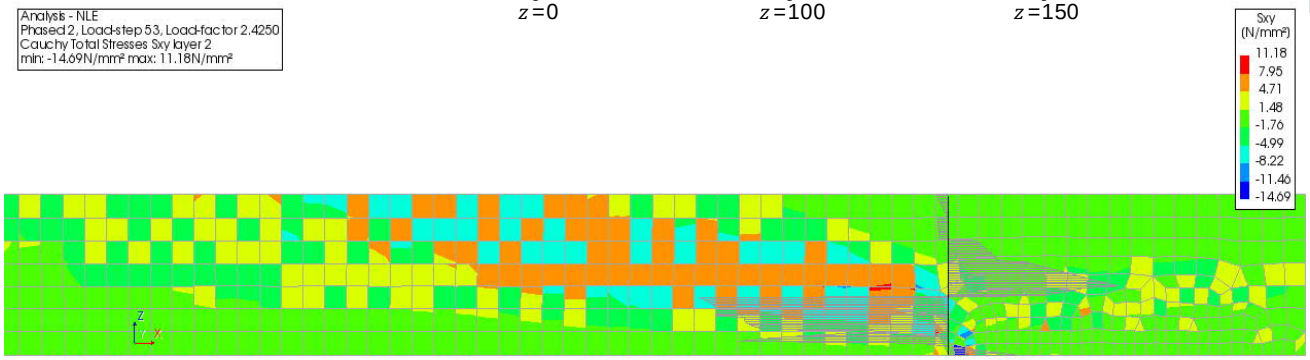


Development of deformation and strain.mp4

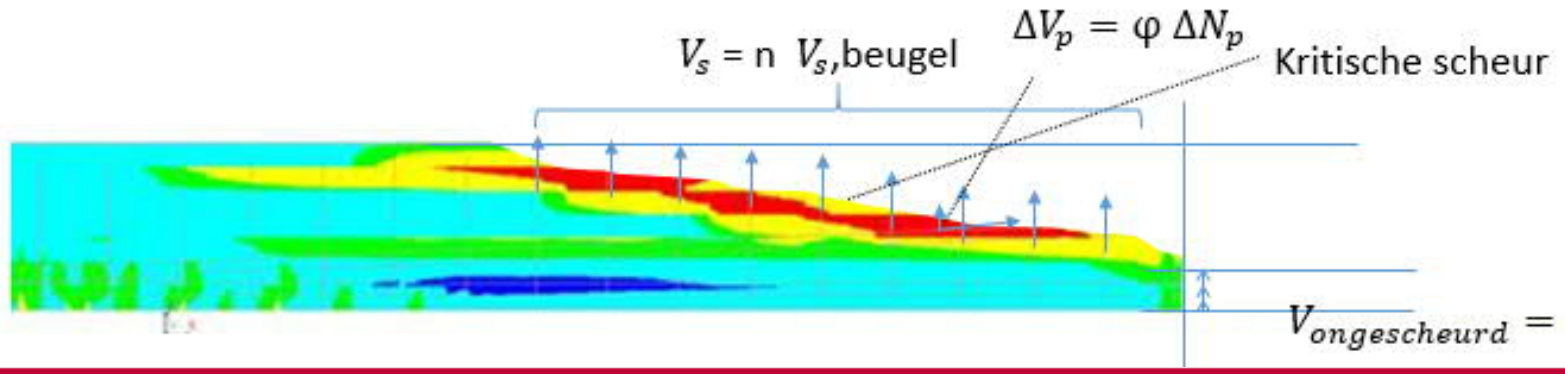
Results NLFEA (V) - Base analysis

$$V_{R,GRF,x} = 1200 \int_{z=0}^{z=100} S_{xy}\,dz + 900 \int_{z=100}^{z=150} S_{xy}\,dz + 450 \int_{z=150}^{z=250} S_{xy}\,dz$$

- Shear stress non-cracked compressive region (bottom flange)

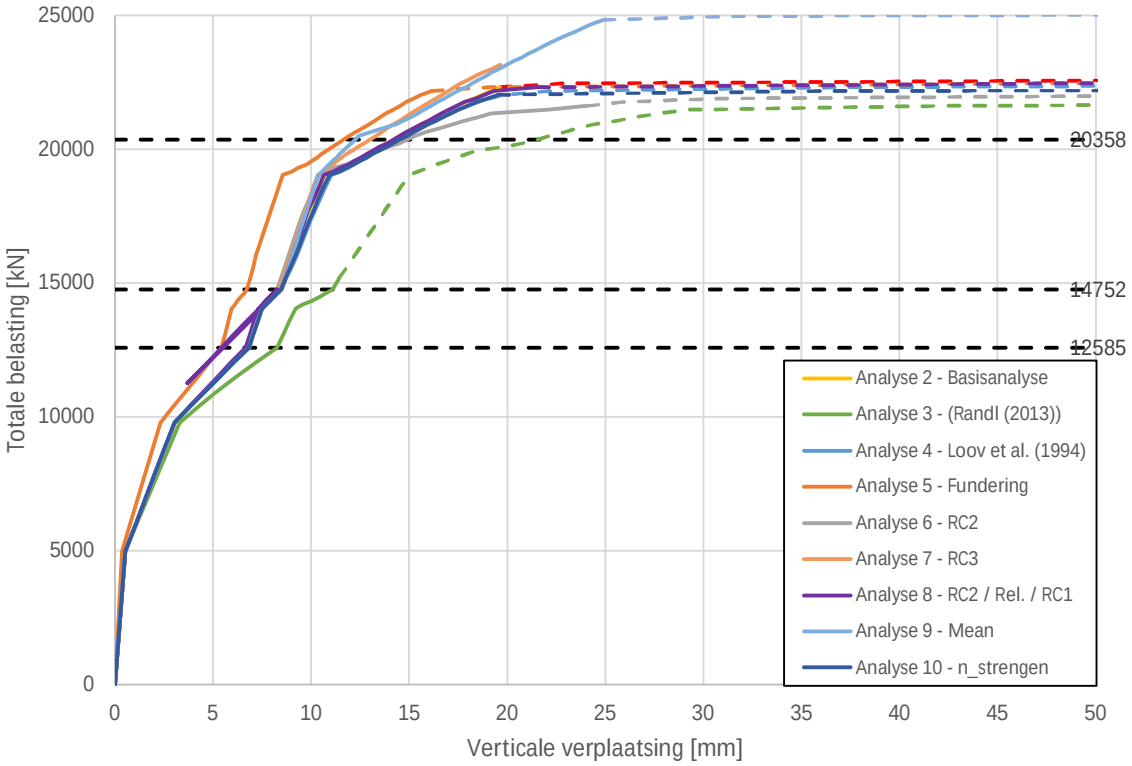


Simulation
≈
Prediction



wagemaker

Results NLFEA (VI) - Sensitivity / parameter study



- Research, e.g.:
  - Influence spring stiffness substructure
  - Positioning Tandemsystems
  - Number of strands
  - MEAN material props
  - Predamaged shear-prone region
  - Etc.

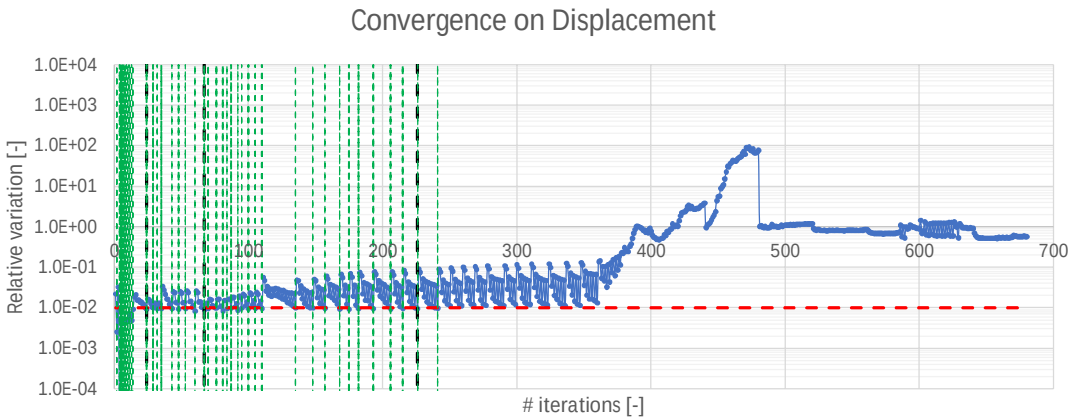
DIANA Users Association

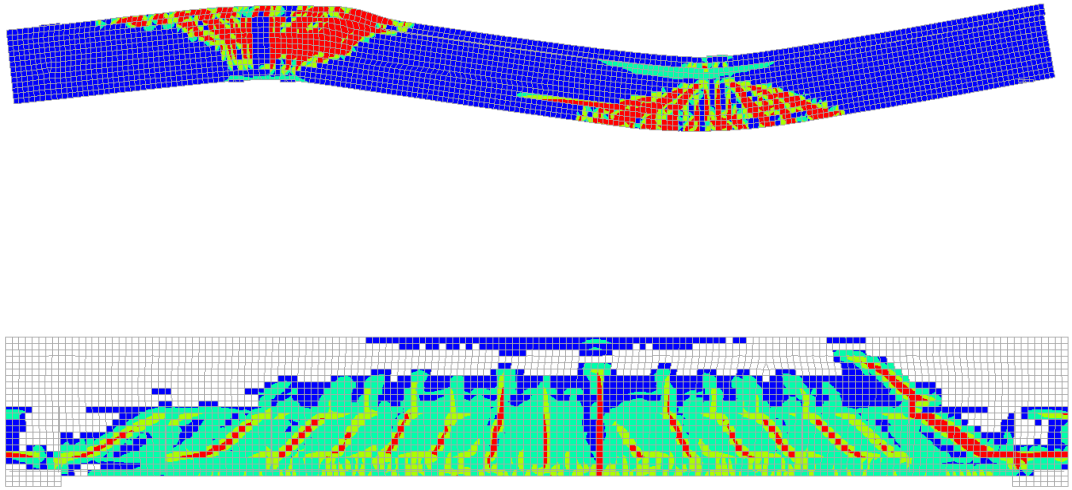
DIANA FEA

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Existing bridge structures

Reassessment of existing shear-prone bridge structures using NLFEA







dr.ir. Dennis Schoenmakers

DOV - June 14th 2023
Amersfoort