12th International

DIANA Users Meeting

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- Universidade do Porto, Porto, Portugal

UNIVERSITY OF SURREY

Long-Term performance of a T-shaped girder bridges by using 1D, 2D and 3D FE modelling

– a comparative analysis –

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** main author and speaker*

Contents

Objectives

- Investigating the time-dependency behaviour of the concrete
- Modelling with different FEA approaches (1D,2D and 3D)
- Comparing the efficiency of the results
- Assessing the time invested on developing an FE model
- Providing a better and overall view useful for further analysis

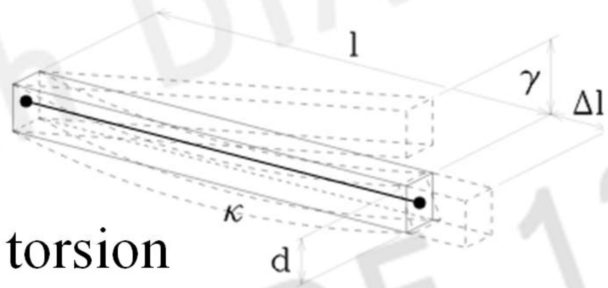
Long-Term Performance

- The Long-Term performance is influenced by the following phenomena:
  - Evolution of compressive strength
  - Variation of the Modulus of Elasticity
  - Shrinkage
  - Creep
  - Steel relaxation
- The fib Model Code for Concrete Structure 2010 has been used to evaluate the aforementioned phenomena.

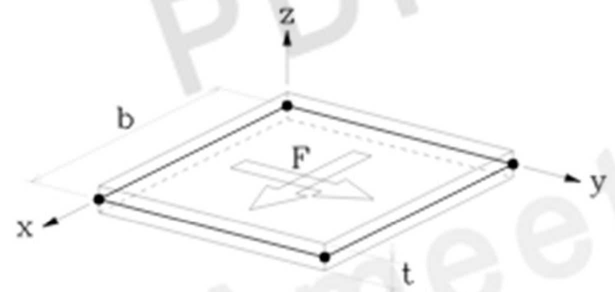
FE Modelling

1D, 2D and 3D approaches

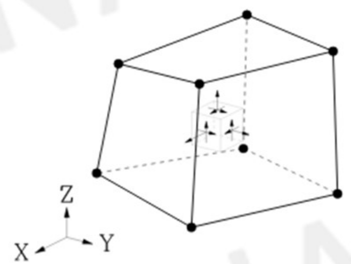
- **1D Beam element**
  - Dimensions *d* are smaller compared to *l*
  - They describe axial force, shear and moments
  - Axial deformation, shear deformation, curvature and torsion



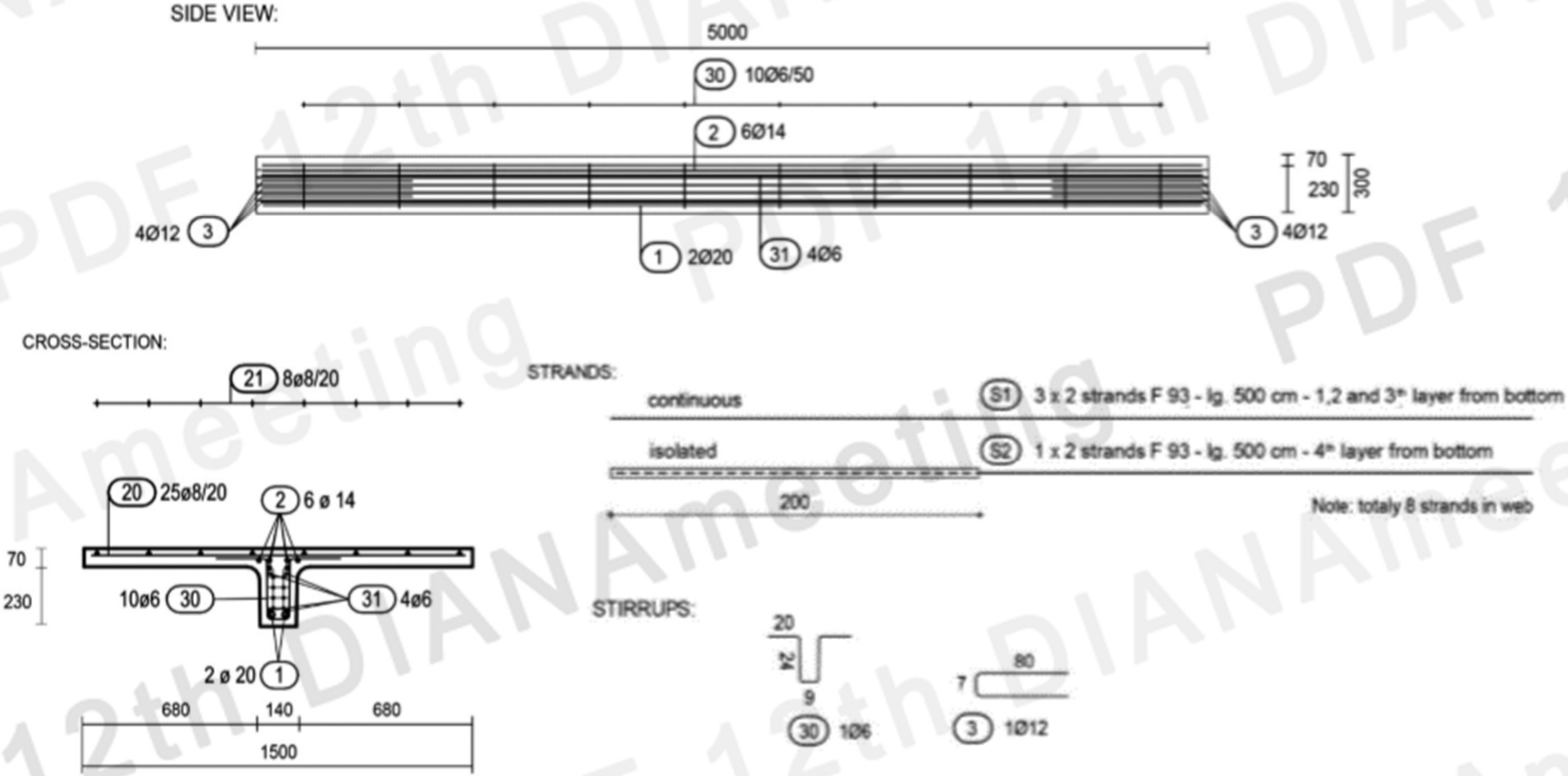
- **2D Plane stress**
  - The thickness must be small compared to b
  - The loading must act in plane of the element
  - There are only stress on the surface
  - The out-plane strain is influenced by Poisson effect



- **3D Solid element**
  - The thickness is relevant compared to the width
  - They may have linear, quadratic or cubic interpolation
  - The stresses are spread in all directions (x,y,z)



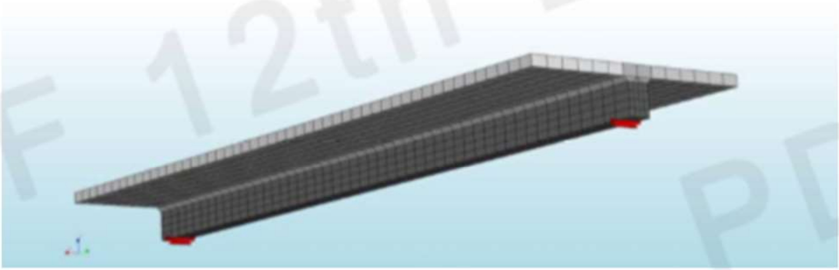
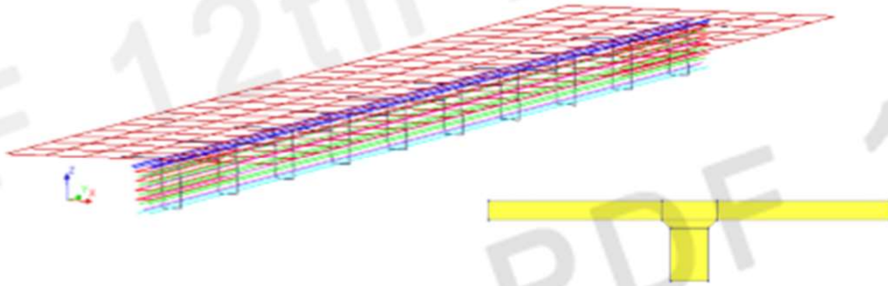
Analysis description
- Prestressed concrete beam*



* *A. Strauss, B. Krug, O. Slowik, and D. Novak, "Combined shear and flexure performance of prestressing concrete T-shaped beams: Experiment and deterministic modeling," Struct. Concr., vol. 19, no. 1, pp. 16–35, 2018*

Analysis description
- Prestressed concrete beam

- **3D Brick elements Model** *

- **2D Plane stress Model** *


- **1D Beam elements Model** *


* (DIANA output)

Analysis description
- Prestressed concrete beam

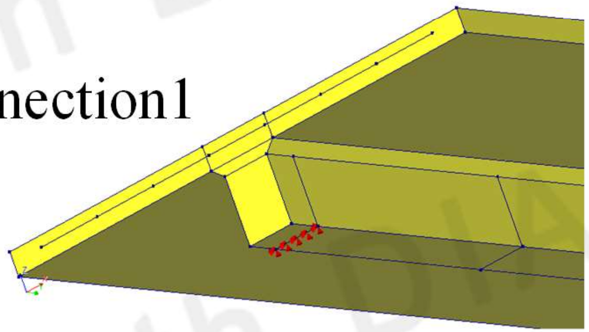
- **Material properties**
  - Concrete
    - ✓ Elastic (static analysis)
    - ✓ Viscous-elastic (time-phased analysis)
  - Passive reinforcement
    - ✓ Elastic
  - Prestressing steel
    - ✓ Elastic (static analysis)
    - ✓ Viscous-elastic (time-phased analysis)

	Concrete	Steel bars	Steel tendons	Steel load plate
Young's Modulus E [GPa]	37.49	200	198	210
Compressive strength [MPa]	45	-	-	-
Tensile strength f_{ct} [MPa]	2.7	-	-	-
Medium Tensile strength [MPa]	3.8	-	-	-
Cement hardening (32.5 N)	Normal	-	-	-
Density [Kg/m^3]	2450	8050	8050	8050
Poisson ratio	0.2	0.3	0.3	0.3
Yield stress [MPa]	-	450	1875	-

- **Loading**
  - Self-weight
  - Prestressing forces
  - Point load (x = 1 m)

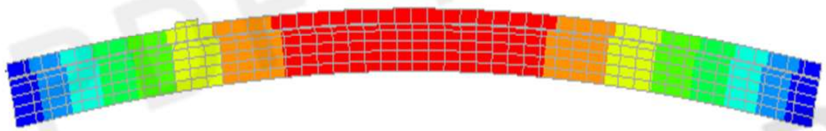
Load type	Magnitude	Analysis
Self-weight	3.36 kN/m	Linear/Phased
Steel bars	898 MPa	Linear/Phased
Point Load	65 kN	Phased

- **Boundary Modeling**
  - Steel cylinders as roller and pinned connection1



Analysis description
- Prestressed concrete beam

- **Linear analysis**
  - Aim of evaluating the primary behaviour of the three models
  - Load cases considered:
    - ✓ prestressing force
    - ✓ Self-weight
    - ✓ Point load

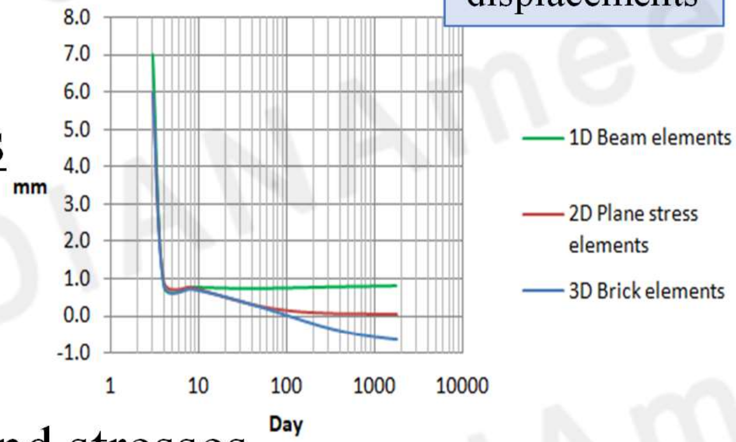


prestressing

  - Results: displacement diagrams

- **Time-phased analysis**
  - Three phases for a period of analysis of 5 years
    - ✓ Pouring and curing period: t ∈ [0 3] days
    - ✓ Prestressing and point loading: t = 3 days
    - ✓ Long-term performance: t = [3 1825] days
  - Results: time series for displacements, forces and stresses

displacements

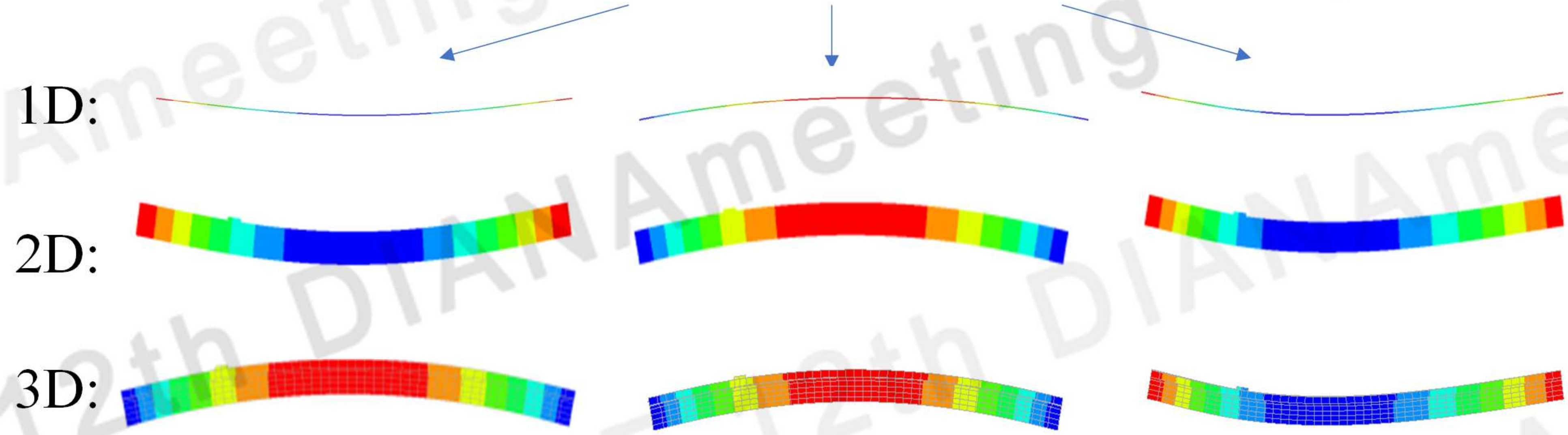


Results – Linear analysis
- Prestressed concrete beam

- **Vertical displacements**

FE model type	Self-weight	Prestressing	Punctual Load	Analytical solution (for a UDL).
1D: Beam elements	-1.6	7.2	-7.8	
2D: Plane stress elements	-1.3	7.0	-6.1	-1.3
3D: Brick elements	-1.5	6.8	-6.3	

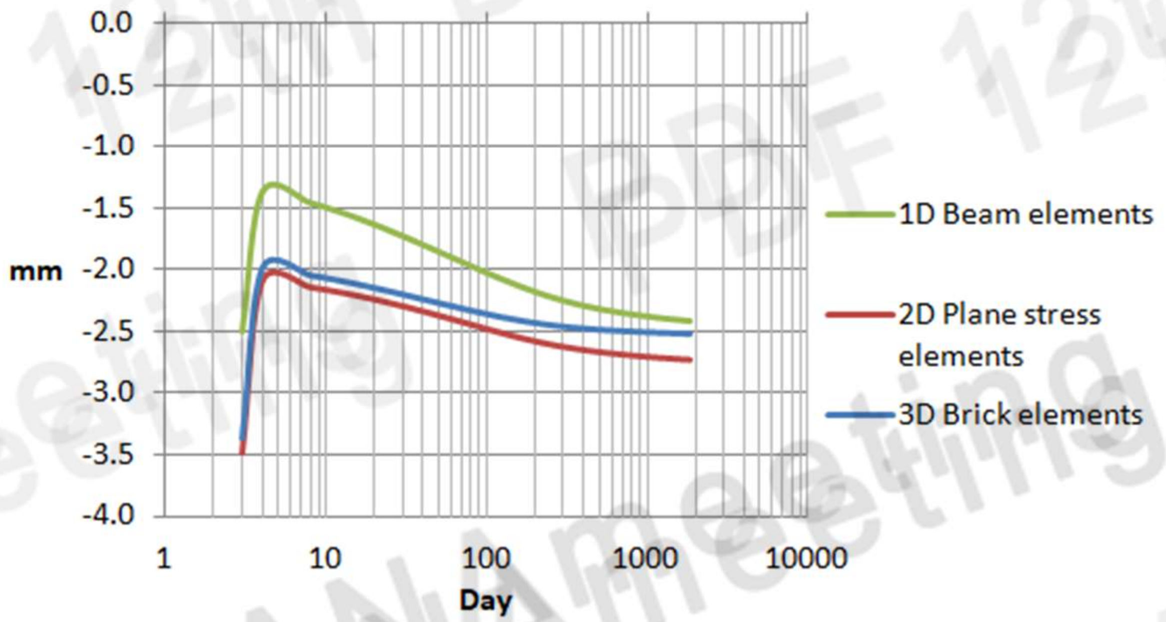
$$\frac{5ql^4}{384EI}$$



∴ The results show good agreement between FE models and with analytical solution (the latter for the case of self-weight)

Results – Phased analysis
- Prestressed concrete beam

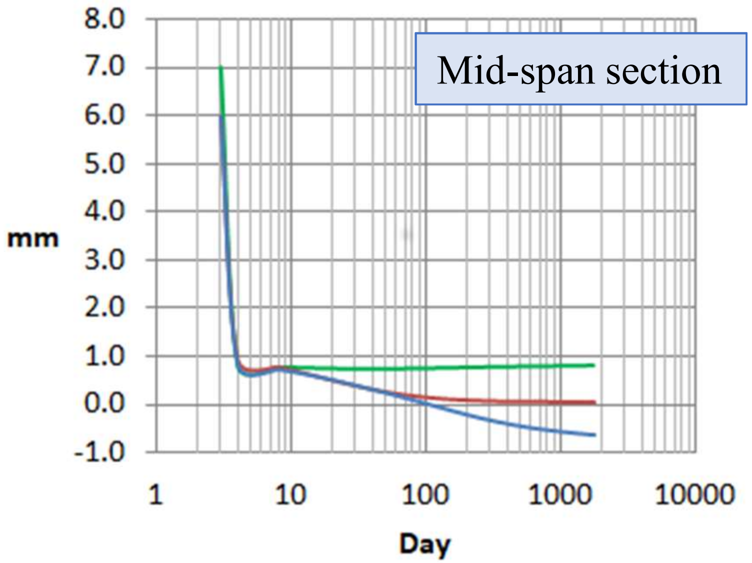
- **Horizontal displacements (support)**

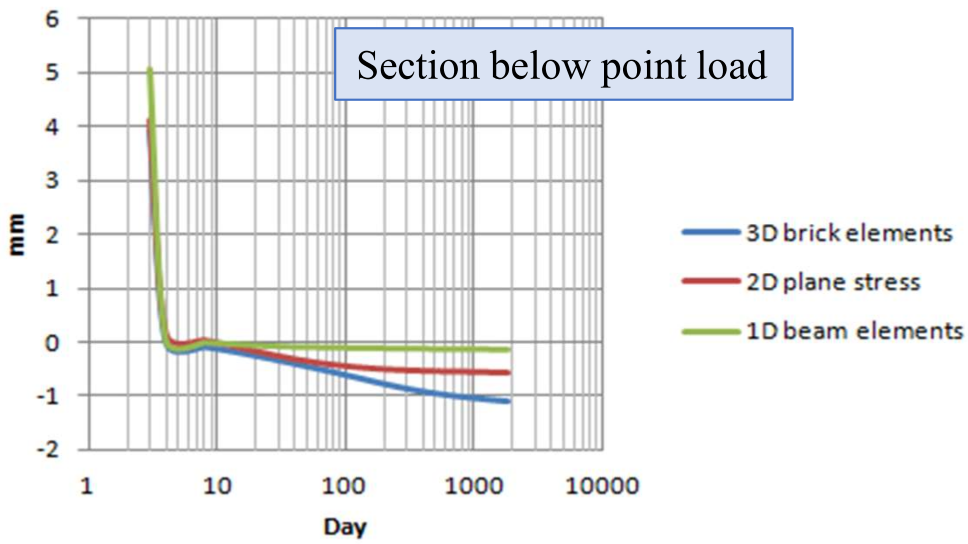


∴ Overall, the results gives evidence that the support displacement tends to converge despite the FE approach

Results – Phased analysis
- Prestressed concrete beam

- **Vertical displacements**





∴ The results gives evidence that 1D and 2D models underestimate vertical deflections over time

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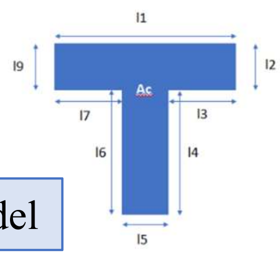
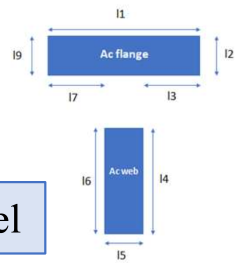
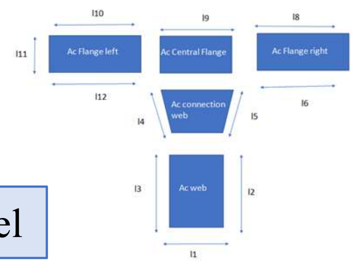
Note on the notional size:



1D FE model



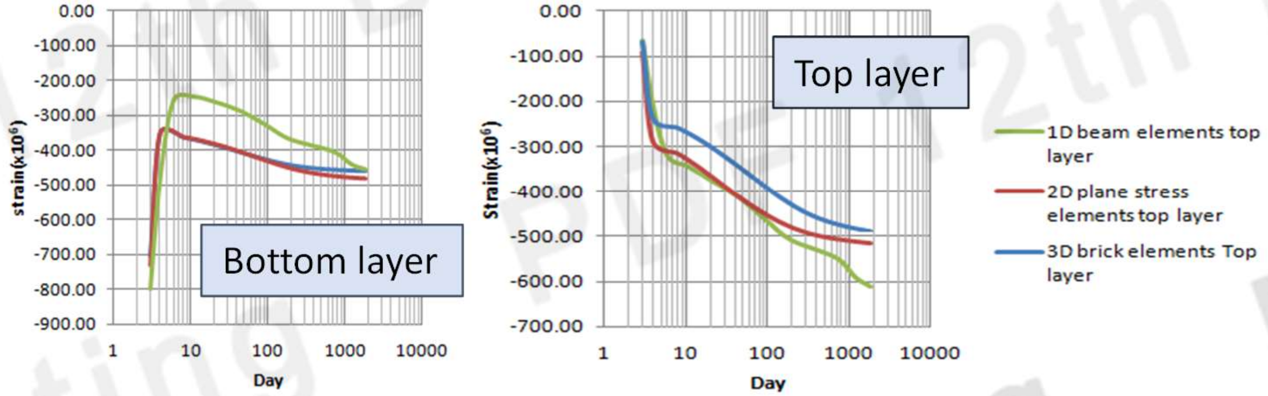
2D FE model



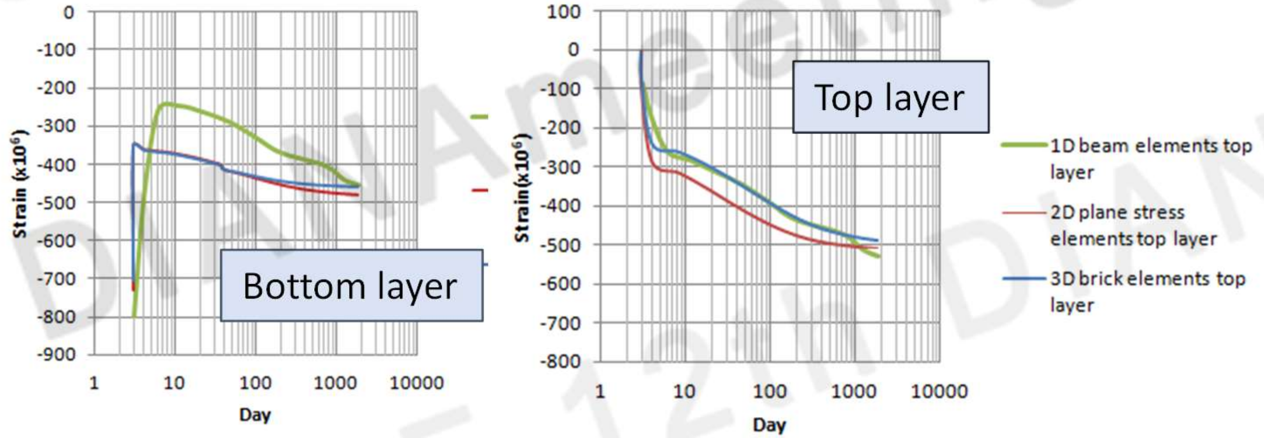
3D FE model

Results – Phased analysis
- Prestressed concrete beam

- **Concrete strains (mid-span section)**



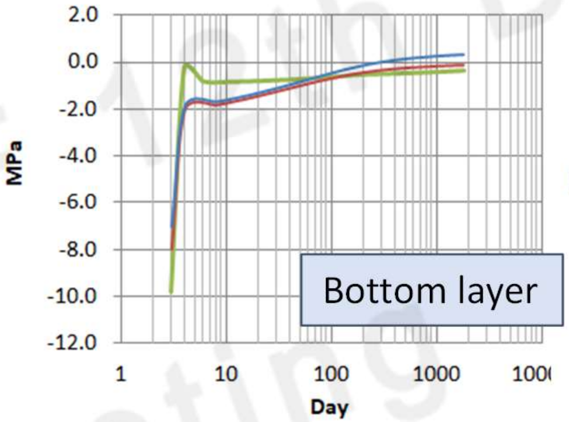
- **Concrete strains (section below point load)**

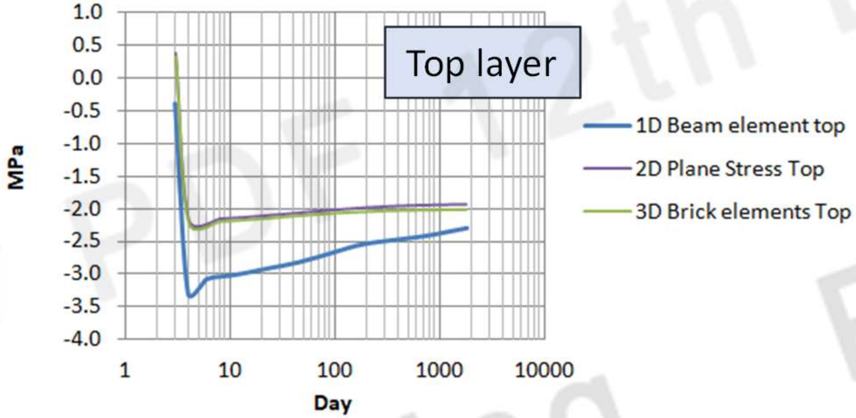


$\therefore$ 1D FE overestimates strain at early stages of the service life, whereas convergence is observed up to the 5 years period, despite the FE approach

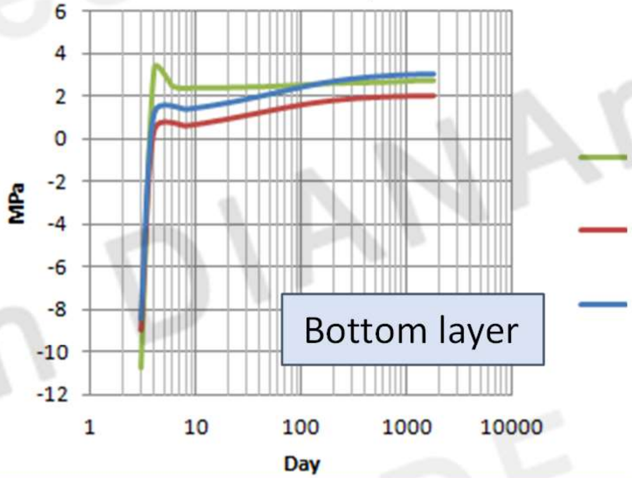
Results – Phased analysis
- Prestressed concrete beam

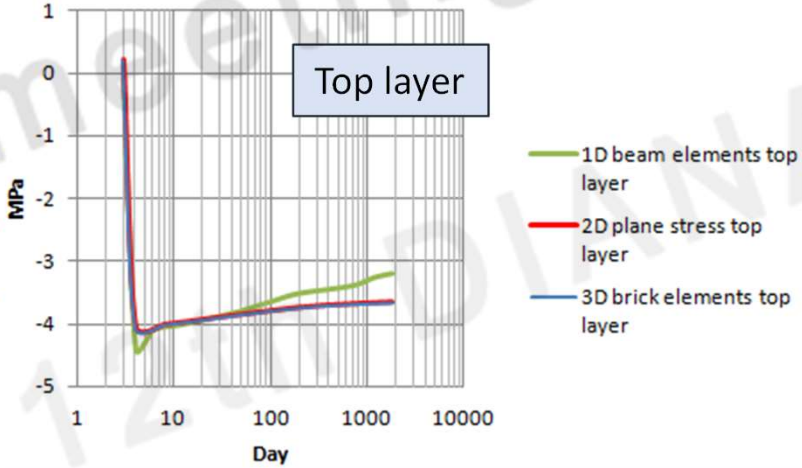
- Concrete stresses (mid-span section)





- Concrete stresses (section below point load)

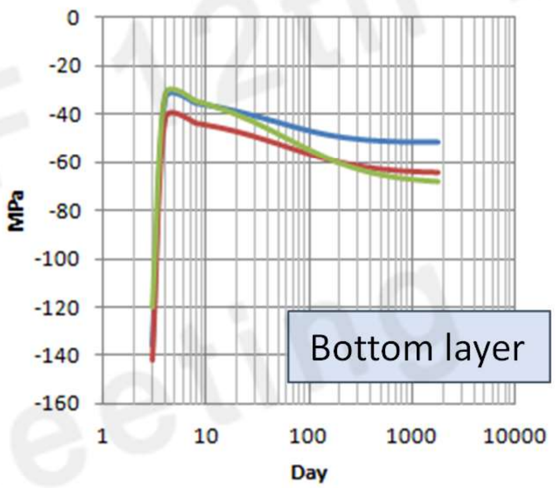


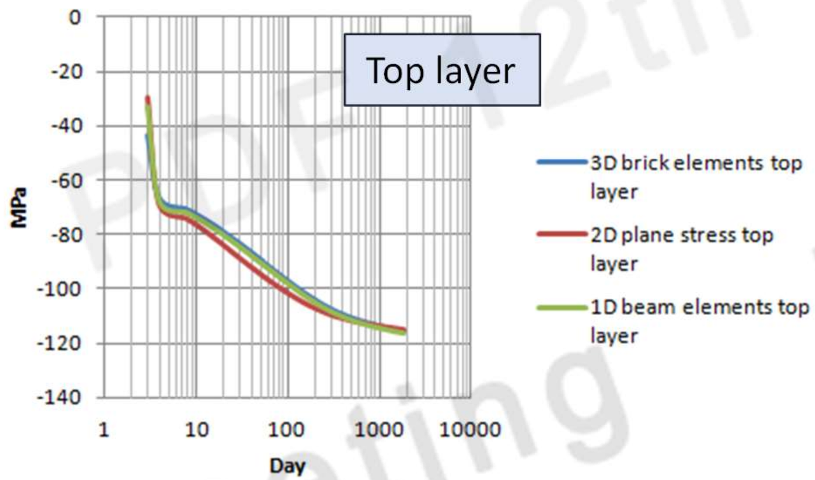


∴ 1D FE overestimates stresses at early stages of the service life, whereas convergence is observed up to the 5 years period, despite the FE approach

Results – Phased analysis
- Prestressed concrete beam

- **Reinforcement stresses**

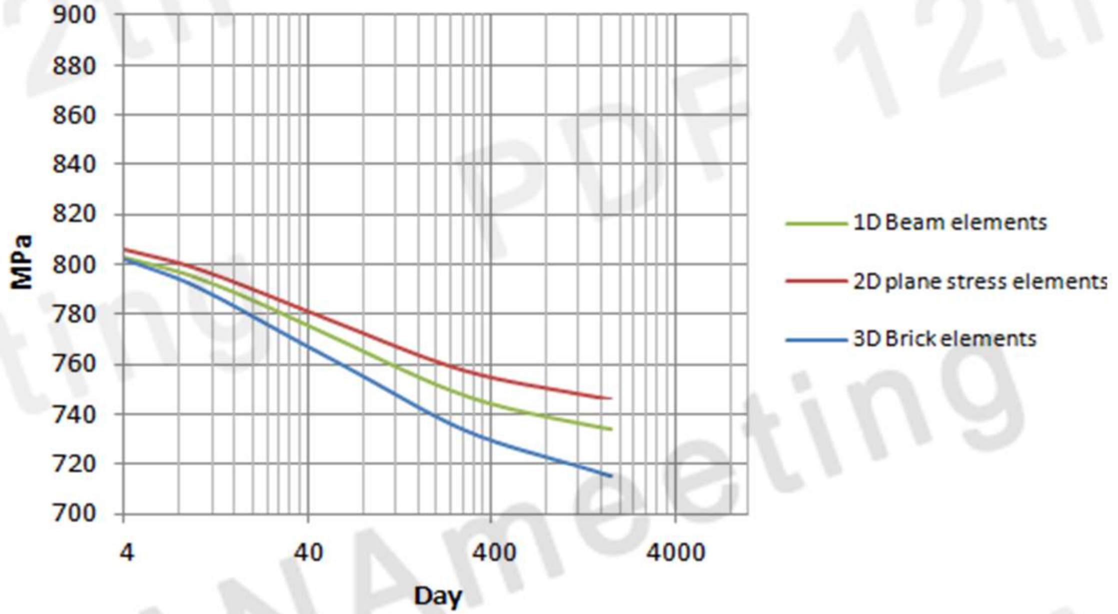




∴ 3D FE approach leads to higher levels of prestress loss. Moreover, the results tends to diverge overtime for the reinforcement layout at the bottom layer

Results – Phased analysis
- Prestressed concrete beam

- **Prestress force in the tendon**



∴ 3D FE approach leads to higher levels of prestress loss. Moreover, the results tends to diverge, with evidence of continuing after the 5 years period

Conclusions

- Linear analysis
  - Results shows good agreement between 1D, 2D and 3D FE approaches, giving confidence for the time-phased analysis.
  - The option for choosing a more complex model (i.e. 3D FEM) seems not worthwhile for the case under analysis

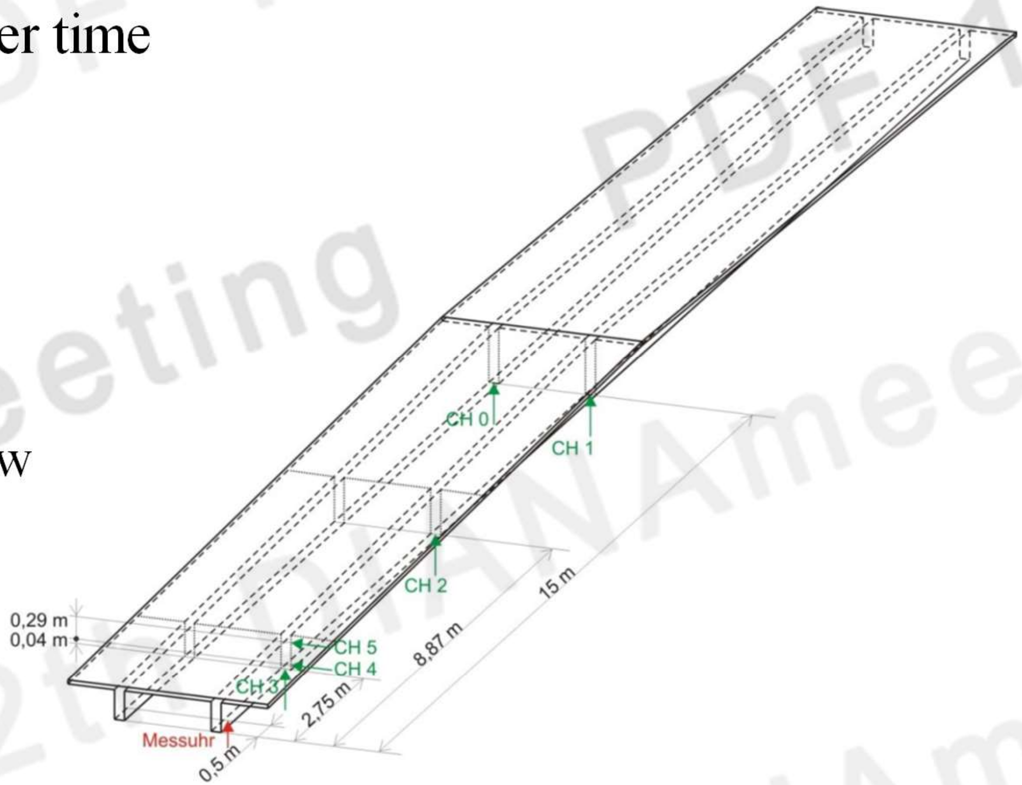
Conclusions

- Time-phased analysis
  - Substantial differences for the vertical displacement in both magnitudes and trends over time
  - 1D and 2D FE model underestimate deflections by showing an asymptotical behavior within the 5 years period, which is against the results obtained with the 3D FE model
  - Overall, concrete stresses and strains are overestimated by 1D FE model at early stages of the service life, despite convergence over time is overall observed between different FE approaches
  - Despite prestress losses are in the same order of magnitude for all FE approaches (up to ≅ 4 %), results shows divergency over time with higher losses obatined by the 3D FE model

Conclusions

- Further steps
  - Comparison of these results to the available monitoring data is planned already for better assessment of the effective structural behaviour of prestressed concrete structures over time

Monitoring:
- Strains (embedded in concrete)
- Rotations
- Accelerations
- Temperatures
- Environment: wind, rain & snow
- Since construction (2013)
  - Construction
  - Loading test
  - Operational lifetime



Luft, T., Strauss, A. and Krug, B. (2015) Tools for measuring data analysis of components equipped with strain gages using the example of three pre-stressed reinforced concrete roof elements, Universität für Bodenkultur Wien, Wien, Austria

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Thank you

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