Meeting Minutes

IABMAS Technical Committee on Bridge Load Testing

Zoom: https://usfq.zoom.us/j/83086667446

Tuesday April 18th, 8:00 – 10:00 CDT, 9:00 – 11:00 EDT, 15:00-17:00 CEDT

Mission: *Bridge Load Testing is a field testing technique that can be used to obtain more information about the performance of bridges. In particular, diagnostic load tests can be used to quantify elements of structural performance such as transverse distribution, unintended composite action, repair effectiveness, etc. and the information of a diagnostic load test can serve to develop field-validated models of existing bridges that can be used to develop a more accurate assessment of the bridge's performance. Proof load testing can be used to demonstrate directly that a bridge can carry a load that is representative of the live load, provided that the bridge does not show signs of distress. Other types of load testing include testing for dynamic properties, and parameter-specific tests. Load test data as well as the analytical assessment of the data can be used to make more informed decisions and manage the life-cycle performance and maintenance of bridges.*

Aspects of bridge load testing that are of particular interest to bridge owners are having an overview of the typical uses for bridge load tests, the decision on when to load test or not, which information to obtain from the load test, and how this information can be used to reduce the uncertainties regarding the tested bridge. This committee is eager to learn about and disseminate the potential for applying new technologies for bridge load testing through learning from technologies used in other industries.

Associated with bridge load testing, the following topics are also of importance to this committee: instrumentation used during load testing and the interpretation of the obtained measurements during the load test, determination of required load, method of load application, methods of updating assessments using collected field data, the link between load testing and structural health monitoring, the uncertainties (probabilistic aspects as well as risks during test execution) associated with load testing, the interpretation of load test results, laboratory testing of bridge components to improve assessment methods in the field, and optimization of related costs keeping adequate reliability to spread their use worldwide.

The IABMAS Bridge Load Testing Committee aims to be an international committee of participants from academia, industry, and bridge owners, which provides a forum for the exchange of ideas on bridge load testing. Best practices as well as the insights from the development of national codes and guidelines will *be exchanged among participants from countries that use load testing for the assessment of their existing bridges, those who are exploring the possibilities of this method, and those who are in the process of standardizing the procedures or developing guidelines.*

Goals:

- *Organize dedicated sessions to the topic of load testing at IABMAS conferences.*
- *Develop national IABMAS group events on the topic of load testing.*
- *Exchange information on the use of load testing in different countries.*
- *Exchange lessons learned and best practices.*
- *Inform about case studies of bridge load testing.*
- *Communicate load testing guides or standards that have been developed.*
- *Provide a forum for new ideas and applications of technology.*
- *Identify potential research topics.*
- *Establish international collaborations.*
- *Liaise with relevant committees internationally outside of IABMAS and liaise with the national IABMAS groups.*

Committee Members

Eva Lantsoght	David Jauregui
Jesse Grimson	Ho-Kyung Kim
Mitsuyoshi Akiyama	**David Kosnik (TRB AKB40 liaison)**
Sreenivas Alampalli	Shane Kuhlman
Numa Bertola	**Marcelo Marquez**
Fabio Biondini	Johannio Marulanda
Tulio Bittencourt	**Piotr Olaszek**
Alok Bhowmick	Pavel Ryjacek
Jonathan Bonifaz	Marek Salamak
Matteo Breveglieri	Gabriel Sas
Anders Carolin	Gregor Schacht
Hermes Carvalho	**Jacob Schmidt**
Joan Ramon Casas	Tomoki Shiotani
Rolando Chacon	Matias Valenzuela
Dave Cousins	**Michal Venglar**
Dan Frangopol	**Esteban Villalobos Vega**
Monique Head	David Yang
Robert Heywood	**Yuguang Yang (fib TG 3.2 liaison)**
Boulent Imam	**Ales Znidaric**

* Member in bold were present at the meeting

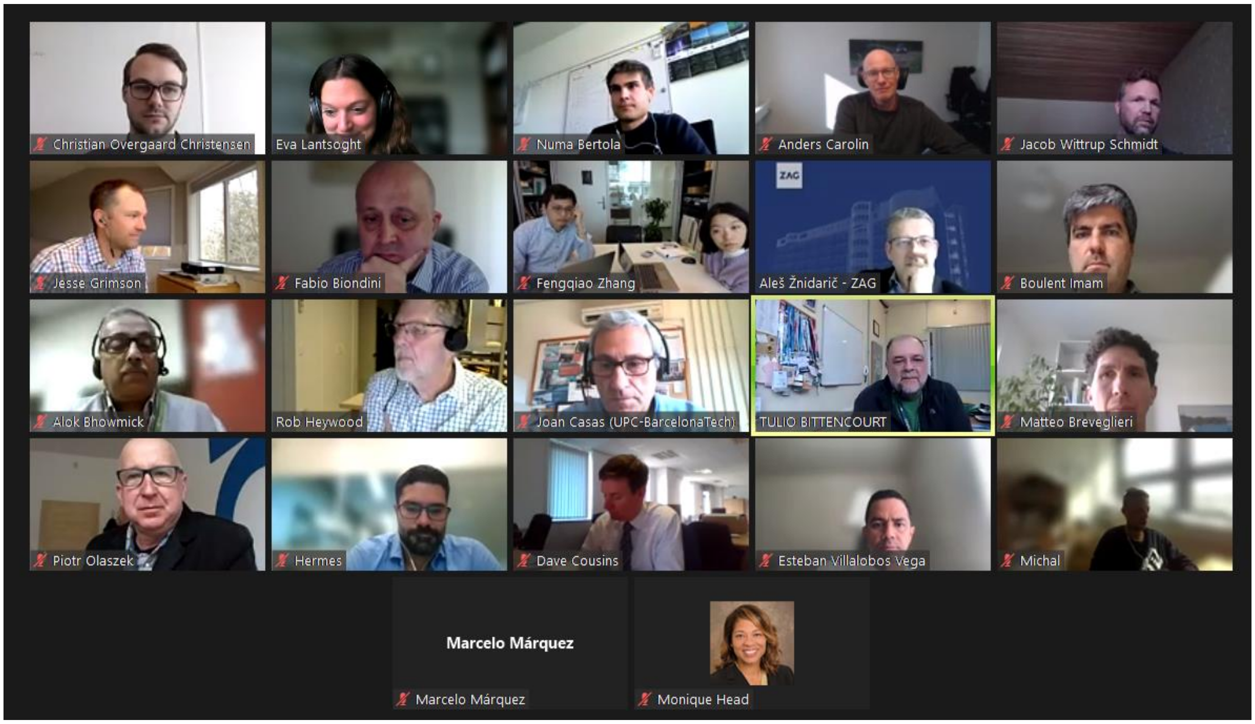
Regrets: Sreenivas Alampalli, David Jauregui, Gabriel Sas

Additional attendees: Christian Overgaard Christensen, Fengqiao Zhang

1. Administrative

1.1. Welcome and introduction

The meeting was called to order by co-chair Lantsoght at 8:03 am. All members introduced themselves with name and affiliation. New member Heywood gave an overview on load testing in Australia and New Zealand and his expertise on this topic since the 1990s.



1.2. Review and approval of agenda

Lantsoght shared the agenda of the meeting. The agenda was approved by the membership.

2. Strategic Planning and Discussion

2.1. Membership

The new members gave a short presentation and update on load testing in their respective countries and relevant activities. Tulio Bittencourt and Hermes Carvalho are working on this topic in Brazil, and in particular for railway bridges. A code is in development in Brazil. Yuguang Yang discussed load testing in the Netherlands, monitoring, and physical modeling of concrete structures as research topics and the development of proof load testing in the Netherlands for the past 10 years.

2.2. Website

On the IABMAS website, the committee information is included. The website will be updated with the new members once we have IABMAS membership numbers of all collected. Lantsoght will send the new information to Akiyama.

2.3. Review of mission

2.4. Review of goals

No comments on the mission and goals were received.

3. New Business

3.1. Research updates

1. Application of DIC for load testing in Denmark – Christian Christensen

   Bhowmick posed a question regarding stop criteria and crack width for the load tests conducted. Answer: this is a difficult subject, the European code was used for crack width stop criteria. During the load tests, no cracks were present so that stop criteria was never met.

   Bertola posed a question regarding camera resolution vs. distance to the structure. Answer: camera resolution must increase with distance to the bridge, optic zoom may help on greater distances.

   Znidaric posed a question on lighting conditions. Answer: additional ambient lighting may be necessary but must be applied indirectly so as not to create reflections. Surface conditions (water) that can cause reflection may also affect the results.

   The slides of these presentations are attached to the minutes of this meeting. Lantsoght will share the thesis of Christensen when it becomes available. The latest publication from his thesis is available online at https://www.mdpi.com/2075-5309/13/4/1060

2. Acoustic emission-based indicators of shear failure of reinforced concrete structures during load testing – Fengqiao Zhang

   The thesis of Zhang is available at https://repository.tudelft.nl/islandora/object/uuid%3A9220a0c2-f4c1-46e6-a0a9-0069e4662730?collection=research

3.2. Development of joint bulletin of proof load testing of concrete structures with fib TG 3.2

Lantsoght gave an overview of the topics discussed during the meeting on Friday 14th of April between IABMAS members and fib TG 3.2 members. Based on these discussions, an outline is developed, with chapter leads and volunteers for the chapters that will be developed first. Introduction, definitions, research needs, and conclusions will be addressed once the main chapters are drafted. The scope is defined, as well as a working procedure. The first step will be to develop extended outlines for the chapters by October 2023. Volunteers from the IABMAS BLT committee are still welcome.

Volunteers from the IABMAS side are: Jesse Grimson, Jacob Schmidt, Eva Lantsoght, Numa Bertola, Dave Cousins, Matteo Breveglieri, Monique Head, Alok Bhowmick, Piotr Olaszek.

Volunteers from the fib TG 3.2 side are: Yuguang Yang, Alfred Straus, Hyunjin Ju, Beatrice Belletti, Joost Walraven, Ane de Boer, Gerrie Dieteren

The outline, scope and timeline of the document are attached to these minutes.

3.3. Collaboration with other IABMAS TCs

Co-chair Grimson explained the topics of the three IABMAS technical committees: SHM (chaired by Necati Catbas), Bridge Management (chaired by Reed Ellis), and Bridge Load Testing. All IABMAS TC chairs met to discuss collaboration between the committees. Topics that came up for collaboration between the committees were during the meeting of the TC chairs last December 2022: how to understand long-term monitoring data for understanding bridge behavior, how to compile all the data into a bridge management system, how to use a digital twin together with load testing and monitoring data.

Co-chair Grimson asked for input to the committee members to these ideas, and other ideas for collaboration between the committees. Casas mentioned that all three committees deal with a digital twin, and that it is relevant for all committees: digital twin for maintenance or management of existing bridges would be a good framework to combine the efforts of the three committees. Heywood asked to clarify how structural health monitoring is used for the three committees (to repeat the explanation given before).

Co-chair Grimson mentioned ideas for activities: a virtual workshop, writing a joint document, etc.

Yang mentioned that structural modeling seems to be missing from these discussions. Grimson mentioned that structural modeling would be key and necessary to be able to develop a digital twin. Lantsoght suggested to see the need for an additional TC on structural modeling and capacity of particular bridge types. Casas mentioned that BMS also needs the structural modeling and that the committee covers this partially. Grimson mentioned there is no way in the USA to update BMS with, for example, load testing data. Heywood commented that this is related to risk-informed decision making, and that the load model is not addressed yet.

Co-chair Grimson will start a short document that can be used to gather information and thoughts on the link between load testing and digital twins that our committee can share with the other committees to start off with.

3.4. Upcoming conferences and events

Znidaric: The 9th International conference on weigh-in-motion in Brisbane, November 2023 (which will also talk about bridge loading) https://www.is-wim.net/wp-content/uploads/2022/08/ICWIM9-First-Announcement-Call-for-Abstracts-full.pdf

Bhowmick: IABSE symposium in Istanbul on long-span bridges next week https://iabse.org/Istanbul2023

Schmidt: IABMAS Copenhagen June 2024 https://iabmas2024.dk/

Breveglieri: https://www.smar2024.org/ in Salerno, Italy

Heywood: PIARC world congress in Prague, October 2023 https://www.piarc.org/en/activities/World-Road-Congresses-World-Road-Association/XXVII-World-Road-Congress-Prague-2023

Lantsoght: IABSE 2024 in September 2024 in San Jose, Costa Rica https://iabse.org/Sanjose2024

Bhowmick: IABSE 2023 Engineering for Sustainable Development in September in New Delhi https://iabse.org/Newdelhi2023/Event

Biondini: IALCCE 2023 in July https://ialcce2023.org in July 2023 in Milan, Italy

4. Adjournment

Grimson adjourned the meeting at 9:57 am.

The next meeting will be during Fall 2023, online. A poll for availability will be sent in August.

Acoustic emission-based indicators of shear failure of reinforced concrete structures

Fengqiao Zhang

Supervisor: dr.ir. Yuguang Yang

Promoter: prof.dr.ir. Max A.N. Hendriks

TU Delft

Background

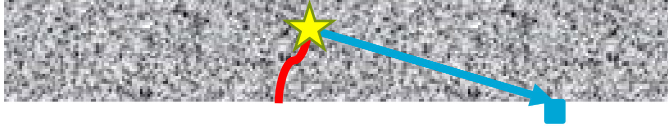
- Existing concrete structures require efficient structural assessment
- Proof load testing
- Monitoring structural behaviour
  - Visual inspection
  - Displacement measurement
  - Acoustic Emission
    - Internal damages
    - Real time
    - Sensitive to cracking

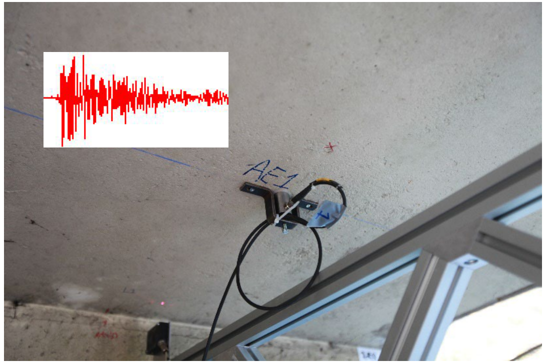
Ruytenschildtbrug, the Netherland

→AE-based indicators of structural failure

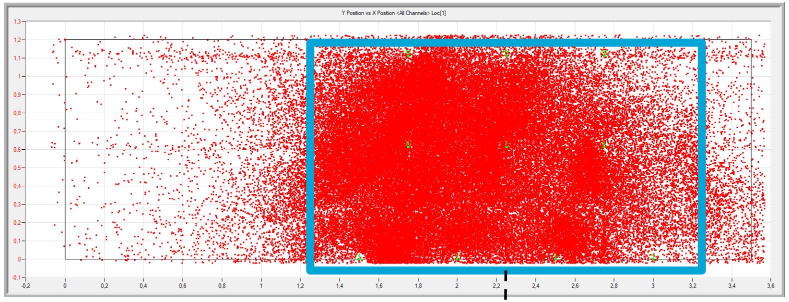
Acoustic emission monitoring

- Sudden changes in concrete releases energy and generates elastic waves → AE
- Capabilities of AE: Source localization, classification,..





→AE-based indicators of structural failure

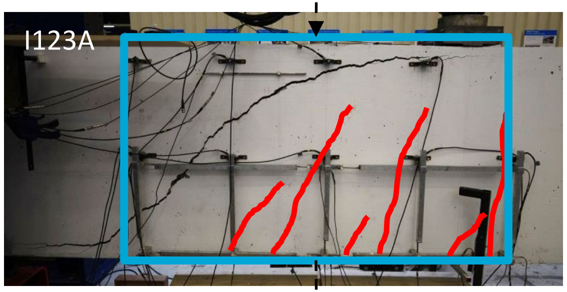


Gap 1: **relationships** between AE and concrete cracking

- Estimate the crack location
- Quantify the crack width

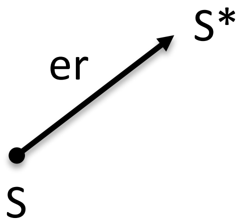
Current AE:

- Source localization
- …



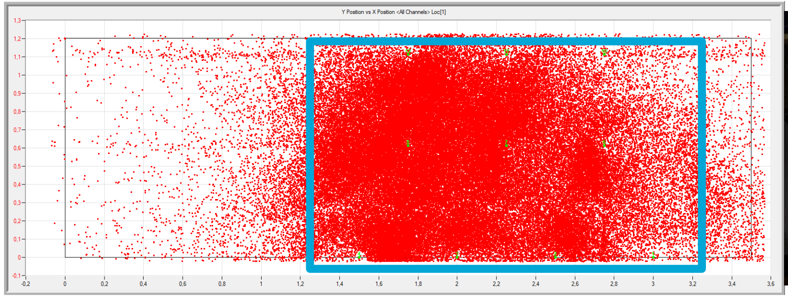
Gap 2: from the **material** (local) level to the **structural** level: how to indicate structural failure

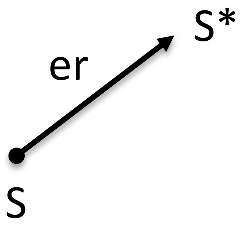
Goal of this thesis



Source localization error

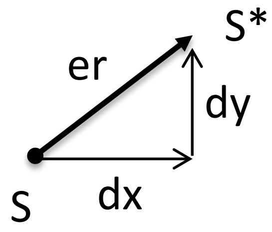
- Source localization error: $$er = \left\| \mathbf{x}_{S*} - \mathbf{x}_S \right\|$$
- Errors may come from:
  - Structural inconsistency: existing cracks
  - Algorithm: arrival time picking error
  - Installation: Sensor location
- Many methods in literature try to reduce the error → longer computational time & errors cannot be entirely removed





A new concept based on probability

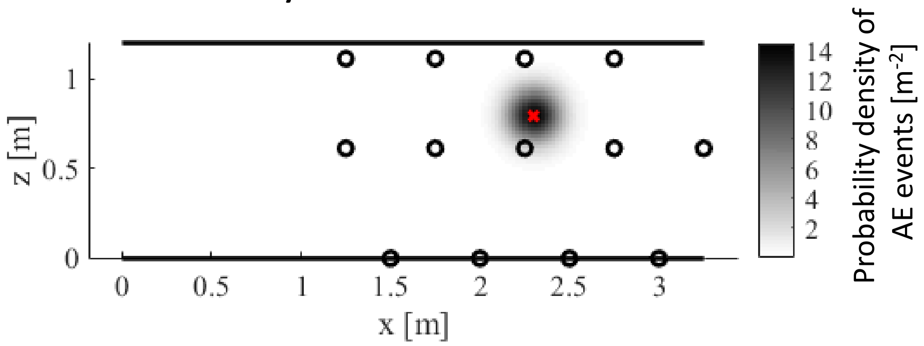
- Instead of correcting the error to get the accurate location, we estimate the chance/probability of the location of source from the error property.



Error study

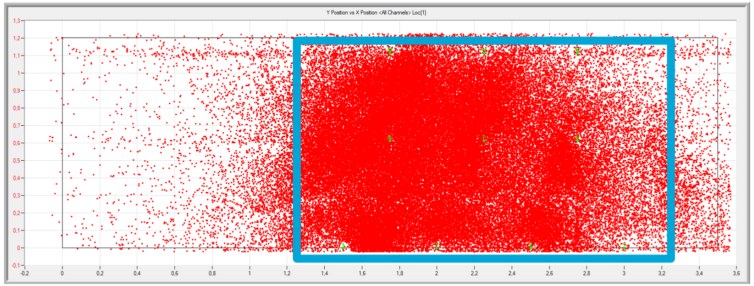
- Quantification of the errors
  - Simulation 11,827,200 tests
  - Experiments 100 points

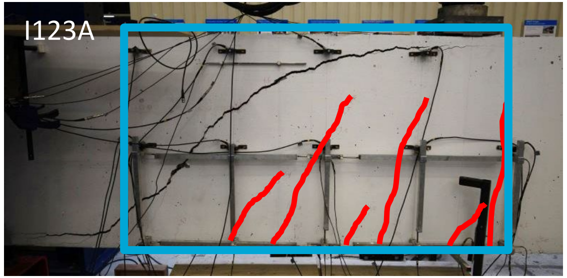
dx dy normal distribution

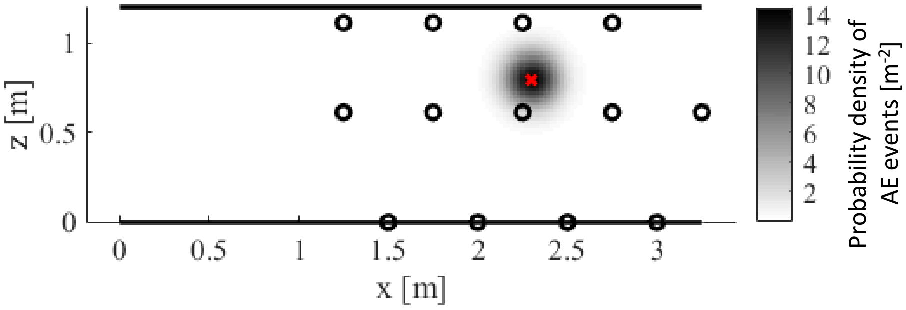


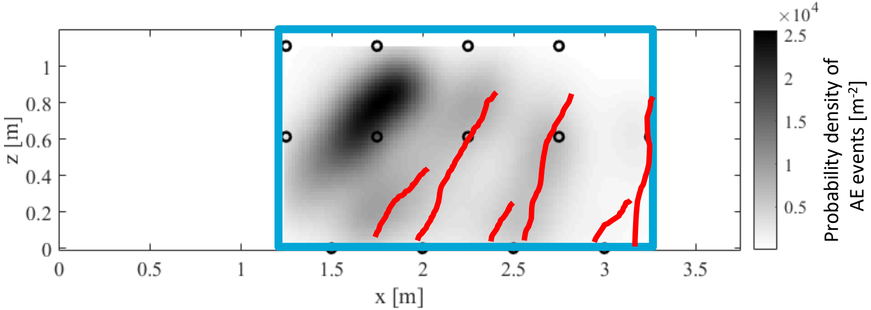
Journal Paper: Evaluation of accuracy of acoustic emission source localization in existing concrete structures

Quantified AE spatial distribution







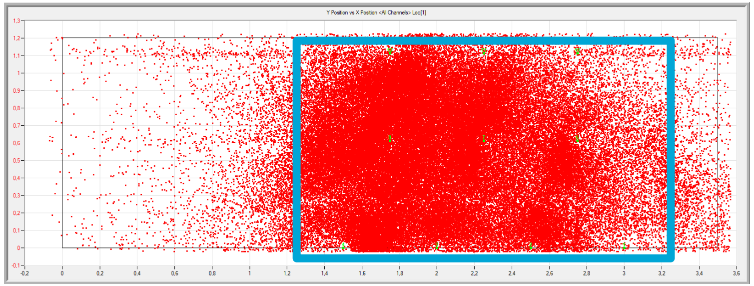


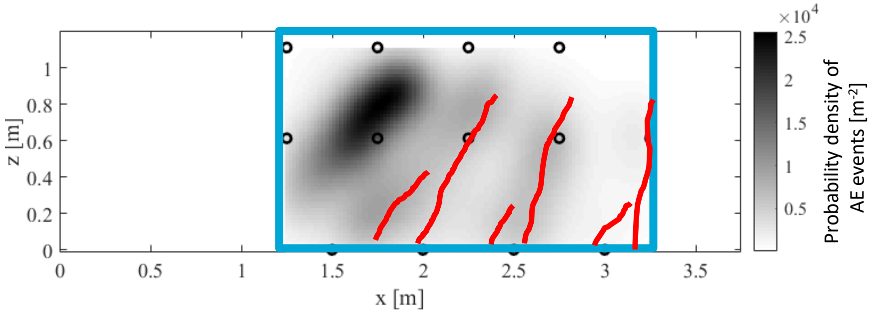
TUDelft

Journal Paper: Probability density field of acoustic emission events: damage identification in concrete structures

Probability density field of AE events

- Benefits:
  - Clear crack pattern, considering source localization error
  - Quantified AE spatial distribution
    - Relationship with crack width
  - Real-time monitoring: 0.12s per event

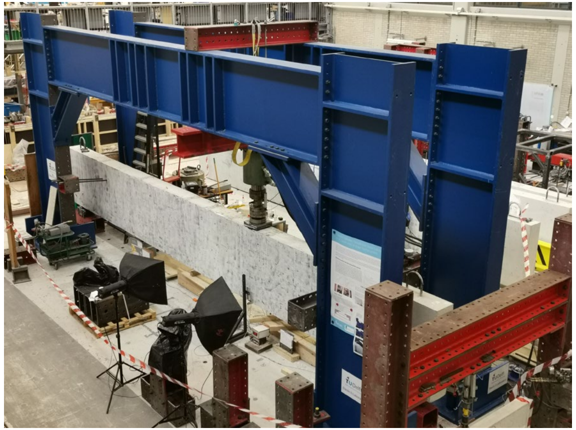


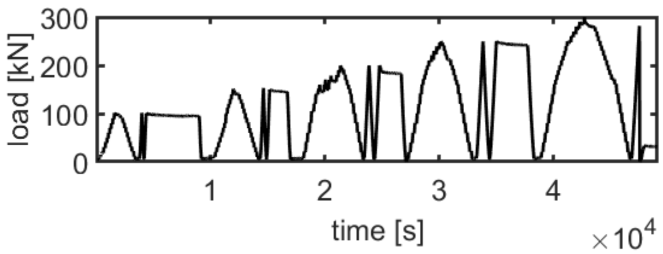


Fill the gap 1: **relationships** between AE and concrete cracking

AE-based indicators of shear failure of reinforced concrete structures

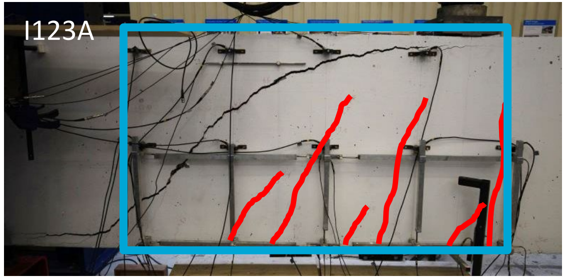
- Full-scale reinforced concrete beam
  - 1.2m height, 10m length and 0.3m width
  - Shear failure

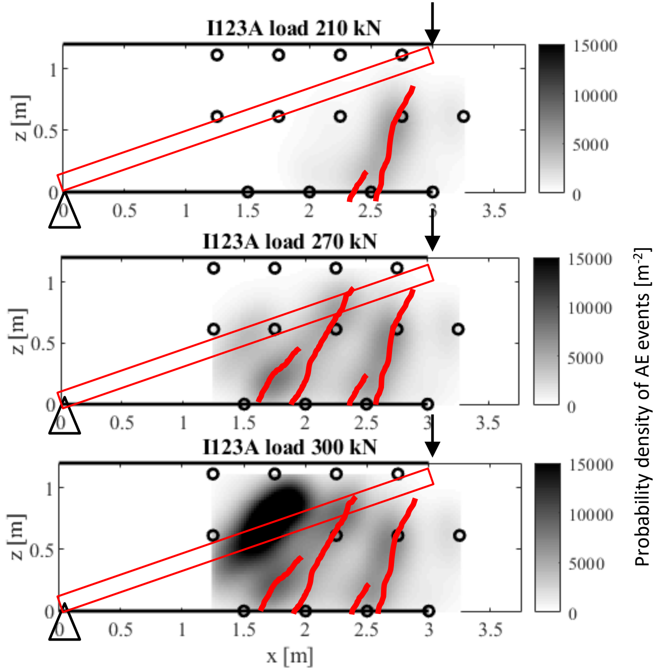




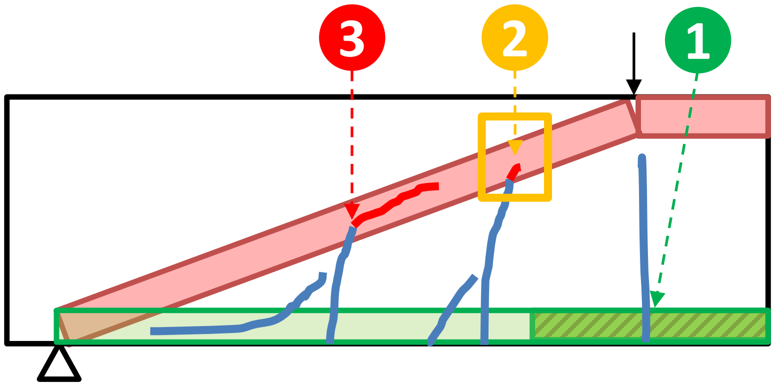
Real-time AE

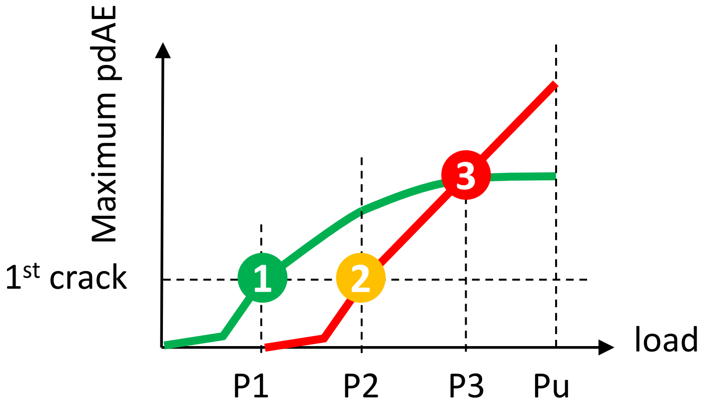
- Integrity of compressive strut is important for structural shear capacity (supported by theories of shear failure mechanisms)





Indication of structural shear failure: the ‘traffic light system’

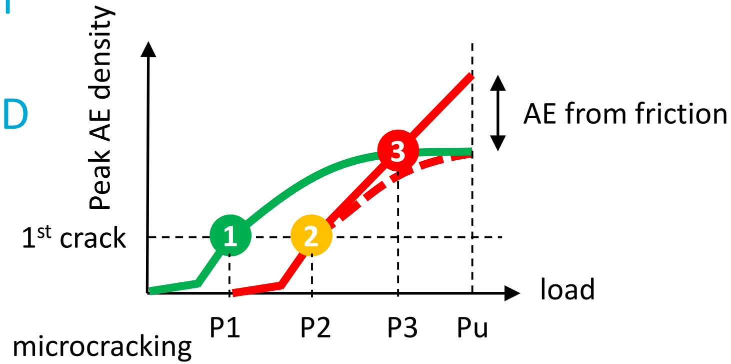


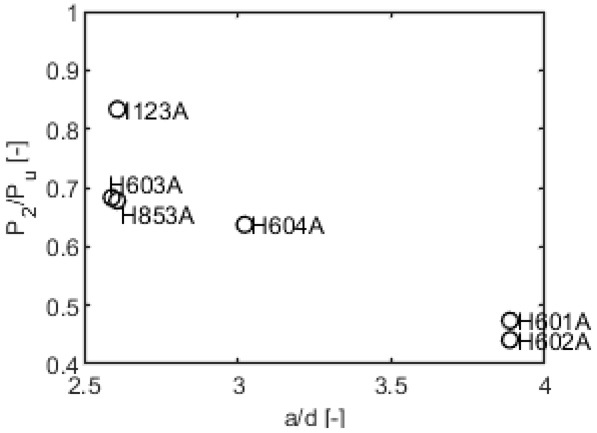


TU Delft

Yellow light:
49%-87% capacity, depending on loading position

- Experimental validation
- Robustness study
- Extension from 2D to 3D



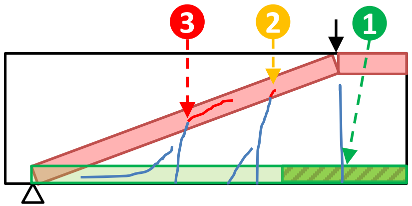


BEAM	a [m]	a/d [-]	ρ [%]	Load scheme	Type of bar	P1/Pu	P2/Pu	P3/Pu
I123A	3	2,61	1,14	Cyclic	Plain	0,6	0,83	0,97
H601A	4,5	3,89	0,57	Cyclic	Ribbed	0,46	0,47	0,78
H602A	4,5	3,89	0,57	Monotonic	Ribbed	0,44	0,44	0,53
H603A	3	2,59	0,57	Cyclic	Ribbed	0,55	0,68	0,85
H604A	3,5	3,02	0,57	Cyclic	Ribbed	0,6	0,64	0,9
H853A	3	2,61	0,85	Cyclic	Ribbed	0,55	0,68	0,68

TU Delft

Decision making based on traffic light system during load testing

- Real-time indication and decision making

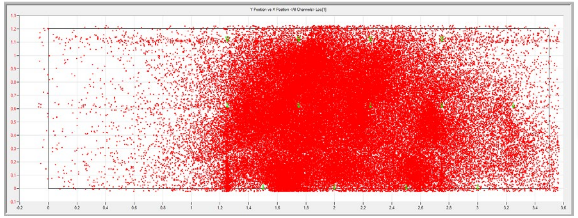


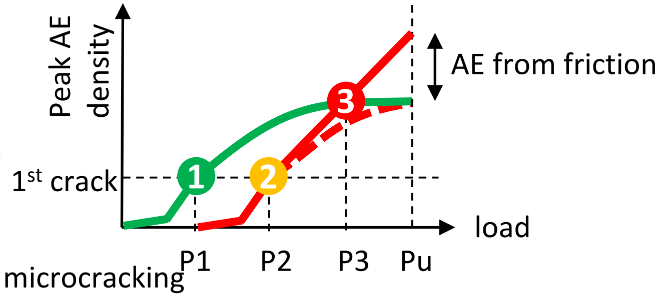
User objective	AE-based indicator	Physical behaviour	Corresponding actions
Estimate the cracking load	Green-light criterion	Cracking in the reference region	Stop loading; Can repair the cracks.
Load the structure to the most, but keep safety against shear failure	Yellow-light criterion	Cracking in the strut	Stop loading; Can keep the structure, but under lower load; Can maintain the structure to prolong the service life.
Approach the actual shear capacity, but avoid collapsing of structure	Red-light criterion	Cracking in the strut that significantly reduces the bearing capacity	Take safety measures for a collapse; Stop loading immediately; Replace or repair the structure

TU Delft

Summary

- My PhD research: a few steps forward for this research field
  - algorithm
    - Quantify AE distribution probabilistically including errors
    - A new source classification criterion
  - quantify internal crack width
  - traffic light system to indicate structural behaviour during load testing



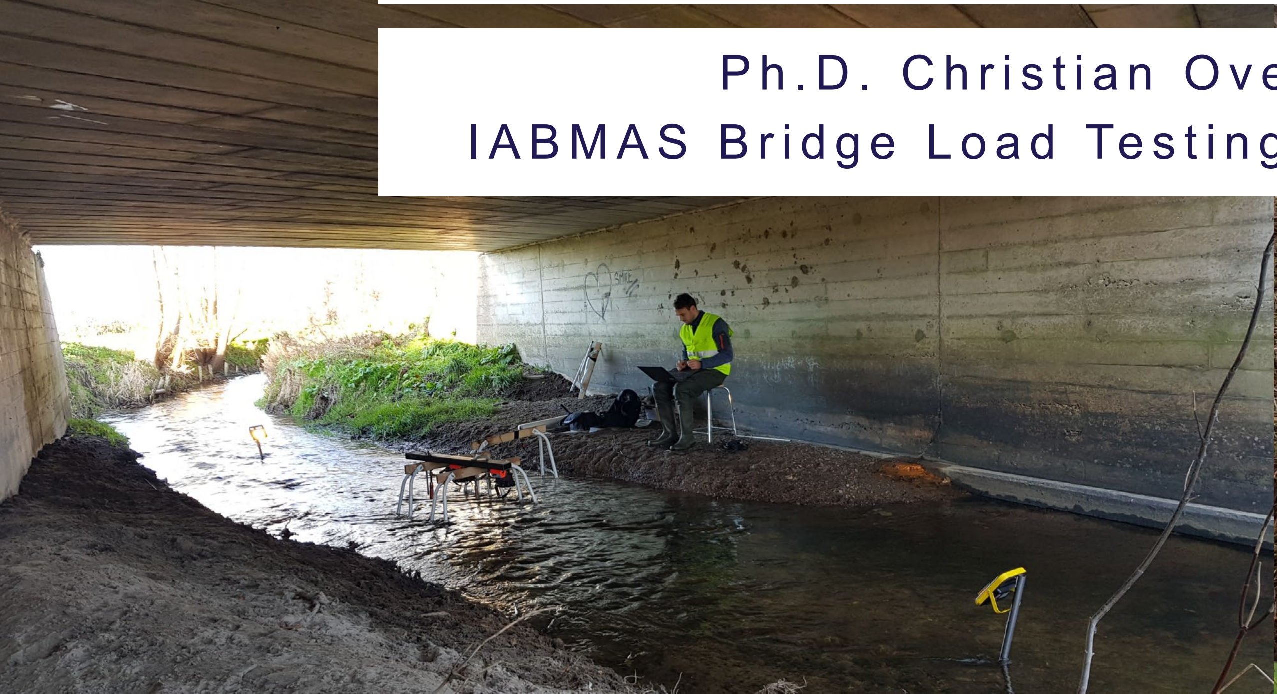


Thanks for your attention!

Application of DIC for load testing in Denmark

Ph.D. Christian Overgaard Christensen

IABMAS Bridge Load Testing Virtual Meeting:18-04-2023



Presentation includes compressed content of Ph.D. thesis: Monitoring thresholds and output assessment related to in-situ concrete bridge testing

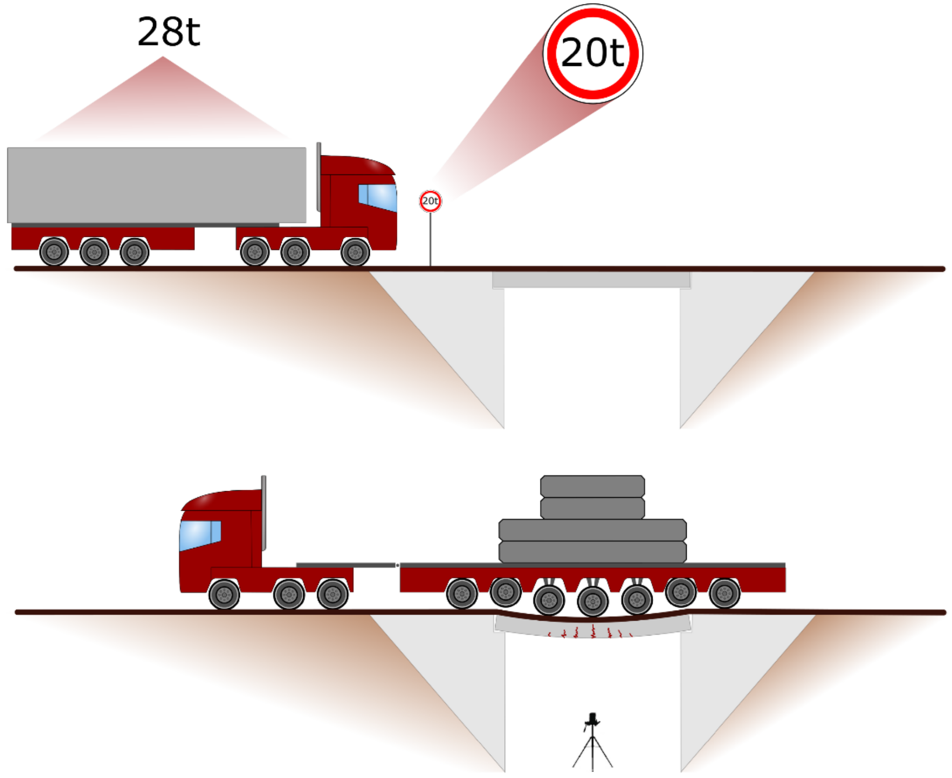
Supervisors

- **Per Goltermann**, professor, Technical University of Denmark.
- **Jacob Wittrup Schmidt**, associate professor, Aalborg University.
- **Eva Lantsoght**, professor, Universidad San Francisco de Quito, and Delft University of Technology.
- **Sebastian Thöns**, professor, Lund University.
- **Jacob Paamand Waldbjørn**, Researcher, Technical University of Denmark.

Assessment Committee

- **Evangelos Katsanos** (chair), associate professor, Technical University of Denmark.
- **Riadh Al-Mahaidi**, professor, Swinburne University of Technology.
- **Anders Carolin**, PhD, Traffikverket.

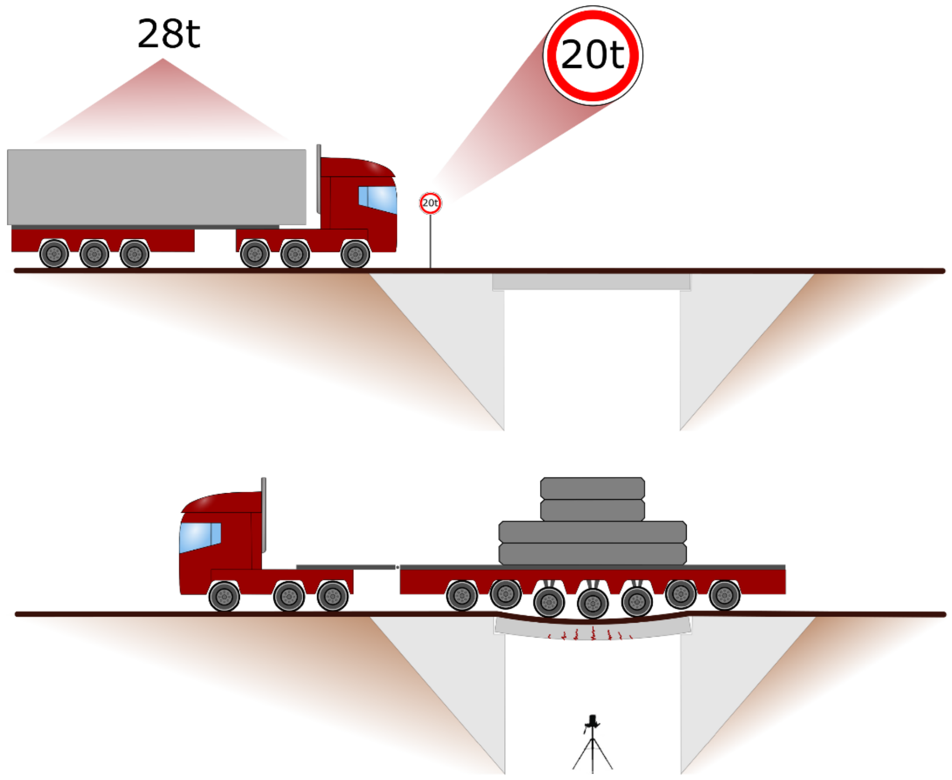
Defended February 9th, 2023



Project background

- Increasing traffic demands
- Aging bridge structures often associated with uncertainties:
    - End of service life
    - Deterioration
    - Limited documentation
    - Lack of understanding of the structural behavior

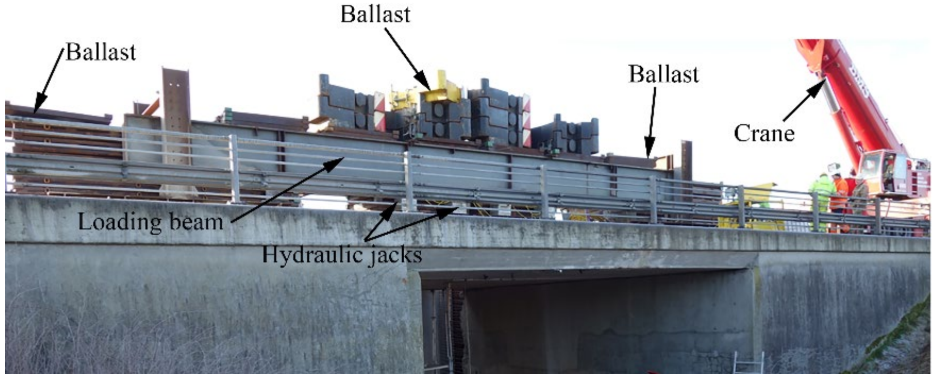
This calls for the use of load testing for direct capacity evaluation!



The Danish bridge evaluation project
(Content presented at previous committee meeting)

- Initiated in 2016
- Considered short-span concrete slab bridges (span up to 12 m)
- Focus on both proof-load testing and collapse testing.
- Has shown a significant capacity reserve in a multitude of bridges.

- My focus: Proof-load testing and monitoring thresholds.



Successful and effective proof-load testing

To achieve a successful result (with regards to monitoring and stop criteria):

- A limited number of relevant monitoring systems capable of monitoring for stop criteria
  - *An overly monitored test is not desired*
  - *Non-contact systems and easy installation is preferred*
- Monitoring-based stop criteria that terminate a test before irreversible damage occurs
  - *Guidelines on proof-loading and stop criteria are limited, and the measured parameters vary significantly*
  - *Robust criteria are an extremely complex task in proof-loading assessment*

Promising systems investigated in the research project:

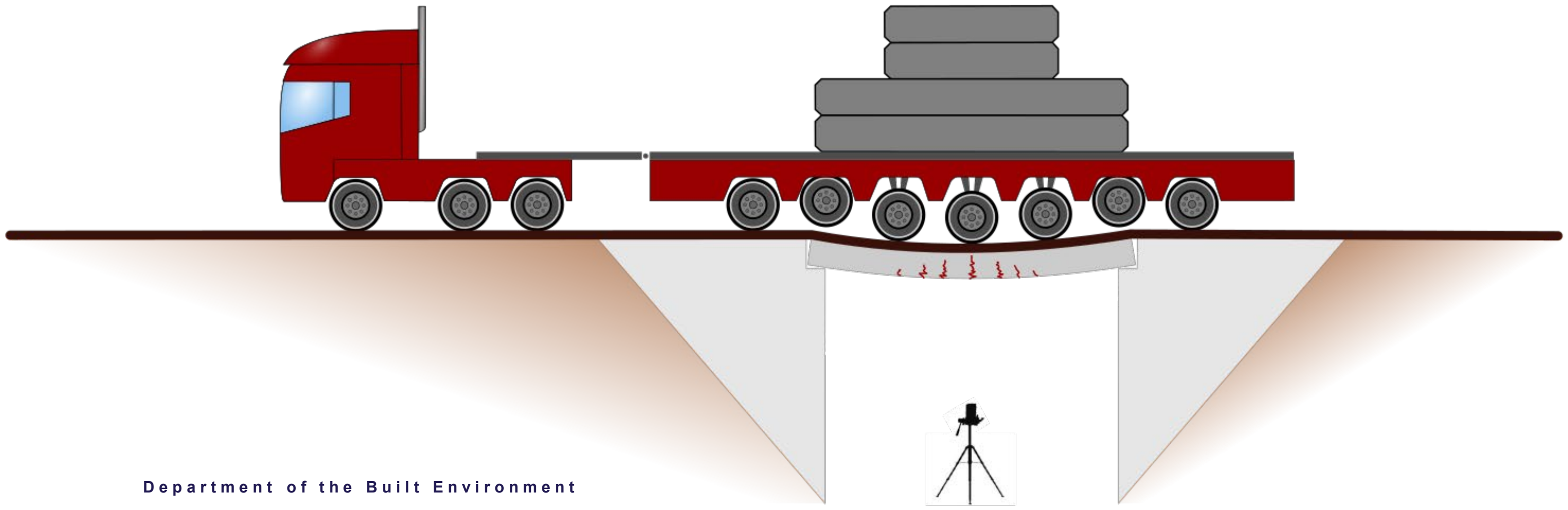
- Digital Image Correlation (DIC)
- Acoustic Emission (AE)

Preliminary assessment of 2D DIC

2D DIC chosen over 3D DIC for field use

- 3D DIC:
  - Expensive
  - Requires comprehensive calibration
  - Sensitive towards environmental conditions

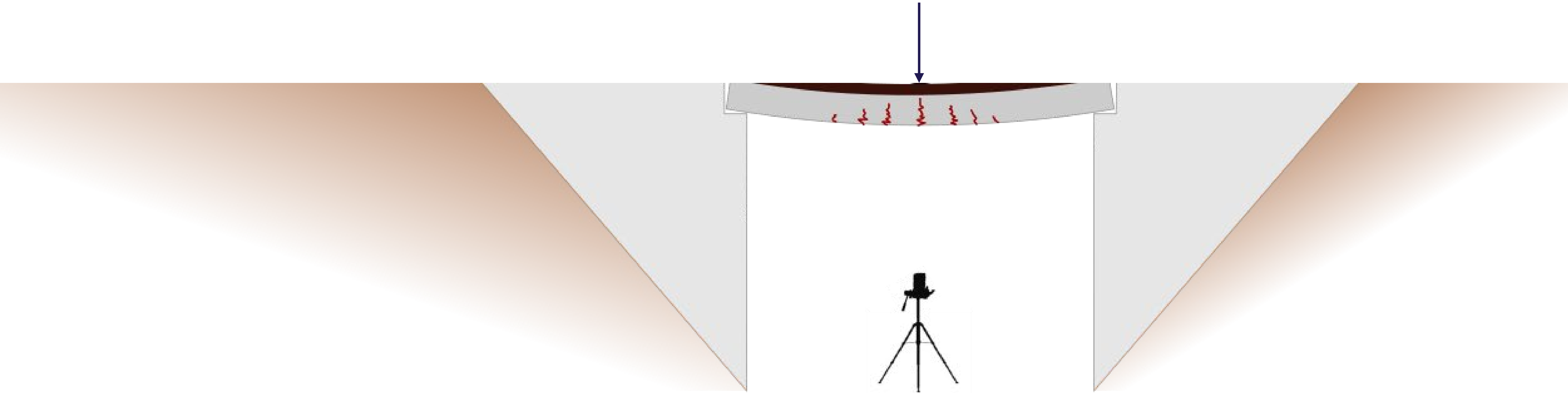
- 2D DIC:
  - Lower cost
  - Higher resolution
  - No calibration required
  - Less sensitive towards environmental conditions
  - However: Involves other challenges for field application



Preliminary assessment of 2D DIC

Some of the challenges associated with field application of 2D DIC:

- Out-of-plane movement of the monitored surface (scaling effect)
- Rotation of the monitored surface (transformation effect)
- Requires real-time DIC measurements



Preliminary assessment of 2D DIC
Out-of-plane effects

Out-of-plane movement (scaling effect):

$$\varepsilon_{oop} = \frac{h}{h-n} - 1$$

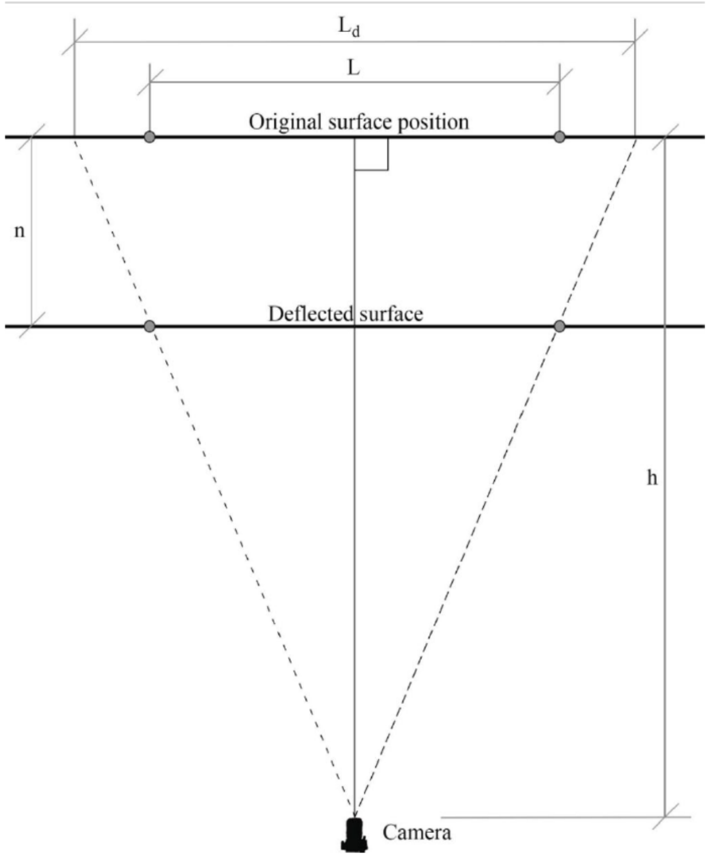


Figure 19. Parameters in the 2D DIC out-of-plane deflection correction of surface strains.

Preliminary assessment of 2D DIC
Out-of-plane effects

Out-of-plane movement (scaling effect):

$$\varepsilon_{oop} = \frac{h}{h-n} - 1$$

Rotation (transformation effect):

$$\varepsilon_{rot} = \frac{\alpha_r - \beta_r}{\alpha_r}$$

Combined:

$$\varepsilon_{true} = \varepsilon_{DIC} - \varepsilon_{oop} - \varepsilon_{rot}$$

Preliminary results:

- Very applicable across the center
- Accurate full-field correction requires accurate full-field deformation measurements
- May also be used to correct crack widths
- The measurements across midspan are larger than the true values

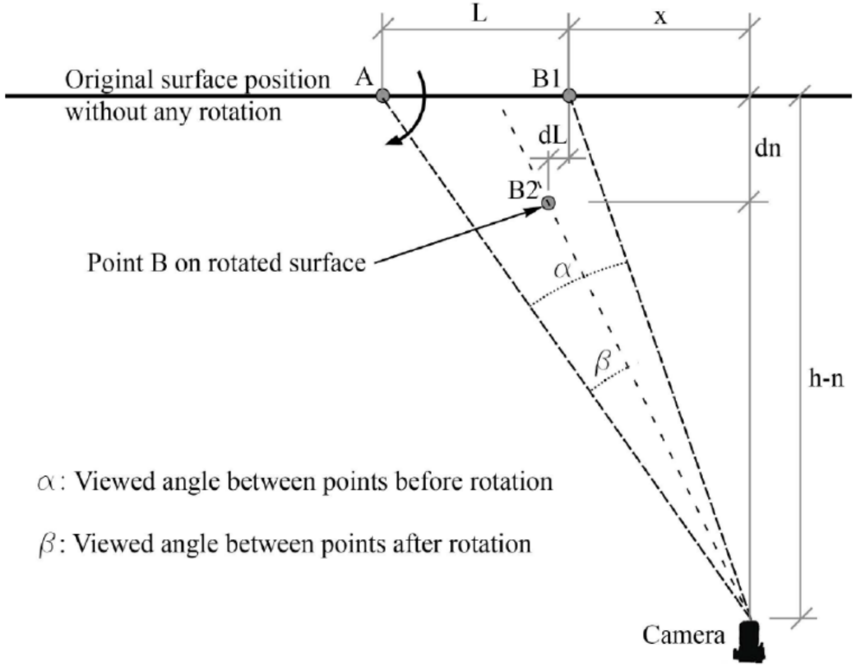


Figure 20. Parameters for calculation of surface rotation correction.

Preliminary assessment of 2D DIC

Real-time DIC monitoring

- Work on open-source algorithm (Ncorr)
- Setup: DSR camera connected by cable
- Continuous loop with updating of plots
- Updating time between 30 and 90 sec
- Practical setup for field application

Figure 24. Open-source real-time DIC operated on a laptop. a) In the Structural Lab at DTU, b) In field testing.

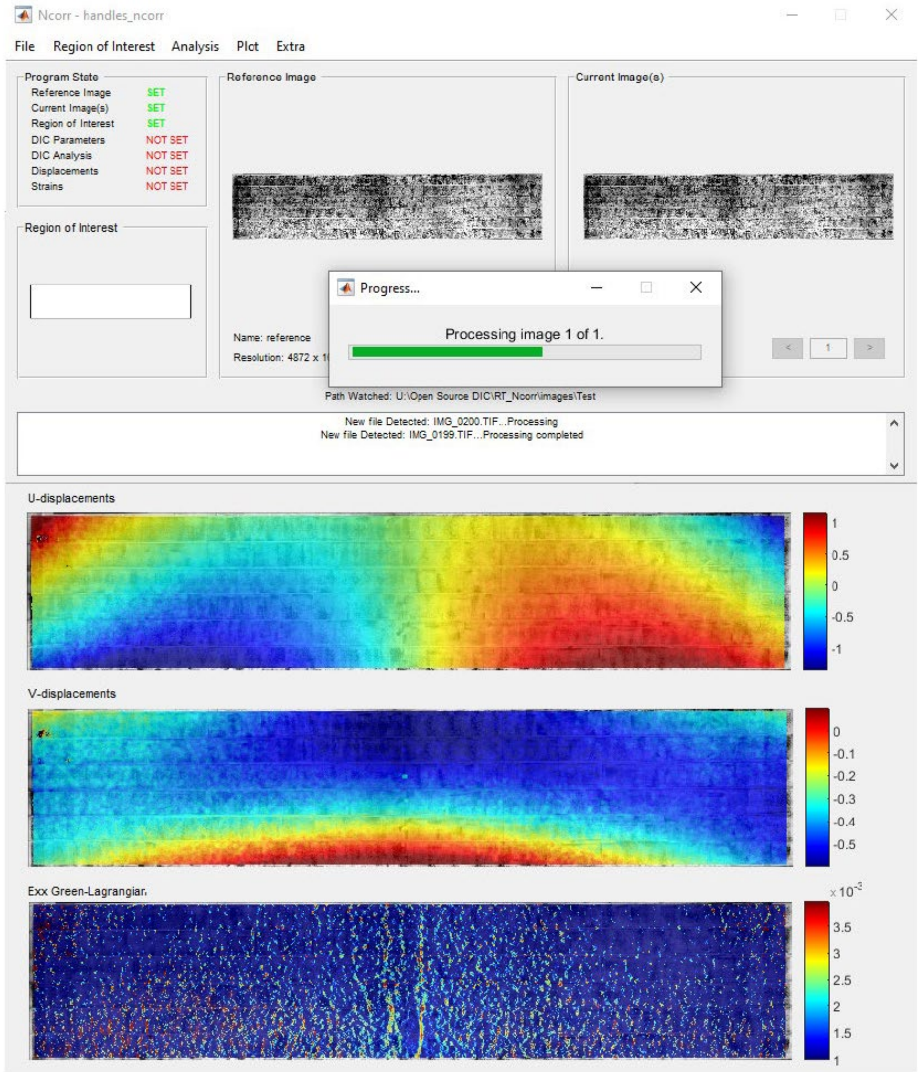


Figure 23. Real-time DIC analysis and plots in Ncorr.

Preliminary assessment of 2D DIC

Remarks on preliminary result on 2D-DIC for field use:

- 2D DIC is very applicable for field work
- Cheap solution compared to commercial systems
- Challenges with 2D DIC are manageable
- Real-time field setup enables quick in-situ decision-making

Large-scale OT-slab laboratory tests
(Presented at previous committee meeting)

- OT-slabs consisting of seven OT-beams. Slab dimensions: 8.4 m × 1.7 m × 0.37 m
- Testing in the Structural Lab at DTU benefitting from the strong-floor structural system
- Testing upside-down for practical, monitoring, and safety purposes

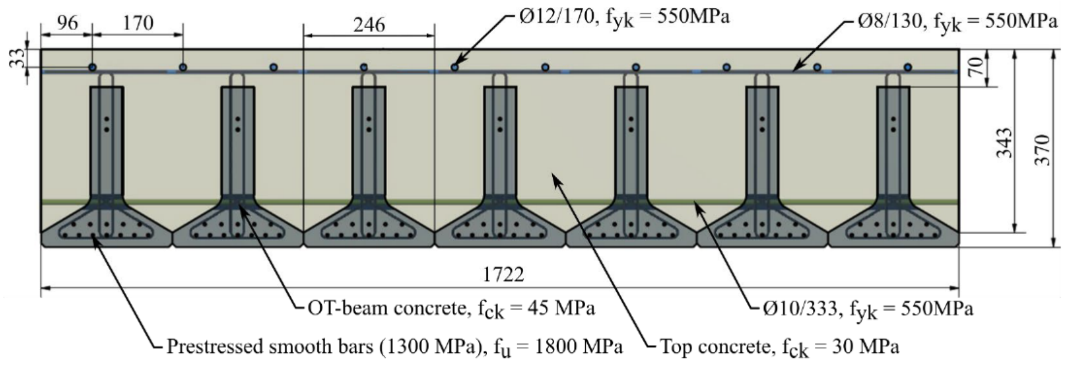


Figure 28. OT test specimen cross-section, all units in mm.

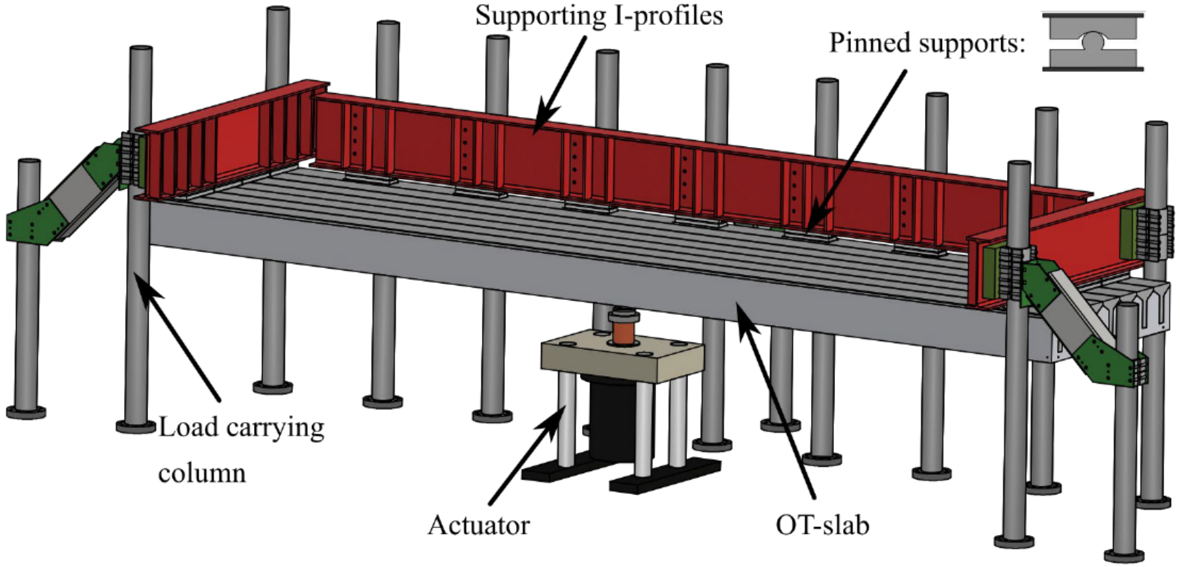


Figure 29. A three-dimensional model of the final test setup.

Large-scale OT-slab laboratory tests
Monitoring setup

- Monitoring rig built around the test setup for independent measurements
- Field logger systems with battery package and up to 60 channels
- Substantial monitoring package with:
  - One primary 2D DIC for full-field coverage (camera dist. 3.8 m)
  - A secondary 2D DIC for partial coverage (camera dist. 2.6 m)
  - Distance lasers
  - Wire potentiometers
  - LVDTs
  - Internal strain gauges
  - Inclinometers
  - Acoustic emission (in OT test 2)

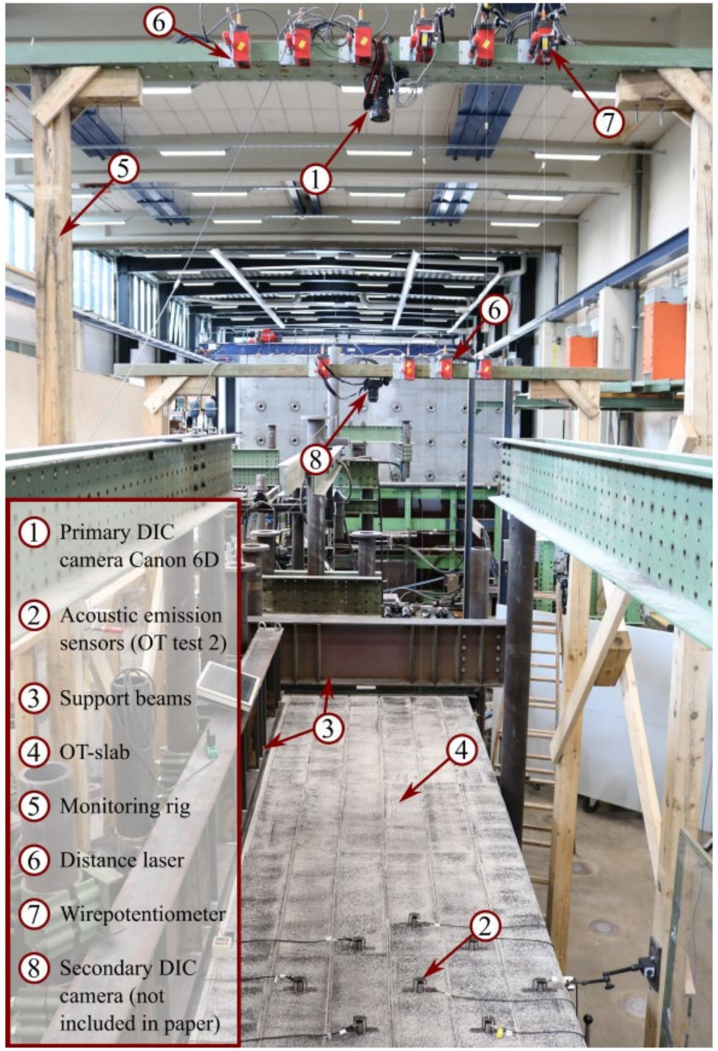
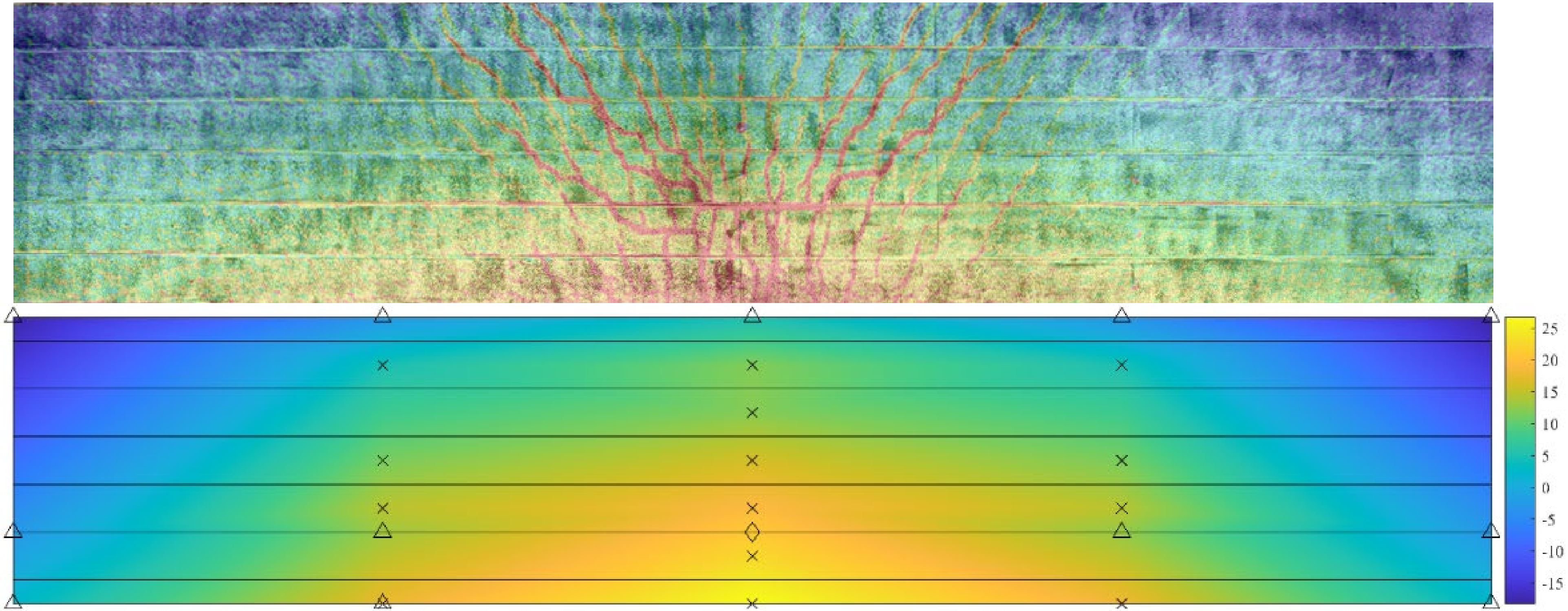


Figure 32. Test setup, monitoring rig, and sensors from above.

Large-scale OT-slab laboratory tests
DIC test results and comparison

- Early crack detection by DIC in the linear elastic regime from 3.8 m camera distance (419 kN - 51% of maximum load)
- Identified crack pattern and structural behavior
- Deflection data and contour (from 20+ sensors) may be redundant



Identification of DIC stop criteria
Digital Image Correlation

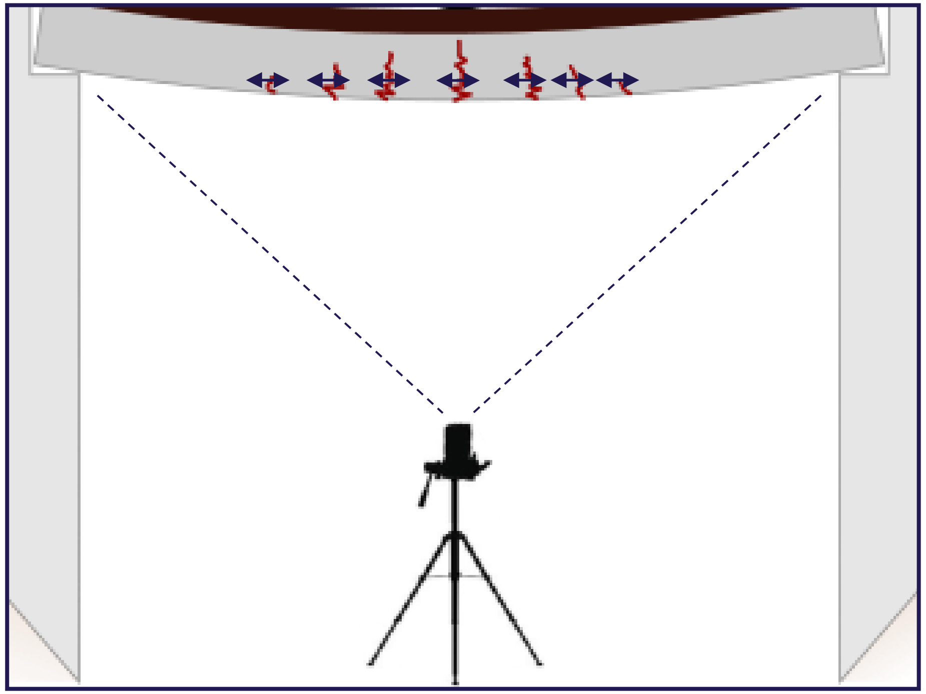
Digital Image Correlation enables full-field monitoring of:

- Strain
- Crack formation
- Crack widths

and reveals structural behavior and crack pattern

Parameters relevant to consider for stop criteria:

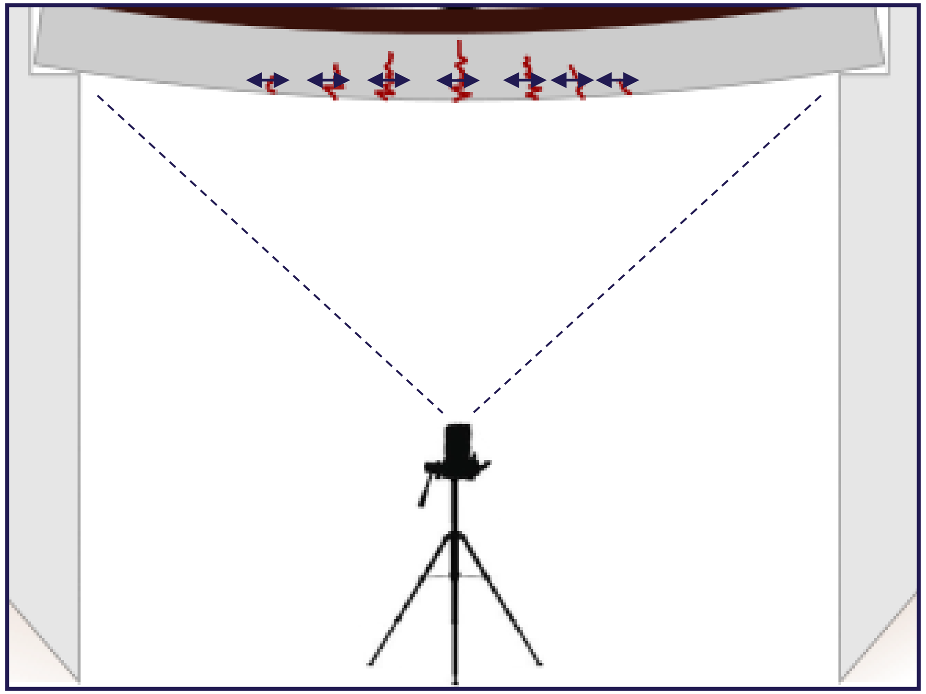
- **Strain** – Quantitative threshold
  - Often associated with noise unless using a long gauge length.
- **Crack detection** – Qualitative observation.
  - Early detection with the 2D DIC setup
- **Crack width** – Quantitative threshold.
  - May be measured and corrected using geometrical correction



Identification of DIC stop criteria
Crack width stop criterion (flexure)

Different approaches in guidelines on crack width stop criteria for flexure:

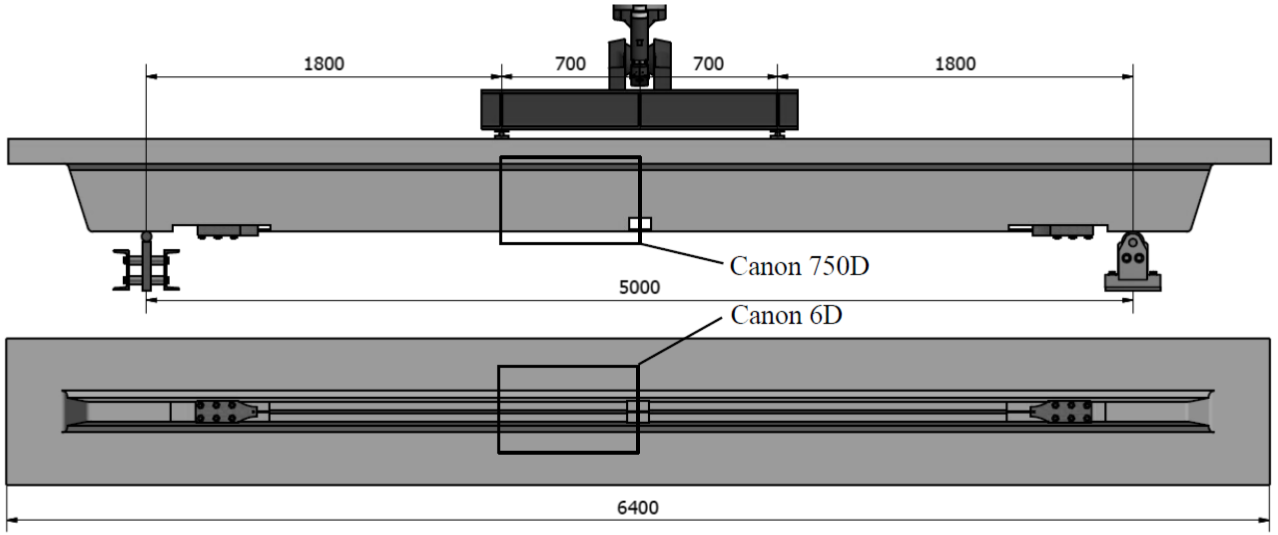
- Fixed threshold
  - German guideline - $w_{max} \leq 0.5$ mm for new cracks and $w_{max} \leq 0.3$ mm for existing cracks
- Theoretically-based methods
  - Study by Lantsoght et al. $w_{max} \leq 0.11$ mm to $w_{max} \leq 0.19$ mm
- Fixed thresholds with Eurocode SLS
  - Reinforced concrete: $w_{max} \leq 0.3$ mm
  - Prestressed concrete: $w_{max} \leq 0.2$ mm
  - Applied in this project



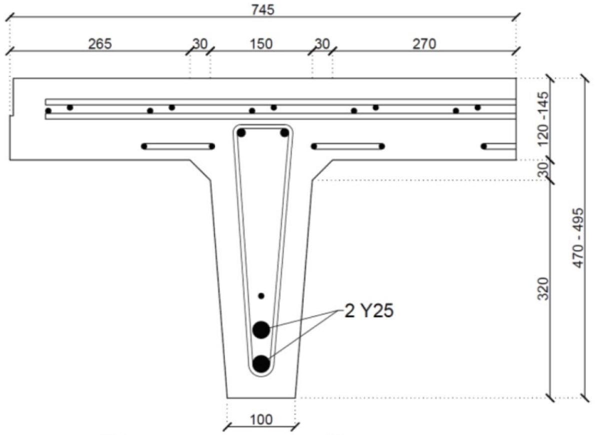
Identification of DIC stop criteria
Research test series

Research output from three test series:

- T-section beam tests without and with prestressing (two and five, respectively)



Test beam and DIC setup. Units: mm.

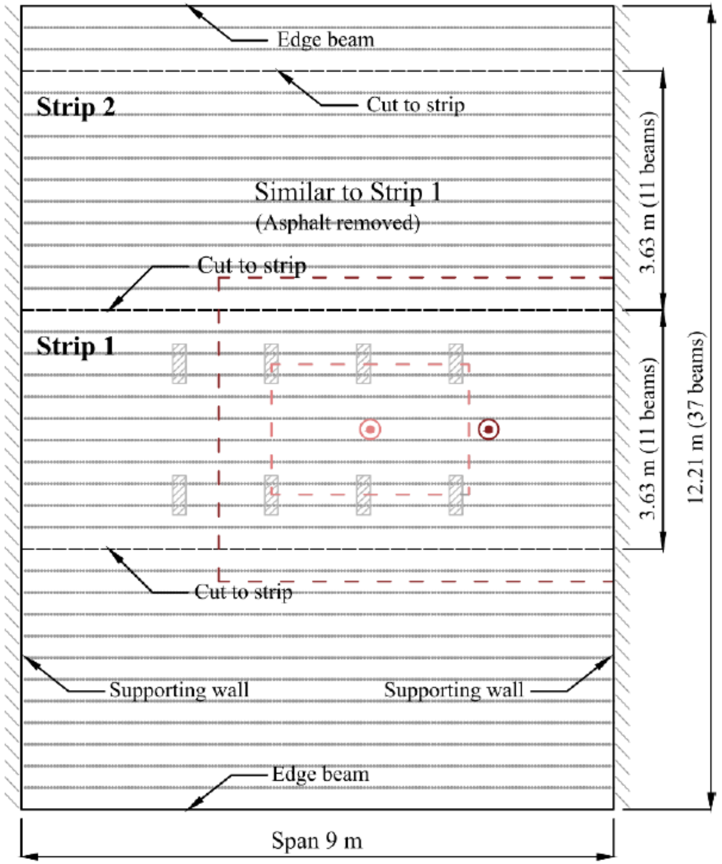


T-beam cross section. Units: mm.

Identification of DIC stop criteria
Research test series

Research output from three test series:

- T-section beam tests without and with prestressing (two and five, respectively)
- In-situ strips from earlier in-situ collapse tests (twosts)



Plan drawing of the two strips and the position of load and DIC cameras.

Identification of DIC stop criteria

Research test series

Research output from three test series:

- T-section beam tests without and with prestressing (two and five, respectively)
- In-situ strips from earlier in-situ collapse tests (two tests)
- Laboratory OT-slab tests (two tests)

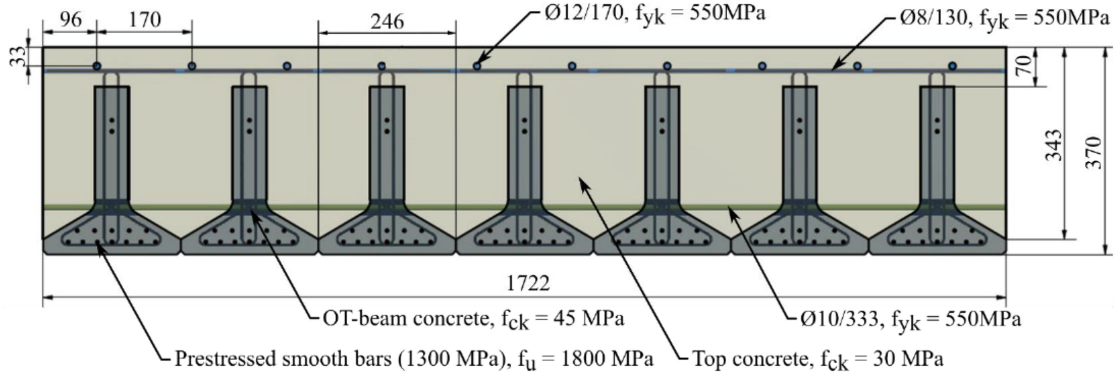


Figure 28. OT test specimen cross-section, all units in mm.

Identification of DIC stop criteria
Test results

T-section beam tests without and with prestressing (two and five, respectively)

- Short camera distance (242 mm)
- Applied surface pattern
- Early crack detection
- Comparison to stop criteria (0.2, 0.3, and 0.5 mm)
- Side- and bottom cameras, with correction
- Difference between crack formation

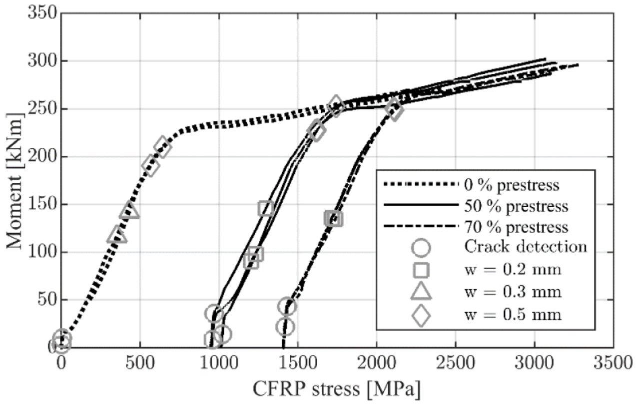


Figure 35. Response curves and flexural crack widths for the side images of the tested T-section beams.

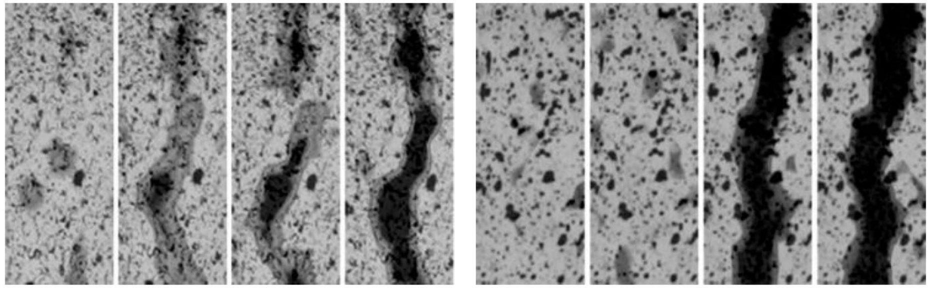


Figure 36. Crack formation. Left: No post-tensioning, Right: 70% post-tensioning. Frame rate 0.1 f/s.

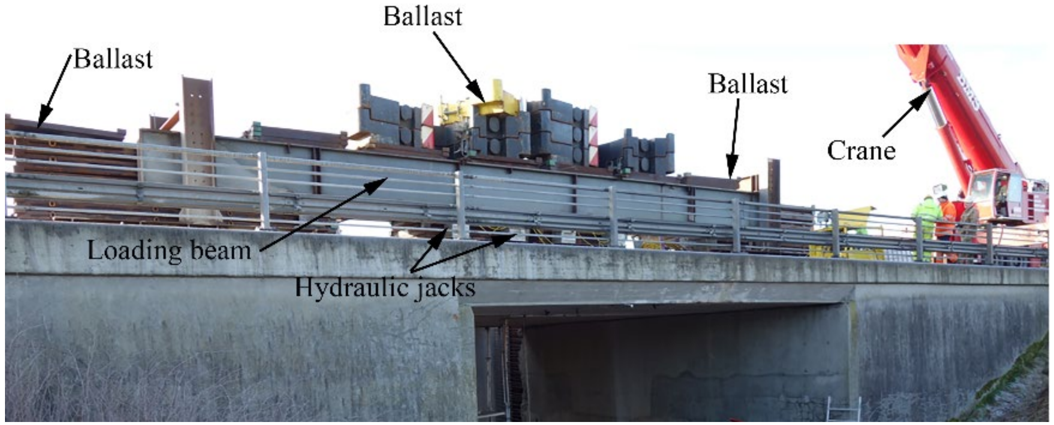
Table 1. Comparison of DIC crack widths for verification of the out-of-plane correction method.

Beam No.	Post-tensioning [%]	Side camera [mm]	Bottom camera, corrected [mm]
Ref-NSMR1	0	0.30	0.29
ANSMR50-2	50	0.20	0.17
ANSMR70-2	70	0.20	0.16

Identification of DIC stop criteria
Test results

In-situ OT-slab strips (two)

- Large camera distance
  - Primary camera, 3.8 m
  - Secondary camera, 2.6 m
- Measurements of raw concrete
- Challenging in-situ conditions
- Slightly delayed crack detection



- Crack widths at crack detection (Eurocode SLS: $w_{max} \leq$ 0.2 mm):
  - Primary camera, 0.24 mm to 0.33 mm
  - Secondary camera, 0.1 mm to 0.24 mm

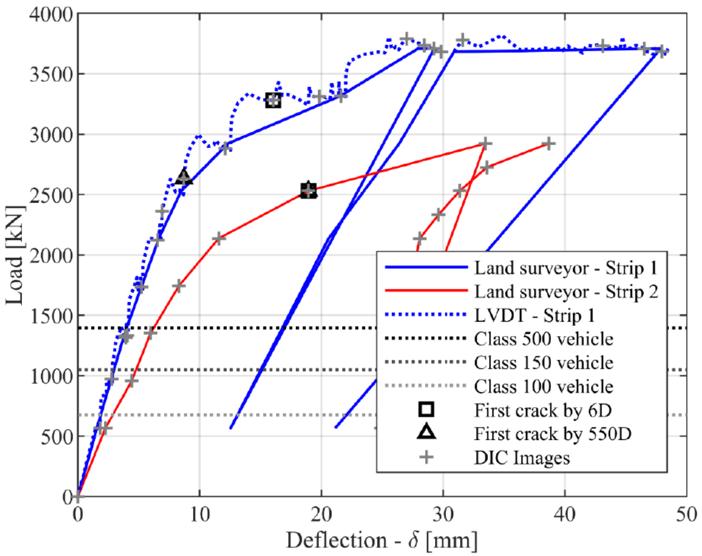


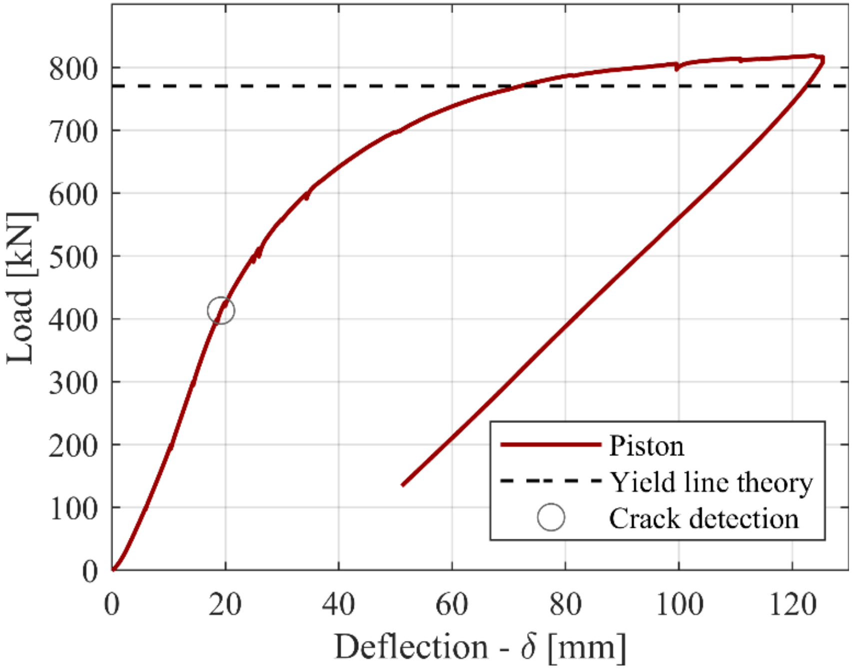
Figure 37. Strip test response curves. Strip 1 with road build-up. Strip 2 with asphalt removed.

Identification of DIC stop criteria
Test results

Laboratory OT-slab tests (two)

- Large camera distance
  - Primary camera, 3.8 m
  - Secondary camera, 2.6 m
- Applied surface pattern
- Controlled laboratory conditions
- Early crack detection (419 kN - 51% of maximum load)

- Crack widths at crack detection ($w_{max} \leq 0.2$ mm):
  - Primary camera, 0.08 mm to 0.13 mm (0.2 mm exceeded at 468 kN)
  - Secondary camera, out of zone



Identification of DIC stop criteria
Digital Image Correlation

Remarks on results and future proof-load application of 2D DIC

- Works well as a stand-alone method
- Monitors several useful parameters for stop criteria identification
- A surface pattern should be applied, if possible
- A primary camera may be used for full-field coverage and a secondary camera for an optional zone of interest

Pilot proof-load tests
(Partly presented at previous committee meeting)

- Proof-loading performed to update a road stretch between Assens and Nørre Aaby
- Four short-span bridges
- Original bridge class: 80
- Desired bridge class: 100

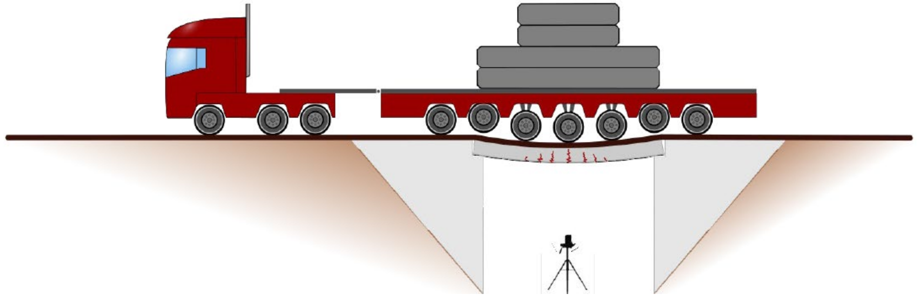
Table 2. Data on bridges subject to proof-load testing on a road stretch between Assens and Nørre Aaby, Denmark.

Test day	Bridge No.	Bridge type	Class	Span [m]
1	3851	In-situ cast slab	80	2.1 m
2	3700	OT-slab	80	6.5 m
2	3699	In-situ cast slab	80	3.8 m
3	3720	In-situ cast slab	80	4.0 m

Figure 43. Photographs of the bridges subject to proof-load testing.

Pilot proof-load tests
(Partly presented at previous committee meeting)

- Proof-loading performed to update a road stretch between Assens and Nørre Aaby
- Four short-span bridges
- Original bridge class: 80
- Desired bridge class: 100
- Tested using special heavy vehicles, corresponding to the Danish classification system



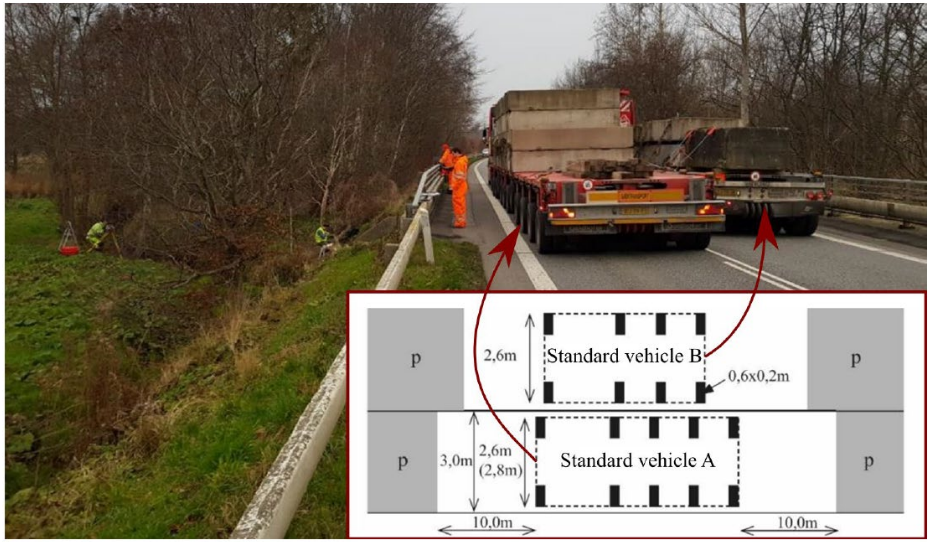
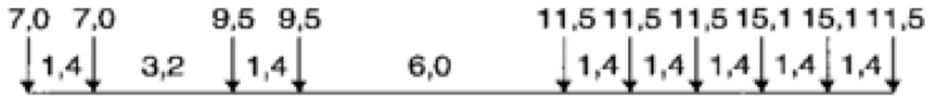


Figure 44. Trucks were used to apply accurate loading in accordance with the Danish classification system [55].

Pilot proof-load tests
(Partly presented at previous committee meeting)

- Proof-loading performed to update a road stretch between Assens and Nørre Aaby
- Four short-span bridges
- Original bridge class: 80
- Desired bridge class: 100
- Tested using special heavy vehicles, corresponding to the Danish classification system
- The number of included axles depended on the bridge span



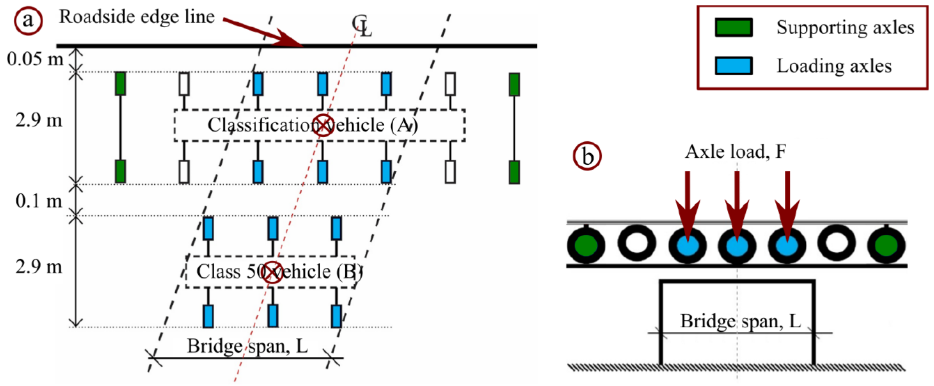


Figure 45. Example of load placing and application for Bridge 3700: a) Placing of vehicle A (the classification vehicle) and vehicle B (a class 50 vehicle), and b) Loaded and supporting axles.

Pilot proof-load tests
(Partly presented at previous committee meeting)

- Proof-loading performed to update a road stretch between Assens and Nørre Aaby
- Four short-span bridges
- Original bridge class: 80
- Desired bridge class: 100
- Tested using special heavy vehicles, corresponding to the Danish classification system
- The number of included axles depends on the bridge span
- Incremental loading was applied

Table 3. Load configurations for the tested bridges, including the number of axles of the vehicles.

Bridge No.	Fixed load of vehicle B [kN]	Load peak 1 [kN]	Load peak 2 [kN]	Load peak 3 [kN]
3851	1×15 tons	1×15 tons	1×25 tons	1×30 tons
3700	3×15 tons	3×15 tons	3×25 tons	3×31 tons
3699	3×15 tons	2×18.1 tons	2×27.8 tons	2×36.1 tons
3720	3×15 tons	2×18.1 tons	2×27.8 tons	2×36.4 tons

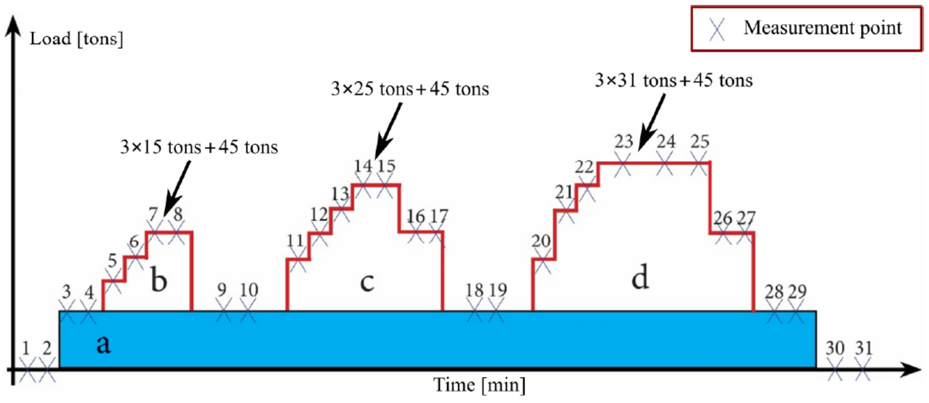


Figure 46. The loading scheme used to test Bridge 3700.

Pilot proof-load tests
Selected monitoring parameters

The selected monitoring parameters were:

- Deflection of the bridge (land surveyor)
- Settling of the foundation (land surveyor)
- The degree of non-linearity of the structural response (land surveyor and hydraulic output)
- Crack identification, crack width monitoring and structural behavior (DIC)

Pilot proof-load tests

Special heavy vehicles

Pilot proof-load tests

Field setup

Pilot proof-load tests

Field setup

Pilot proof-load tests

Field monitoring and testing

Pilot proof-load tests

Test results

- All tests reached the target load, and the four bridges were thus successfully upgraded!
- Maximum deflection of 0.45 mm, 2.0 mm, 0.63 mm, and 0.65 mm, respectively. Hence, a large capacity reserve may still be present.
- Continuous updating of DIC results without signs of distress – not in post-analysis either.
  - No signs of non-linearity
  - No signs of cracking

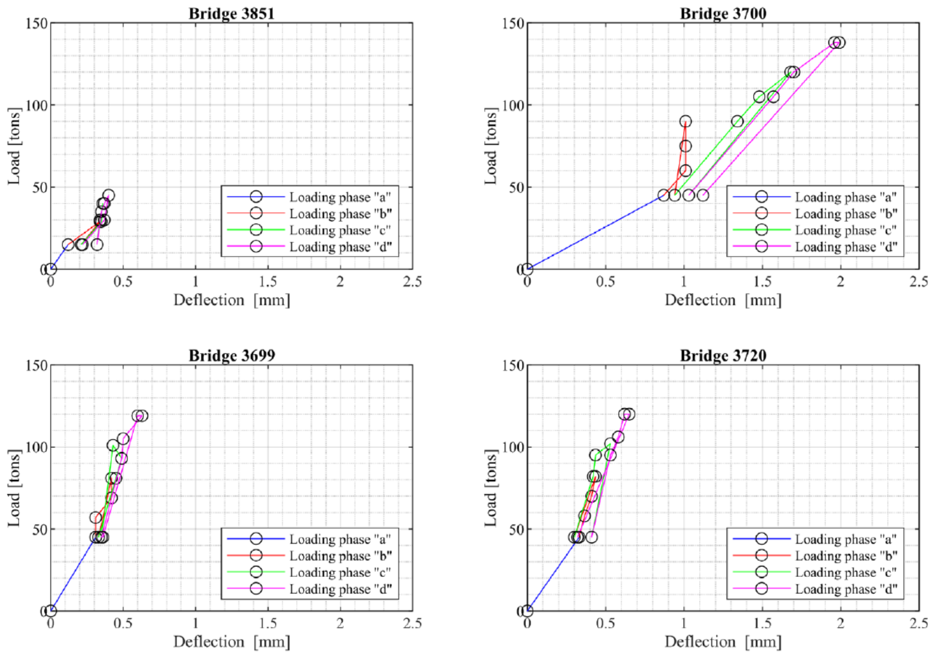


Figure 50. Response curves for the tested bridges.

Thank you for your attention!

Scope: focused on proof load testing of existing concrete structures: reinforced and prestressed bridges
(Scope: small-span bridges)
(Scope: how to deal with bridges with missing information - various levels of information)

1. Introduction
   Scope – span lengths (what is “small”), types of bridges, levels of information, simply supported and continuously supported bridges
2. Definitions
   what is a load test
   stop criteria
   acceptance criteria
   target proof load
   test load
   proof load
3. Load testing as an assessment tool (Numa, <u>Dave</u>)
   (explain that there are different options: inspection, monitoring, advanced Nonlin-FEM, field testing, diagnostic load testing (reference to available documents), choices for strengthening etc. And what are the relationship between these options).
   Approaches in different countries
4. Historical sketch (<u>Eva</u>, Jacob)
   (discussion on why proof load testing is forbidden in the UK, and why it can be a good tool and where caution is needed; safety and risk associated with load testing).
   discussion on load testing use in various countries over the past decades, and how better monitoring techniques reduce the risk during proof load testing / update on developments in various countries, what is in the works as well – efforts of various committees (fib TG 3.1, 3.2, 3.3, 3.5, ?)
   List of references to previous documents, focus on new work
   new codes in various countries vs overview of recent publications
5. Considerations for load testing as a function of the bridge type (Dave, <u>Eva</u>, Yuguang, Alok)
   1. RC and PC slab bridges
   2. RC vs PC
   3. ULS vs SLS
   4. considerations for arch bridges – what are the challenges
   5. integral bridges
   6. bridges with half-joints/ dapped ends
   7. bridges with compression hinges
6. Steps of a typical load testing (Numa, Jacob, <u>Jesse,</u> Yuguang, Piotr)
   1. preparation
   2. execution, including the estimation of the elastic and permanent values
   3. analysis and decision-making
7. Reliability substantiation of proof load testing (<u>Eva</u>, Jacob – check with Eurocode developments as well, Gerrie/Diego/Agnieszka, *Alfred, Gregor (?)*, Alok)

1. Link between proof load testing and structural reliability targets
2. Recommendations for target proof load – magnitude of the load and number of axles/ loads to apply? Discussion of the link to the applied live load versus the resulting sectional moment/shear that is developed (AASHTO approach/ European approach – difference with assessment strategies and load classification methodologies) + effect of IM (dynamic amplification of live load)
3. Effect of spatial variability on the structural resistance
4. Various levels of information - link to load level required to address the open questions about the bridge
5. Discussion on internal condition of structure and uncertainty of the internal condition (post-tensioned bridges)
6. Robustness considerations

8. Preparation (Jesse, Jacob, Numa, <u>Yuguang,</u> Piotr)
    1. deciding if load testing is suitable, assessment of the bridge, can we design a proof load testing setup that is suitable?
    2. When to load test and when not to load test
    3. Inspection related to the discussion on internal condition of structure and uncertainty of the internal condition (post-tensioned bridges) – and how relevant are the insights from the proof load test in the future
    4. Selection of monitoring technology and advances in measurement techniques and monitoring during bridge testing
    5. Analytical/numerical modeling of the bridge
    6. How to deal with various levels of information in a practical way – which additional information to obtain through additional testing (material, NDE, …)
    7. Target load and how to apply it practically
9. Execution of proof load testing (Yuguang, <u>Eva</u>, Dave, Jacob, Numa, Piotr, Grzegorz)
    1. Loading protocol recommendations – load levels, cycles, test setup, link between loading protocol and instrumentation used for stop criteria
    2. Traffic light system for decision making during a load testing
    3. Stop criteria / RC vs PC, bending vs shear – crack growth and propagation
    4. 2) Estimating the time when the bridge materials approach their elastic limit – with the support of acoustic emission
    5. Acceptance criteria
10. Analysis and decision-making (<u>Eva</u>, Numa, *Alfred,* Agnieszka)
    1. combination with finite element modeling / digital twin
    2. data necessary for a repeat test in the future (separate changes in structure from environmental circumstances during the test, long-term monitoring data)
    3. link with laboratory testing
    4. performance criteria linked with inspection outcomes and observed performance during the test – post-test reflection on criteria and recommendations for follow-up actions
11. Research needs
    1. digital twins
    2. link with laboratory testing

    3. combination of load testing, NLFEA, probabilistic methodologies
    4. AI
    5. load modeling and uniform approach
12. Conclusions
13. References

<u>Timeline</u>

- Extended outline: 1-pager of topics to include in chapters, identify new topics and where to refer to work that has been done previously, detailed timeframe for the chapters (October 2023)
- First draft of chapters (potentially end of 2024)
- Internal review of working group
- Review of parent committees
- Steps within fib for publishing the bulletin

State-of-the-art bulletin? (TBD by fib TG 3.2)