Push the Limits – But Not Too Far

Stop Criteria in Proof Load Testing of Non-Shear Reinforced Multi-Span Bridges

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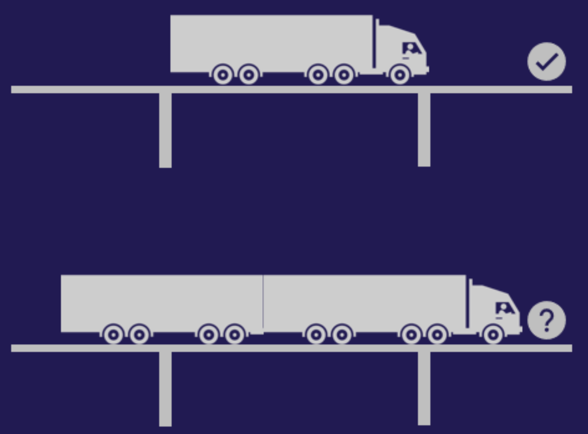
1. Motivation

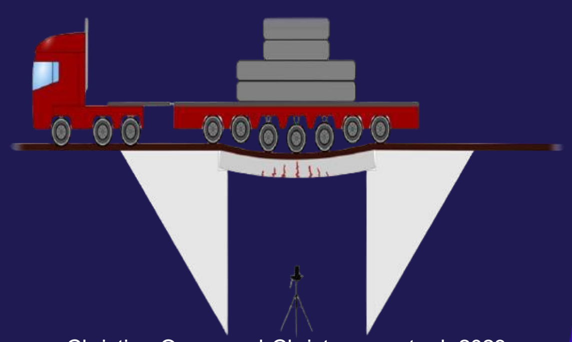


As the vehicles are becoming larger, the current classification of bridges is becoming insufficient. Demolishing old bridges and building new ones results in high costs and large emissions of CO_2, which is undesirable.
Therefore, analysing existing bridges for their capacity, and potentially upclassifying them to accomodate heavier vehicles, for example using in-situ testing methods, presents a more sustainable and cost-effective alternative.

OpenAI 2025, *Image generated by ChatGPT*, OpenAI, www.chatgpt.com

As a significant number of bridges in Denmark are slab bridges, primarily serving as highway bridges, significant economic savings and reductions in environmental impact can be achieved by investigating this bridge type. Furthermore, many of these slab bridges are constructed without shear reinforcement, which raises concerns about brittle failure.

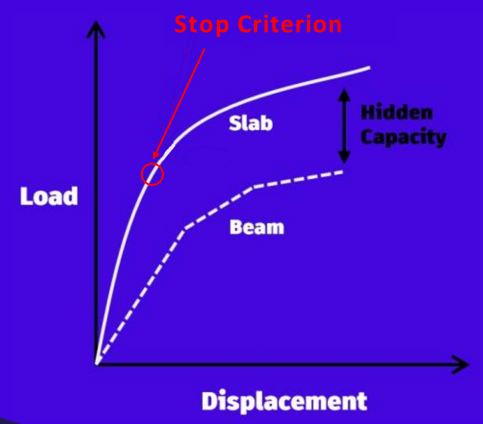
To investigate the capacity of bridges, proof load testing of existing bridges is a valuable tool. During proof load testing, it is essential to prevent unacceptable irreversible damage to the bridge. This requires the use of either a predefined target load or well-defined stop criteria to terminate the test before such damage occurs. However, there are currently no standardised stop criteria for proof-loading testing of multi-span bridges, hence, this project aims to suggest possible criteria.



Christian Overgaard Christensen et. al. 2023, *Reliability-Based Proof Load Factors for Assessment of Bridges*, MDPI, www.mdpi.com

Key Findings

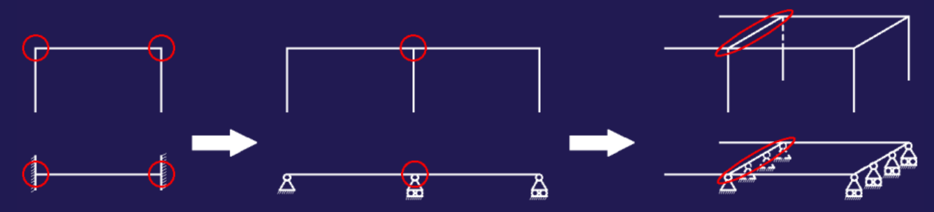
- ✓ The slab model indicates a significantly increased load-bearing capacity due to slab behaviour, compared to the simplified beam model, suggesting that traditional analytical methods may underestimate the true structural performance of non-shear reinforced multi-span slab bridges.
- ✓ The stop criterion defined in the project is evaluated to occur at a load level exceeding the load-bearing capacity predicted by the beam model, indicating that the proposed criterion offers valuable insight into the potential hidden capacity of non-shear reinforced multi-span slab bridges.
- ✓ The development and distribution of cracks throughout the slab are effectively captured using the FEA software DIANA, highlighting its value as a reliable tool for future investigations into the behaviour of non-shear reinforced multi-span slab bridges.
- ✓ Although the shear failure was brittle, the system showed a ductile response up until failure, as the DIC detected early warning signs in the form of cracks, which suggests that concerns about sudden brittle collapse may be overstated.



2. Current Practice

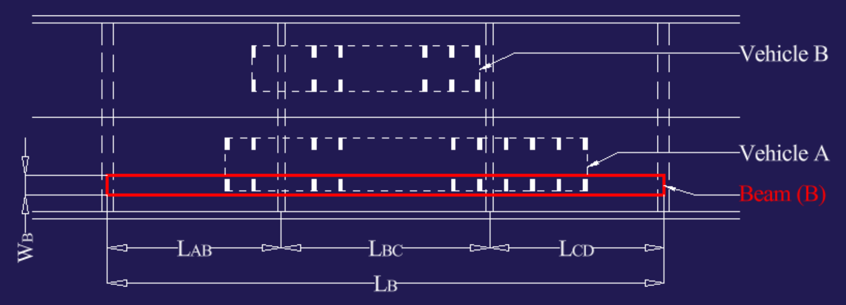
In regard to proof load testing of multi-span bridges, there are no specific criteria defined in the applicable building codes. However, several criteria are proposed for inclusion, where criteria regarding crack widths are of interest in this project.

Standard / Guideline	Crack width
Dutch Guideline	≤ 0.5 mm
DS/EN 1992-2 DK NA 2015	≤ 0.3 mm
DS/EN 1992-2 DK NA 2015	≤ 0.2 mm



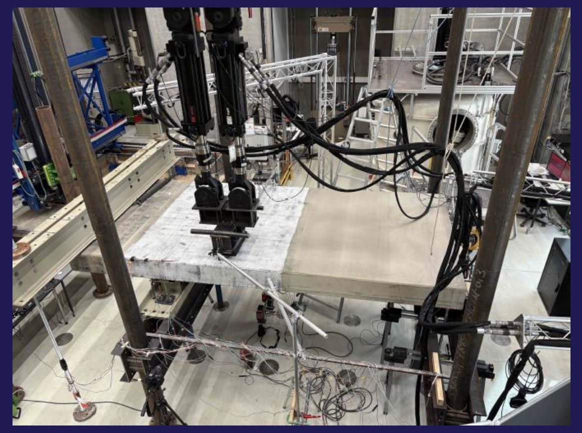
Simple beam models and multi-span concrete slabs can be related through the combination of negative bending moments and shear forces that arise over the intermediate supports. Consequently, high tensile stresses develop in these regions, leading to the formation of cracks.

Two case study bridges were examined using common analytical methods, where the structural system of the bridge was reduced to a beam model. Furthermore, the analytical method was complemented by Finite Element Analysis (FEA), using the software DIANA. The aim was to investigate possible stop criteria regions regarding crack formation.

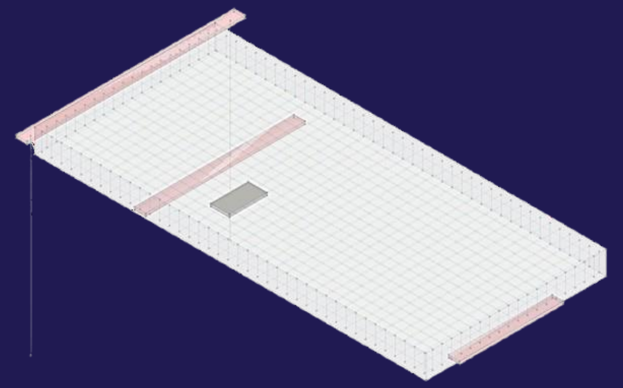


3. Test Setup

An experimental test was conducted on a concrete slab, representing the two case study bridges, to investigate its structural behaviour. Here, the key objective of the experiment was to replicate the support conditions described for the case study bridges and to induce a shear failure mechanism. The setup was monitored with various measurement devices to capture detailed data on the response of the slab under loading.

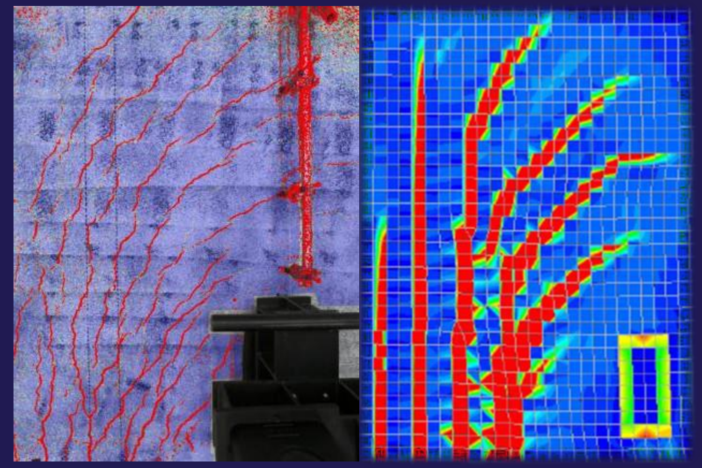


A 3D finite element model was created in the FEA software DIANA to validate the numerical model with the structural response measured in the experiment. The model was created to represent the actual test setup as accurately as possible. This involved performing material tests on the concrete and reinforcement steel used in the slab to accurately obtain material parameters to use in the model.



4. Results

The experiment was terminated when failure occured in the slab. The results showed a shear crack going from the applied load and down to the support, which was aimed for in the slab design. The collected data was reviewed and processed to analyse the structural response of the slab. Based on the data analysis, possible stop criteria were investigated and suggested, and the failure mode was evaluated.



By using Digital Image Correlation (DIC), the crack pattern on the top surface of the slab was identified and mapped. This experimentally observed crack pattern was then compared with the crack pattern predicted by the numerical model in DIANA. The comparison indicated a good correlation between the two, demonstrating that the numerical model effectively captured the cracking behaviour of the slab under loading.

This project is part of a broader collaboration between AAU, DTU, COWI, and the Danish Road Directorate (Vejdirektoratet)