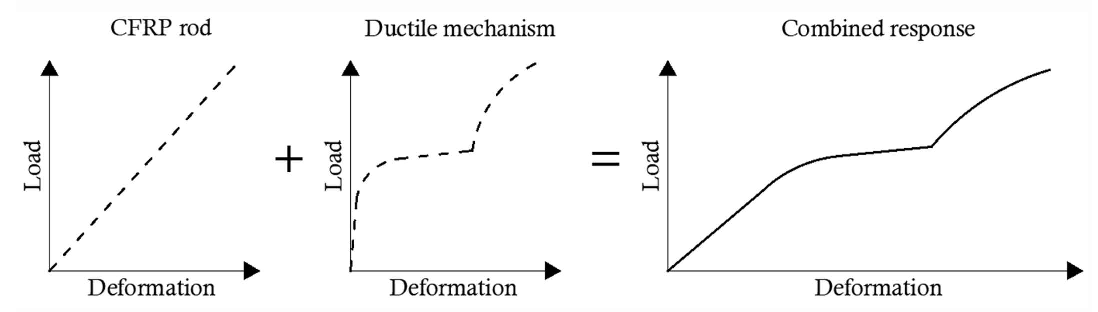
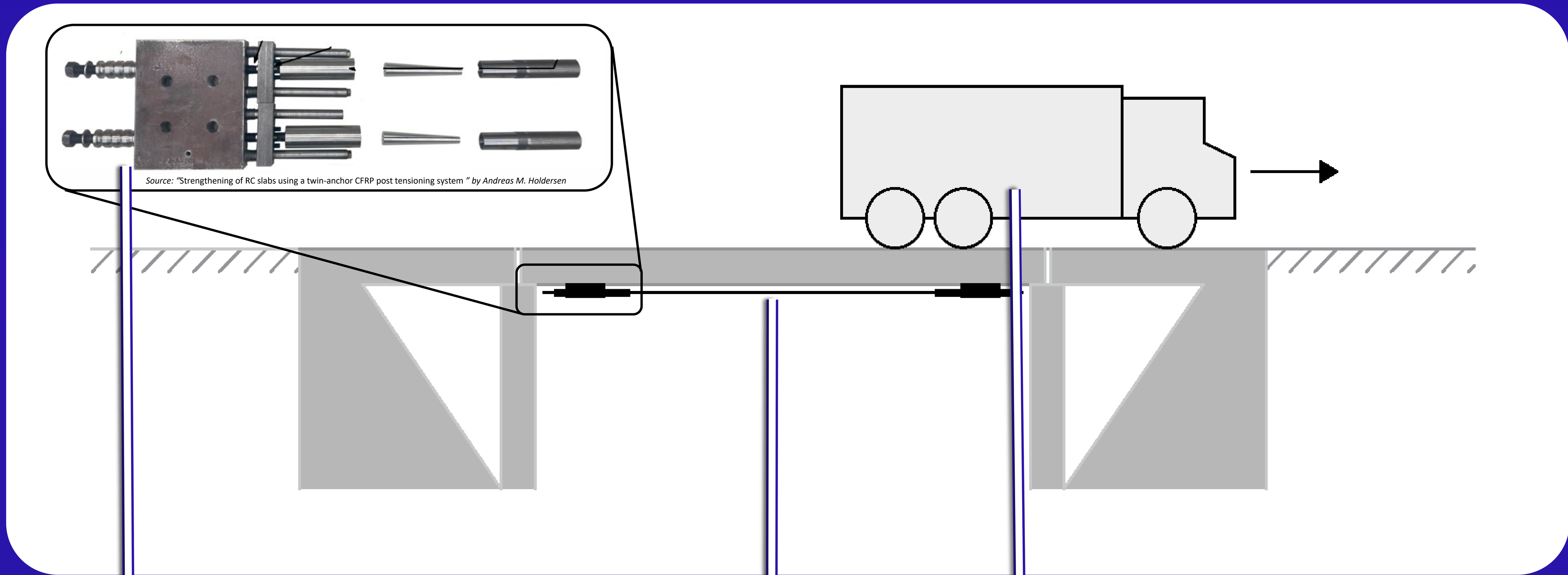
Application of Ductile Twin-Anchor CFRP System for Structural Response Evaluation of Existing Reinforced Concrete Bridges

Motivation

The demand for complex infrastructure has risen over the years. This leads to challenges for the capacity of existing bridges. Instead of demolishing, strengthening of old bridges can be applied. A solution to strengthening, is the twin anchor Carbon Fiber Reinforced Polymer (CFRP) system. Carbon is a brittle material, but acts more ductile by combining with a ductile mechanism.

Ductile response of the system



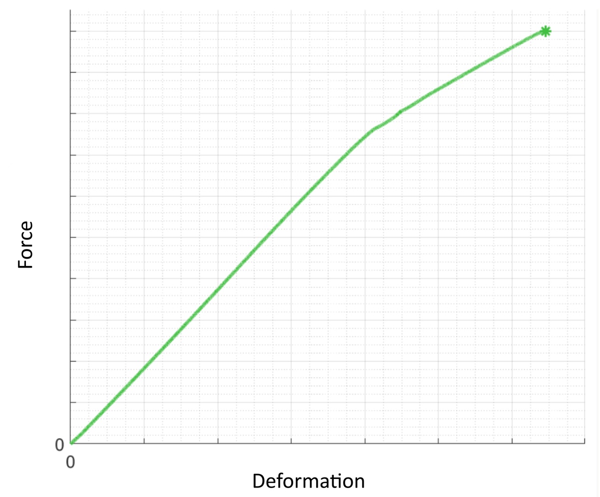


Twin anchor CFRP system

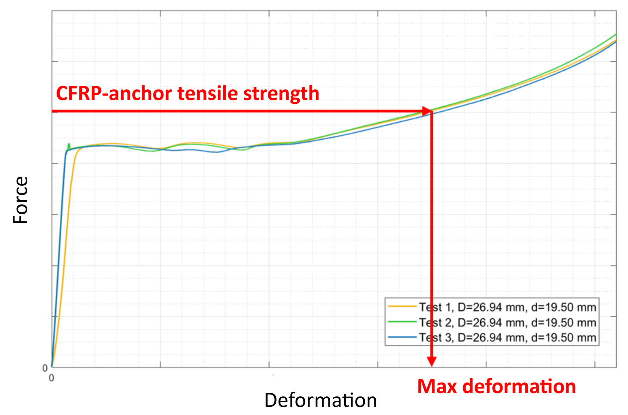
The carbon rods are held with anchors in each end. A new design iteration was made for the CFRP anchor, to increase versatility and reduce the complexity of assembly. During the iterative process a variety of different failure types were obtained.

- Two significant components of the CFRP system was tested:
  1. An anchor to connect the CFRP rod to the beam. Successful "birds nest" failure mode was obtained, with sufficient tensile strength.
  2. A ductile mechanism to add ductility to the beam, reaching yield and collapsing at a pre-determined force.

CFRP-anchor system



Ductile mechanism

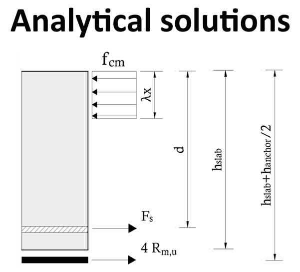


Strengthening of bridges

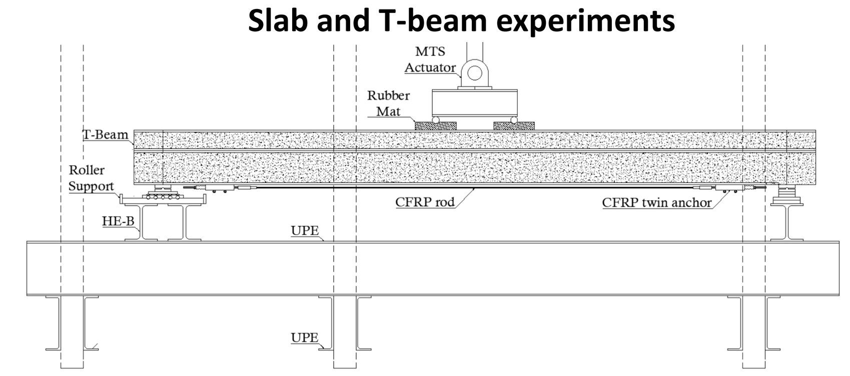
Three concrete slabs and three T-beams were strengthened with the CFRP system. They were evaluated analytically and tested to failure. The tests of each strengthened beam showed similar results and a high strengthening factor.

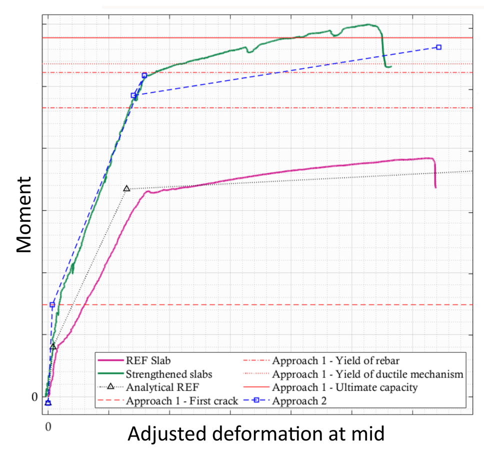
- Slabs and T-beams with and without strengthening have been tested.
- Analytical solutions are compared and validated using the experimental data. Two analytical solutions are validated:
  1. An analytical approach based on equilibrium of forces.
  2. An analytical approach based on compatibility of strains.
- Significant experimental strengthening effects are obtained for both the slabs and T-beams.
- The beams with CFRP system gives less deformation at failure compared to ordinary RC-slab/beams; The ductility decreases compared to the reference.

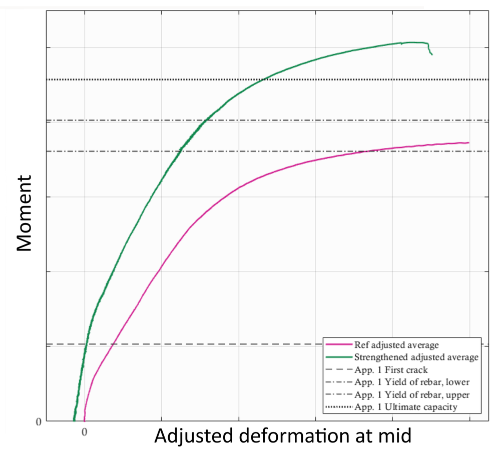
Analytical solutions



Slab and T-beam experiments





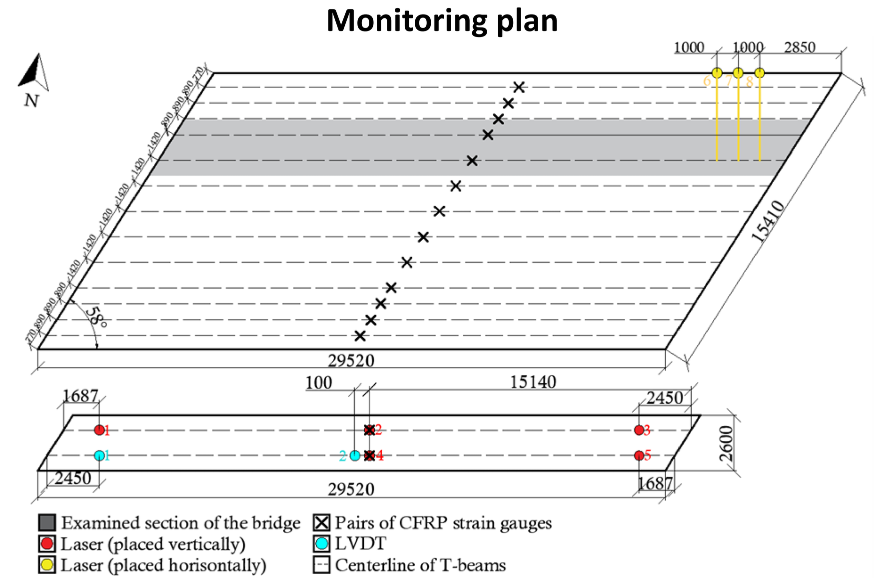


Monitoring of strain DAF

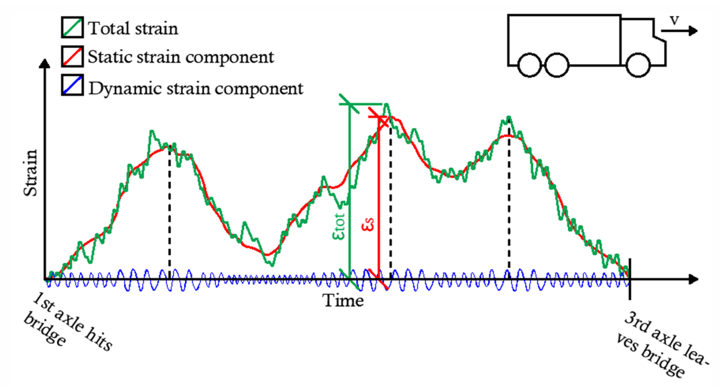
In synergy with strengthening, the system can be used to gather response measurements from vehicles. This information can be used to evaluate the dynamic amplification of axle loads, which is too conservative in current standards.

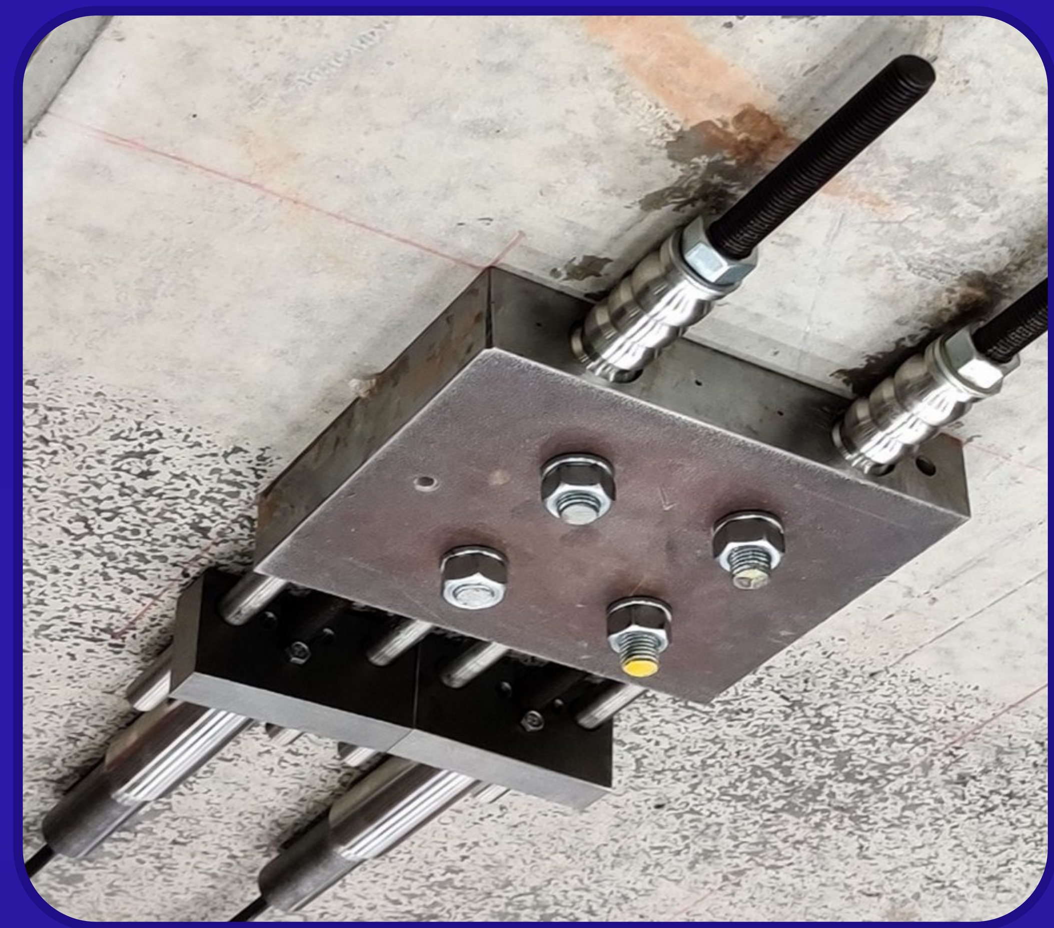
- A monitoring plan is made for the CFRP system on an existing bridge, using the already installed CFRP strain gauges, lasers and LVDT's.
- DAF can be determined using the twin-anchor CFRP system.
- Three methods for data interpretation are proposed, varying in complexity.
  1. Direct measurements using calibration vehicles.
  2. Fourier analysis to filter out high frequency dynamic responses.
  3. Using strain influence lines on every-day traffic crossing the bridge.
- Characteristic DAF-values within each vehicle class, with a return period of 50 years, can be statistically determined using either Poisson's Spike Process or Extreme Value Theory.

Monitoring plan



Interpreting total and static strain





Conclusion

- Using the twin-anchor CFRP system results in a high strengthening effect, for both a slab configuration and T-beam configuration.
- The analytical solutions give good approximations of the moment at relevant load-stages; First crack, yield of rebar, yield of ductile mechanism and ultimate capacity.
- The optimized anchor allows for an easier installation in-situ, as fewer steps are required. Further tests of the optimized anchor could result in an even higher tensile capacity.
- The system can be used to determine DAF for different vehicles and finding a characteristic DAF value for each vehicle class with a chosen return period.
- The strengthening effect and monitoring of dynamic amplification factor work in synergy, resulting in a higher capacity and determination of lower maximum load.

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