Force distribution between interior and externally bonded reinforcement under cyclic loading

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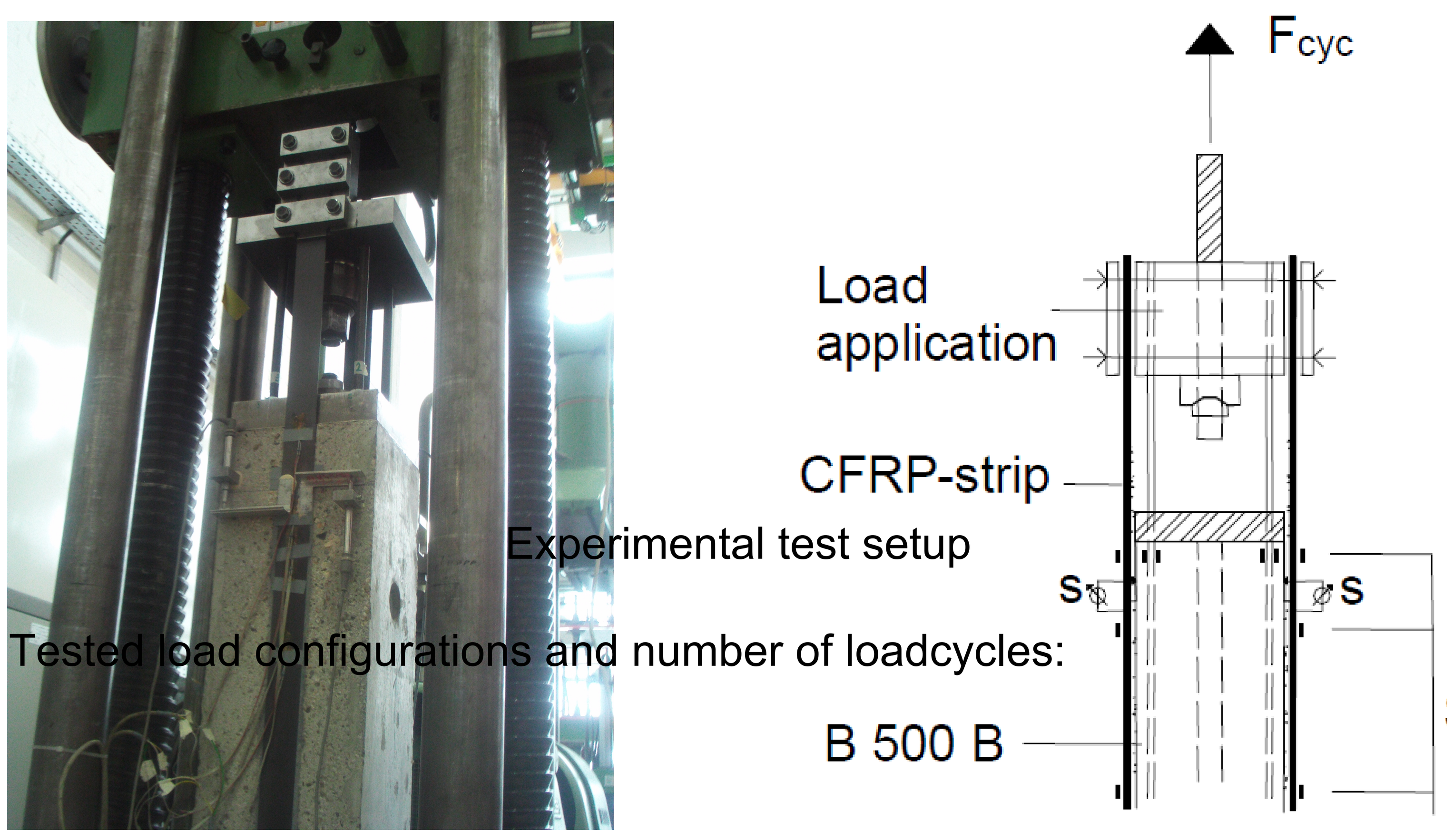
Motivation

Strengthening with externally bonded carbon fiber reinforced plastics (CFRP) is an effective technique to counteract aging and overloading of reinforced concrete bridges. For the prediction of the bridges service life the forces in the interior steel and the externally bonded reinforcement (EBR) have to be exactly known. But the different bond characteristics of EBR and interior reinforcement leads to a force distribution, which can be different from the distribution determined assuming a plane strain distribution. Experimental test results show that the strain in the EBR is higher than assumed particularly at low strain values, as they occur in the load cases of fatigue. In case of cyclic loading the difference between assumed and measured strain is reduced as a result of bond damage. However, an accurate prediction of the force distribution is only possible if the bond behavior of EBR and the cast-in reinforcement under cyclic loading is considered.

Experimental Test

The test setup is designed as a combined double shear and pull-out test at two CFRP strips and four steel bars under cyclic loading. The cyclic tests are carried out in a hydraulic testing machine with pulsator for applying sinusoidal loads.
The concrete test specimen have a length l=1.35m and a square cross section with an edge length a_c=250mm. The two externally bonded CFRP strips have a bonded length l_L=1.15m, a width b_L=50mm and a thickness t_L = 1.4 mm and the four steel bars have a diameter d_s of 16 mm.
The CFRP strain is measured with a chain of strain gauges and the slip is measured with displacement transducers. The steel strains are measured with additional strain gauges on the steel bars inside the concrete in a bondless area



Experimental test setup

Tested load configurations and number of loadcycles:

Test	Lower Load F^U/F_{LRd}	Upper Load F^O/F_{LRd}	Load Cycles N
A 1	0.15	0.32	2,000,000
A 2	0.15	.64	6,72
B 1	0.34	0.51	2,000,000
B 2	0.33	0.59	428,569

Reference

Leusmann, T.; Budelmann, H.: Force distribution between interior steel reinforcement and externally bonded CFRP of RC beams under cyclic loading. In: 8th International Conference on FRP Composites in Civil Engineering (CICE 2016): 14-16 December 2016.

Model Aproach

The test results can be recalculated taking the crack propagation rate da/dN for EBR and the bond coefficient d_L for the consideration of the different bond characteristics into account using the following procedure for every load step:

1. Calculation of crack growth da

$$\frac{da}{dN} = \frac{1}{N^*} \times \left(\frac{F_L^O - F_L^U}{c_1 \times \left(\Delta F_{LRd} - F_L^U \right)} \right)^k$$

with upper, lower load and bond capacity F_L^O, F_L^U and ΔF_{LRd}

2. Determination of slip increase ds_L and actual slip $s_{L,I}$

$$ds_L = da \times \frac{F_L^O}{E_L \times A_L} \qquad s_{L,i} = s_{L,i-1} + ds_L$$

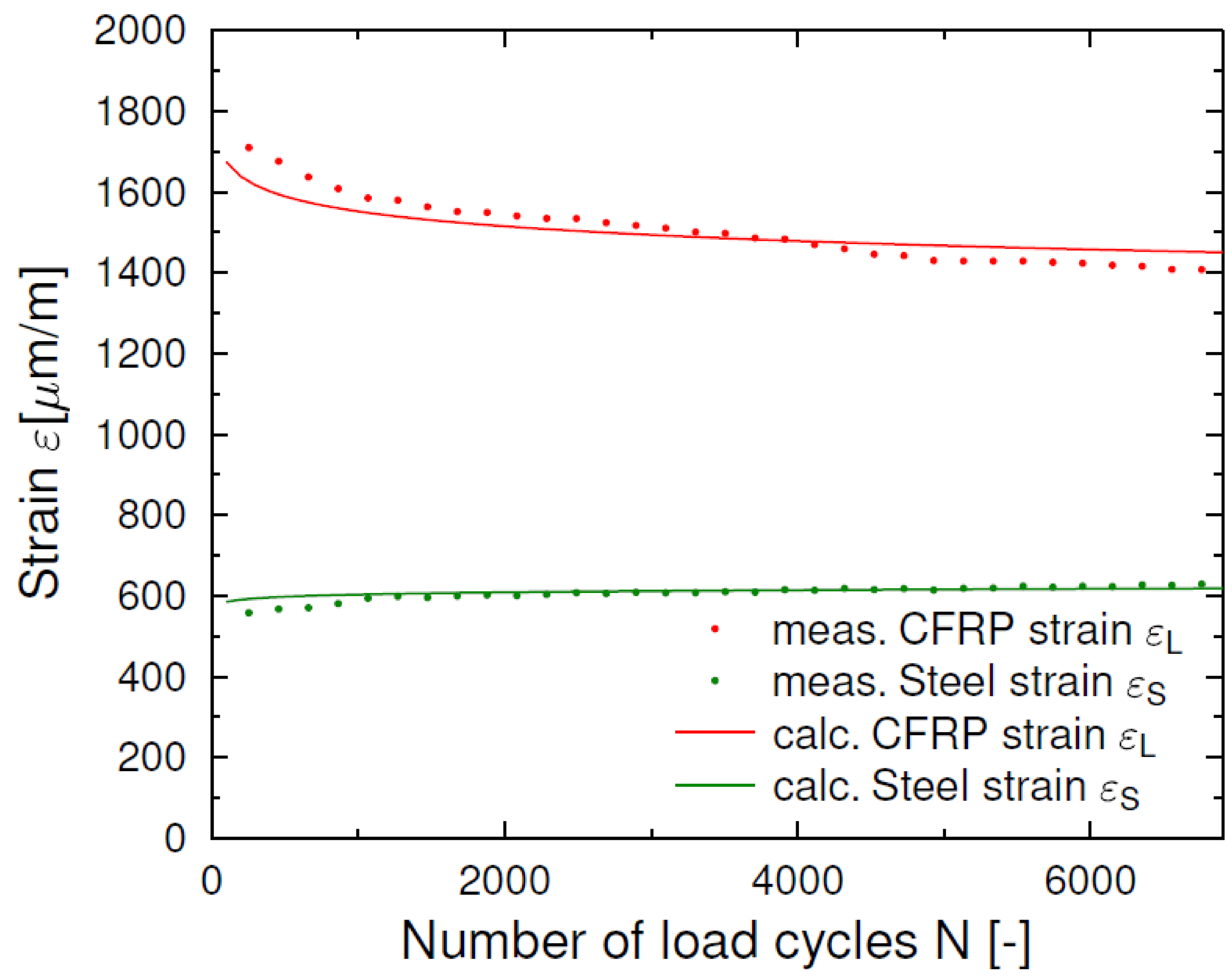
3. Calculation of the actual bond coefficient $\delta_{Lk,I}$

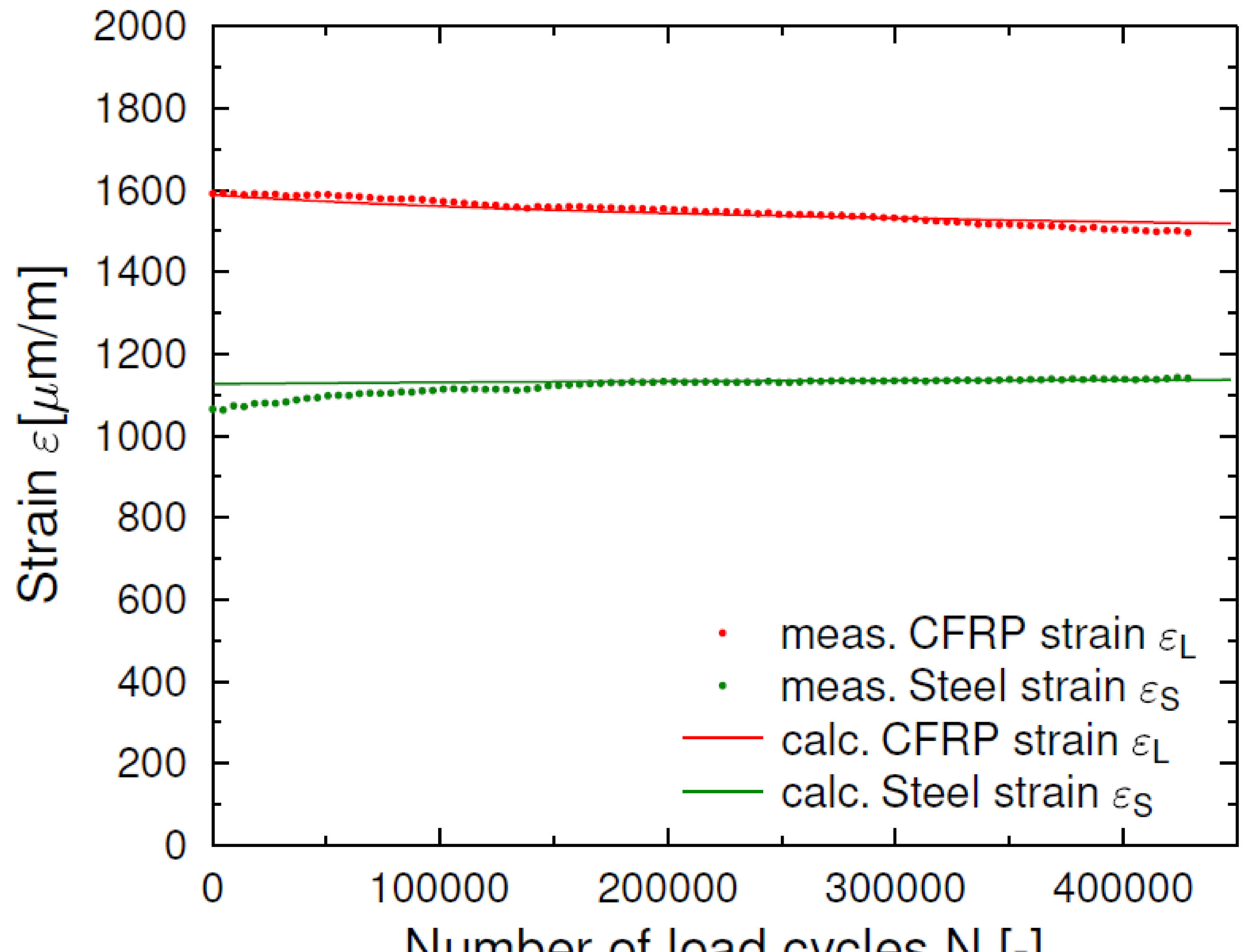
$$\delta_{Lk,i} = \frac{\varepsilon_{L,i-1}}{\sqrt{\frac{8k_s\sqrt{f_{cm}}}{(\alpha_s+1)E_s d_s}} \times \left(\frac{s_{L,i}}{k_{\delta i}\frac{d_L - x}{d - x}} \right)^{\frac{\alpha_s+1}{2}}} \times \frac{d - x}{d_L - x}$$

4. Calculation of the actual strain and force distribution

Verification

The redistribution of the forces during the tests can be observed by the strain measurements and calculated with the model approach presented above. The decoupling caused by the crack formation in the concrete substrate along the bonded length leads to a decrease of the CFRP strain ε_L and an increase of the steel strain ε_s.





Mea … er of load cycles during test A2 and B2