

Quasi-Static and Fatigue Behavior of GFRP Bars Embedded in Concrete: a Comparison between Pull-out Tests and Flexural Tests of Slabs

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FRPRCS 16

March 23 and 24, 2024 in New Orleans, Louisiana, USA

In Conjunction with ACI Spring Convention, Sponsored by ACI Committee 440



OUTLINE

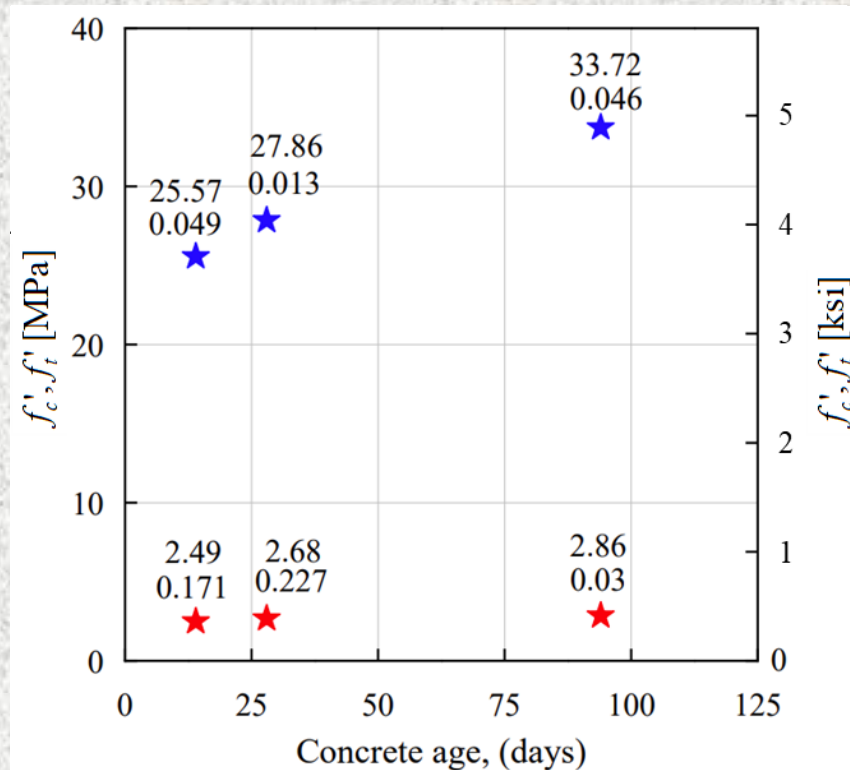
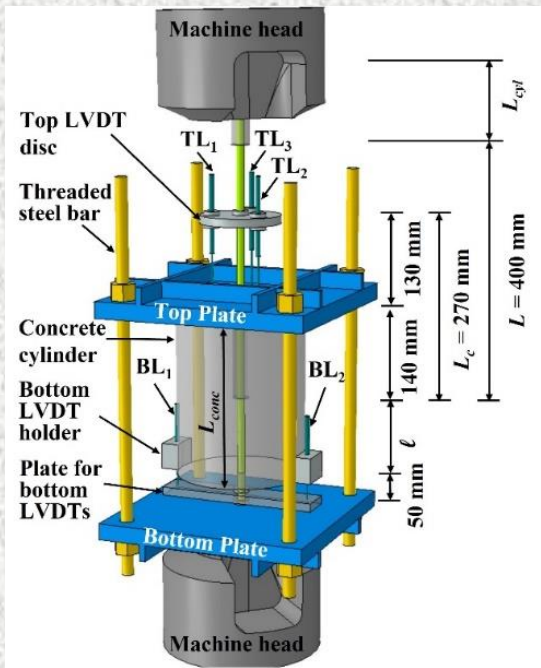
- 1) Introduction
- 2) Pull-out tests
- 3) Quasi-static and Fatigue behavior of slabs
- 4) Cross-sectional analysis and strain profiles
- 5) Crack opening analysis
- 6) Conclusion

INTRODUCTION

Research significance:

- 1) There is a growing interest in the FRP bar community on the long term/durability behavior of the bars
- 2) There is ongoing interest to confirm the ACI formula for crack opening
- 3) Even if the fatigue behavior of FRP bars embedded in concrete is not a concern, is it possible that the crack opening can increase due to slippage of the bars?

PULL-OUT TESTS



$f_c = 27.9 \text{ MPa}$

$f_t = 2.7 \text{ MPa}$

Unlacquered



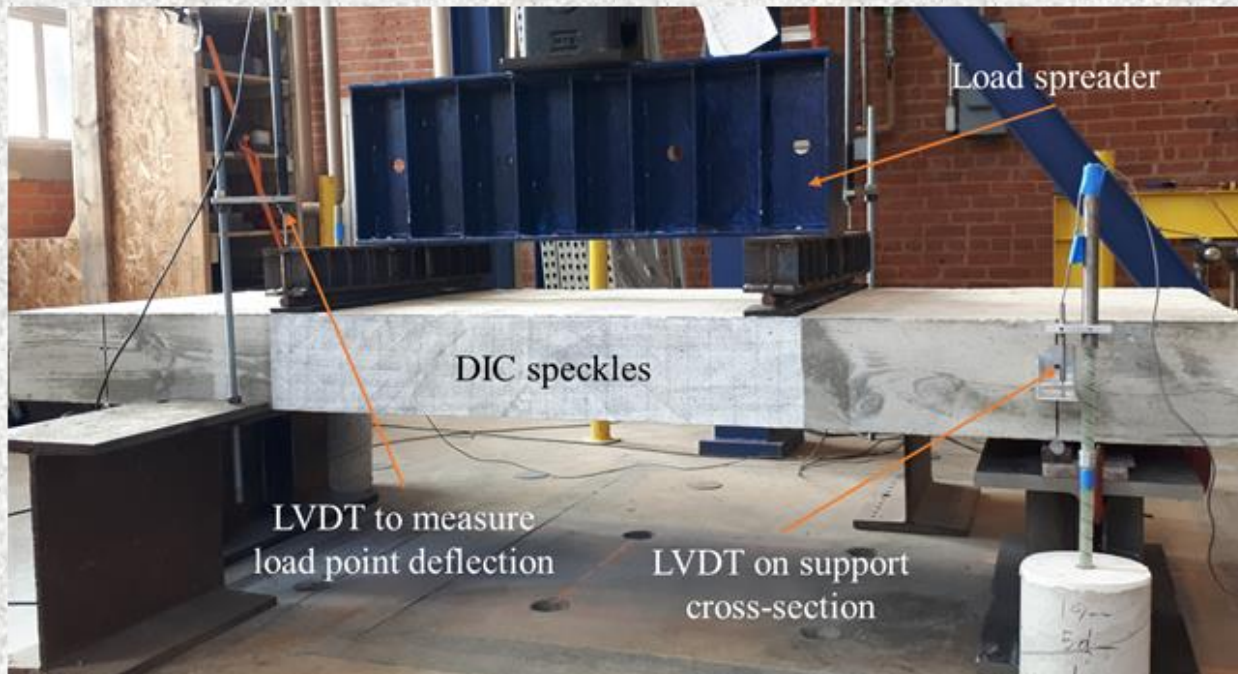
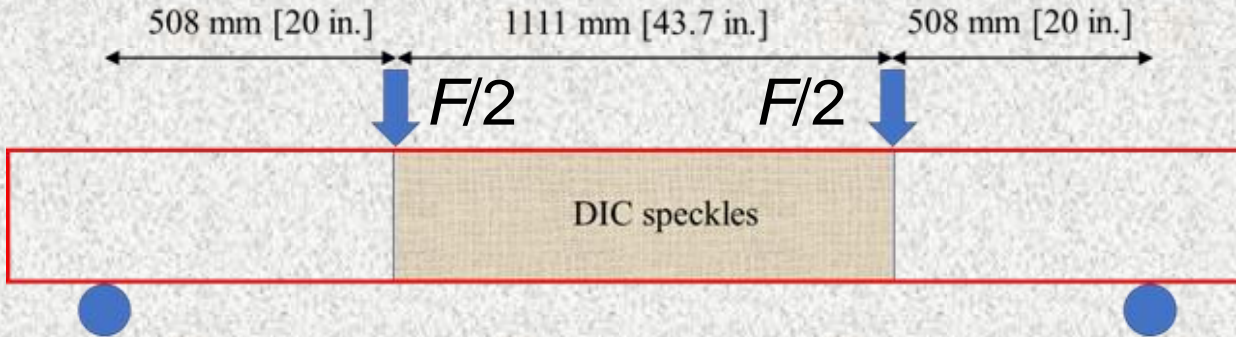
10.5 mm

Lacquered



GFRP bar type	Tensile Strength, f_{fu} (MPa)	Modulus of Elasticity, E_f (GPa)	Ultimate Tensile Strain, ϵ_{fu}
Lacquered	1096 [159 ksi]	64.2 [9311 ksi]	1.8 %
Unlacquered	1155 [168 ksi]	62.5 [9064 ksi]	1.9 %

STATIC AND FATIGUE TESTS ON SLABS



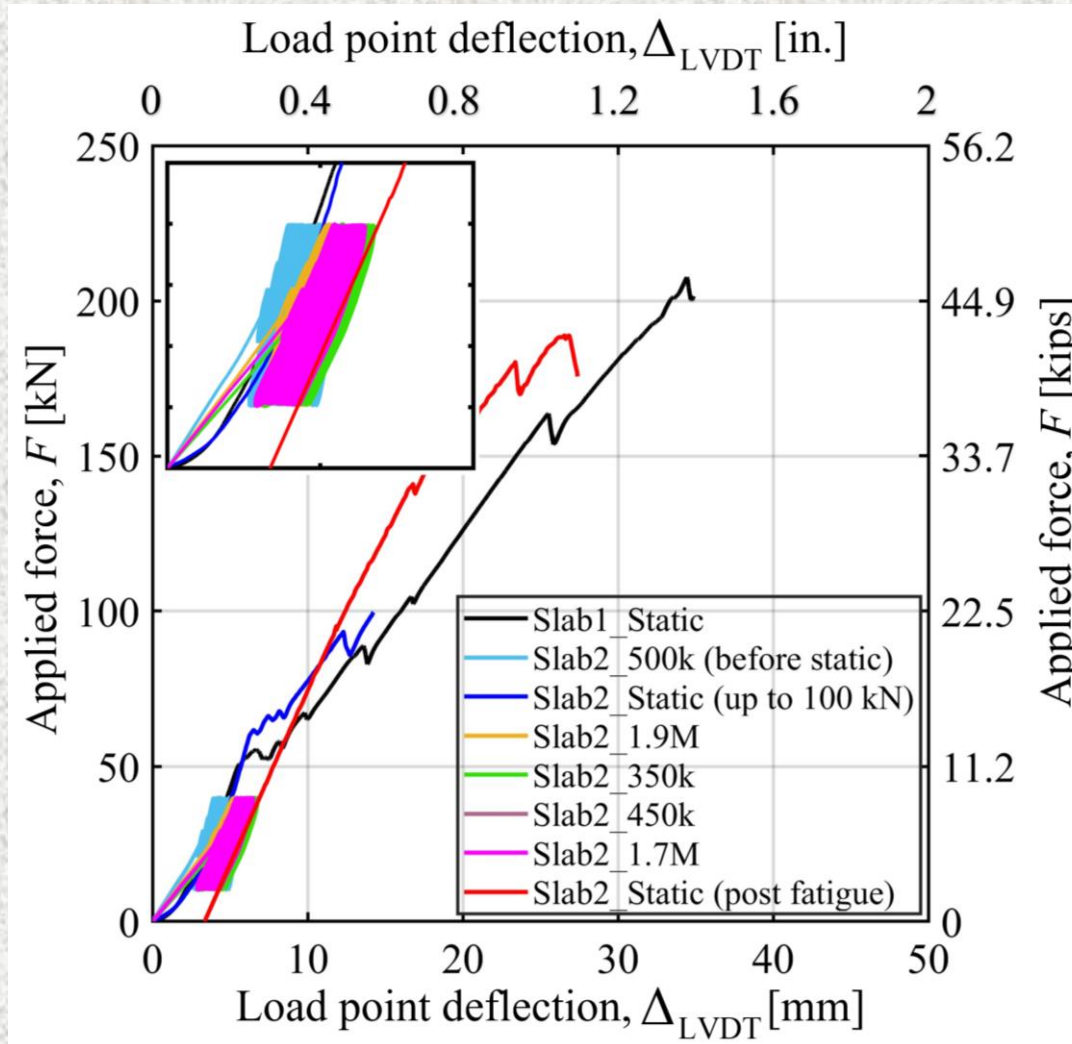
Slab 1:
 tested under quasi-static conditions

Slab 2(1):
 tested under quasi-static conditions up to 100 kN

Slab 2(2):
 tested under quasi-static conditions up to failure after 5M cycles

Fatigue range: 5-20% of reduced strength of GFRP

STATIC AND FATIGUE TESTS ON SLABS



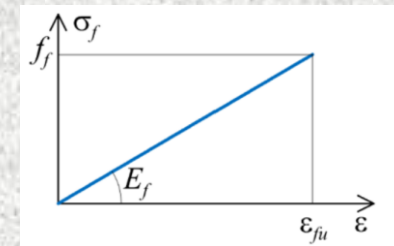
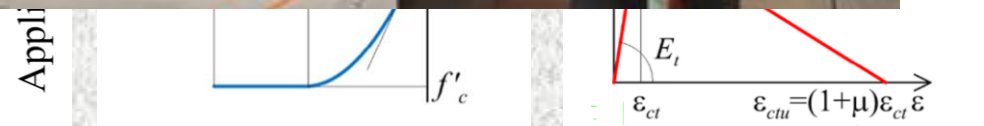
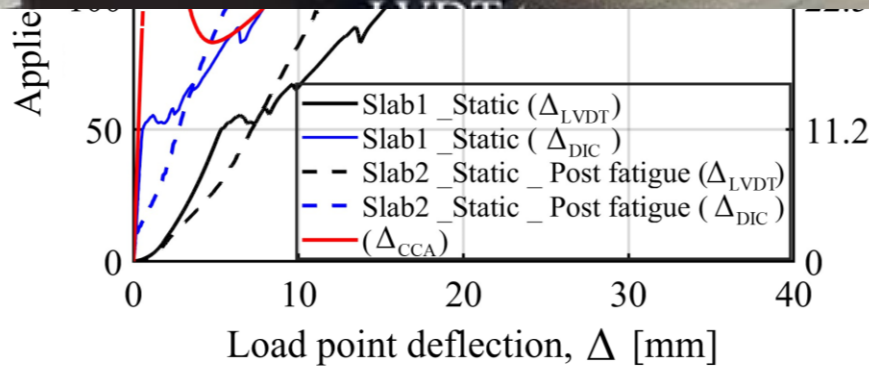
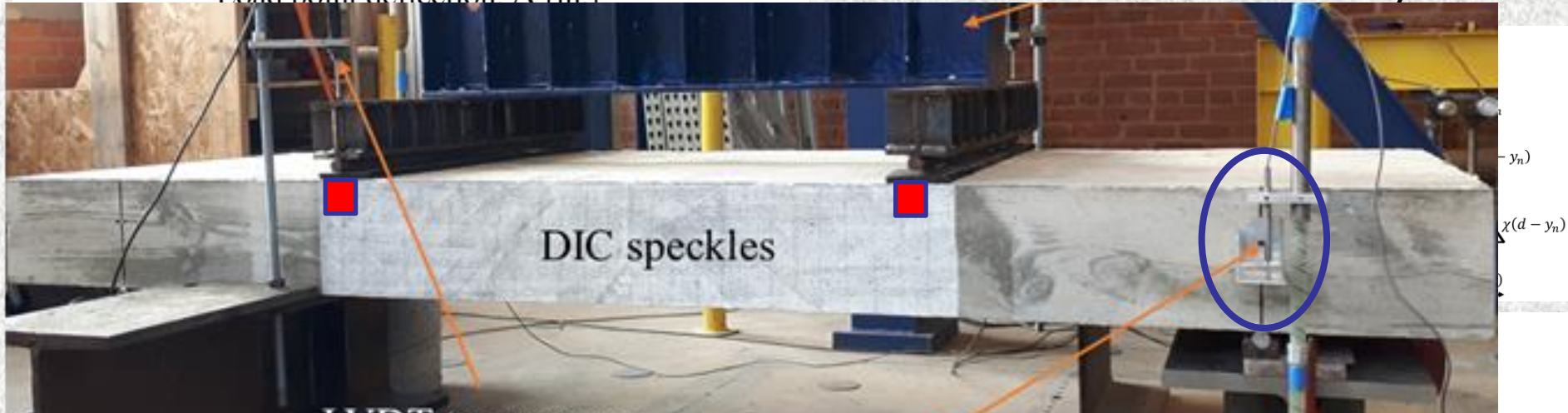
STATIC AND FATIGUE TESTS ON SLABS



CROSS-SECTIONAL ANALYSIS

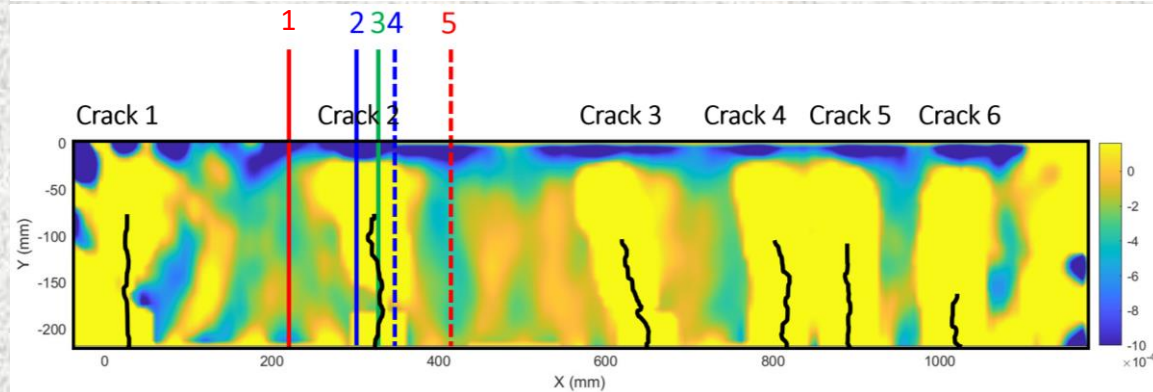
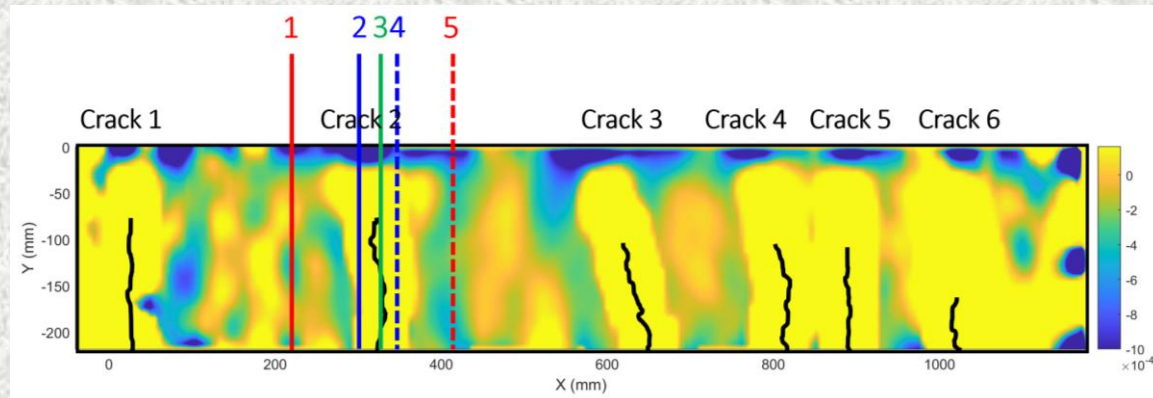
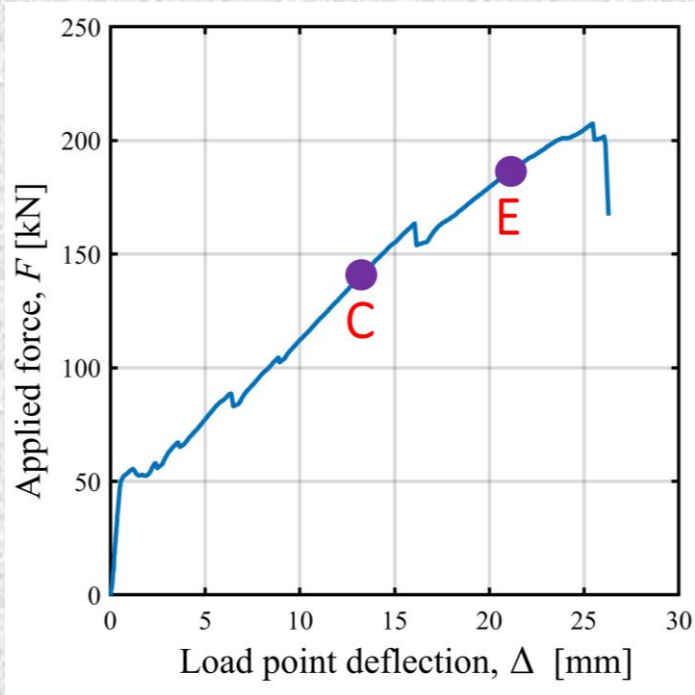
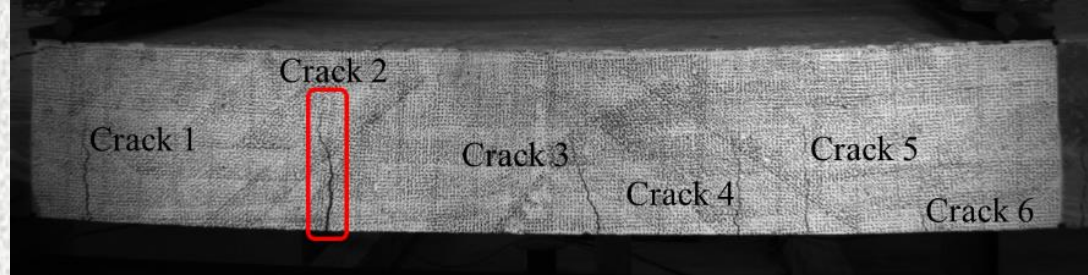
Load point deflection Δ [in]

cross-sectional analysis

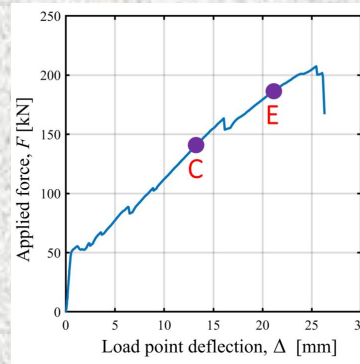
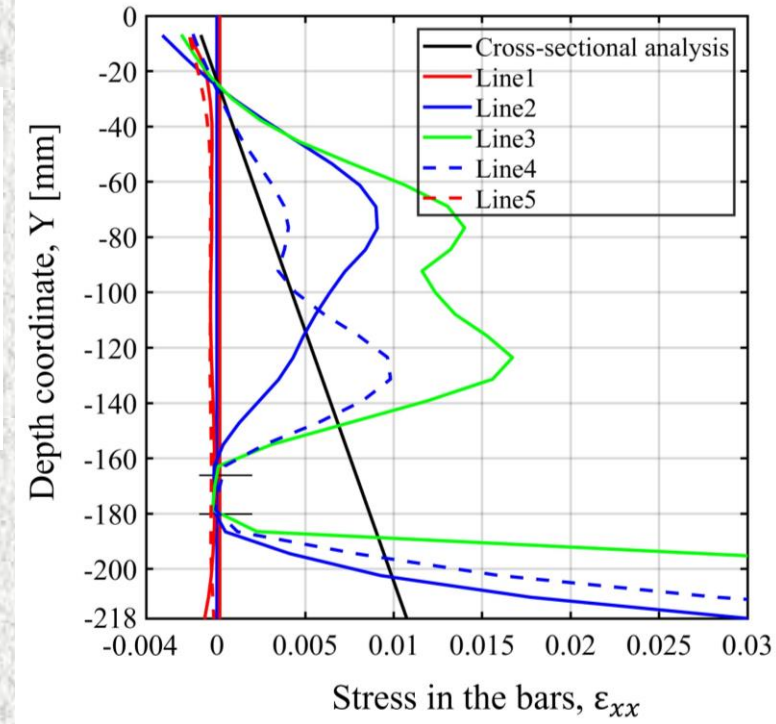
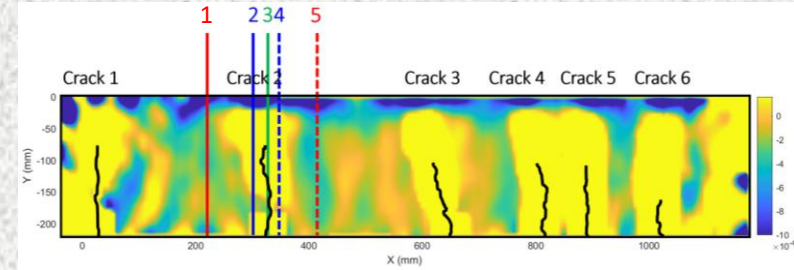
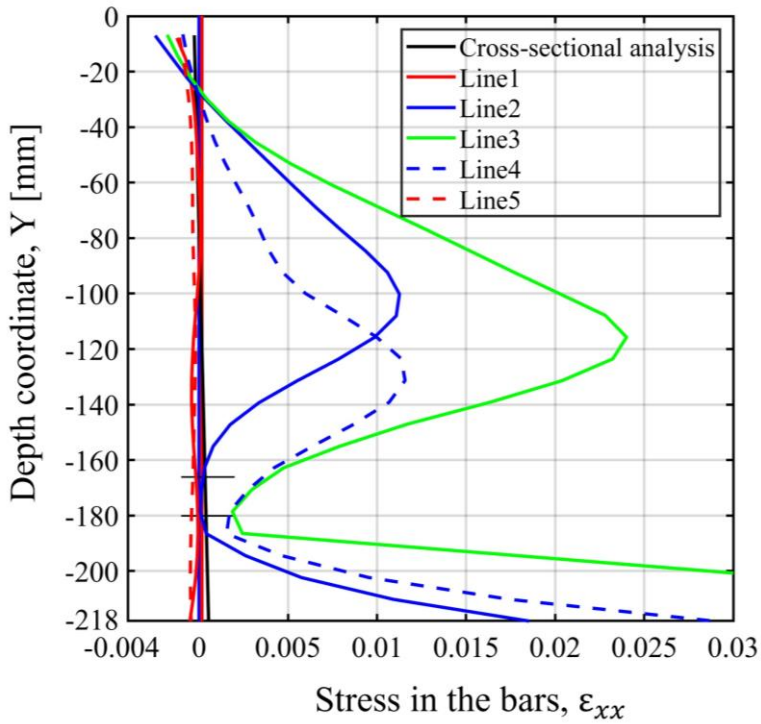
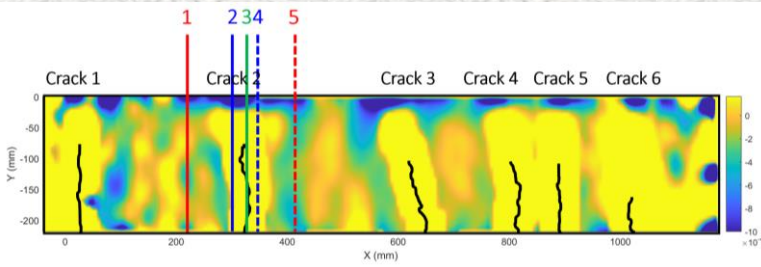


STRAIN PROFILES

Slab 1
 Crack 2



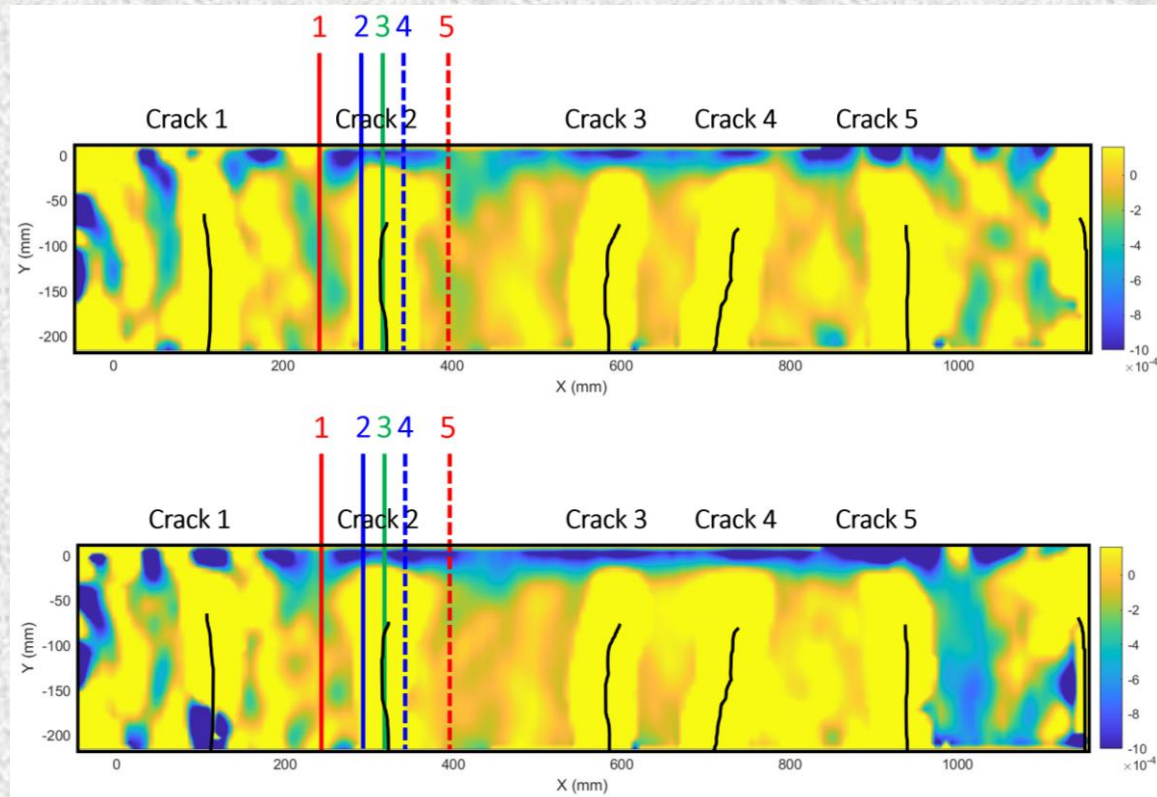
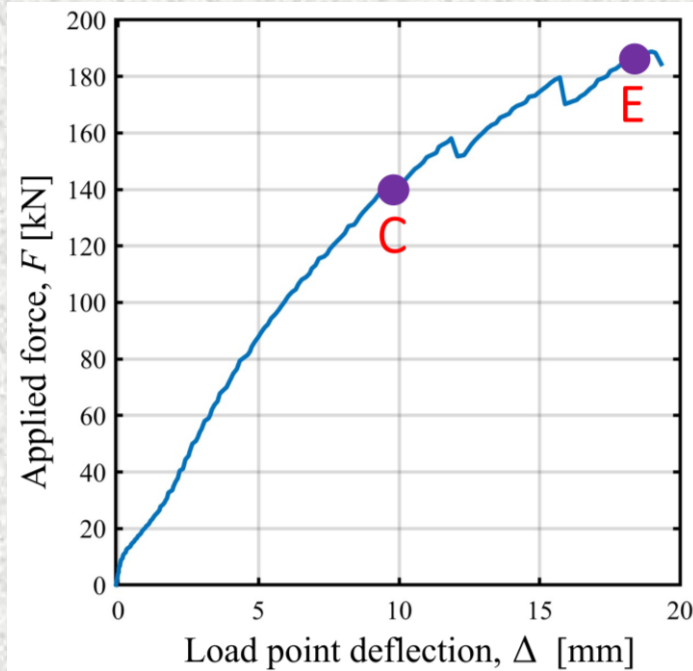
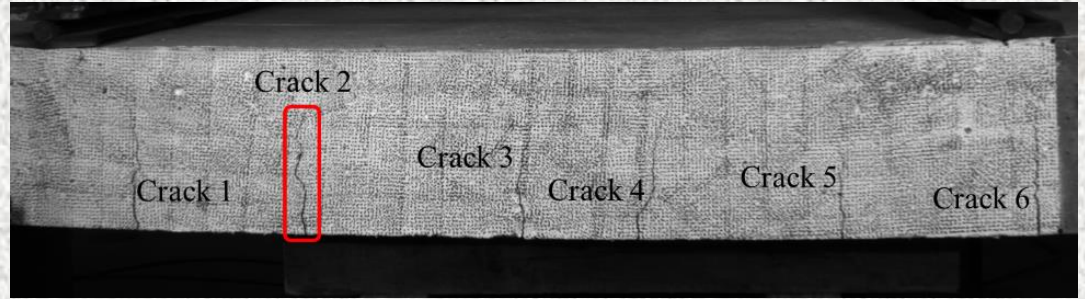
STRAIN PROFILES



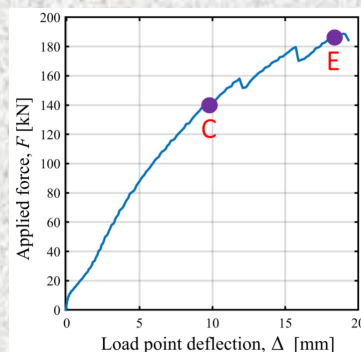
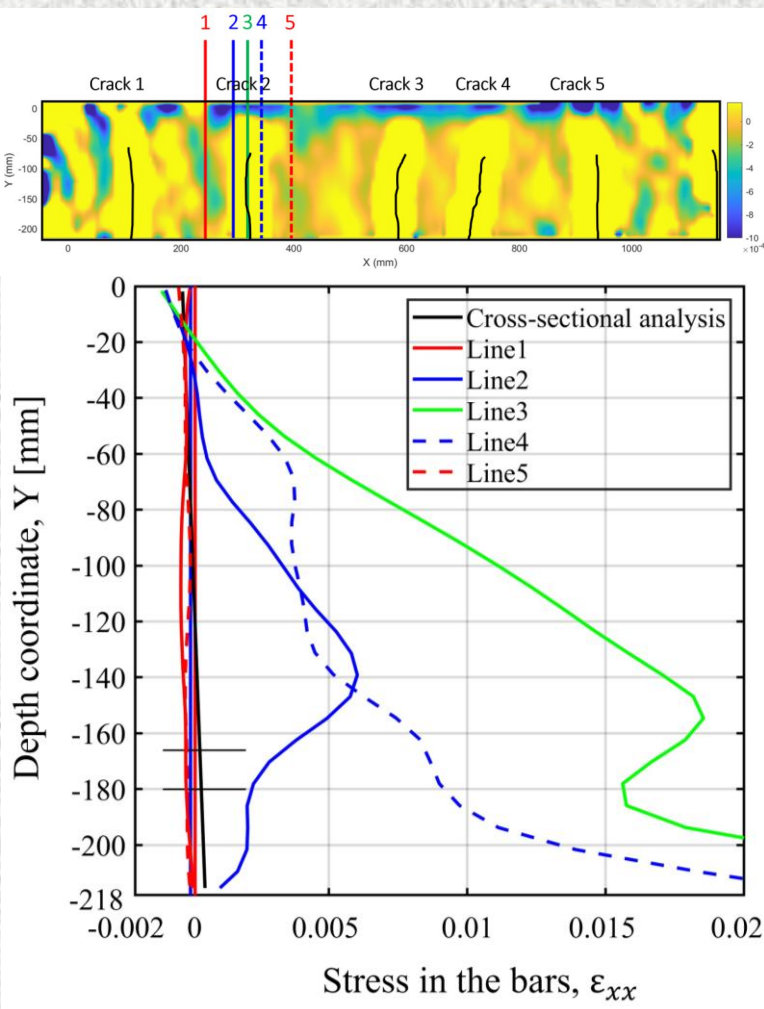
**Slab 1
Crack 2**

STRAIN PROFILES

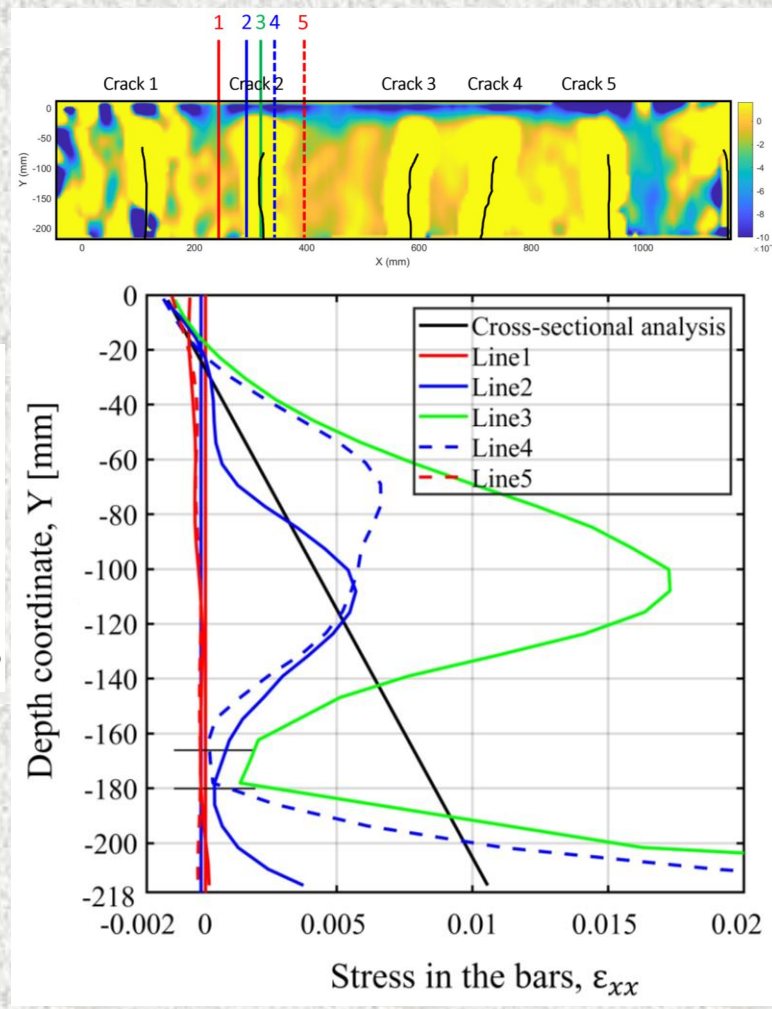
Slab 2
 Crack 2



STRAIN PROFILES

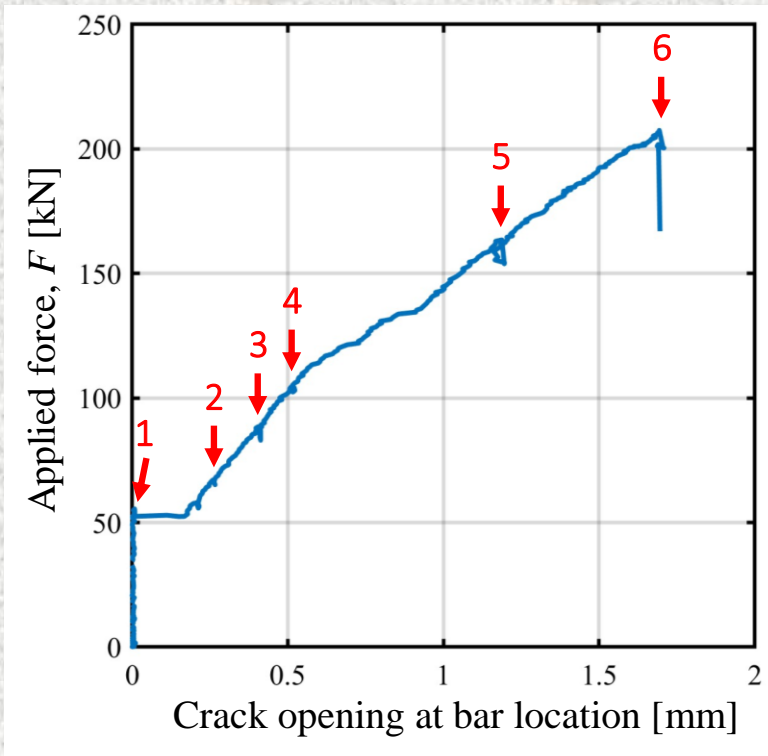
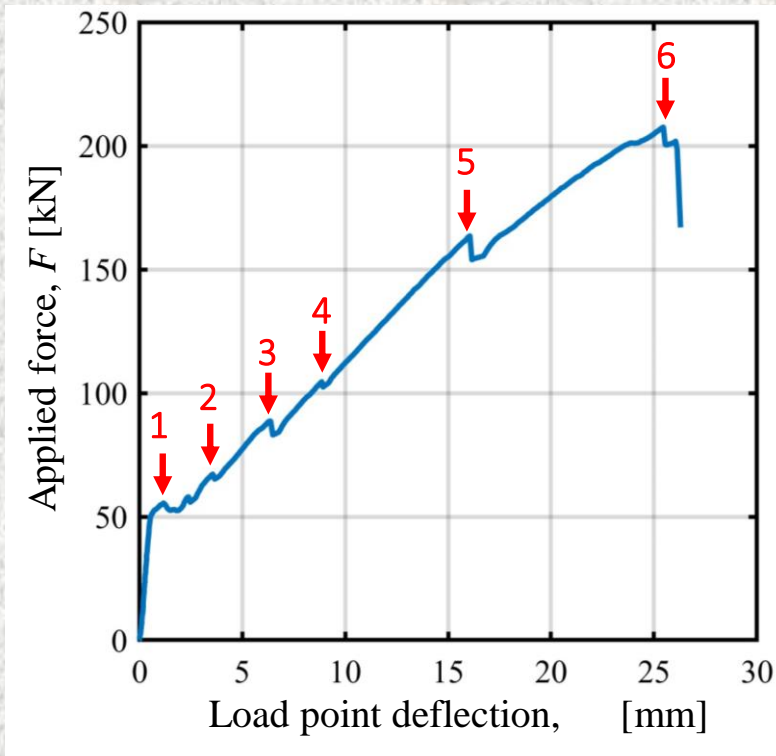
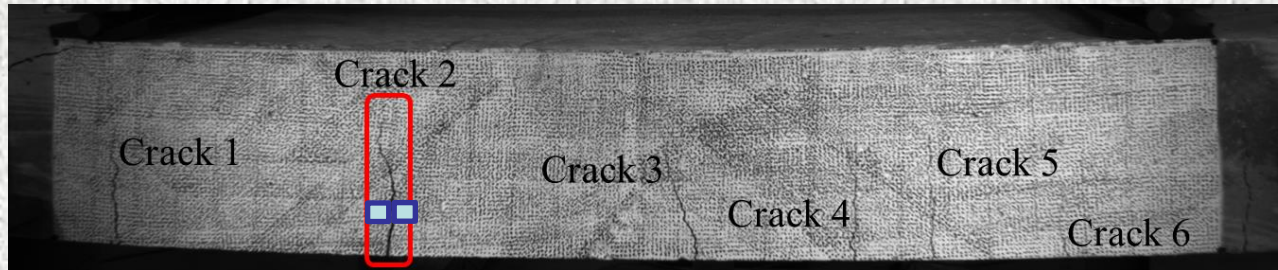


**Slab 2
Crack 2**



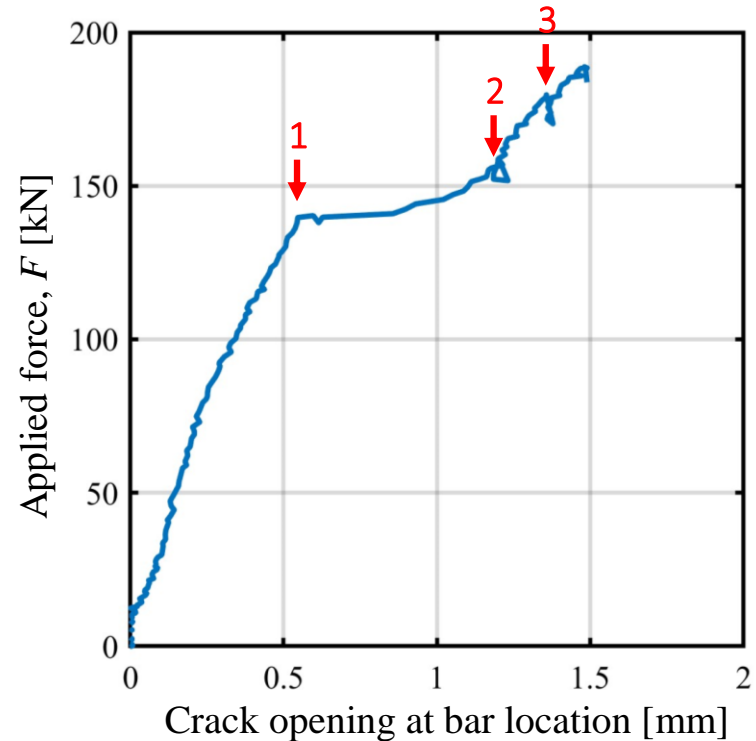
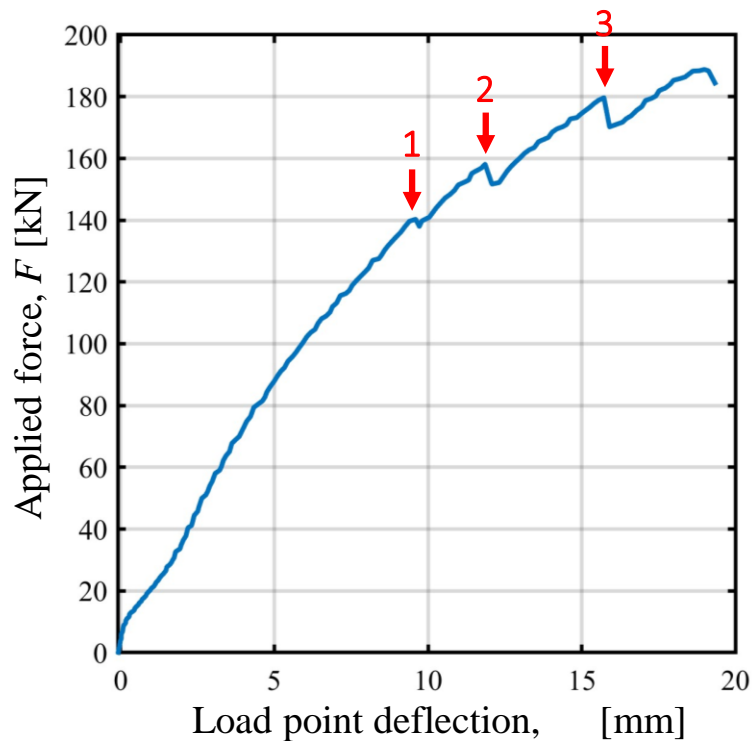
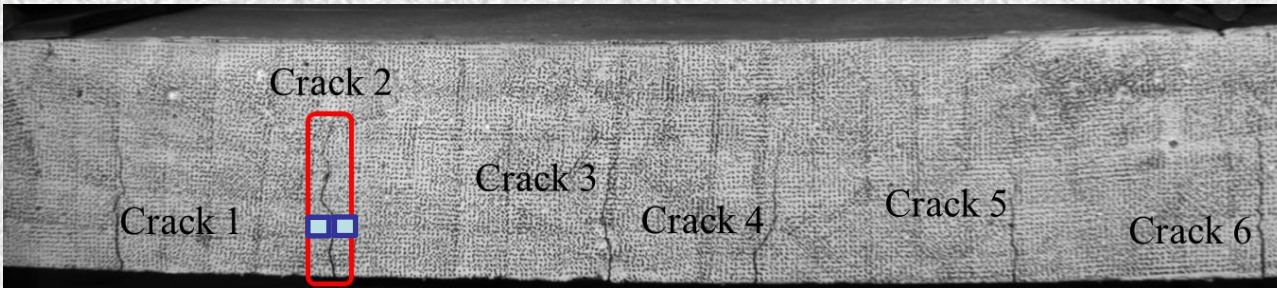
CRACK OPENING ANALYSIS

Slab 1, Crack 2



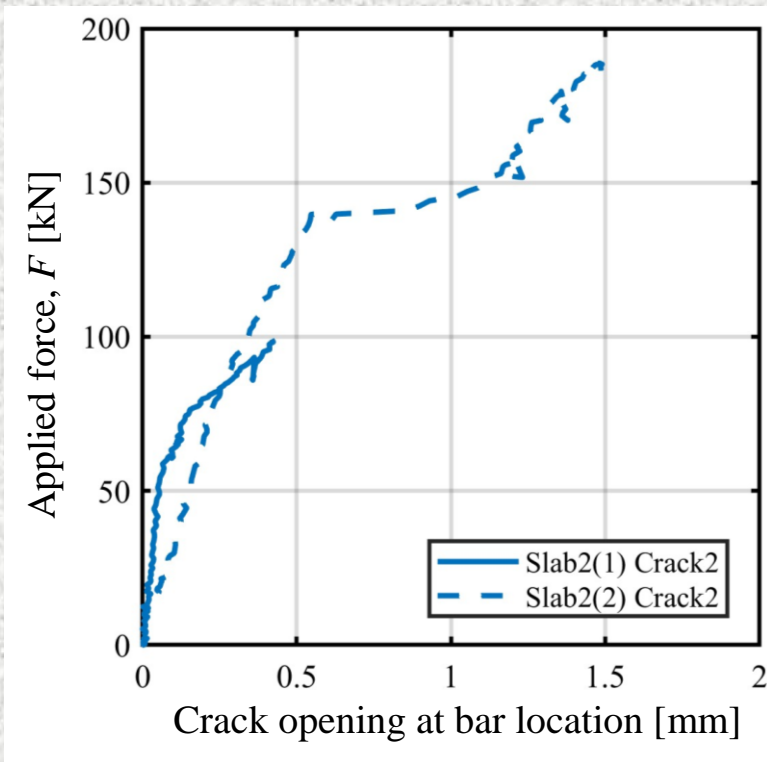
CRACK OPENING ANALYSIS

Slab 2(2), Crack 2

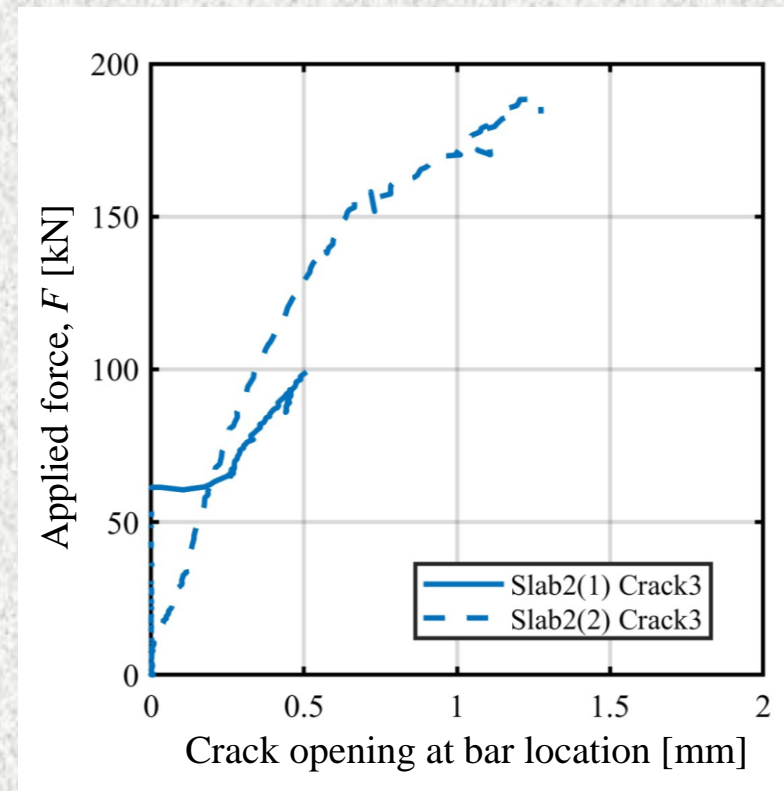


CRACK OPENING ANALYSIS

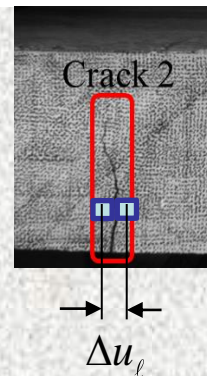
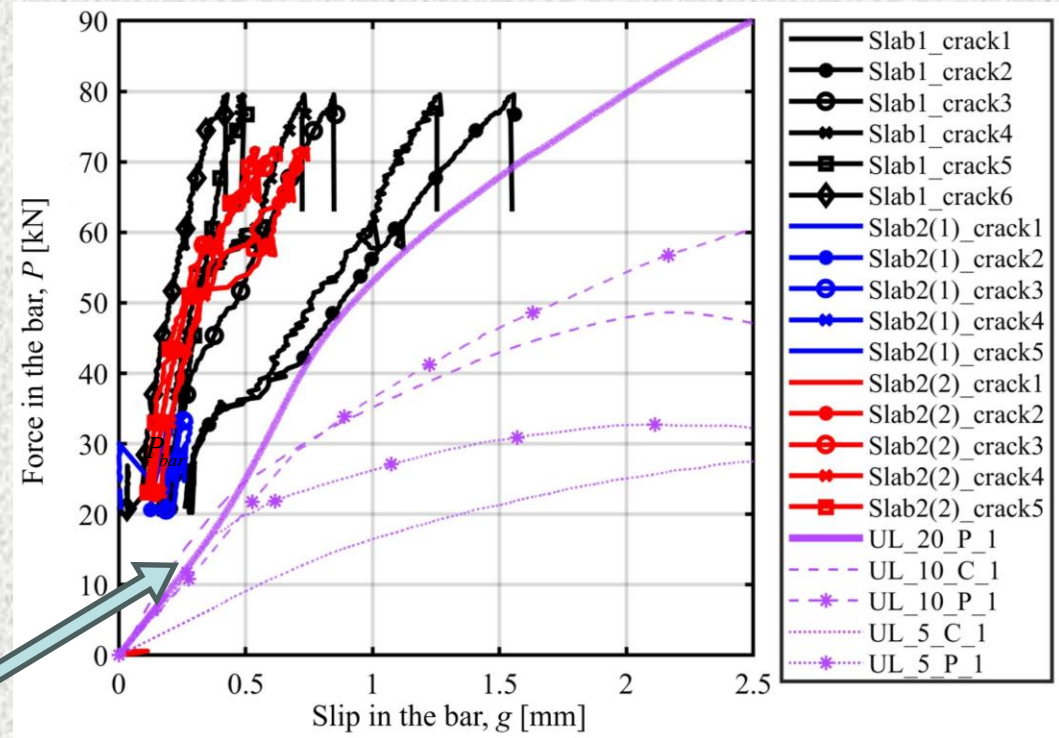
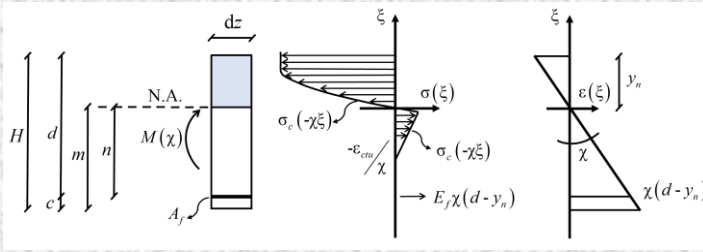
Slab 2(1) vs Slab 2(2),
Crack 2



Slab 2(1) vs Slab 2(2),
Crack 3



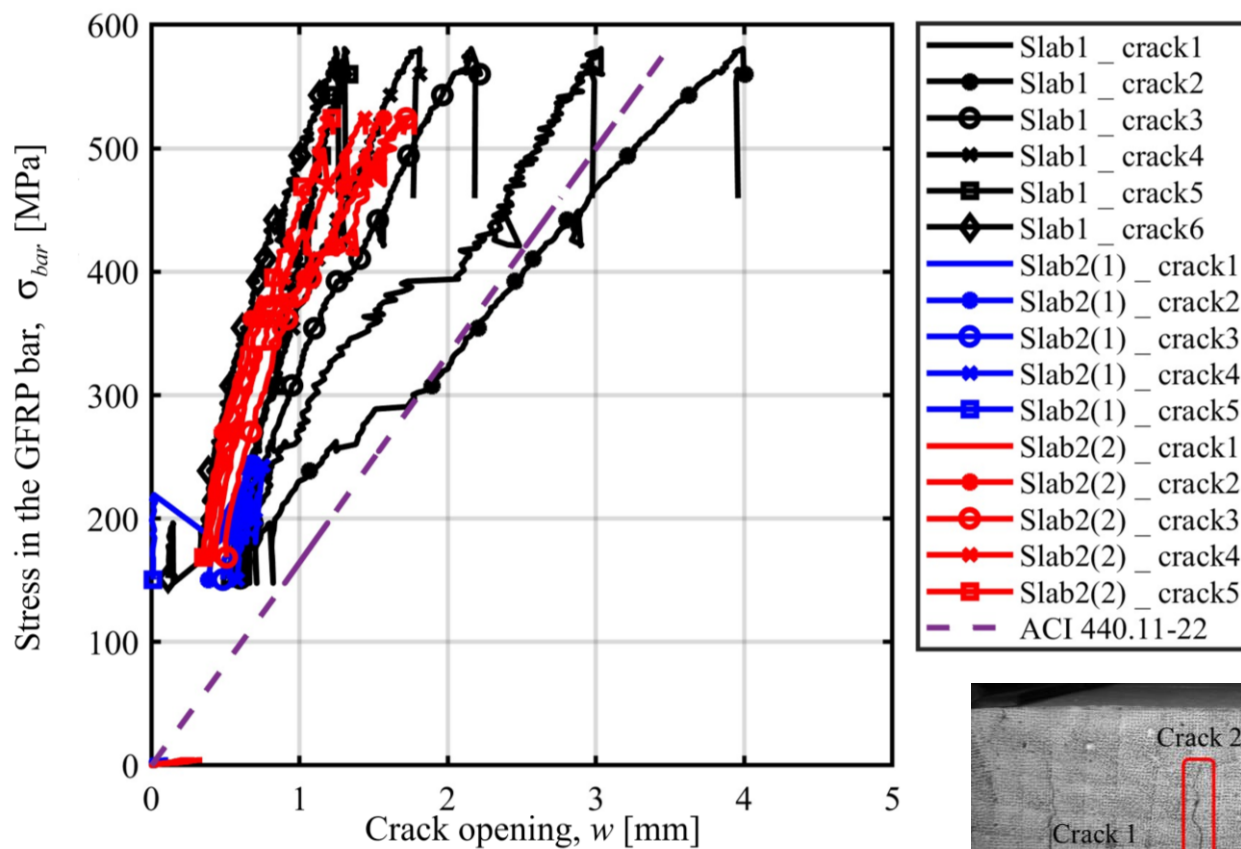
CRACK OPENING ANALYSIS



$$g = \frac{1}{2} \left[\Delta u_l - \frac{P_{bar} \ell}{A_{bar} E_{bar}} \right]$$

CRACK OPENING ANALYSIS

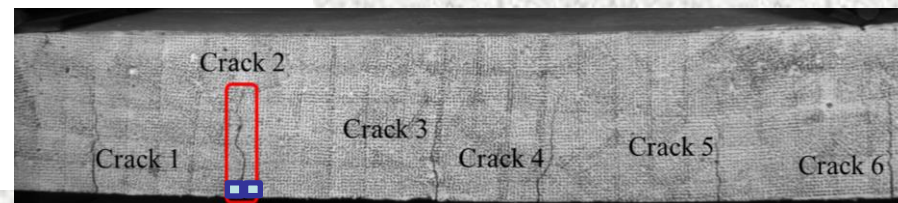
Comparison of the crack opening at the bottom of the beam for different stress levels in the bars and the ACI formula



$$w = 2 \frac{\sigma_{bar}}{E_{bar}} \beta k_b \sqrt{d_c^2 + \left(\frac{b_s}{2}\right)^2}$$

Shield C, et al., 2019,
 J Compos Constr
 10.1061/(ASCE)CC.1943-5614.0000978

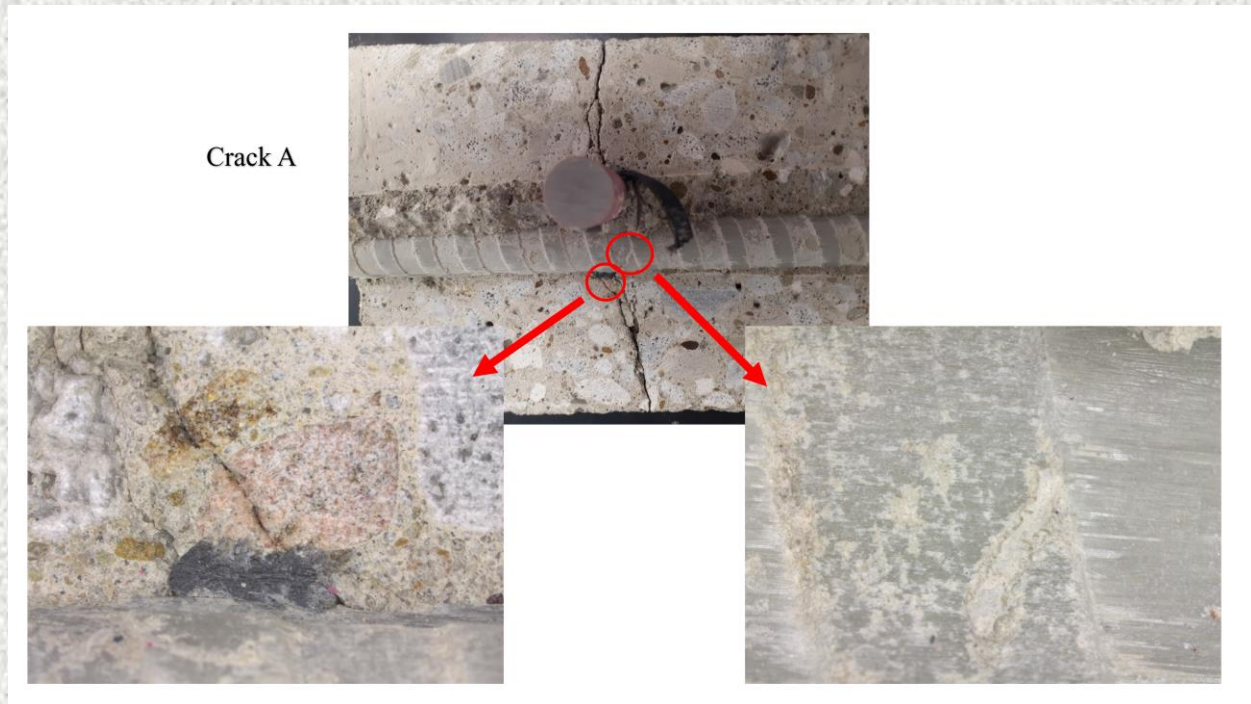
$$k_b = 1.2$$



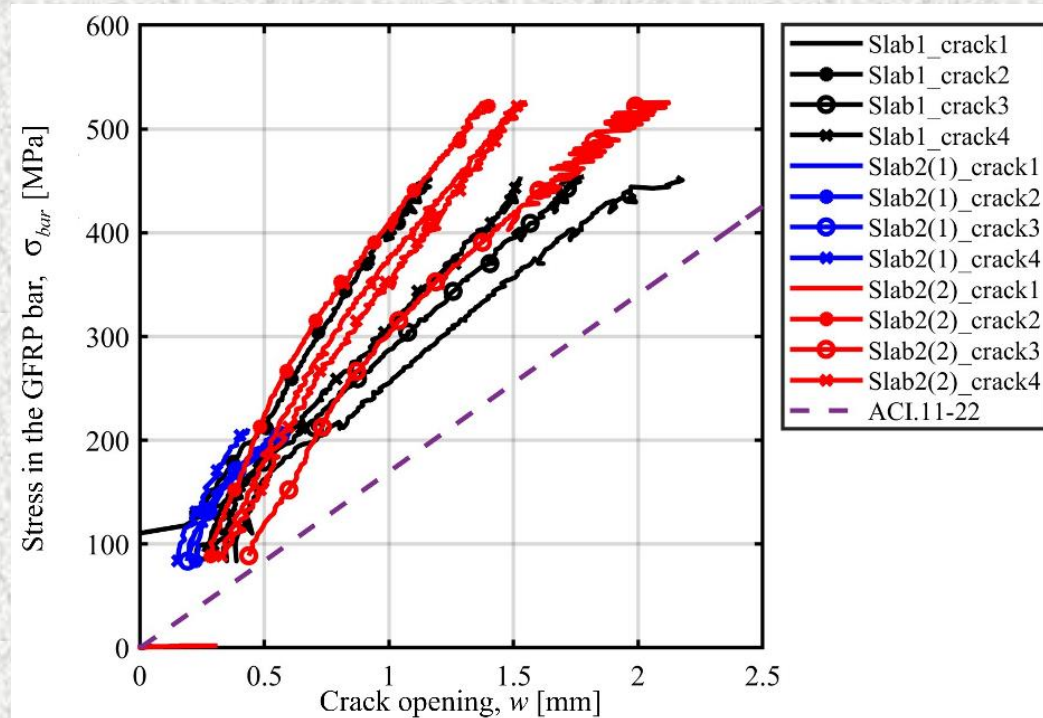
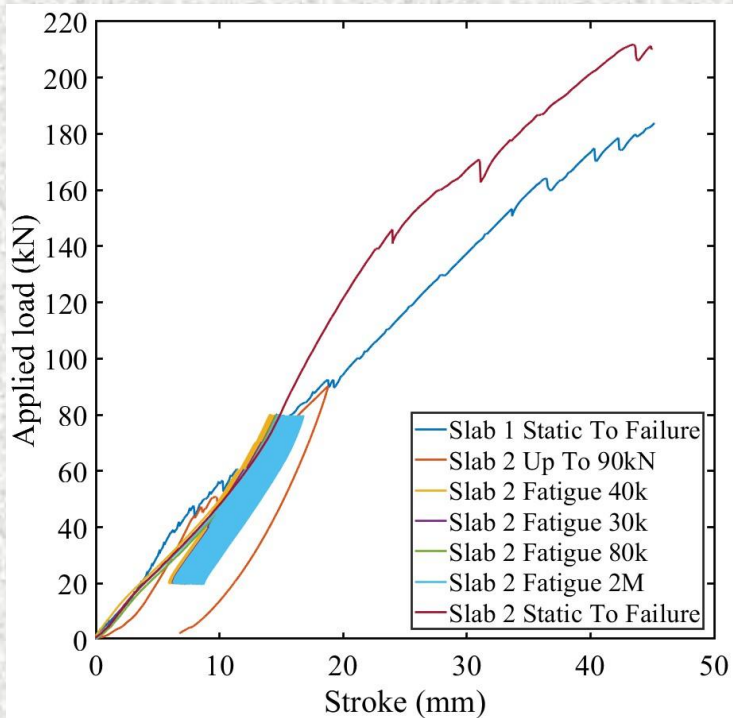
BAR-CONCRETE INTERFACE



Slab 2
Crack A



ADDITIONAL TESTS



CONCLUSION

- 1) For stress level up to 20% of the reduced strength of the GFRP bar, fatigue does not seem to be a concern
- 2) Crack opening at the bar level might indicate that fatigue damage increases slippage of the bar
- 3) The ACI formula predicts well the crack opening at the bottom of the slab
- 4) Pull-out tests (with longer bonded length) might provide information on crack opening

THANK YOU



CRC 2022