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Workshop

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TRUSS
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Fatigue testing of reinforced concrete beam instrumented with distributed optical fiber sensors (DOFS)

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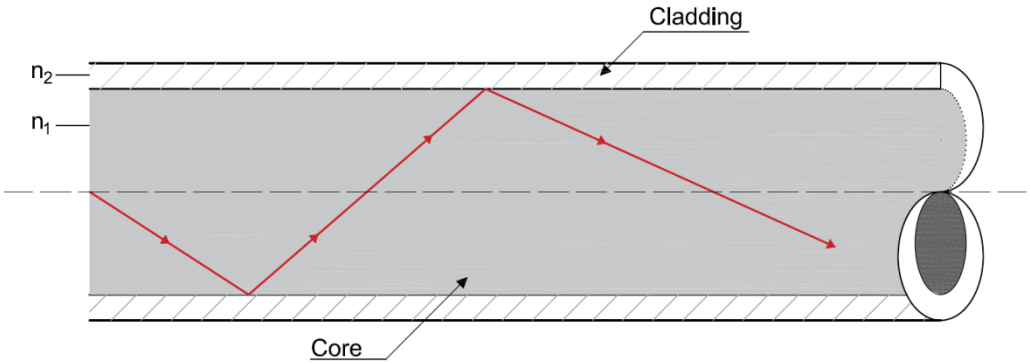
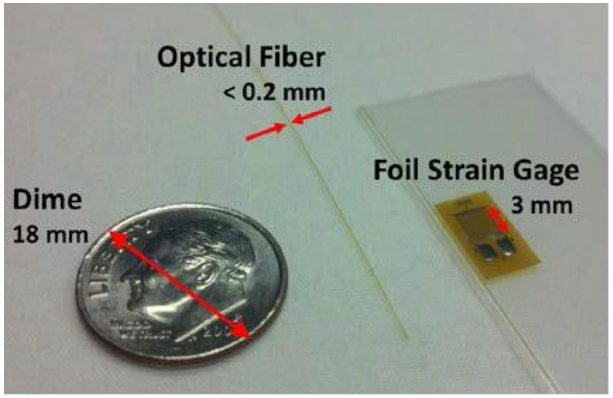
Overview

- Introduction – Fiber Optic Sensors
- Optical Backscattering Reflectometry (OBR) system
- Motivation
- Laboratory test
- Test results and discussion
- Conclusion

Introduction – Optical Fiber Sensors

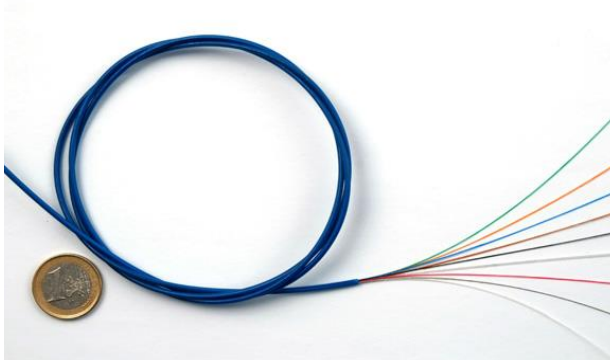




- Cylindrical symmetric structure that is composed by a central "core" with a **diameter** between **4** and **600 µm** and a uniform refractive index

Advantages:

- Immunity from electromagnetic interferences
- Small size and lightweight
- High sensitivity
- Withstand high temperatures
- Chemically inert – free from corrosion

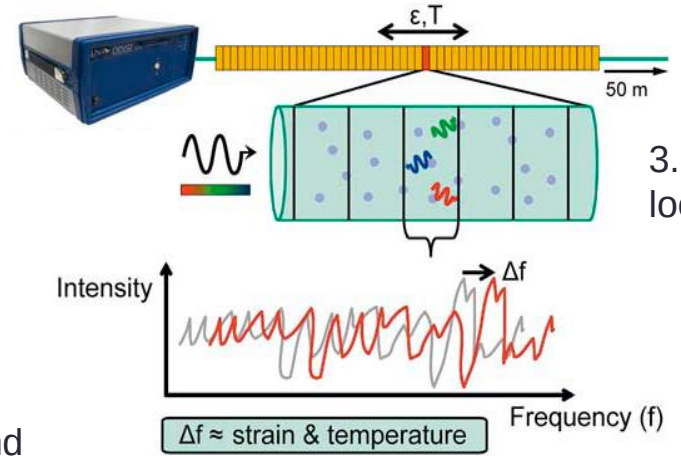


OBR System

1. OBR system measures the **Rayleigh backscatter** as a function of length in an optical fiber with high spatial resolution **(1mm)**

Swept wavelength interferometry
(fiber is divided in small windows)

2. External stimulus



3. Temporal and spectral shifts in the local backscattered pattern

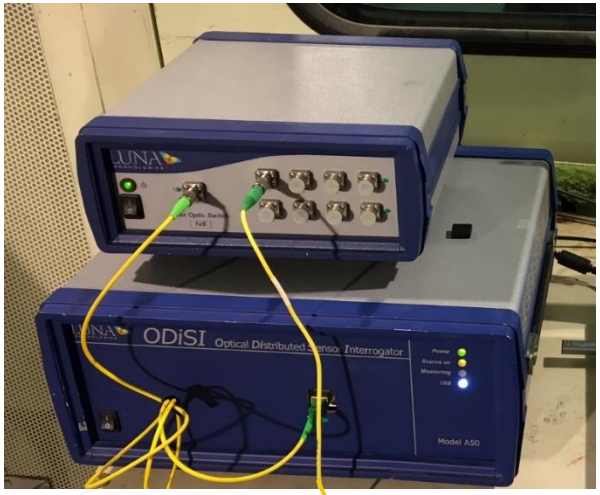
4. Shifts can be measured and scaled to give distributed **strain** or **temperature** measurements

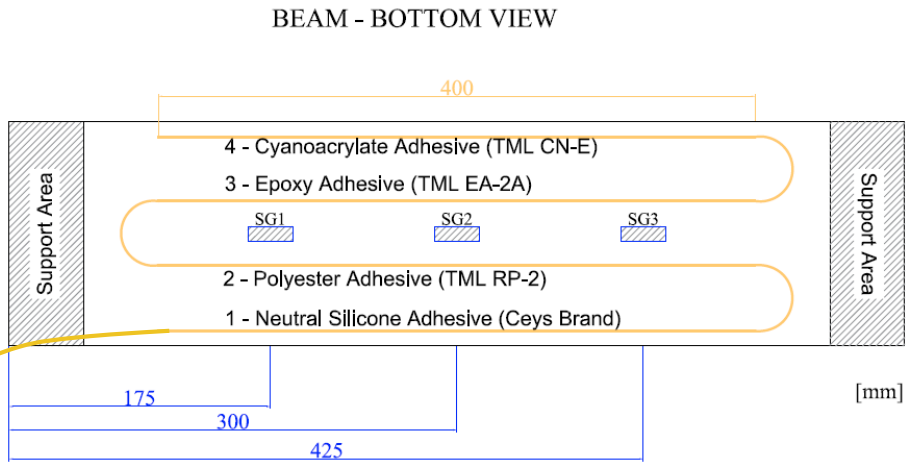
- Sensing range – up to 70 m
- Spatial resolution – up to 1 mm
- Strain resolution – ± 2 με
- Measurement range – ± 13000 με

Motivation

- Despite past successful applications, **there is still a lack of knowledge** regarding the use of OBR DOFS, especially in its use **in reinforced concrete structures**;
- Some of these uncertainties are related, for instance, with the **best optimal bonding adhesive**;
- This is even a more critical issue when applying **DOFS without any protective thick coating**, such as the case of the deployed fiber in this research.
- Moreover, the **performance of these sensors** regarding its accuracy and reliability over time in real world structures during **long term periods is still unstudied**;
- To the authors knowledge, **all previous experiences of OBR** implemented in elements under fatigue loading, corresponds **to cases with composite structures**, where surface characteristics of the material which may highly affect the fatigue response are completely different from the case of concrete elements.

Laboratory Test

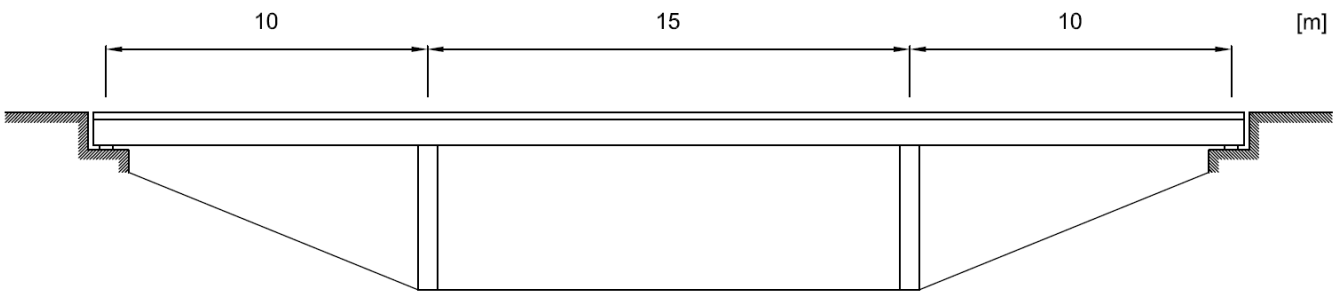




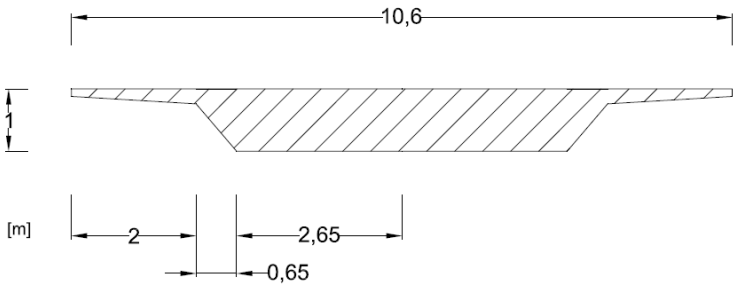
- Two reinforced concrete beams with 60x15x15 [cm] dimensions;
- 5,2m polyimide DOFS was instrumented to each beam;
- Four different adhesives were used: Silicone, Polyester, Epoxy and Cyanoacrylate;
- Subjected to fatigue loading.

Laboratory Test

Load cycle definition



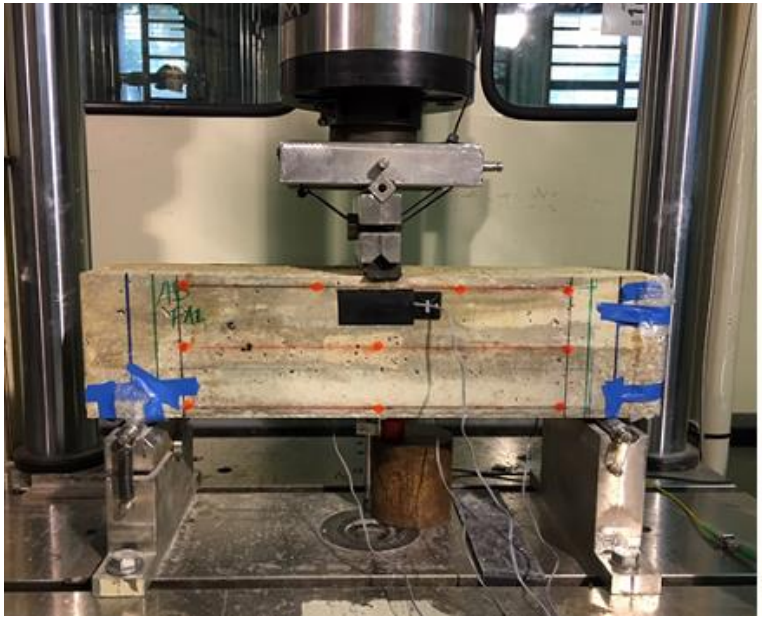
Four axle truck with load of 120 kN by axle multiplied by dynamic factor of 1.3 – Fatigue Load Model 3 of EN 1991-2



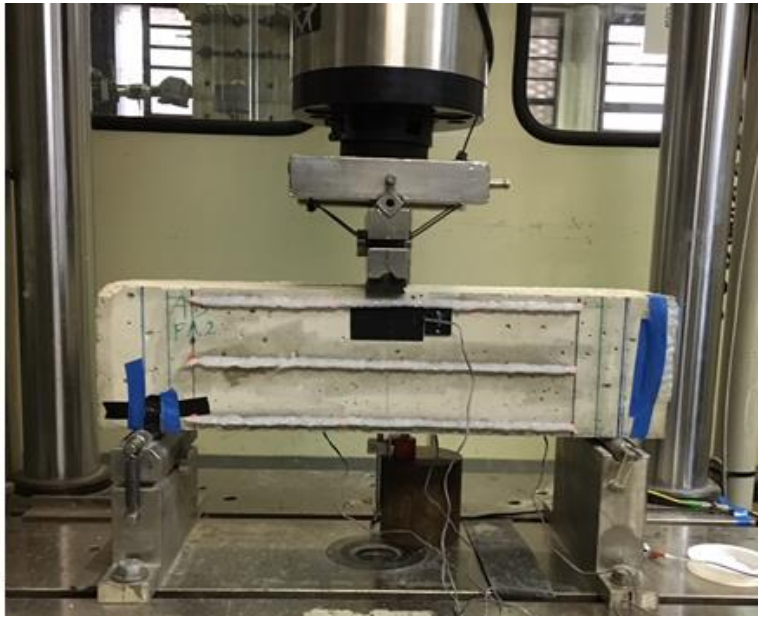
	Load combination	Maximum bending moment [kN.m]	σ [MPa]	Equivalent load to apply to beam specimen [kN]	Expected strain [με]
Load Cycle Level [inf]	permanent load	3712.9	2.612	11.75	68.9
Load Cycle Level [sup]	permanent load + additional traffic	4336.3	3.050	13.73	80.5

Laboratory Test

View of loading arrangement



Beam FA 1

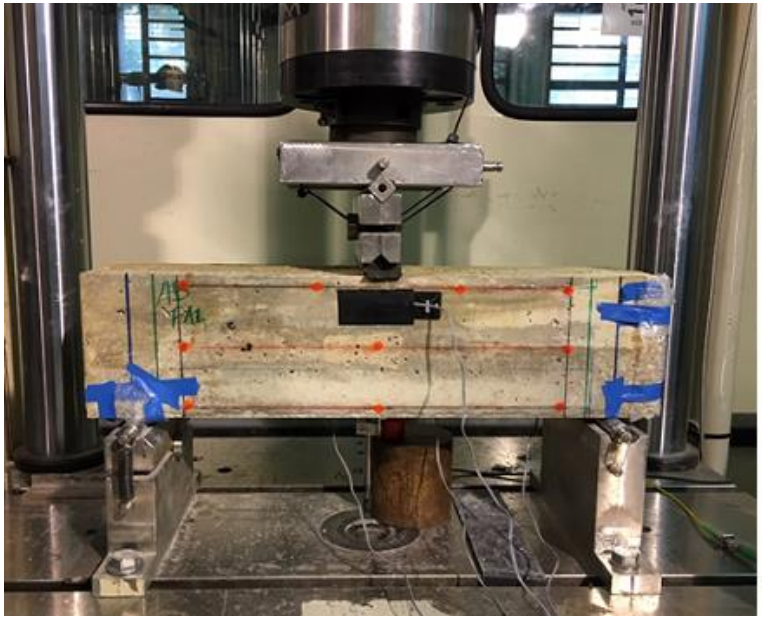


Beam FA 2

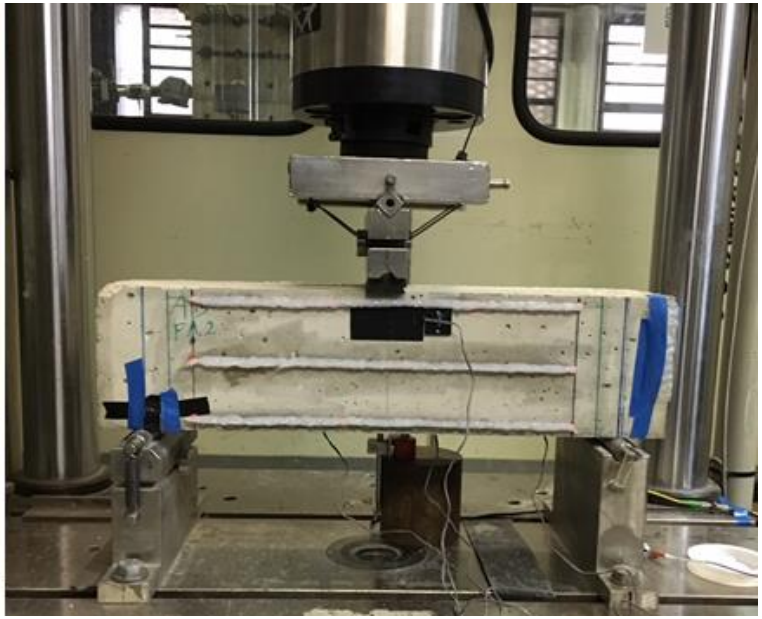
- The cycling load was introduced with a frequency of 4 Hz and with a sinusoidal profile until reaching 2 million cycles;
- Beam FA1 was loaded directly to the 2 million cycles in an un-cracked condition;
- Beam FA2 was initially loaded statically until 28 kN (inducing cracking), then unloaded and only afterwards loaded with 2 million cycles identical to beam FA1;

Laboratory Test

View of loading arrangement



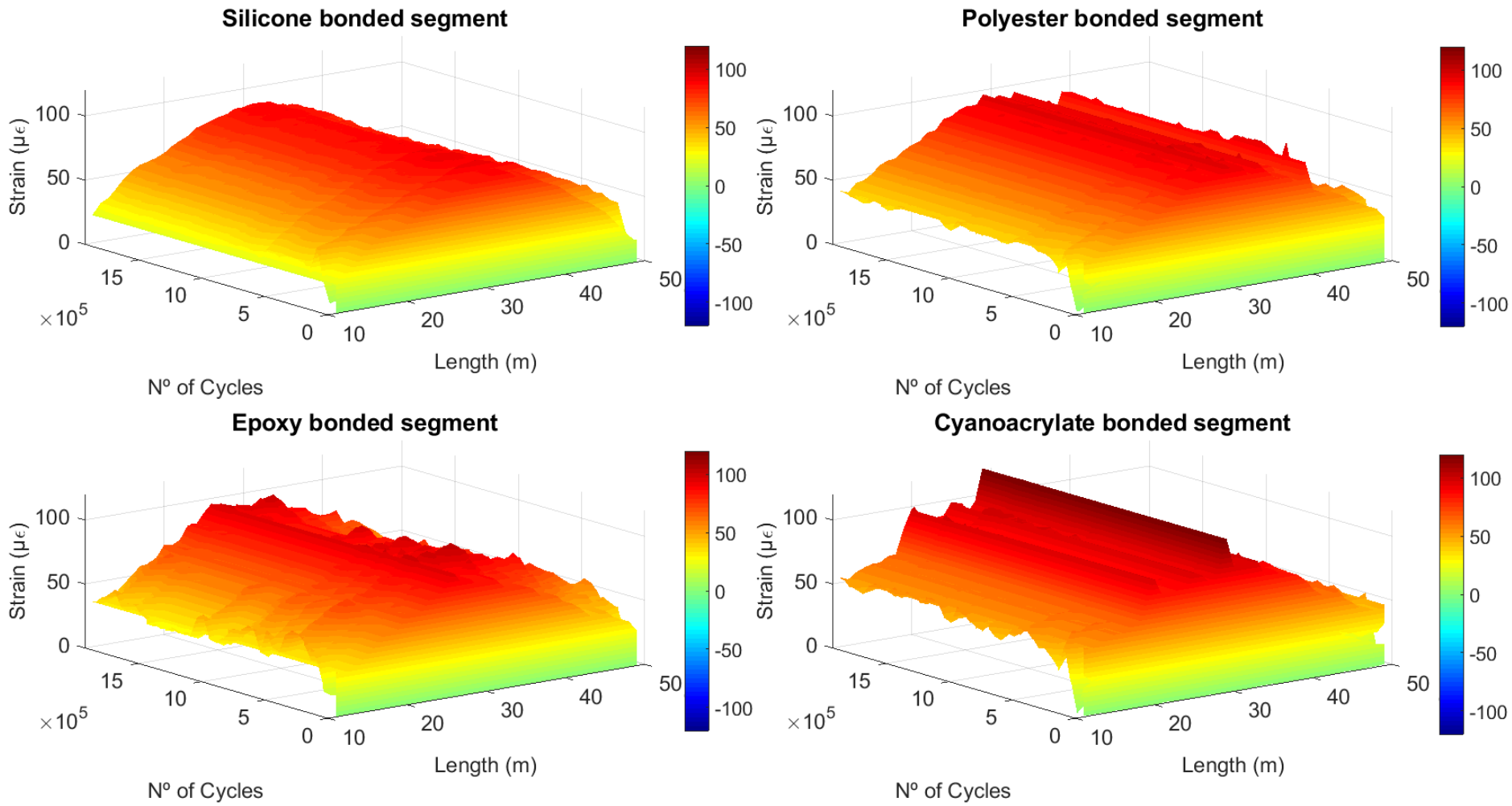
Beam FA 1



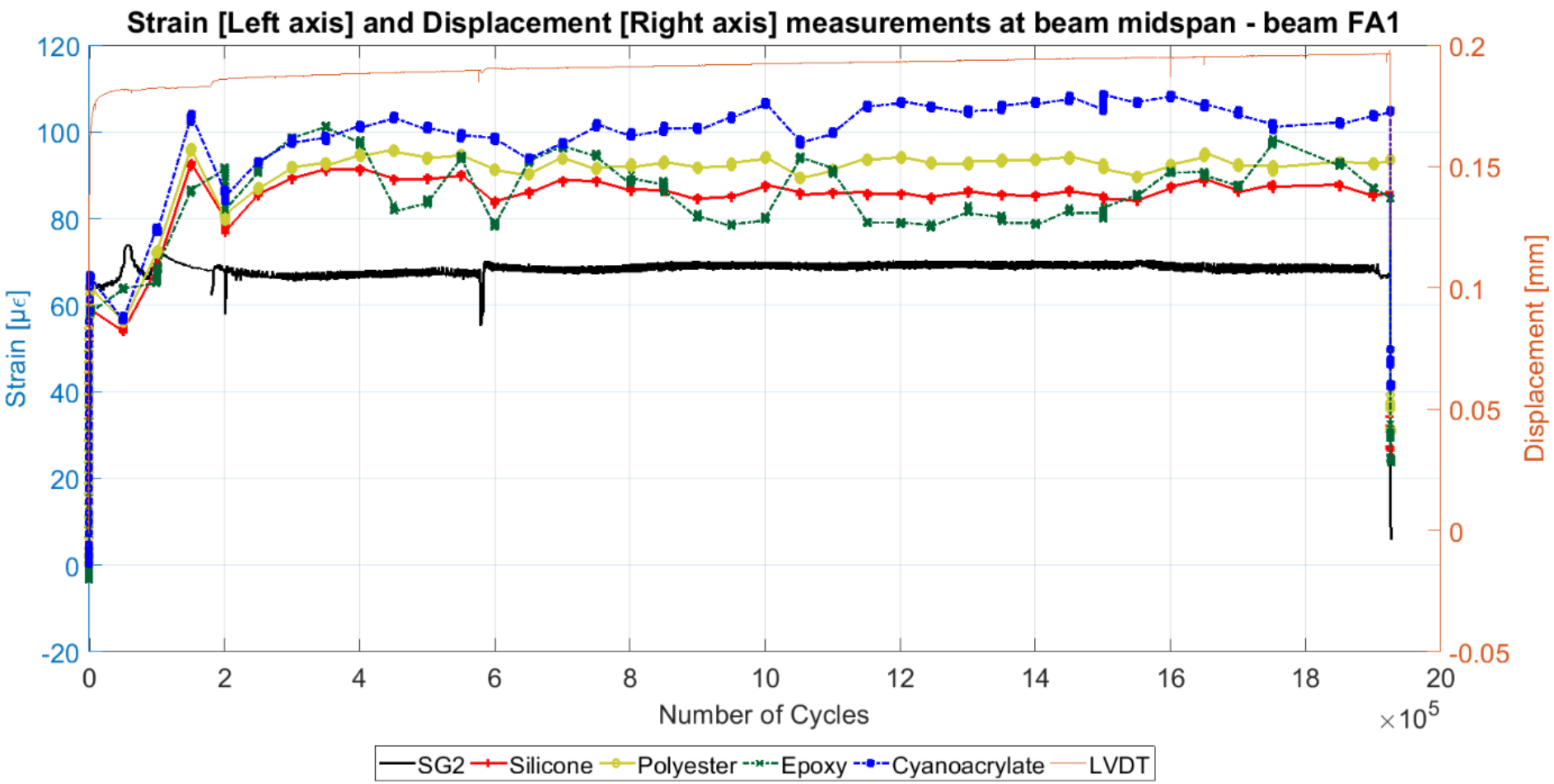
Beam FA 2

- DOFS spatial resolution of 1 cm – 520 measuring points;
- Sampling acquisition frequency of 0,2 Hz for DOFS and 1 Hz for strain gauges, LVDT and load cell info
- Due to the extensive duration of the test and the large amount of collected data, the DOFS's measurements were stored for a duration of 5 minutes (1200 load cycles) every 50 thousand cycles

Results – Beam FA1

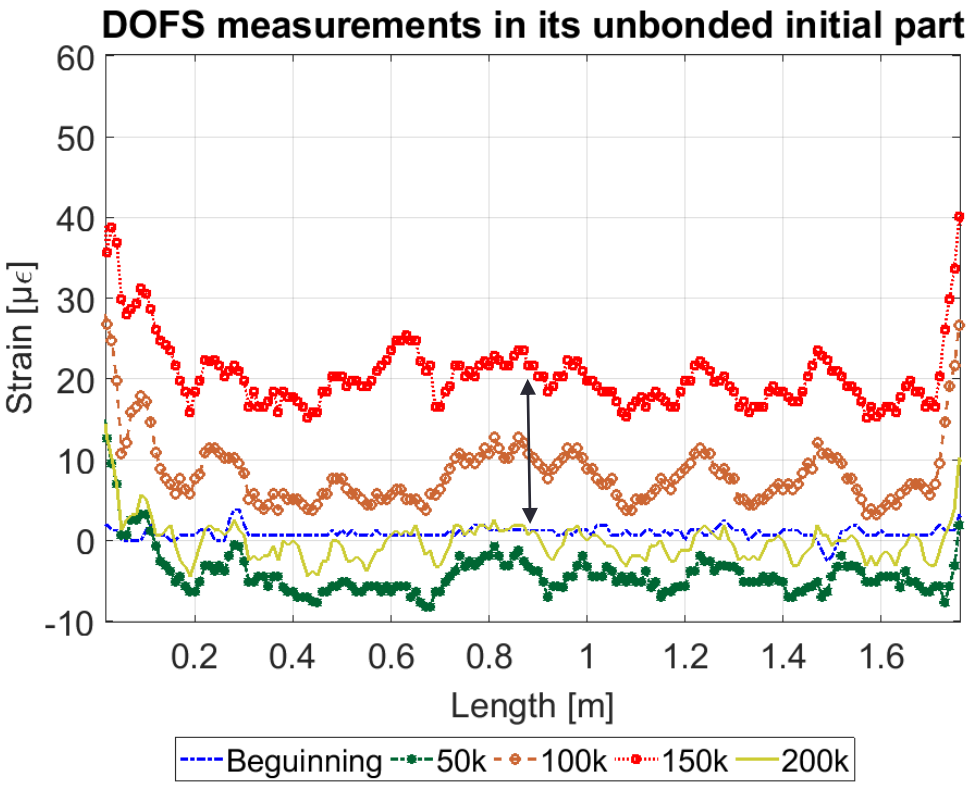


Results – Beam FA1

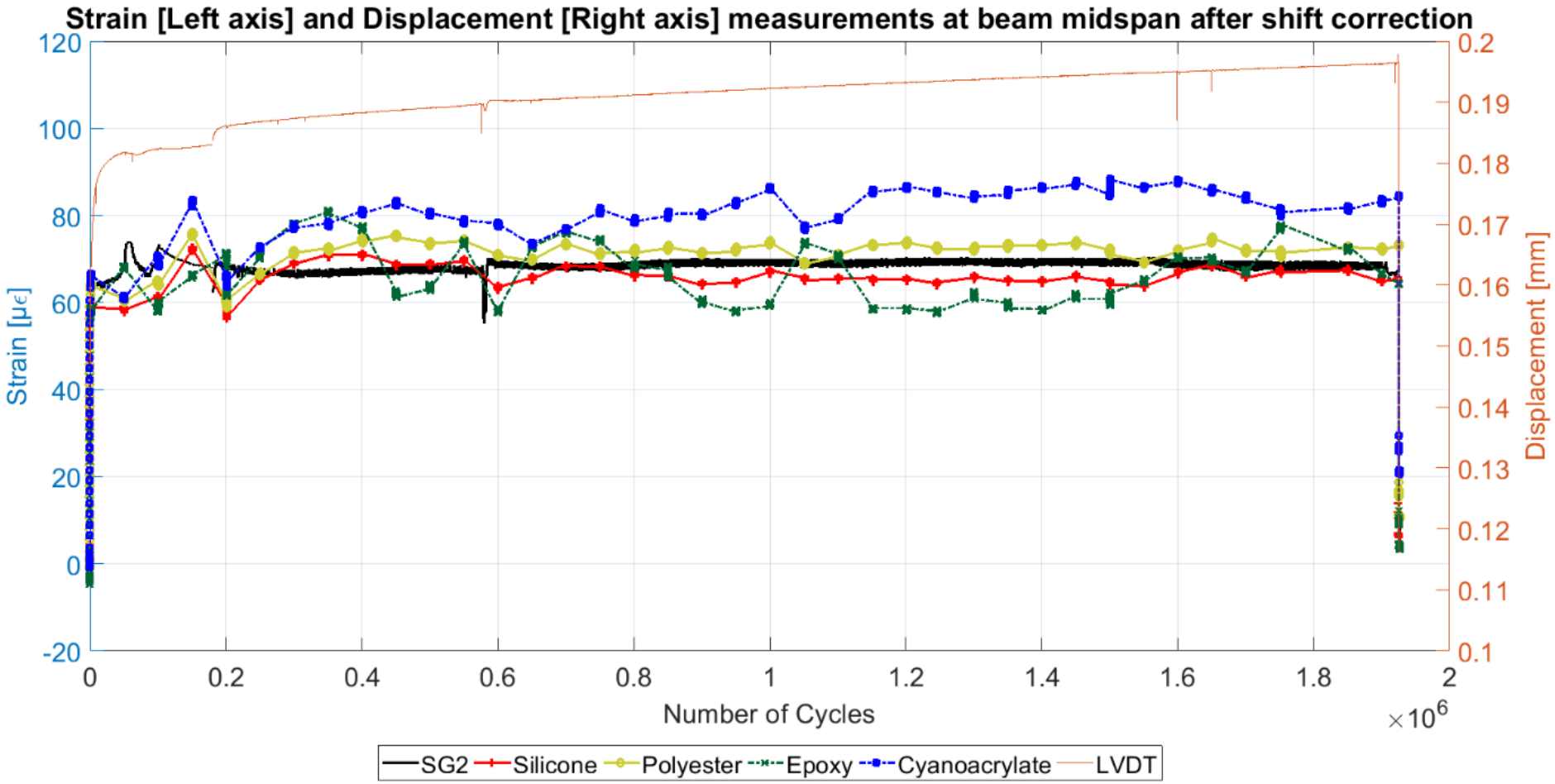


Results – Beam FA1

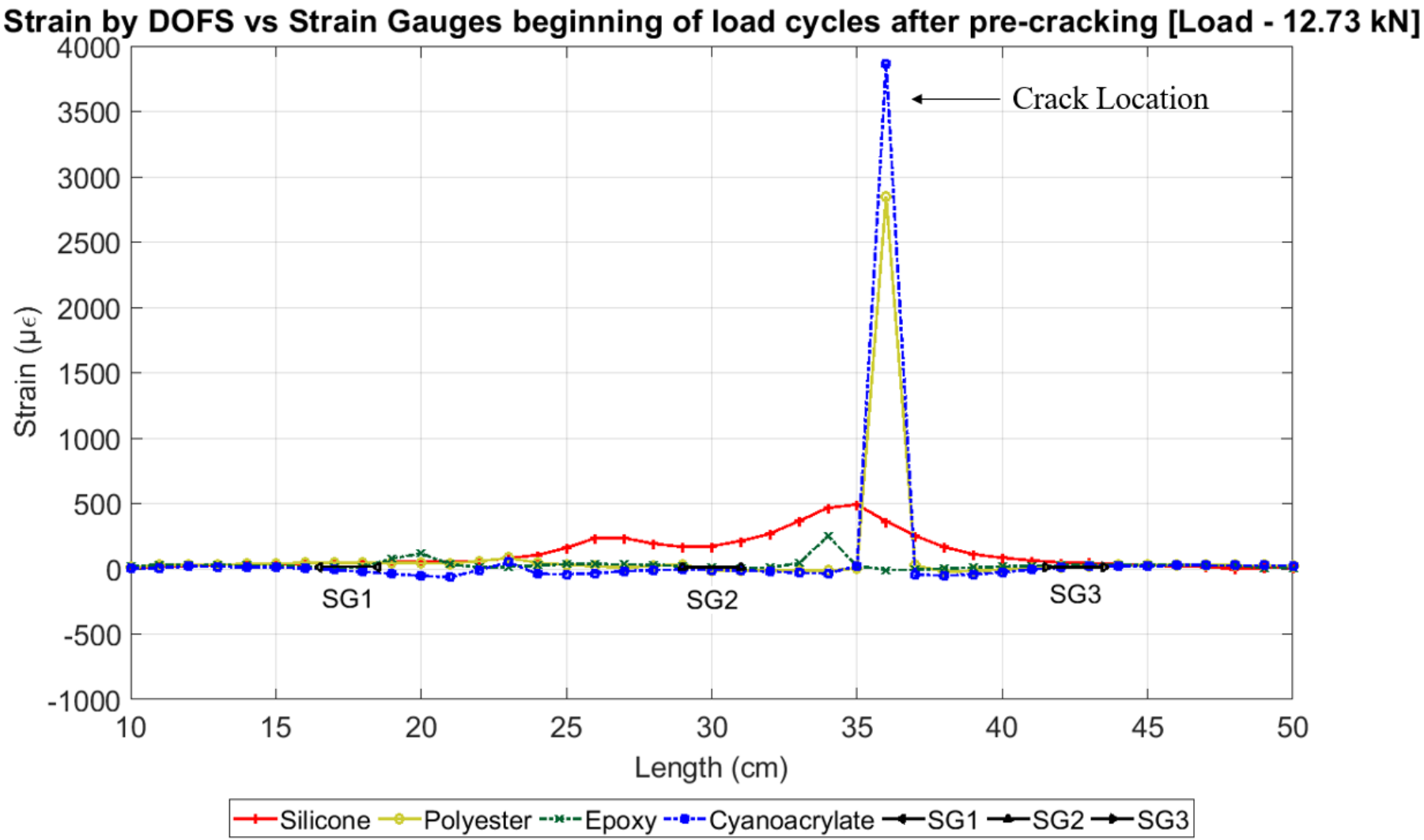
- Global **divergence** in **the unbonded segment** from the first measurements until the **150k cycle** mark.
- On the next DOFS cycle measurement the aforementioned divergence disappears.
- However, **for the remaining bonded parts** of the deployed fiber the new measurements after the 200k cycle **the shift still remains**.
- Calculate the **average** of strain measurements in its **unbonded part for 150k** cycle and **subtract it to following measurements**.



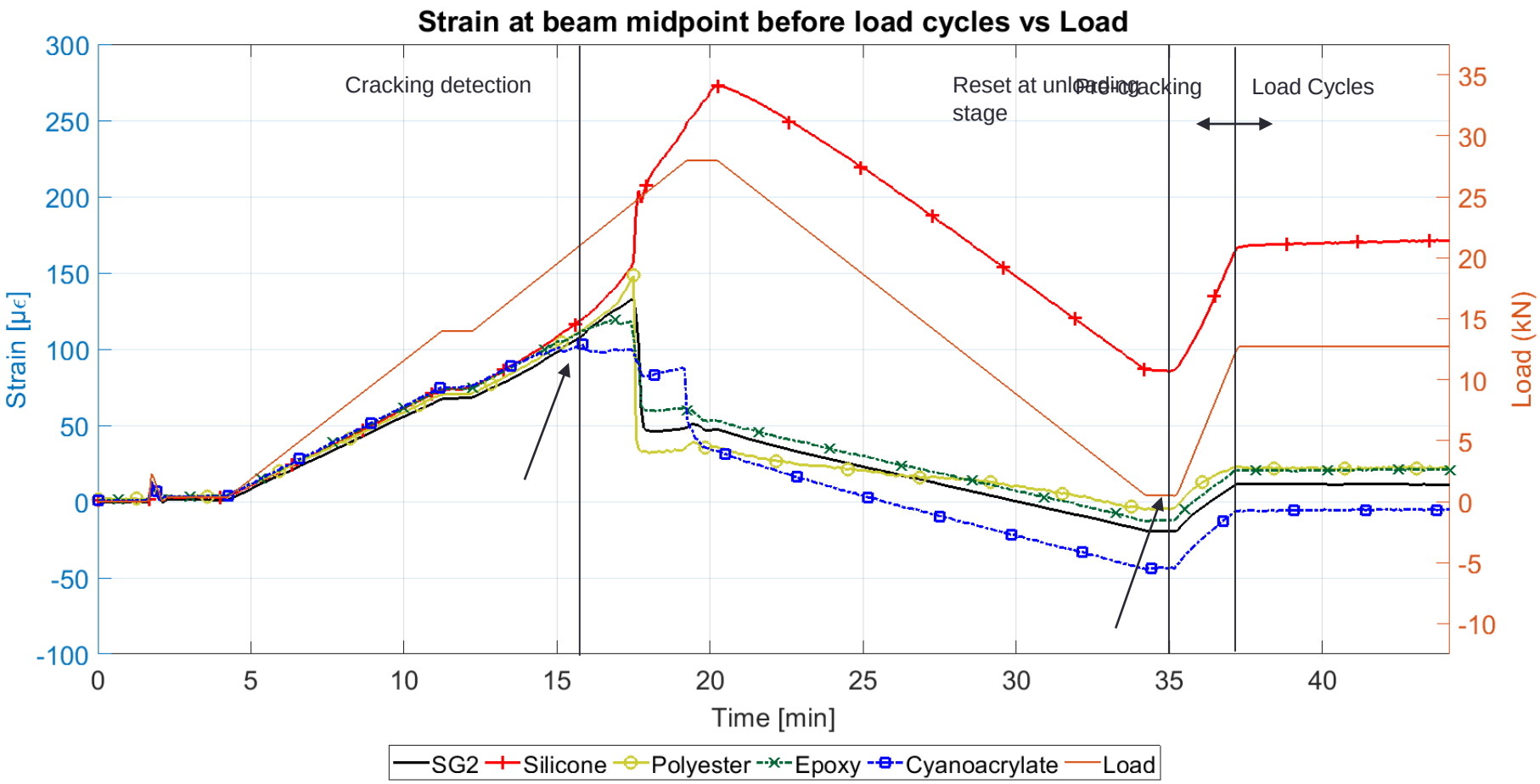
Results – Beam FA1



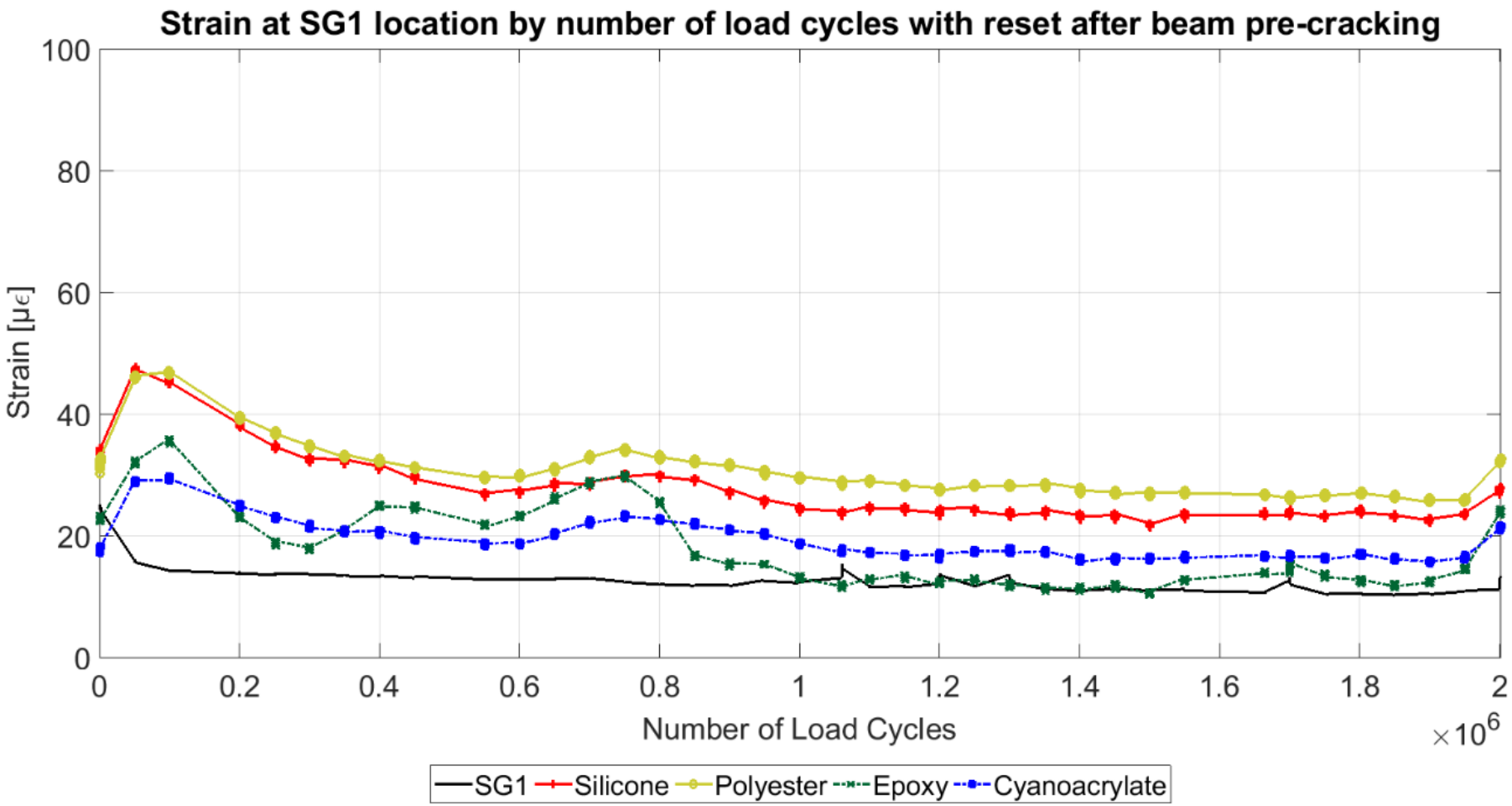
Results – Beam FA2



Results – Beam FA2



Results – Beam FA2



Conclusions

- In this paper, the **performance of DOFS when deployed in reinforced concrete elements subjected to fatigue load was assessed**. Two reinforced concrete beams (FA1 and FA2) were instrumented with a 5.2 m long polyimide DOFS and subjected to 2 million load cycles with a stress range representative of actual fatigue loading because of traffic in standard highway bridges.

- In **beam FA1**, which was fatigue loaded in **un-cracked state**, the results show that the **DOFS measurements agreed reasonably with what was expected and measured by the strain gauges** as well and for all adhesives tested. The measured differences, in the order of magnitude of 12 microstrains are due to the different sampling rates used in the two sets of sensors, the frequency of the load and the resolution of the two types of sensors. However, the **results show good stability** along the number of cycles and **no malfunction due to fatigue effects can be observed**.

- In **beam FA2**, which was **intentionally pre-cracked** before the fatigue test, it was observed how **after cracking the DOFS continued to provide strain measurements coherent with the applied load**. These values were, however, different depending on the bonding agent used in the DOFS segment and also different of the readings from the strain gauges.

Conclusions

- In all cases **the measurements showed a good stability along the number of cycles**, indicating no fatigue failures or debonding in the fibre or the adhesive.
- In this way, **this test provided encouraging results regarding the use of this novel technology in real world applications for long-term monitoring periods** when a high number of load cycles with low stress range are seen by the monitored concrete structure. **The DOFS showed a good performance under fatigue loading, without malfunctions for a number of cycles up to 2 million**. The strains measured along the tests were accurate when compared to the results obtained with strain gauges, with good stability and both for the un-cracked and cracked conditions. Therefore, fatigue loading does not affect the performance of the DOFS for obtaining strain profiles along their length.
- Notwithstanding, **it would be interesting in the future to conduct similar tests on larger RC beam specimens and also with higher stress ranges**. In order to better compare with the results of strain gauges and to obtain more conclusive results about the accuracy of the strain data, **it will be also of interest to carry out tests where the frequency of the cycling load will allow the sampling rate of the DOFS acquisition system to follow the load profile of the variable load**.

Thanks for your attention

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