SOFT ELASTOMERIC CAPACITORS WITH AN EXTENDED POLYMER MATRIX FOR STRAIN SENSING ON CONCRETE

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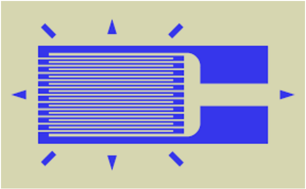
HEALTH MONITORING OF CIVIL STRUCTURES

- Static and dynamic strain could result into Structural failures

- Surface strain sensors, such as linear variable differential transformers, Fiber Bragg gratings, and resistive strain gauges, have seen significant use for monitoring concrete infrastructure

- Limited by area covered



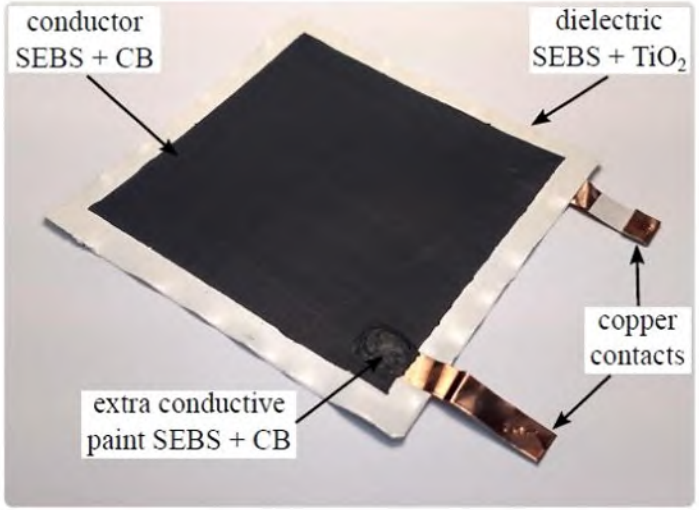
Resistive strain gauge

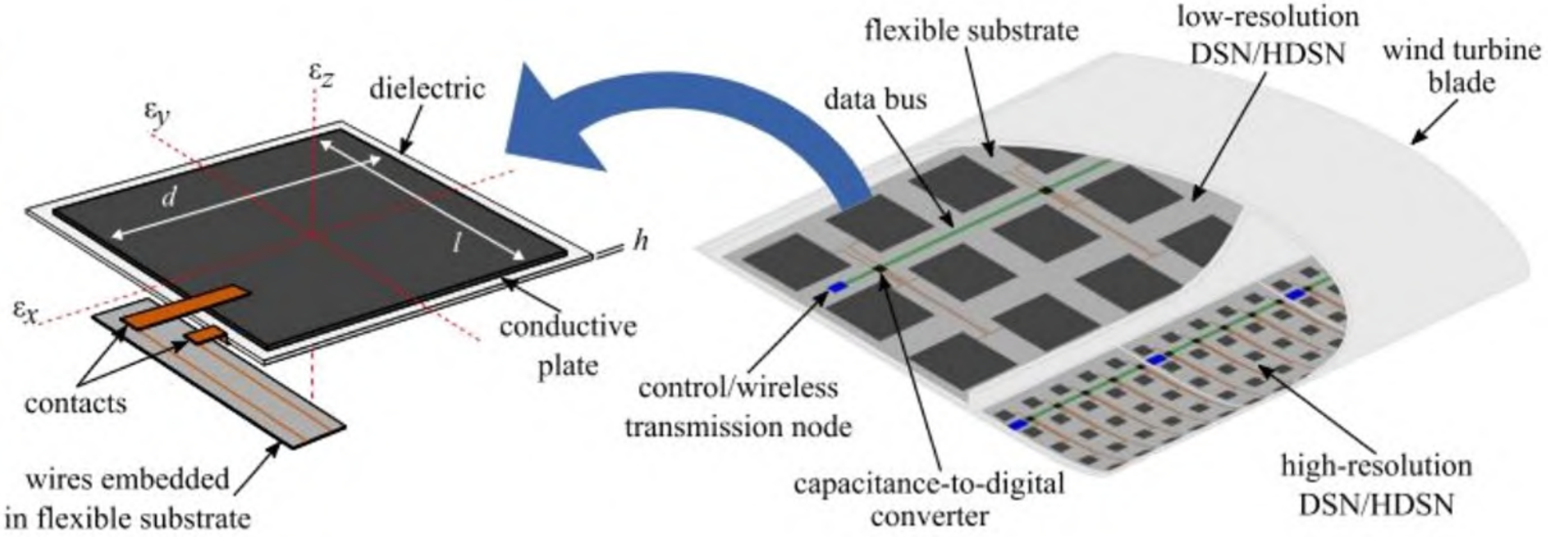
Fiber Bragg gratings

linear variable differential transformers

https://i0.wp.com/theconstructor.org/wp-content/uploads/2016/10/structural-failures-of-concrete-structures.jpg?fit=675%2C364&ssl=1
https://www.geokon.com/Bridges https://www.rp-photonics.com/bg/products/hbk_fibersensing/fiber_bragg_gratings.jpg
https://en.wikipedia.org/wiki/Strain_gauge

BACKGROUND: SOFT ELASTOMERIC CAPACITOR



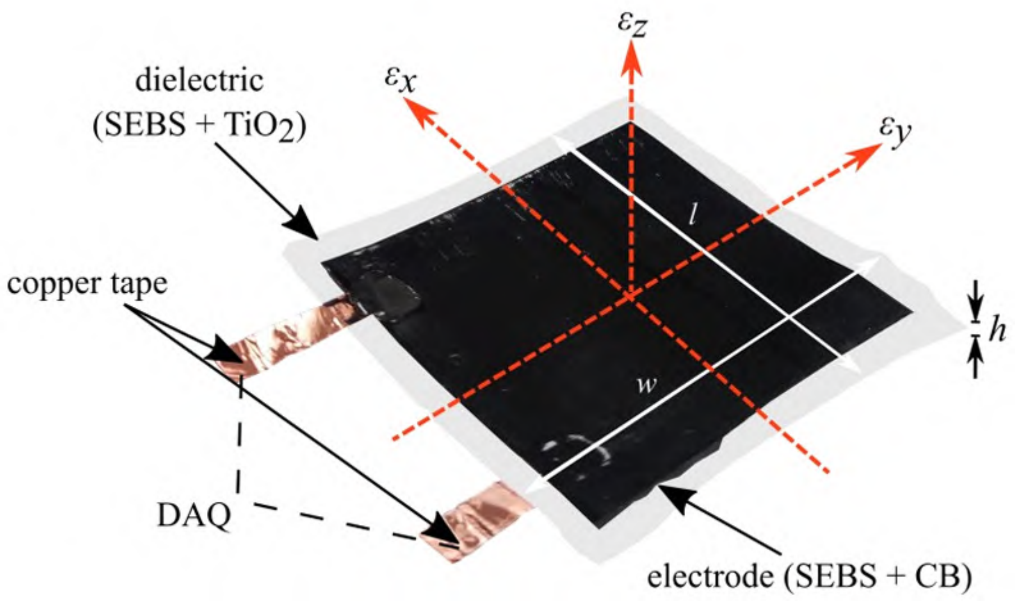


The sensor has the following features:

- Low cost,
- Great ultra flexibility,
- Mechanical robustness,
- Ease of installation, and
- Low power consumption required for sensing

Laflamme, Simon, et al. "Soft capacitive sensor for structural health monitoring of large-scale systems." Structural Control and Health Monitoring 19.1 (2012): 70-81.

SENSING PRINCIPLE



Functions as a parallel plate capacitor

- Respond to changes in the sensor geometry
- Linearly in sensor area and inversely to thickness
- Inherits the mechanical properties of an elastomer

Laflamme, Simon, et al. "Soft capacitive sensor for structural health monitoring of large-scale systems." Structural Control and Health Monitoring 19.1 (2012): 70-81.

BACKGROUND: ELECTROMECHANICAL MODEL

$$C = \epsilon_0 \epsilon_r \frac{lw}{h}$$

Parallel plate capacitor

$$\nabla C = \epsilon_0 \epsilon_r \left(\frac{l}{h} dw + \frac{w}{h} dl - \frac{lw}{h^2} dh \right)$$

Gradient w.r.t. deformation

$$\Delta C = \epsilon_0 \epsilon_r \left(\frac{l\,\Delta w}{h} + \frac{w\,\Delta l}{h} - \frac{lw\,\Delta h}{h^2} \right)$$

Assume uniformity of deformation

$$\frac{\Delta C}{C_0} = \frac{\Delta w}{w} + \frac{\Delta l}{l} - \frac{\Delta h}{h}$$

Normalize difference in capacitance

BACKGROUND: ELECTROMECHANICAL MODEL

$$\frac{\Delta C}{C_0} = \frac{\Delta w}{w} + \frac{\Delta l}{l} - \frac{\Delta h}{h}$$

Normalized difference in capacitance

$$\frac{\Delta C}{C_0} = \varepsilon_{\mathrm{w}} + \varepsilon_{\mathrm{l}} - \varepsilon_{\mathrm{h}}$$

Definition of strain

$$\varepsilon_{\mathrm{h}} = -\frac{\nu}{E}(\sigma_{\mathrm{l}} + \sigma_{\mathrm{w}}) = -\frac{\nu}{1-\nu}(\varepsilon_{\mathrm{w}} + \varepsilon_{\mathrm{l}})$$

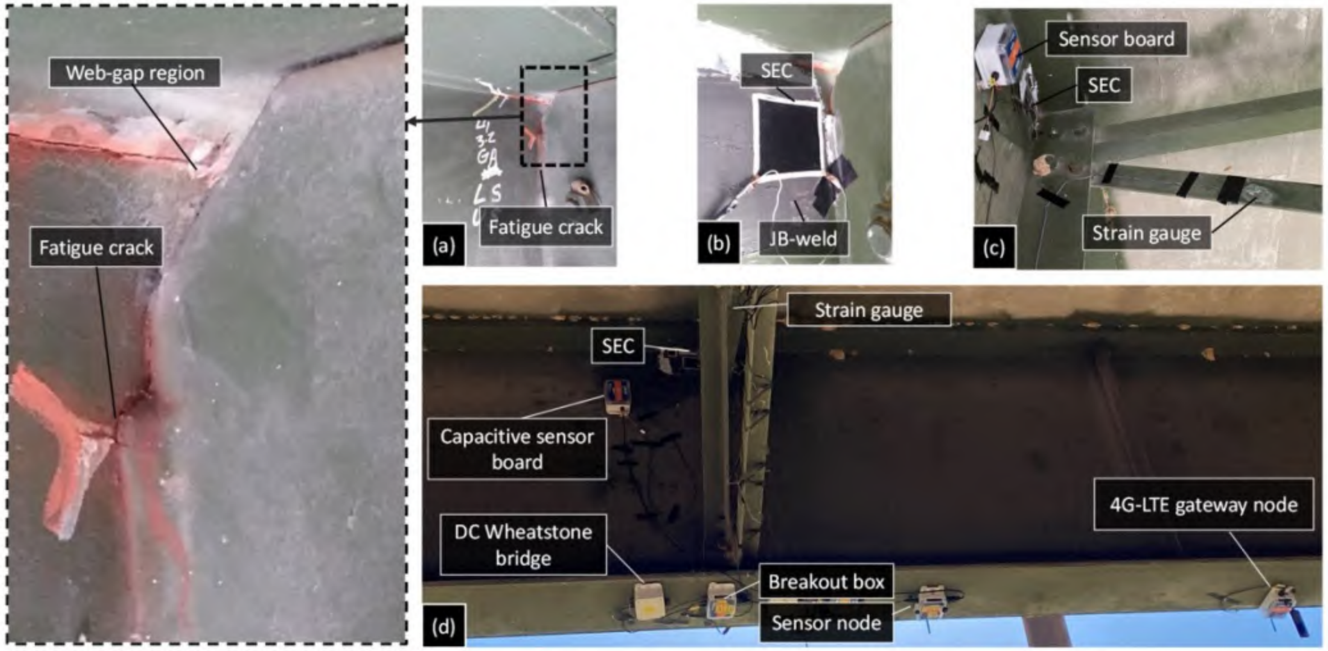
Plane stress assumption

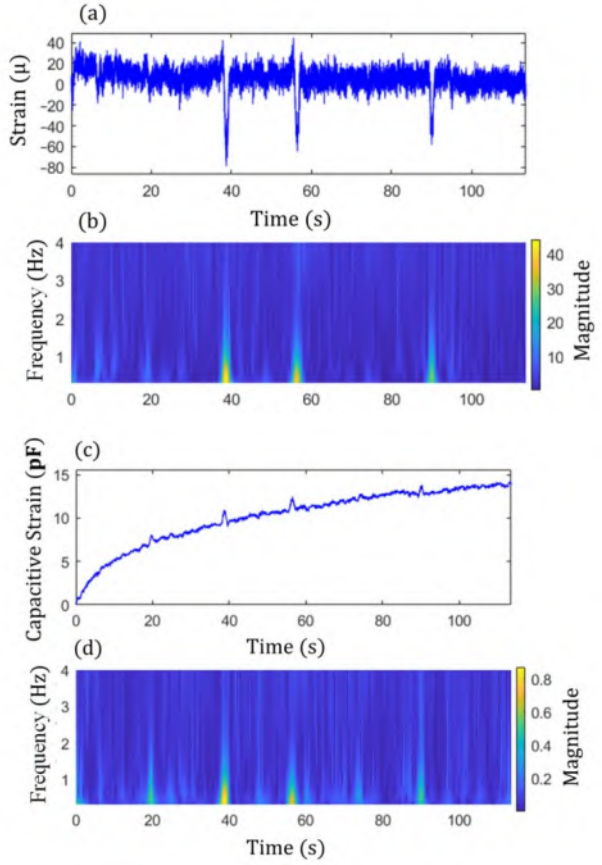
$$\frac{\Delta C}{C_0} = \frac{1}{1-\nu}(\varepsilon_{\mathrm{l}} + \varepsilon_{w})$$

Capacitance in areal deformation

BACKGROUND: PREVIOUS WORKS

Structural health monitoring of fatigue cracks for steel bridges with wireless large-area strain sensors

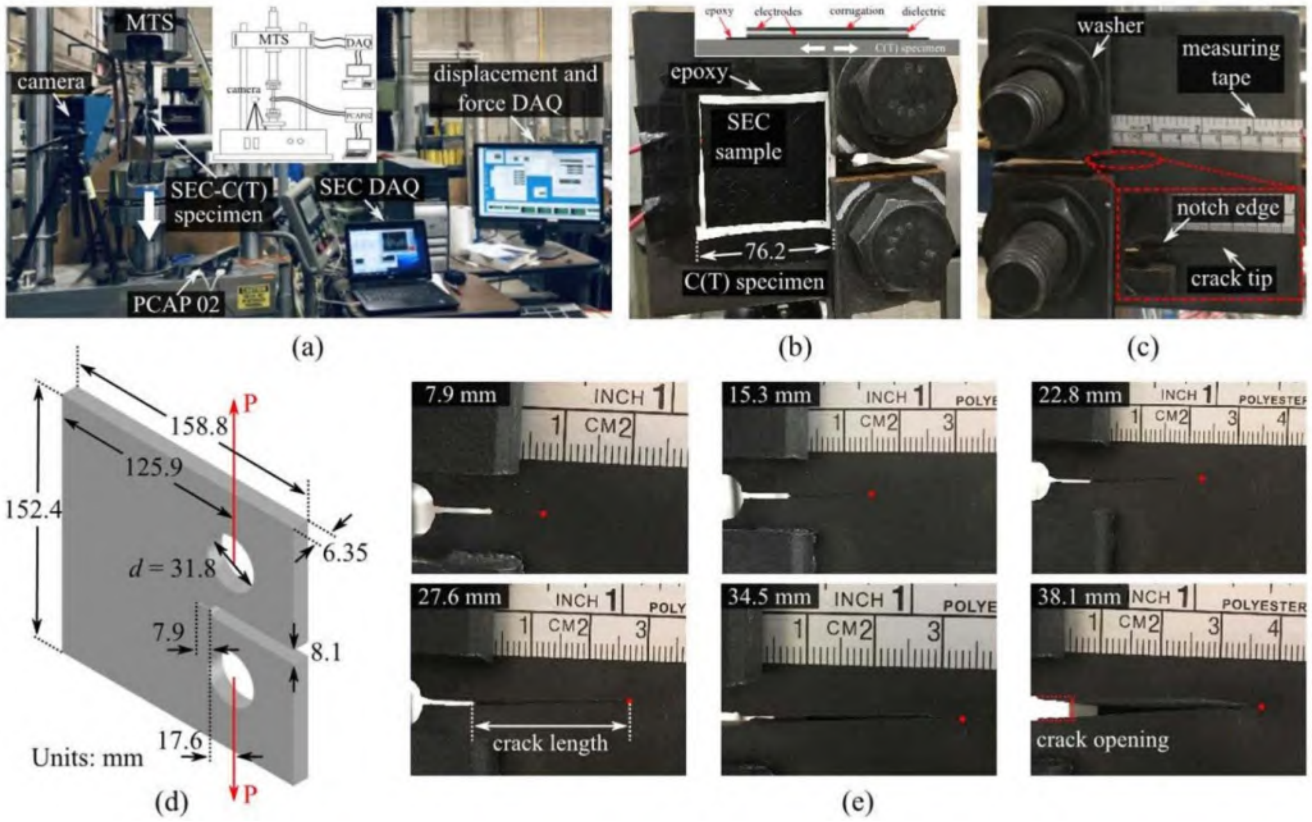




Taher, S. A., Li, J., Jeong, J.-H., Laflamme, S., Jo, H., Bennett, C., Collins, W. N., and Downey, A. R. J., *"Structural health monitoring of fatigue cracks for steel bridges with wireless large-area strain sensors," Sensors* ***22****, 5076 (jul 2022)*

BACKGROUND: PREVIOUS WORKS

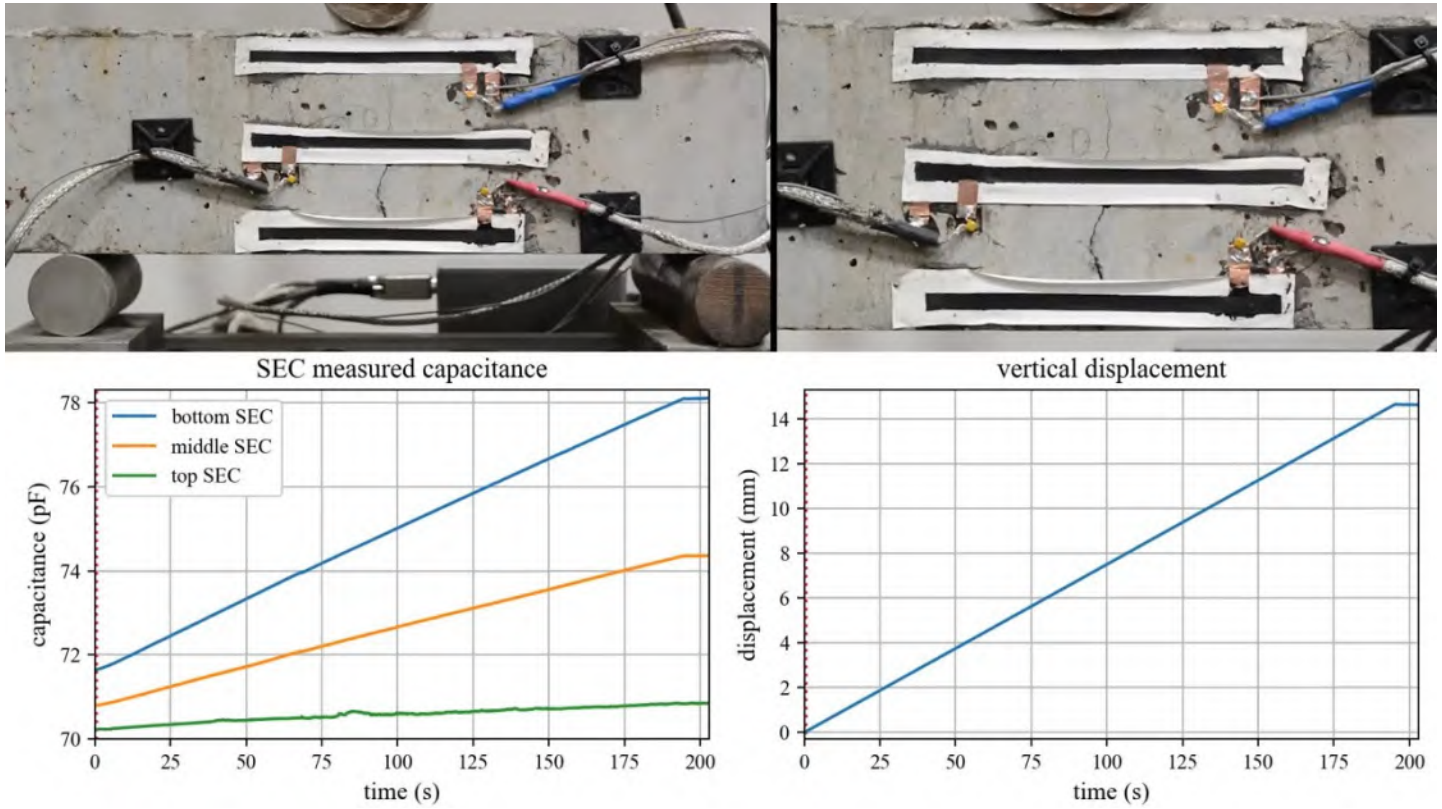
Investigation of surface textured sensing skin for fatigue crack localization and quantification



Liu, Han, et al. "Investigation of surface textured sensing skin for fatigue crack localization and quantification." Smart Materials and Structures 30.10 (2021): 105030.

BACKGROUND: PREVIOUS WORKS

Concrete Crack Detection and Monitoring Using a Capacitive Dense Sensor Array



Yan, Jin, et al. "Concrete crack detection and monitoring using a capacitive dense sensor array." Sensors 19.8 (2019): 1843.

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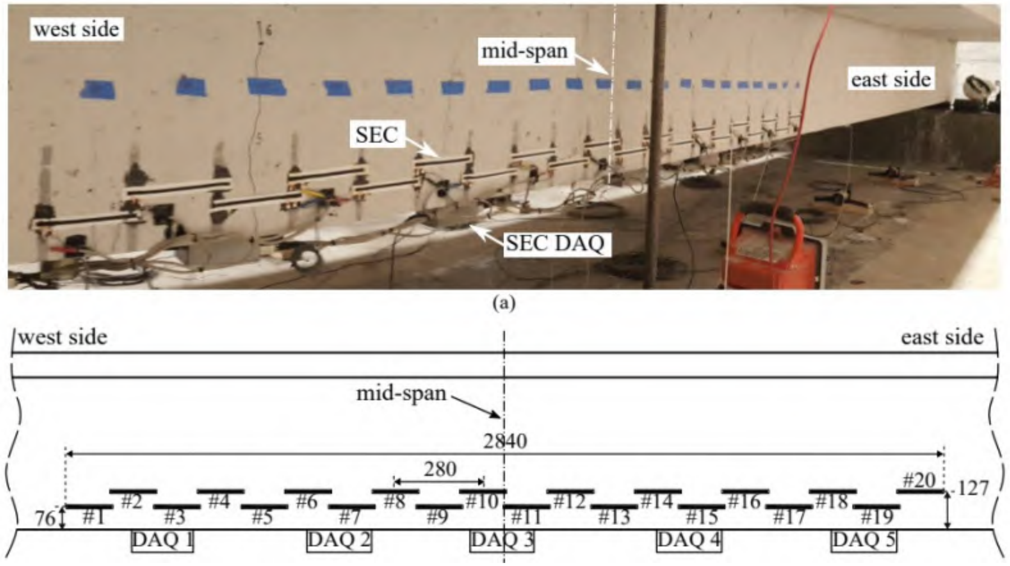

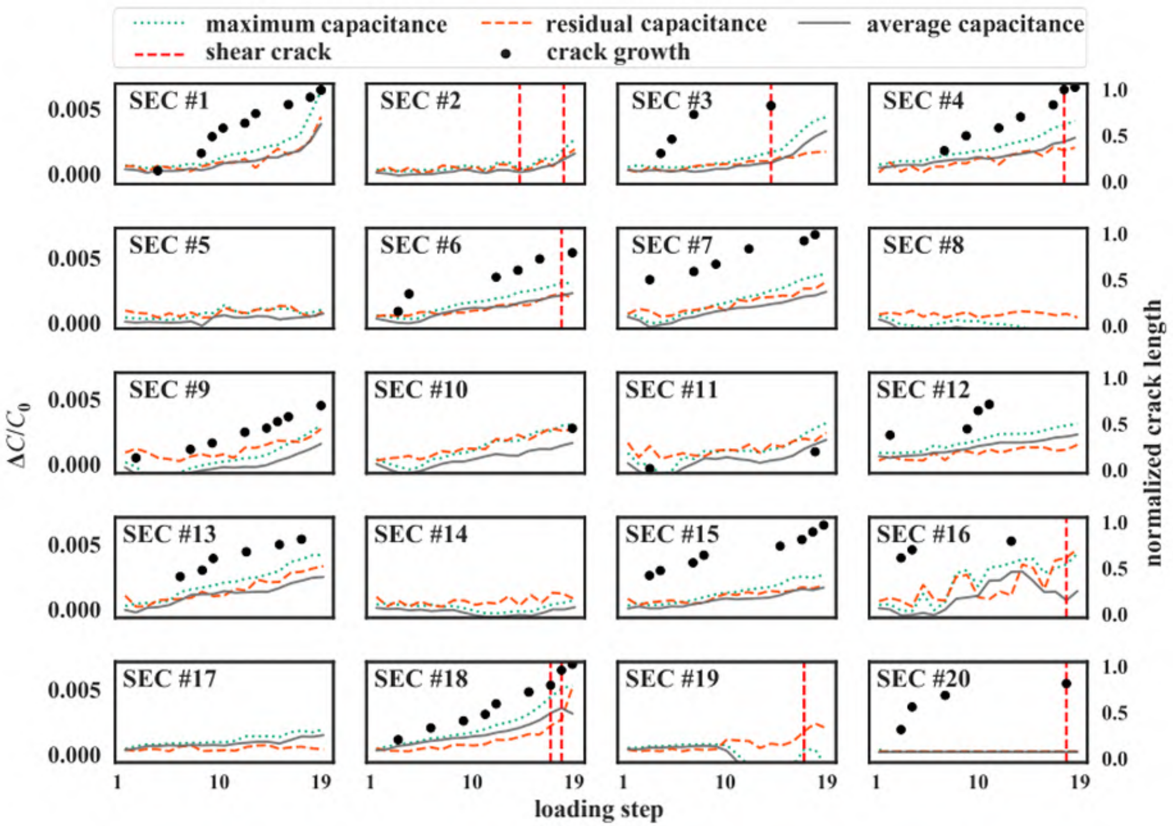

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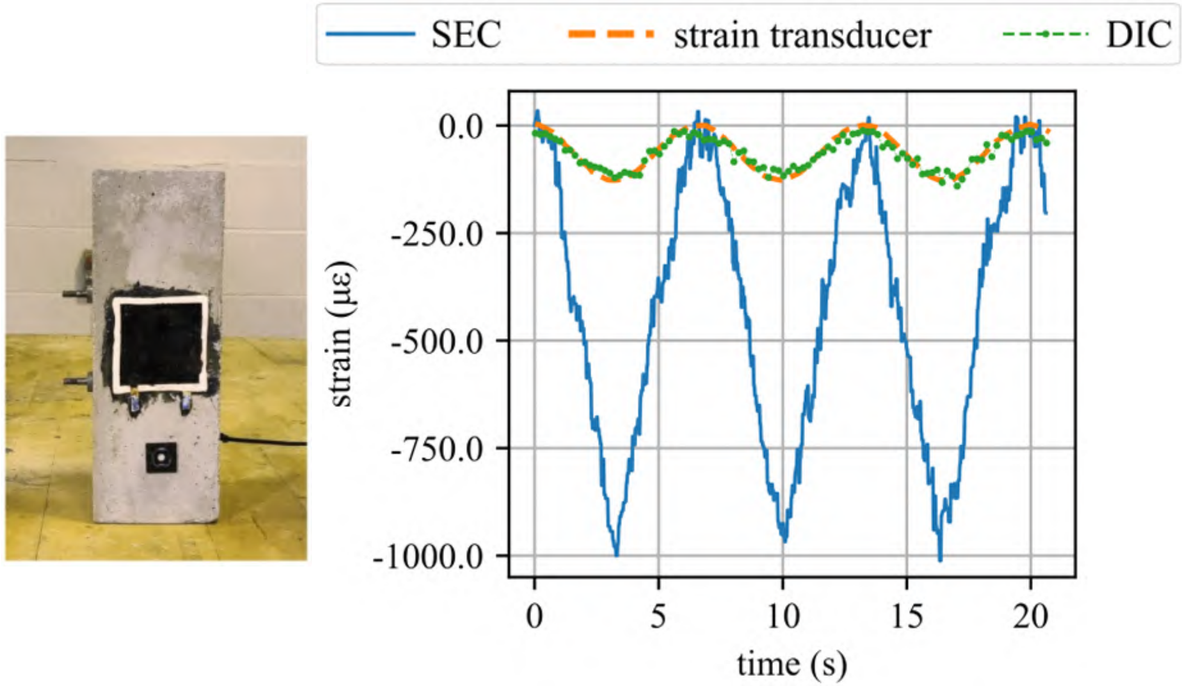
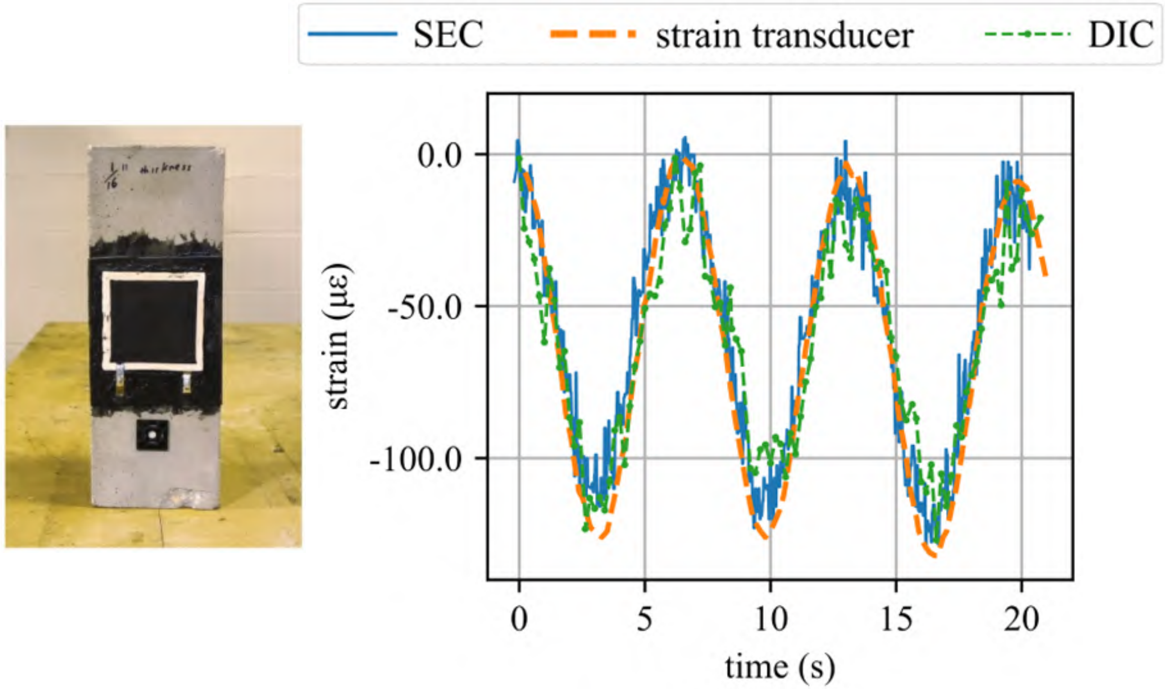
BACKGROUND: PREVIOUS WORKS

Investigation of electrically isolated capacitive sensing skins on concrete to reduce structure/sensor capacitive coupling





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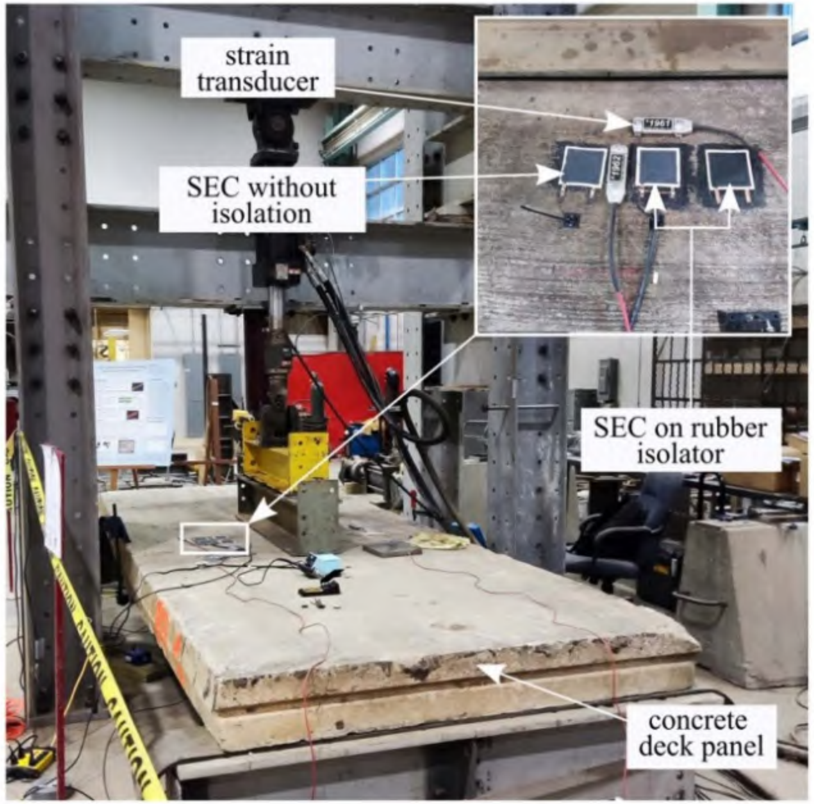

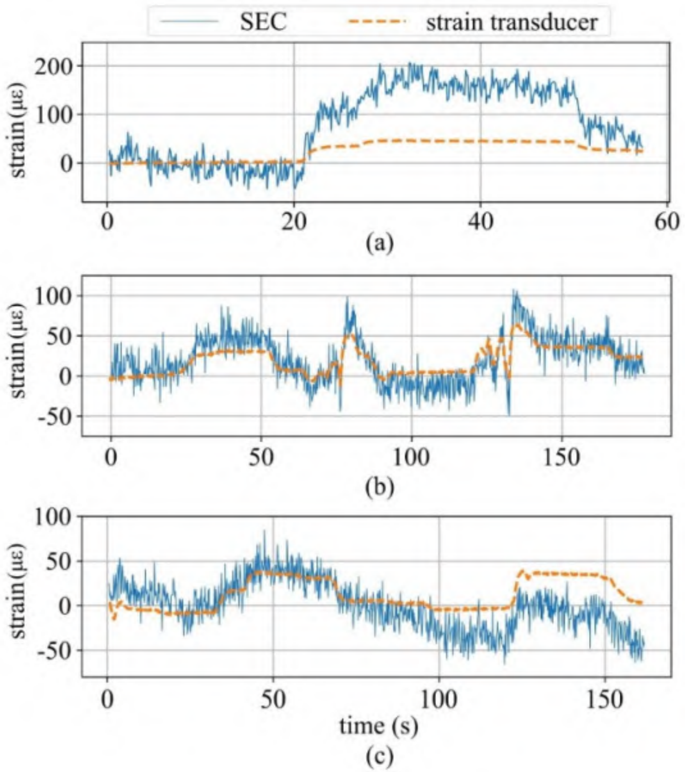

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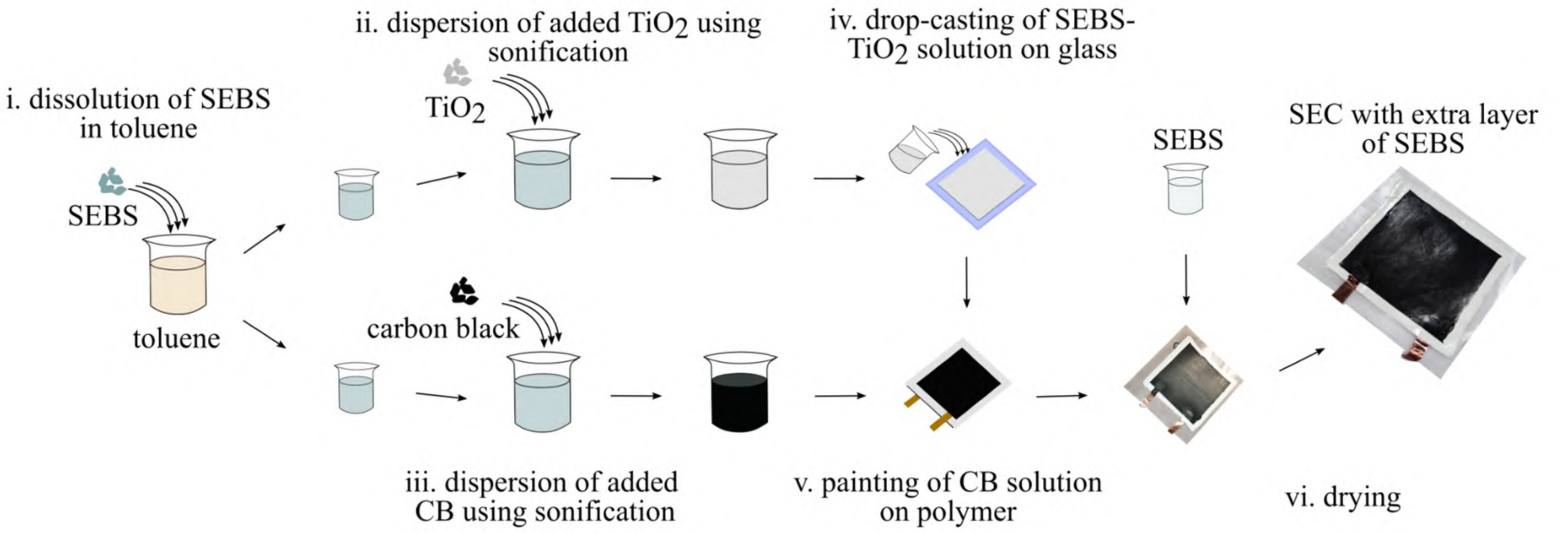
FABRICATION PROCEDURE : EXTENDED SEC



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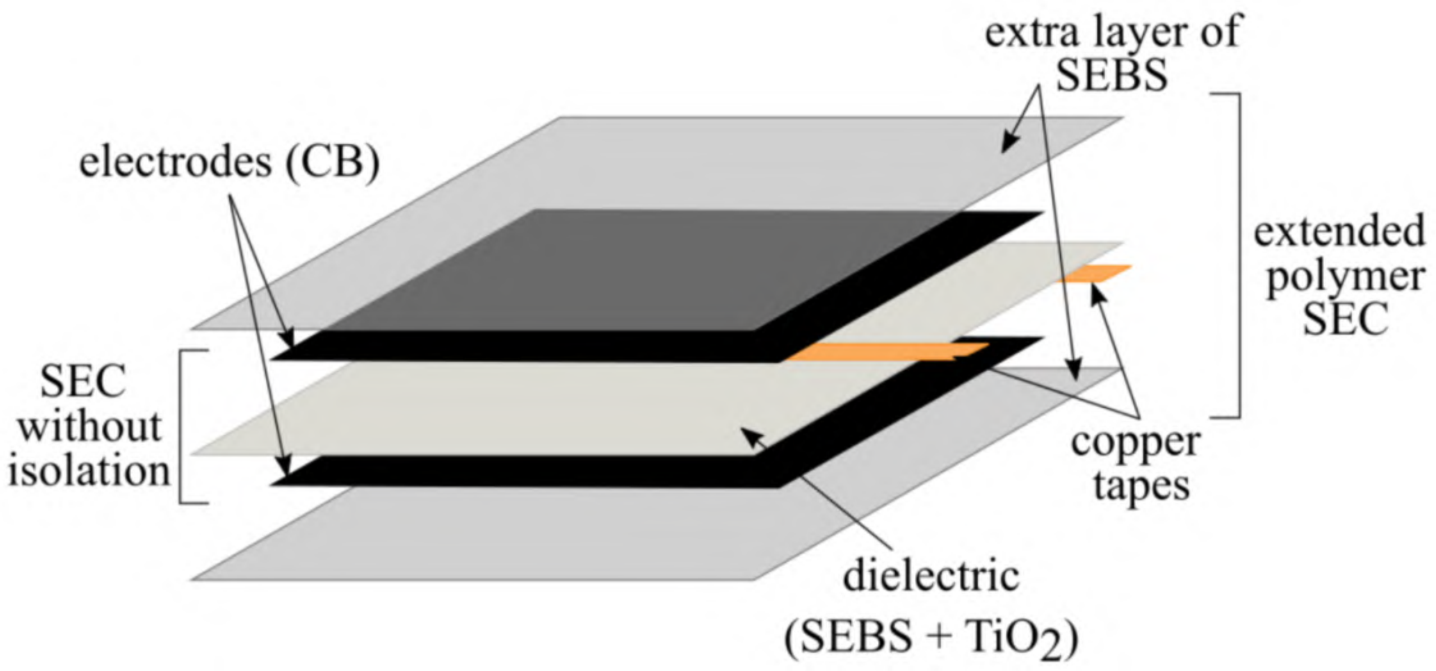
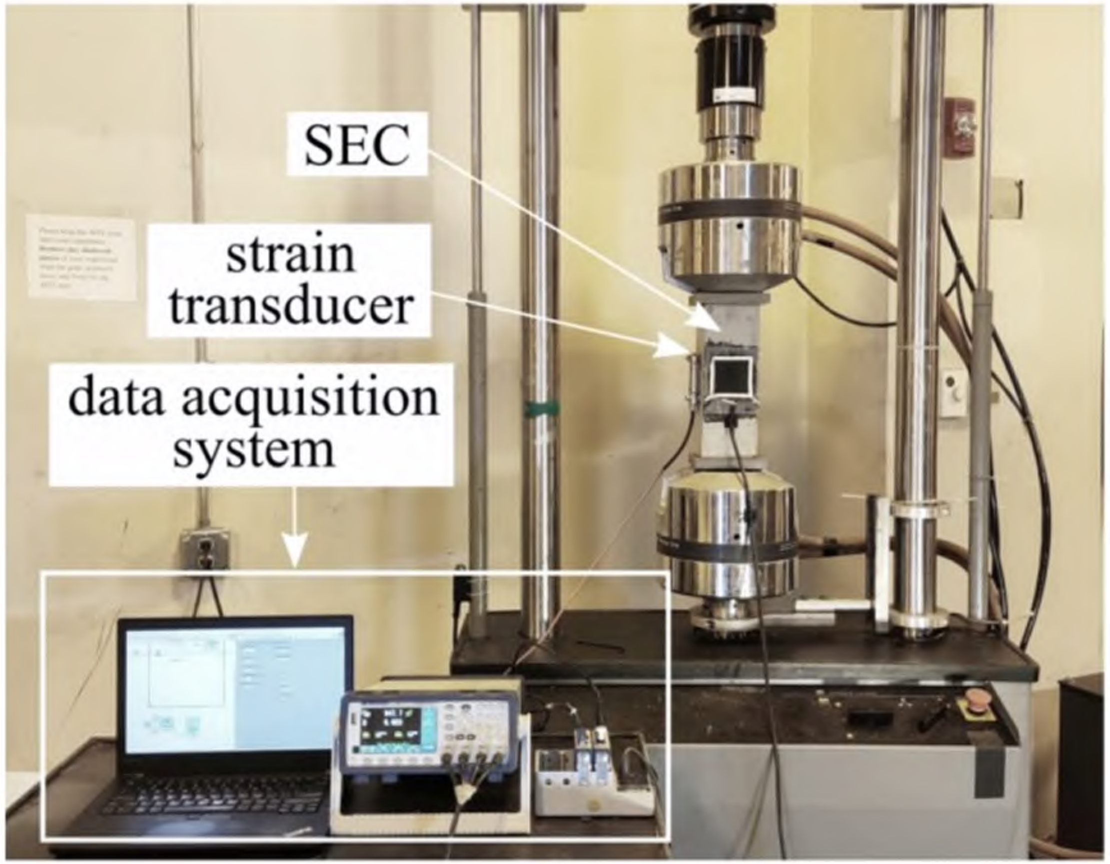
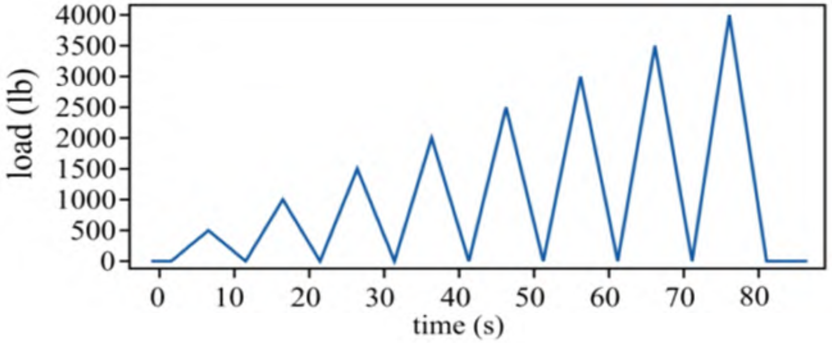
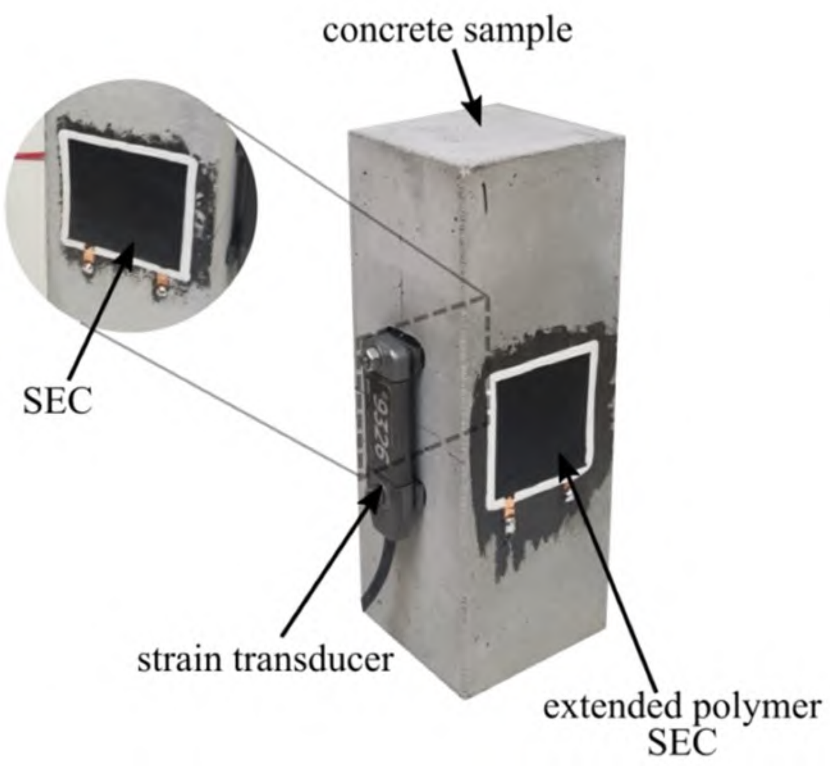


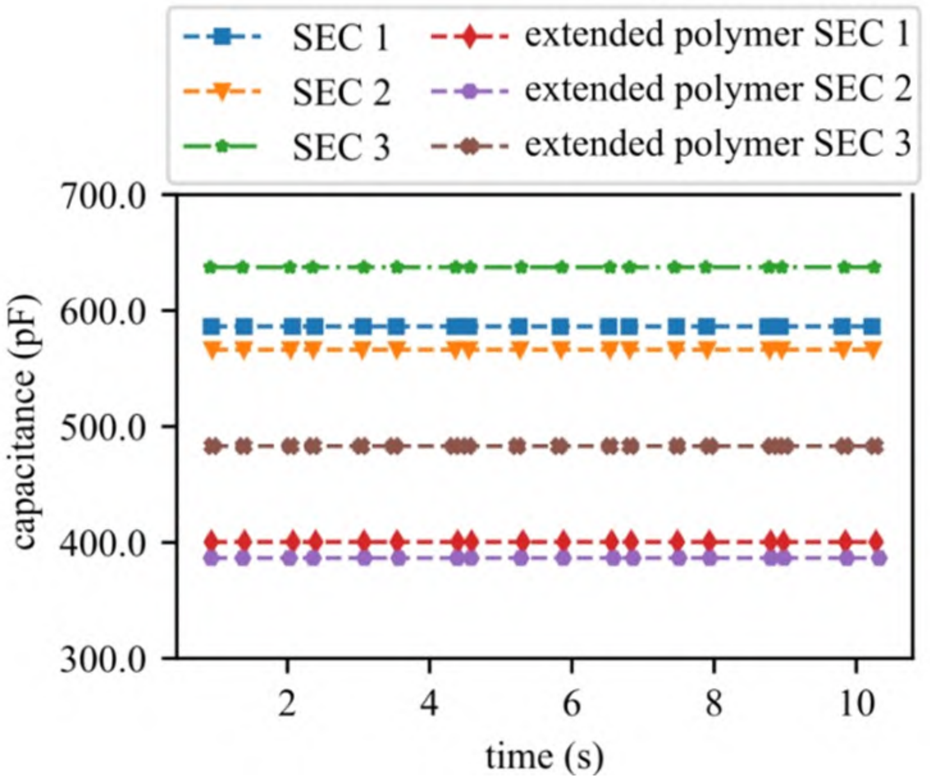
EXPERIMENTAL PROCESS : MATERIAL, SET UP AND LOADING



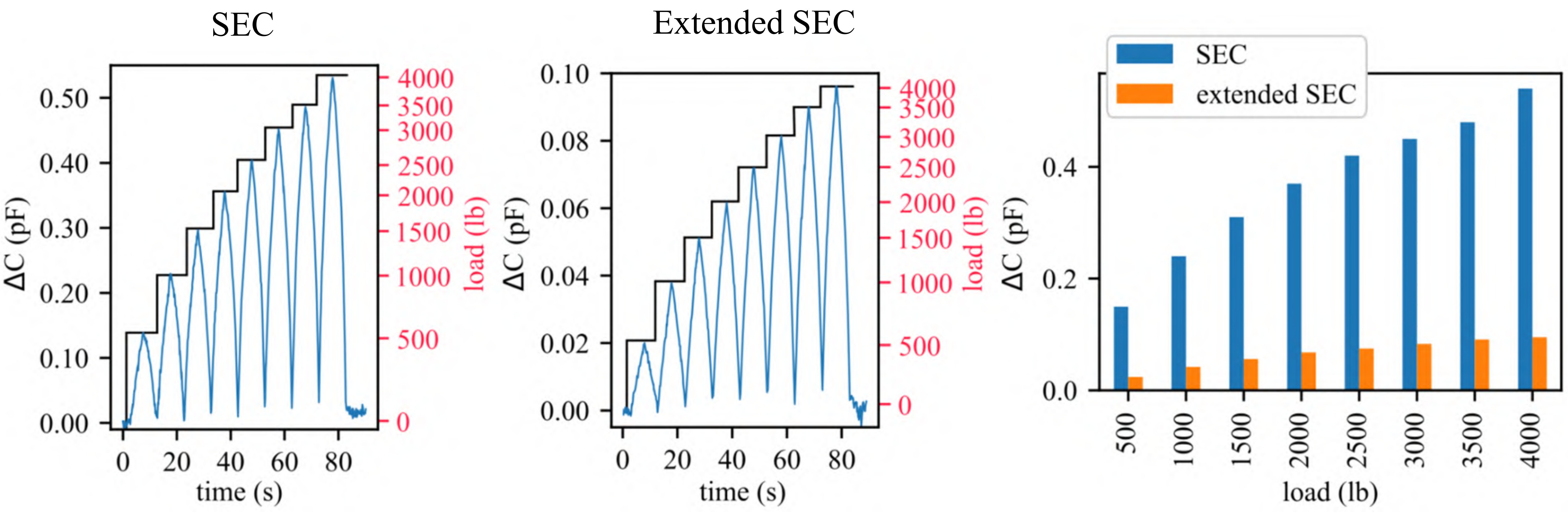


RESULTS AND DISCUSSION: NOMINAL CAPACITANCE

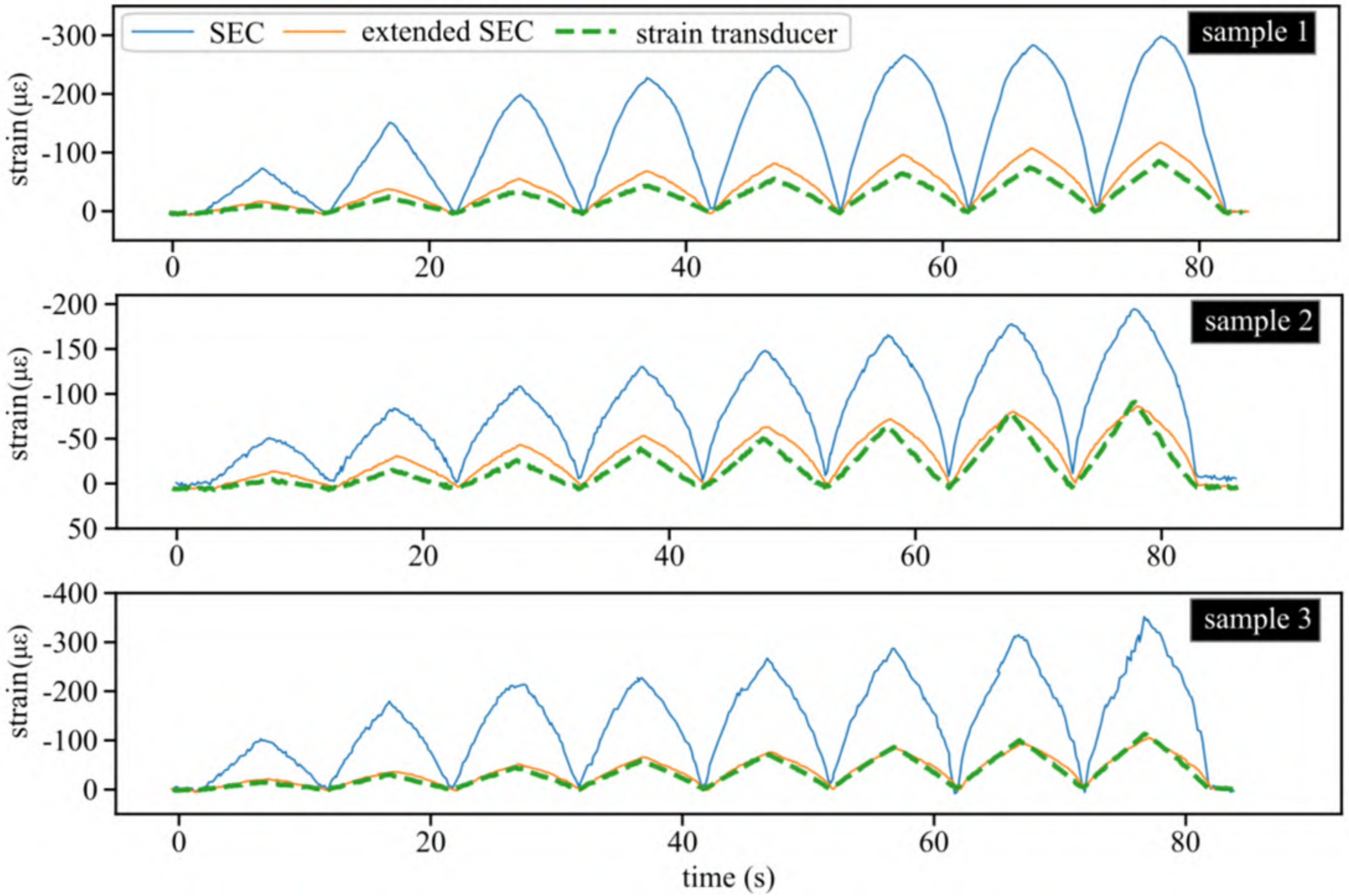




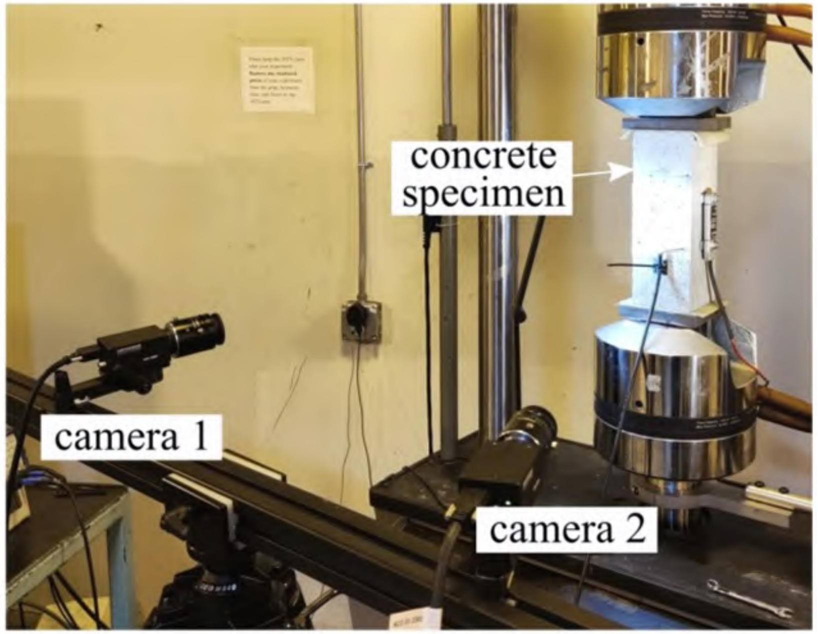
RESULTS AND DISCUSSION : CAPACITANCE AS A FUNCTION OF LOAD

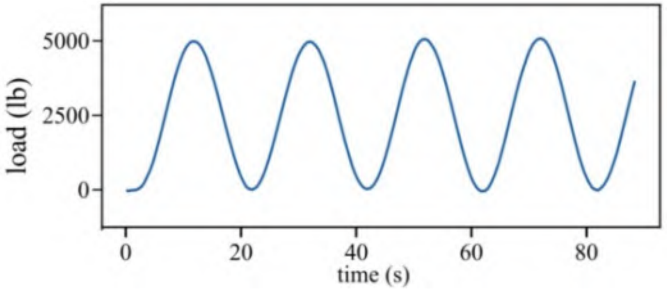


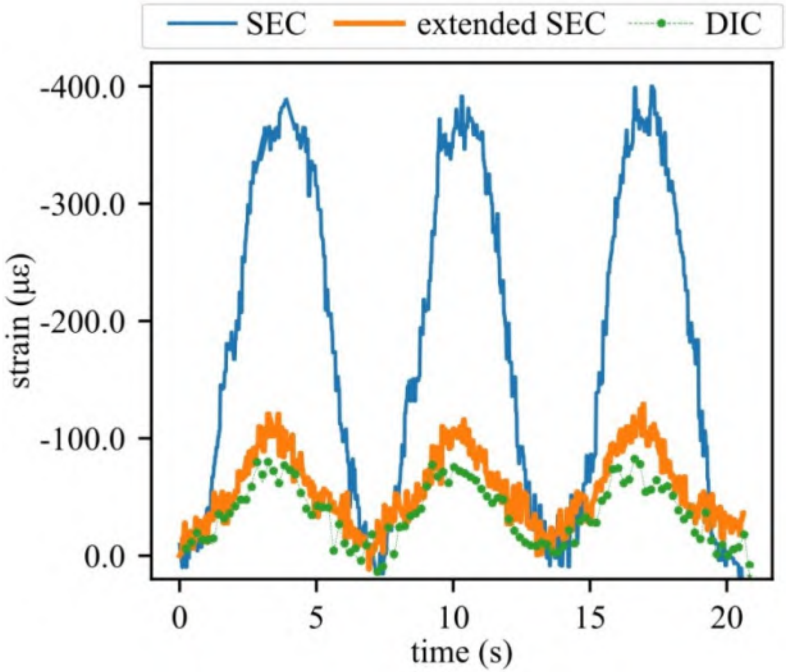
RESULTS AND DISCUSSION: STRAIN DATA FROM THREE SAMPLES



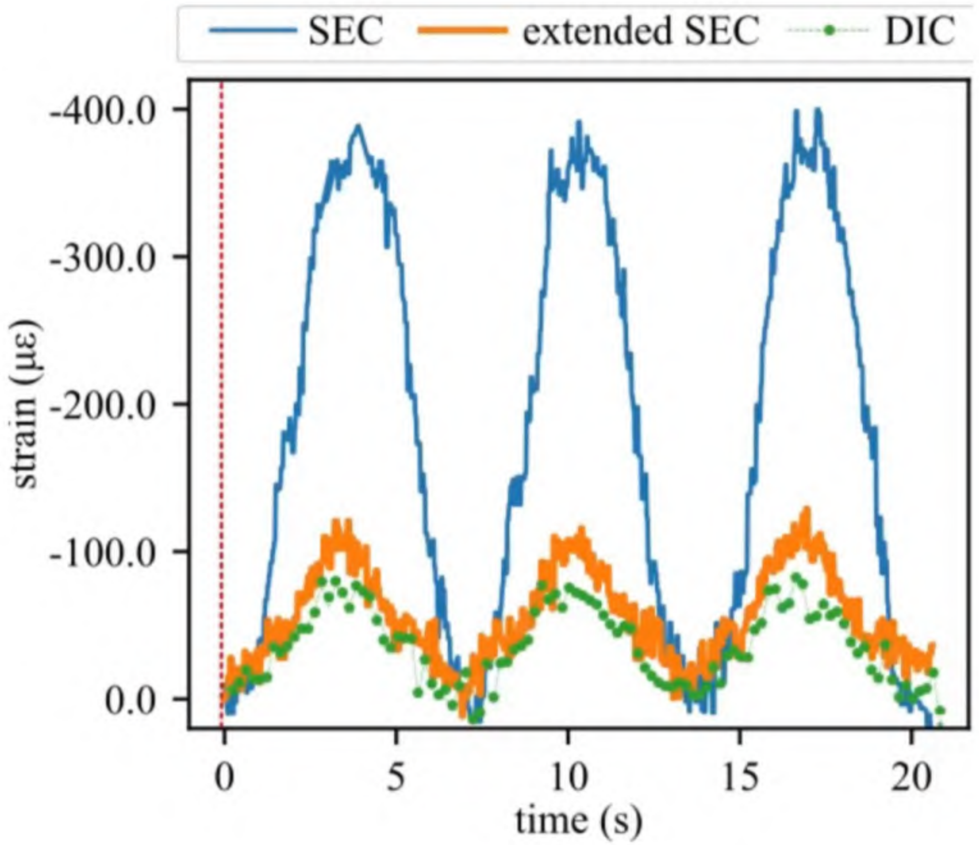
RESULTS AND DISCUSSION : DIC SET UP AND STRAIN DATA

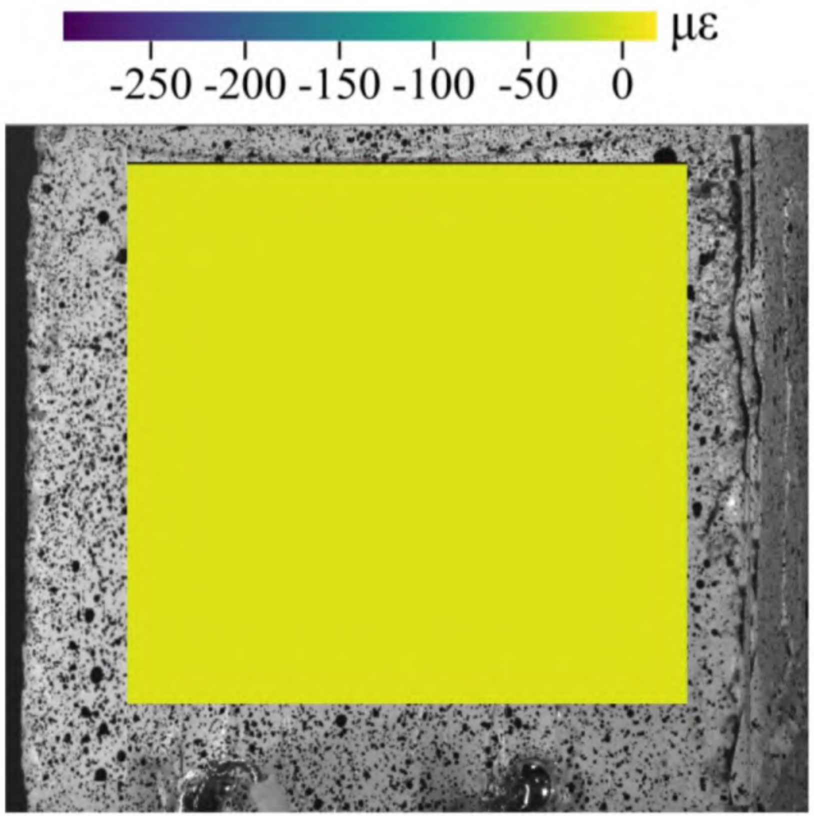




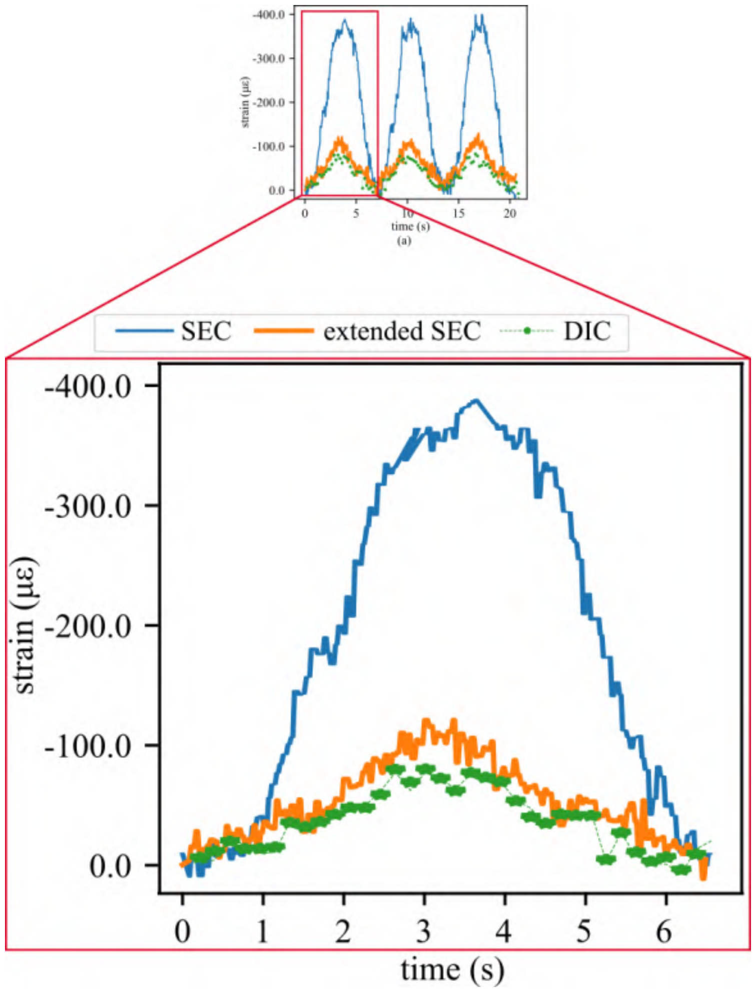


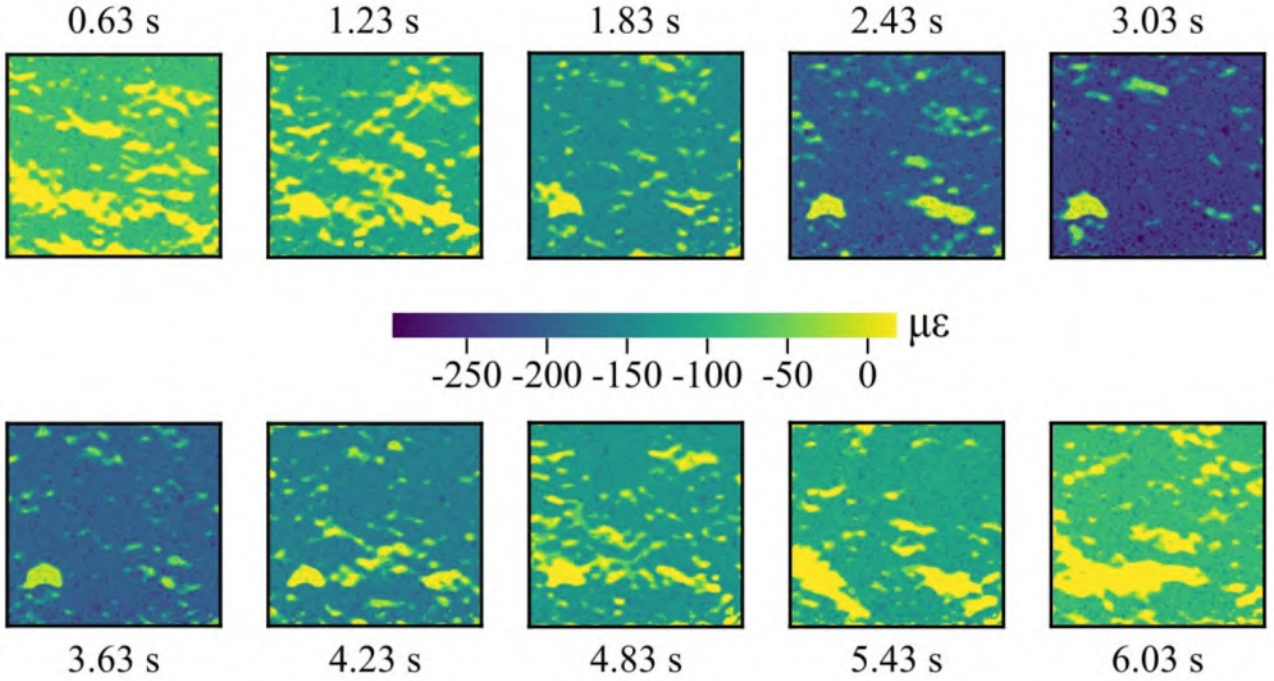
RESULTS AND DISCUSSION : DIC STRAIN DATA





RESULTS AND DISCUSSION : DIC strain data





CONCLUSION

- The investigation showed that added extra layer of SEBS lowers the nominal capacitance of the sensor

- Strain results from the extended SEC aligns better with the strain transducer and Digital image correlation showing reduction of capacitive coupling between the sensor/concrete interface.

Future Work

- The extended SEC will be applied for long time monitoring of fatigue cracks in concrete infrastructures

ACKNOWLEDGEMENT

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THANKS!

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