4th International Electronic Conference on Sensors and Applications

Recent advances on SHM of reinforced concrete and masonry structures enabled by self-sensing structural materials

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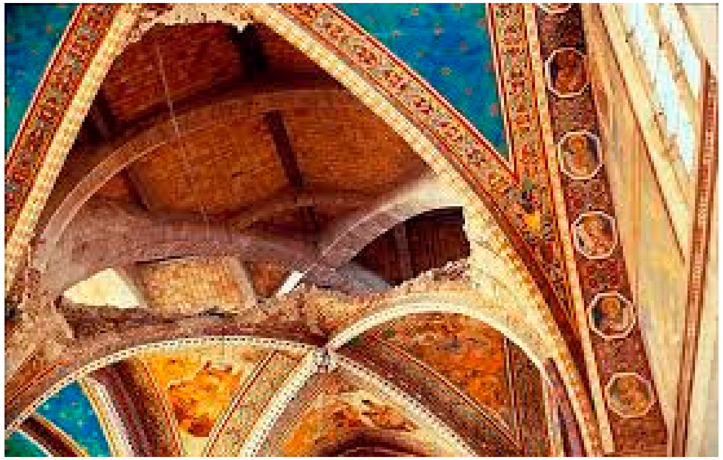
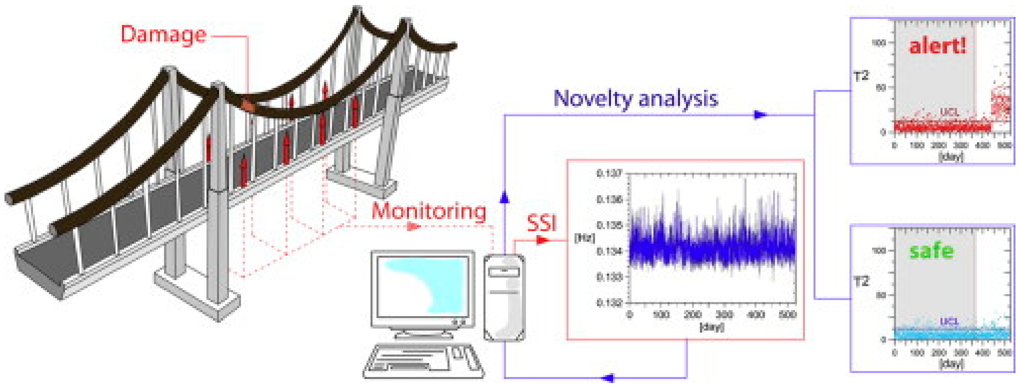
November 15th 2017

Outline

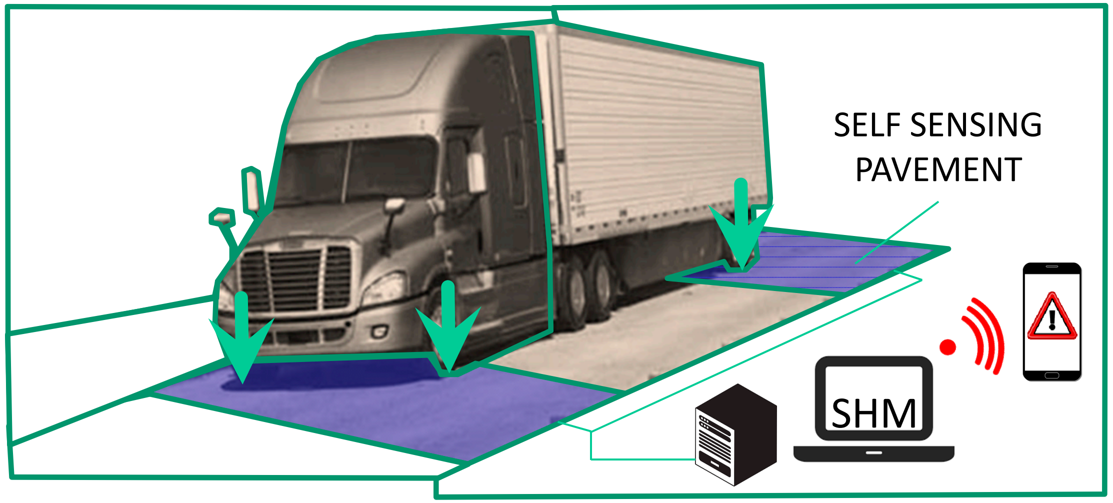
Aim: to introduce a novel approach to SHM of civil structures based on self-sensing structural materials and sensors

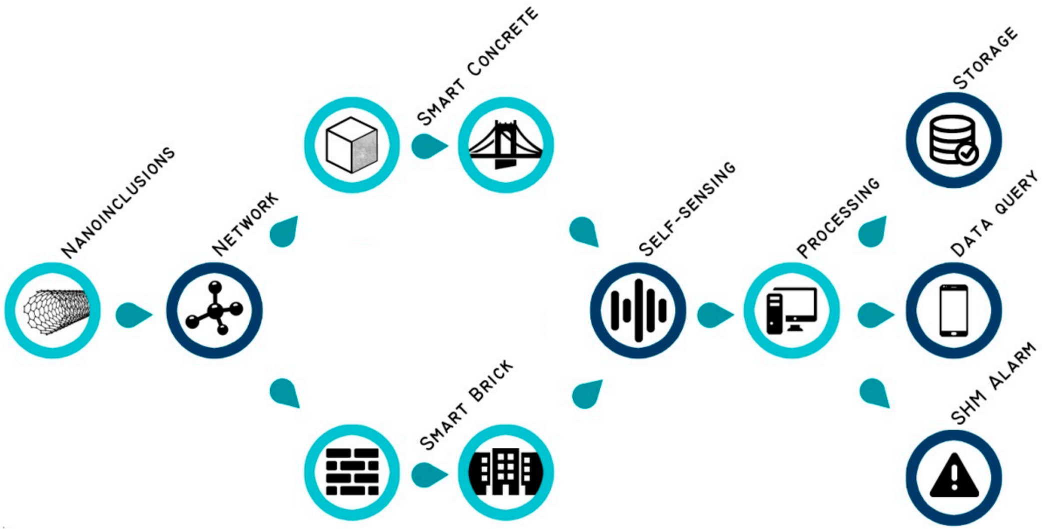
Motivation: the scalability challenge in SHM





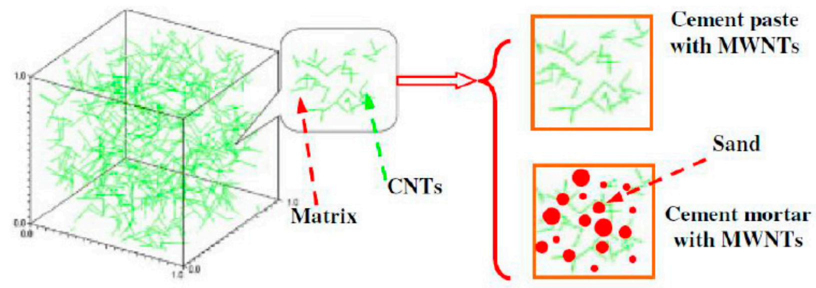
Motivation: what is a self-sensing system?





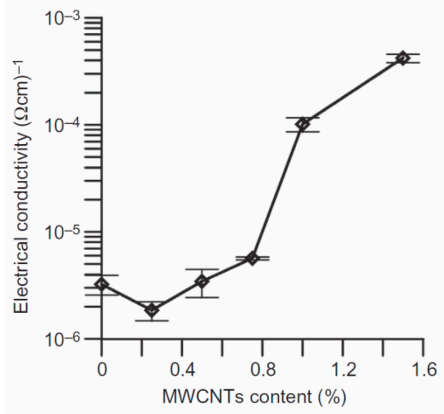
Smart Concrete: concept and fabrication

Idea: diffused sensing for SHM of concrete structures



Han et al., 2011

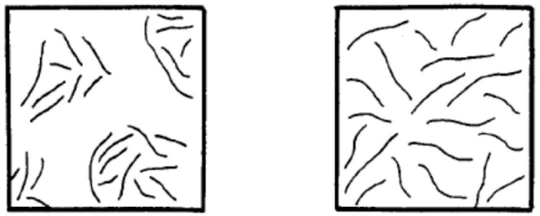
Percolation



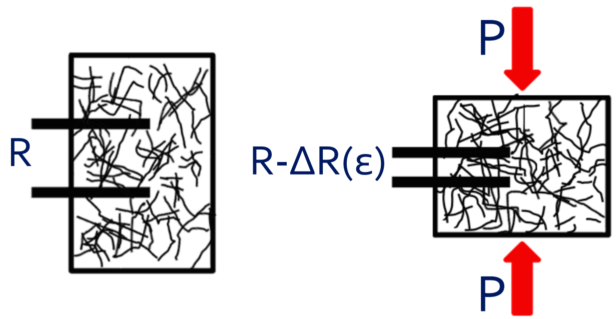
Effect of dispersion

Bad dispersion: no percolation R=∞

Good dispersion: percolation (R<∞)

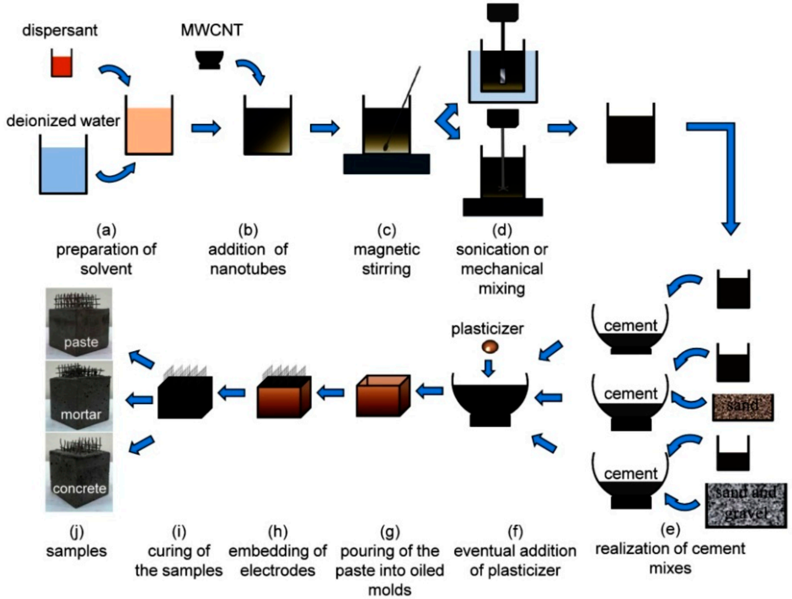


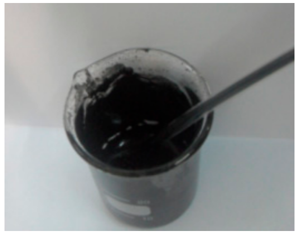
Chung et al., 2003

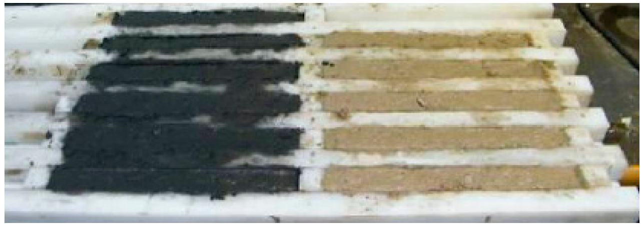


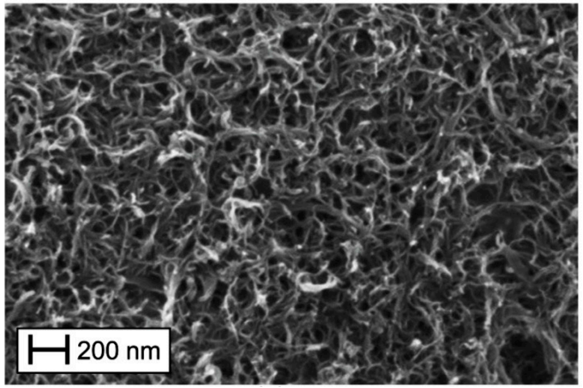
$$\frac{\Delta R}{R} = -\lambda \varepsilon$$

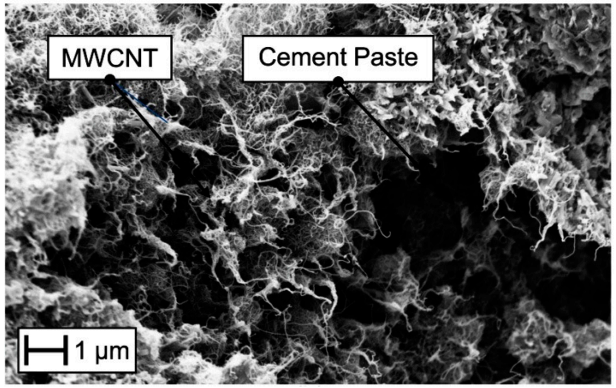
Smart Concrete: concept and fabrication







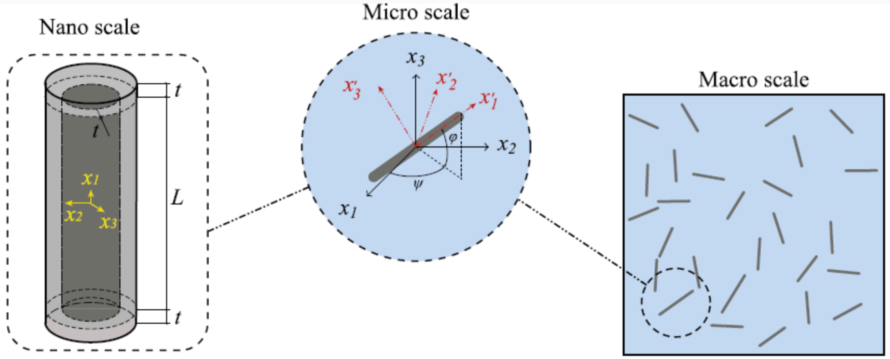




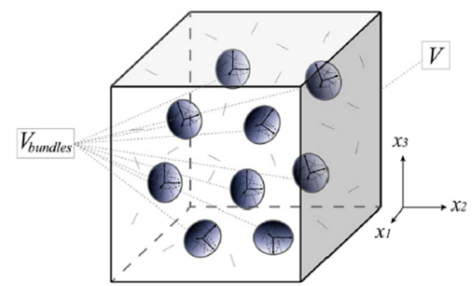
A.L. Materazzi, F. Ubertini, A. D'Alessandro, 2013, Carbon nanotube cement-based transducers for dynamic sensing of strain, Cement & Concrete Composites, 37(1): 2-11.

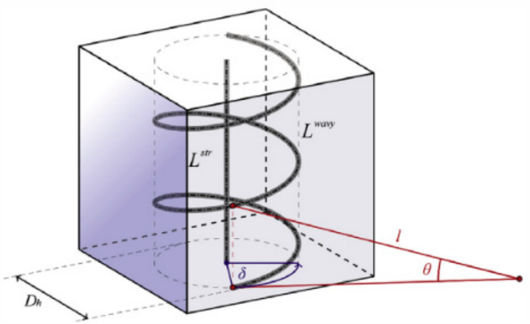
Smart Concrete: micromechanics modeling

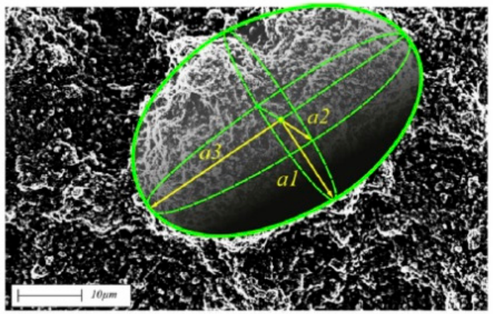
Mori-Tanaka extension of single inclusion Eshelby's problem to multiple inhomogeneities embedded in a finite domain.

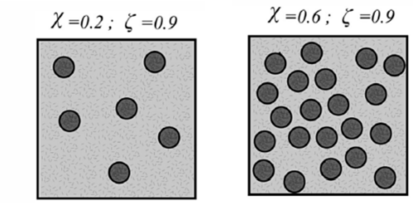


$$\boldsymbol{\sigma}_{eff} = \boldsymbol{\sigma}_m + (1-\xi)\frac{\int_0^{2\pi}\int_0^{\pi}\{f_{eff}(\boldsymbol{\sigma}_{EH}-\boldsymbol{\sigma}_m)\boldsymbol{A}_{EH}\}p(\varphi,\psi)\sin\varphi \mathrm{d}\varphi \mathrm{d}\psi}{\int_0^{2\pi}\int_0^{\pi}p(\varphi,\psi)\sin\varphi \mathrm{d}\varphi \mathrm{d}\psi} + \xi\frac{\int_0^{2\pi}\int_0^{\pi}\{f_{eff}(\boldsymbol{\sigma}_{CN}-\boldsymbol{\sigma}_m)\boldsymbol{A}_{CN}\}p(\varphi,\psi)\sin\varphi \mathrm{d}\varphi \mathrm{d}\psi}{\int_0^{2\pi}\int_0^{\pi}p(\varphi,\psi)\sin\varphi \mathrm{d}\varphi \mathrm{d}\psi}$$





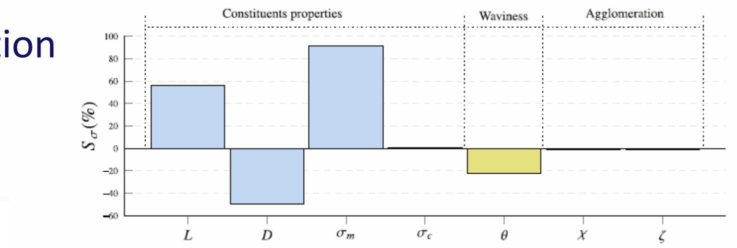


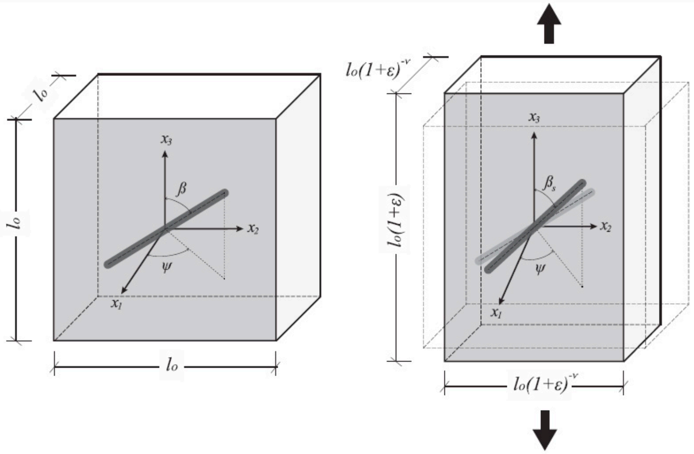


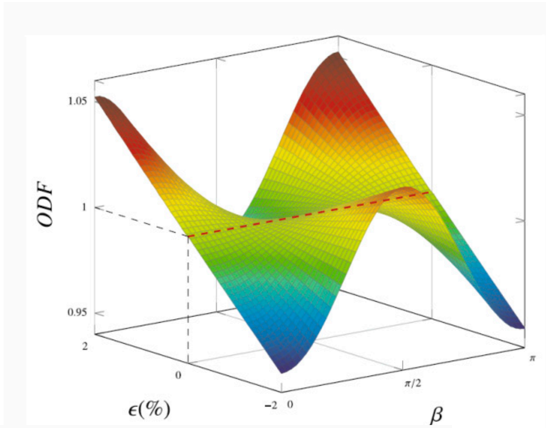
García-Macías, E., D'Alessandro, A., Castro-Triguero, R., Pérez-Mira, D., Ubertini, F., Micromechanics modeling of the electrical conductivity of carbon nanotube cement-matrix composites (2017), Composites Part B: Engineering, Volume 108, Pages 451-469.

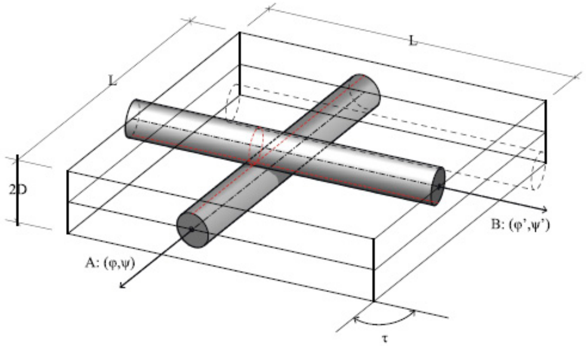
Smart Concrete: micromechanics modeling

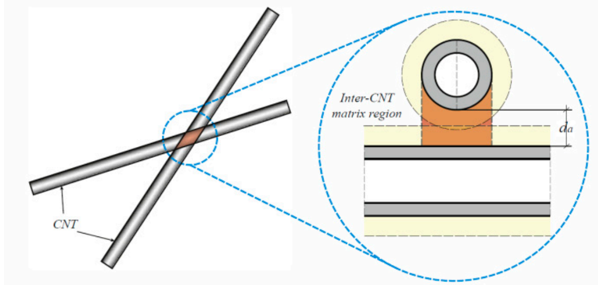
1. Volume expansion and fibers re-orientation
2. Change in conductive networks
3. Change in the tunnelling resistance











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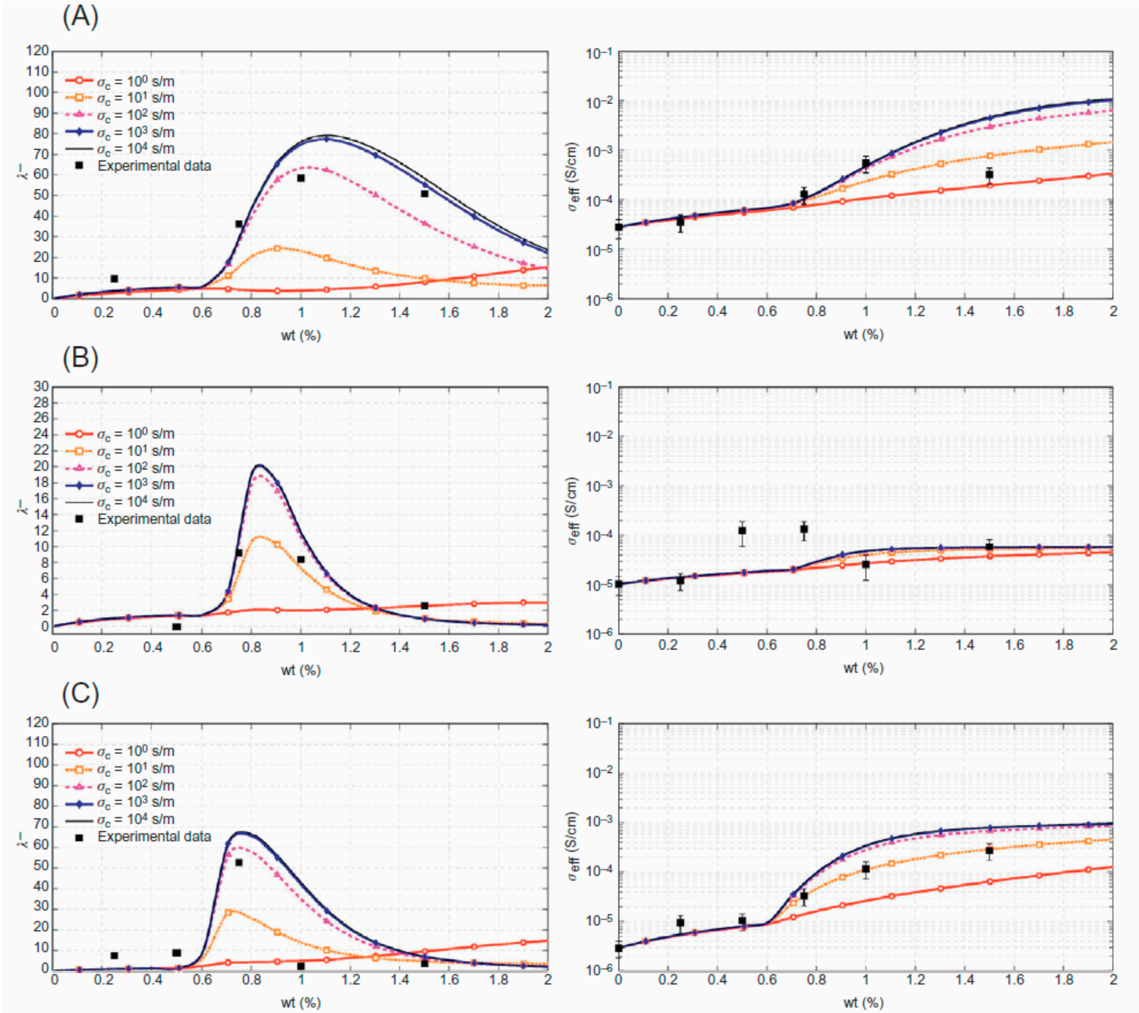
García-Macías, E., D'Alessandro, A., Castro-Triguero, R., Pérez-Mira, D., Ubertini, F., Micromechanics modeling of the uniaxial strain-sensing property of carbon nanotube cement-matrix composites for SHM applications (2017) Composite Structures, 163, pp. 195-215.

Smart Concrete: micromechanics modeling



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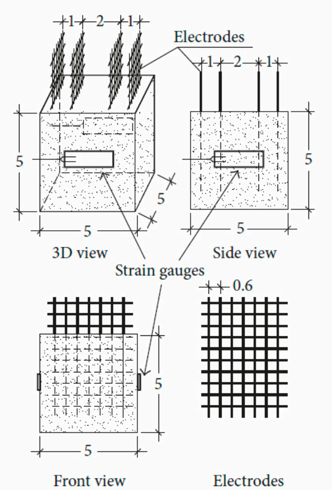
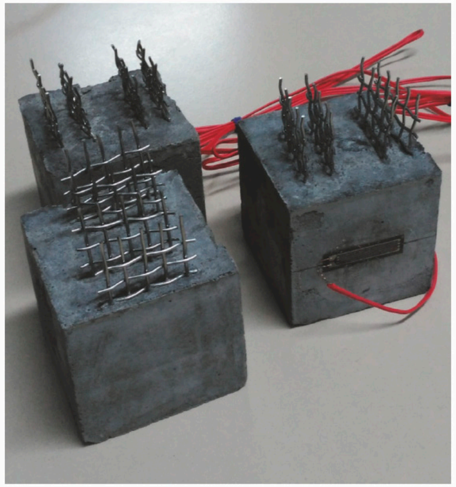
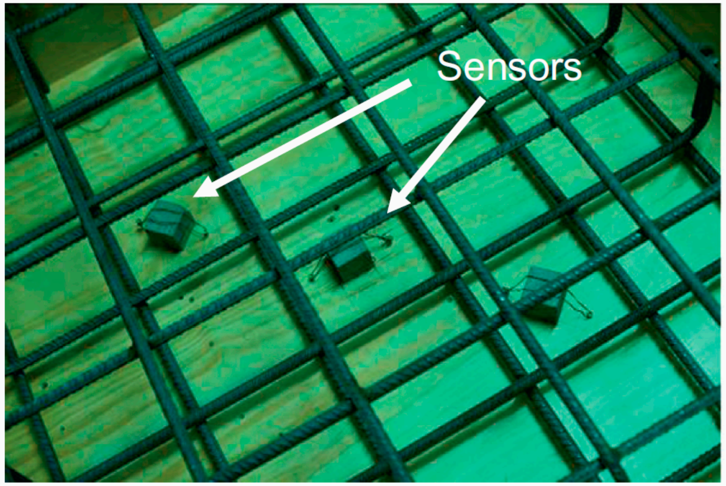
Smart Concrete: smart strain sensors







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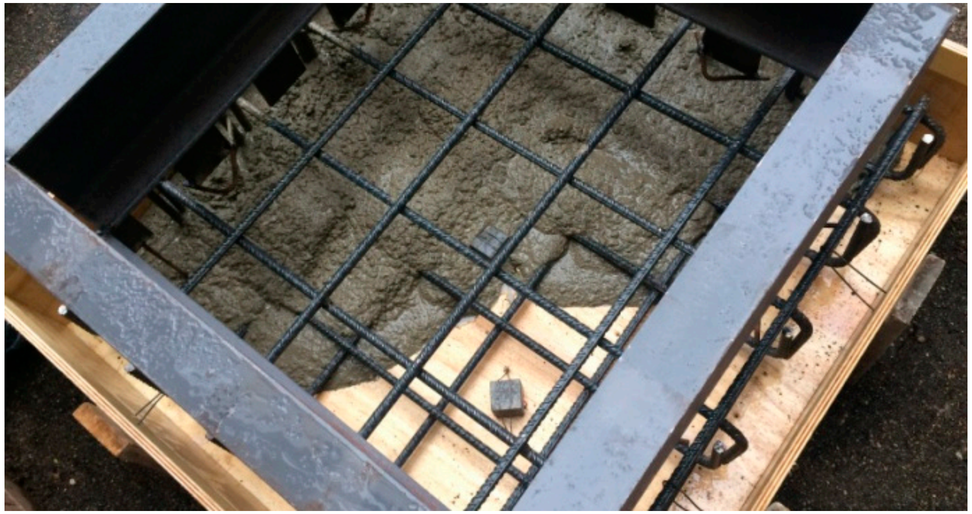

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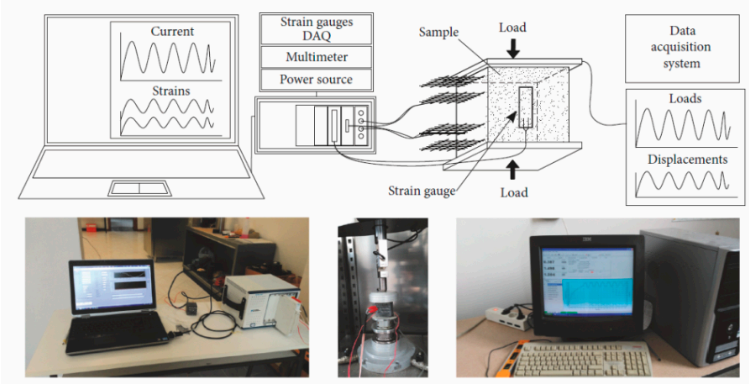
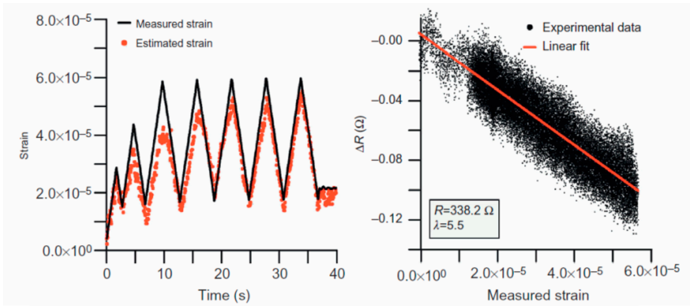
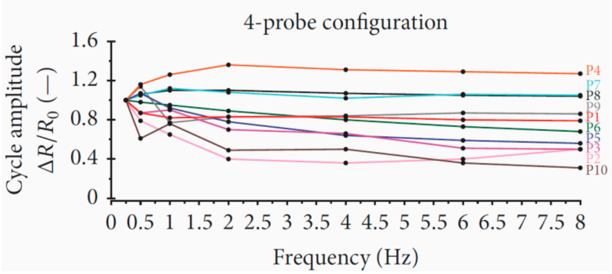
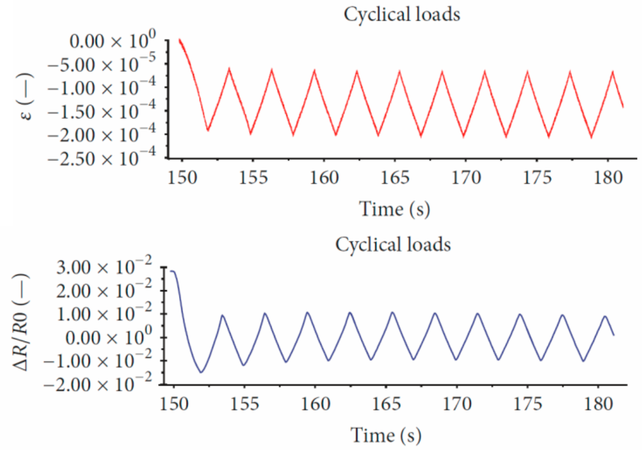
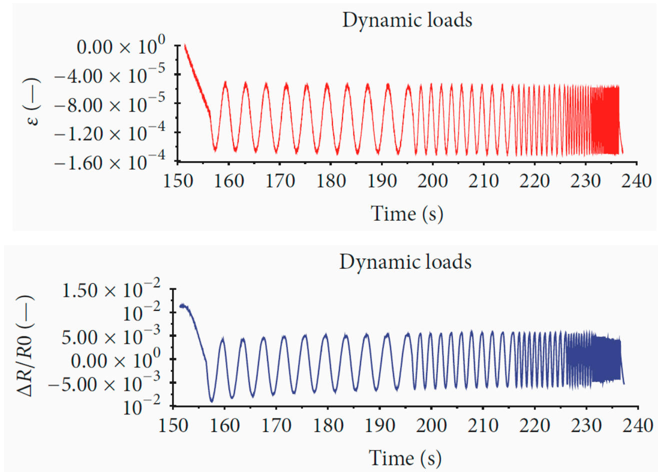
Smart Concrete: characterization of smart strain sensors











D'Alessandro, A., Ubertini, F., García-Macías, E., Castro-Triguero, R., Downey, A., Laflamme, S., Meoni, A., Materazzi, A.L., Static and Dynamic Strain Monitoring of Reinforced Concrete Components through Embedded Carbon Nanotube Cement-Based Sensors(2017) Shock and Vibration, Volume 2017, Article ID 3648403, 11 pages.

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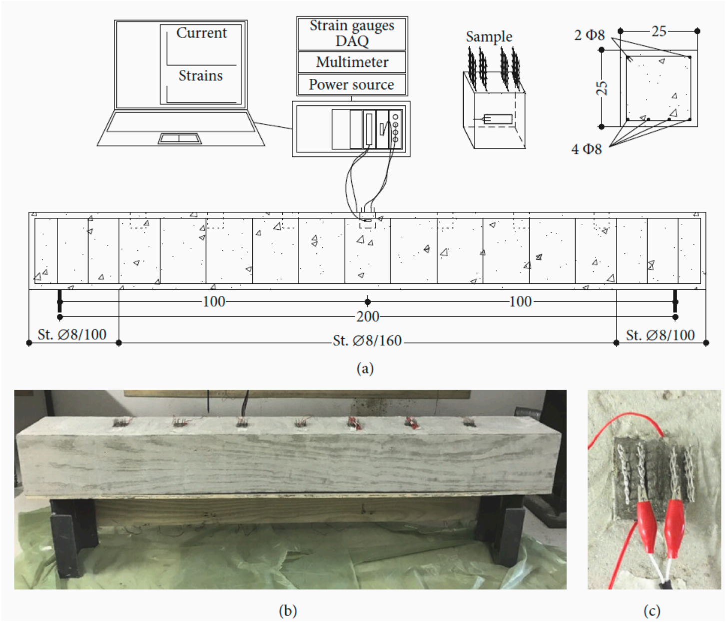
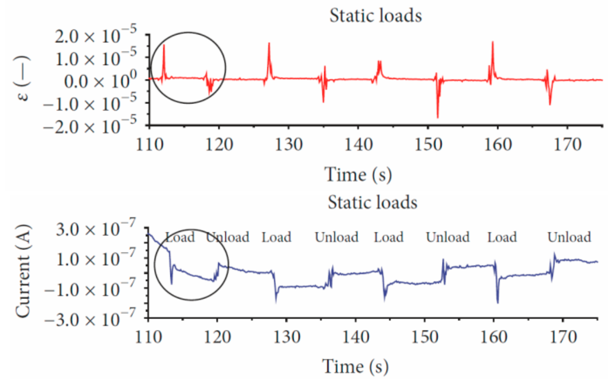
Smart Concrete: embedded smart strain sensors

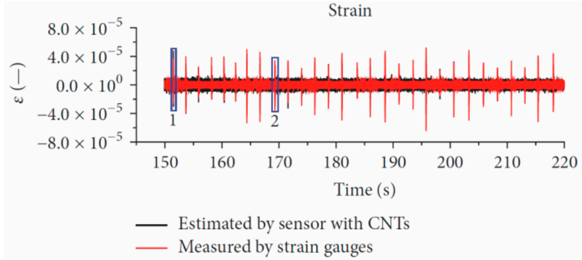


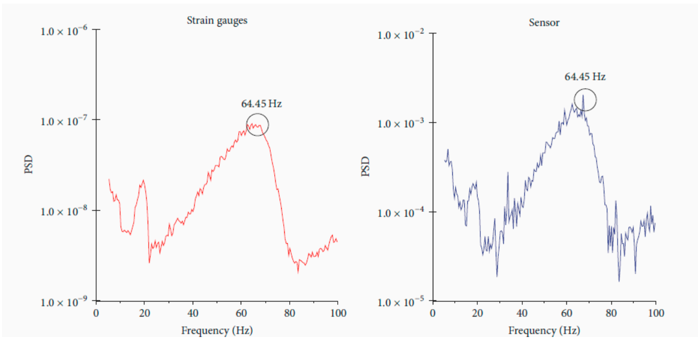
(a)

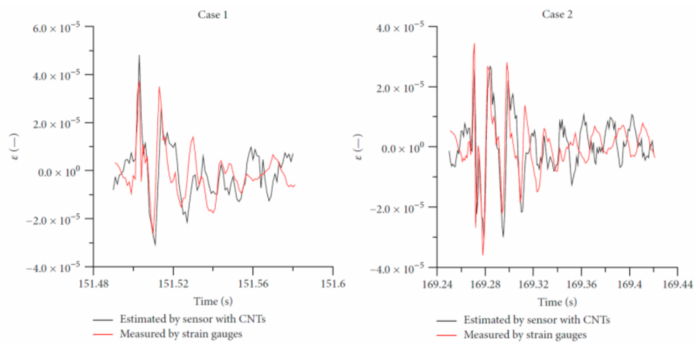
(b)

(c)









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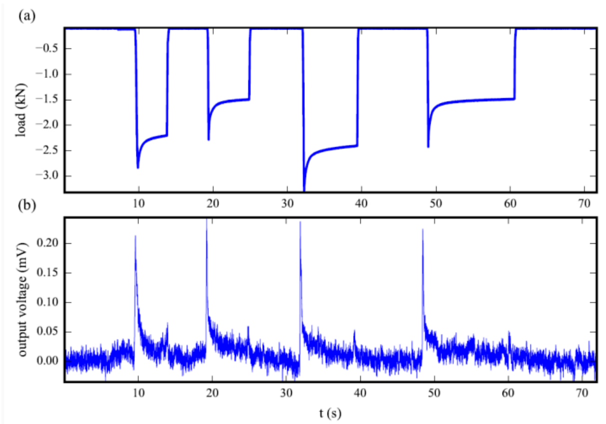
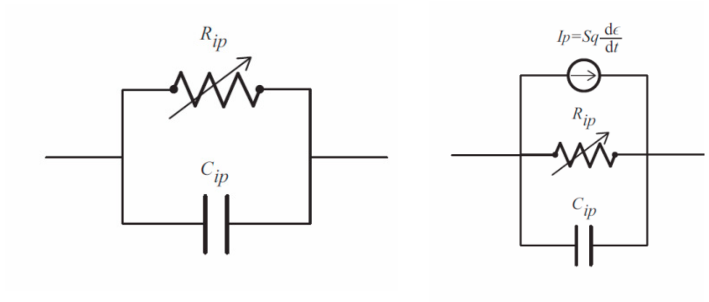
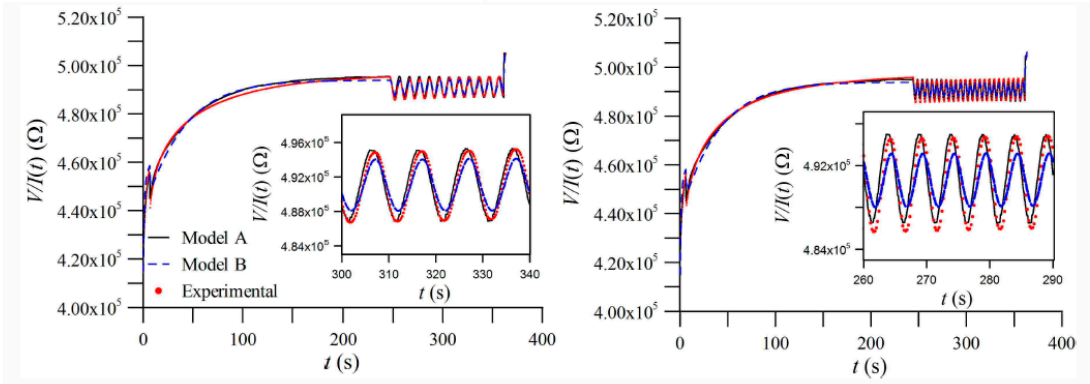
Smart Concrete: electromechanical modeling of smart sensors







Model A (piezoresistive/piezoelectric)						Model B (piezoresistive)					
R_{ct} (kΩ)	200.00	C_{ip} (μF)	300.00	λ	300.00	R_{ct} (kΩ)	404.01	C_{ip} (μF)	19.98	λ	802.55
R_{ip} (kΩ)	289.50	C_{pm} (μF)	2.00E+04	λ_C	2.21E-09	R_{ip} (kΩ)	46.41	C_{pm} (μF)	745.78	λ_C	3.08E-14
R_{pm} (kΩ)	50.00			S_q (A)	-0.40	R_{pm} (kΩ)	54.84			S_q (A)	-

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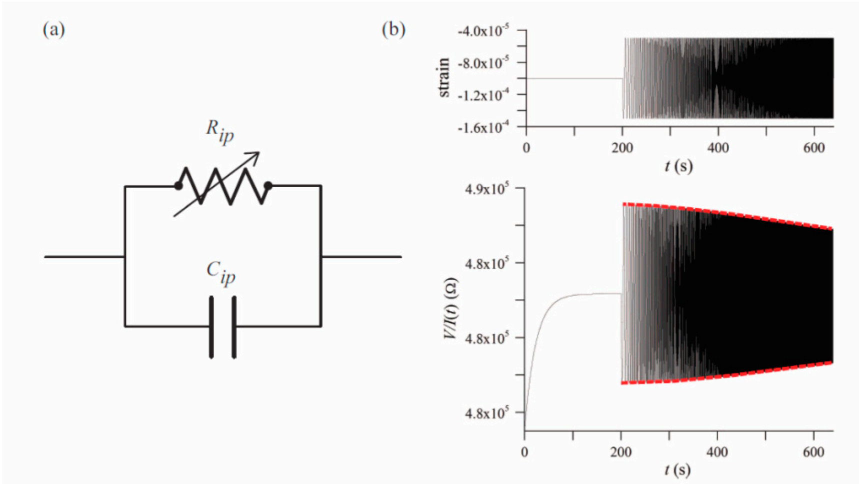
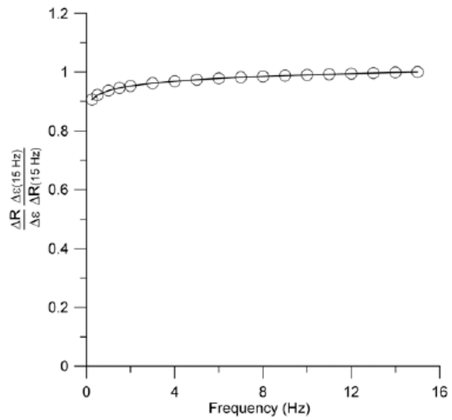
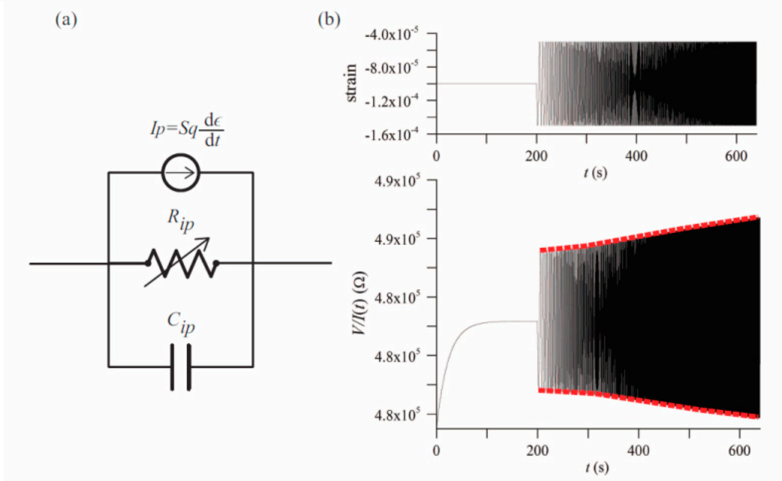
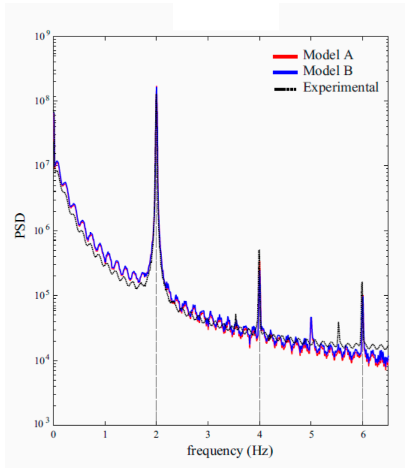
García-Macías, E., Downey, A., D'Alessandro, A., Castro-Triguero, R., Laflamme, S., Ubertini, F., Enhanced lumped circuit model for smart nanocomposite cement-based sensors under dynamic compressive loading conditions (2017), Sensors and Actuators, A: Physical, Volume 260, Pages 45-57.

Smart Concrete: electromechanical modeling of smart sensors









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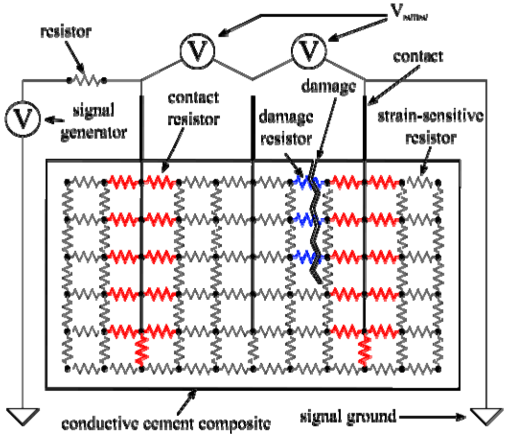
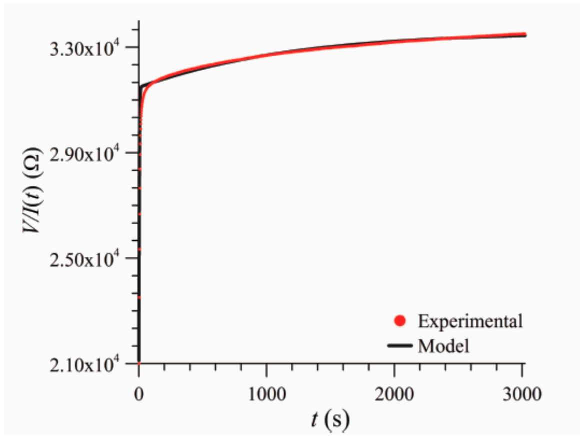
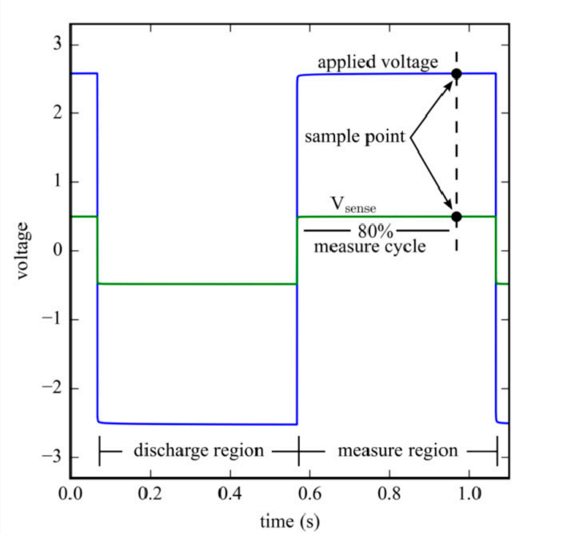
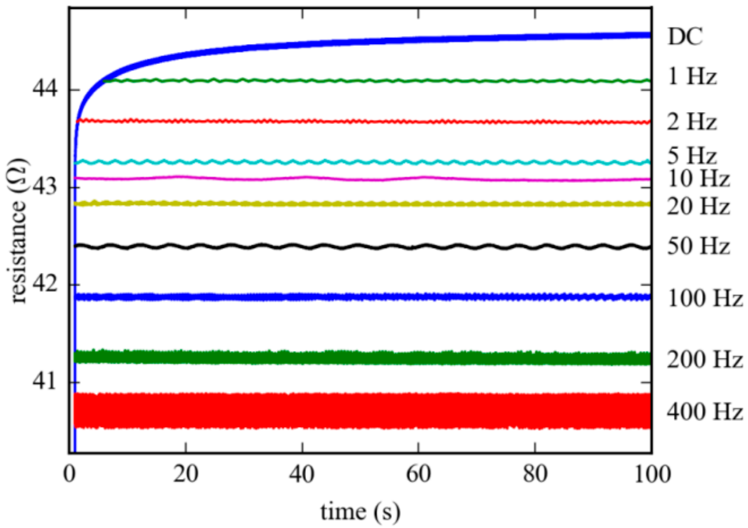
Smart Concrete: smart RC structural components



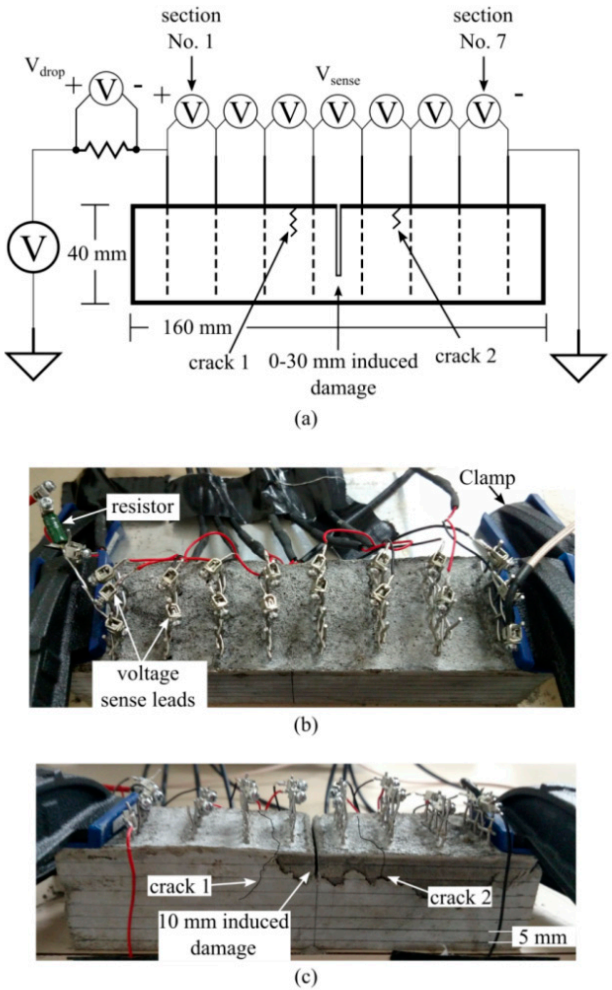


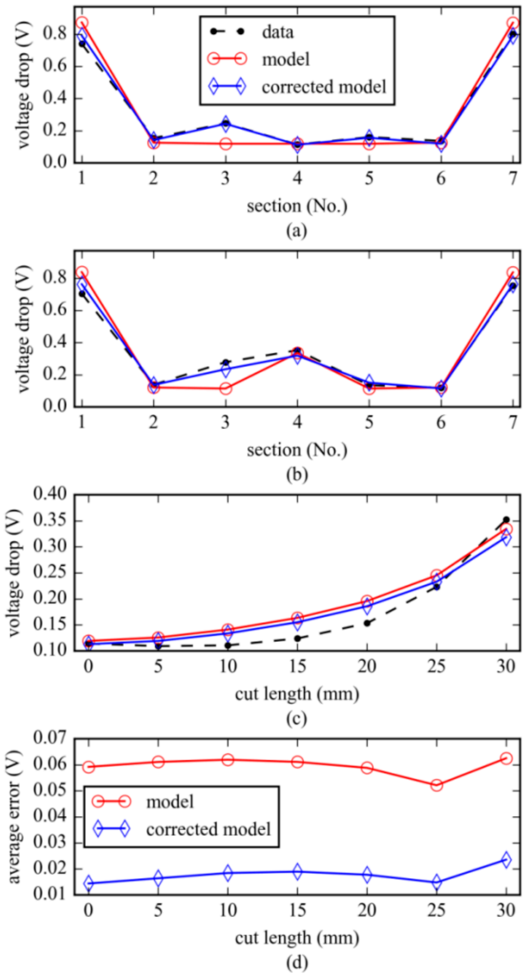




Downey, A., D'Alessandro, A., Ubertini, F., Laflamme, S., Geiger, R., Biphasic DC measurement approach for enhanced measurement stability and multi-channel sampling of self-sensing multi-functional structural materials doped with carbon-based additives (2017), Smart Materials and Structures, Volume 26, Issue 6, Article number 065008.

Smart Concrete: experiment on smart RC beams





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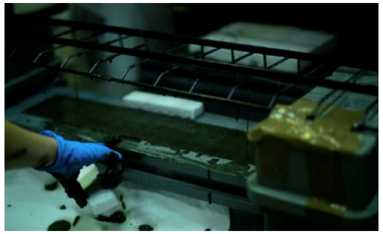

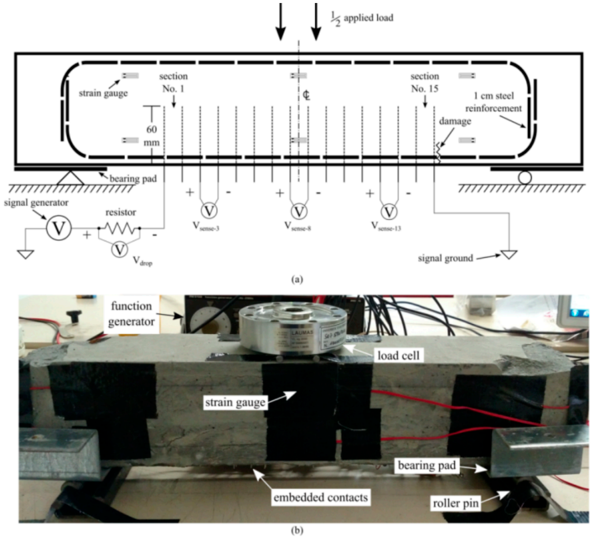

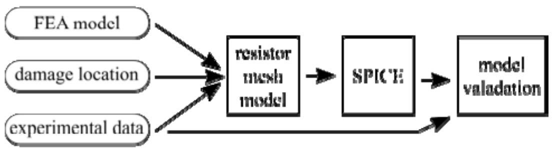

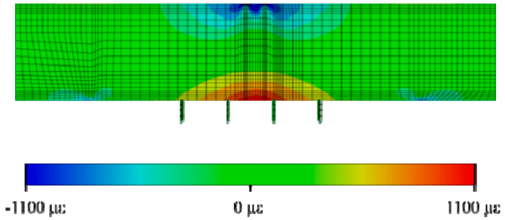

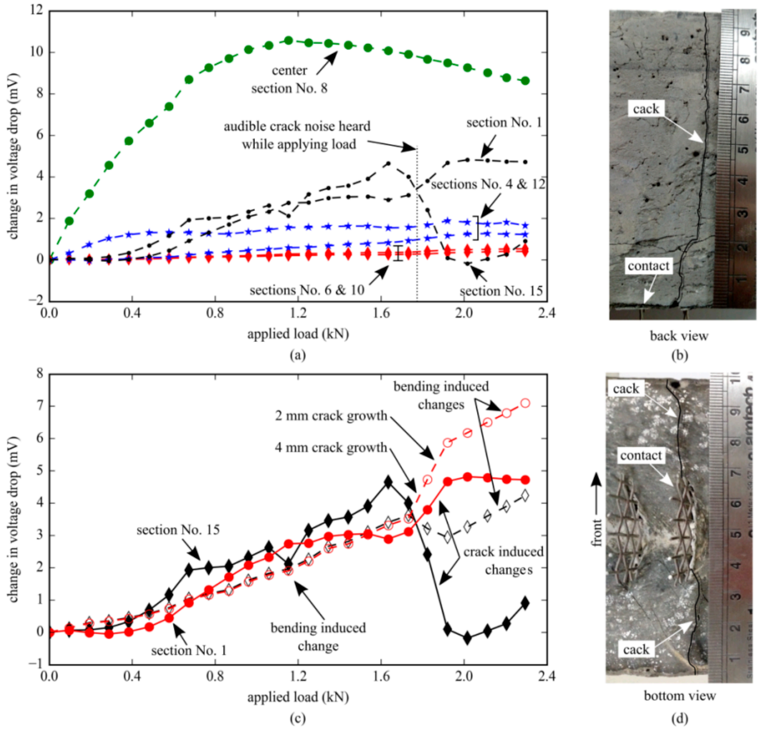

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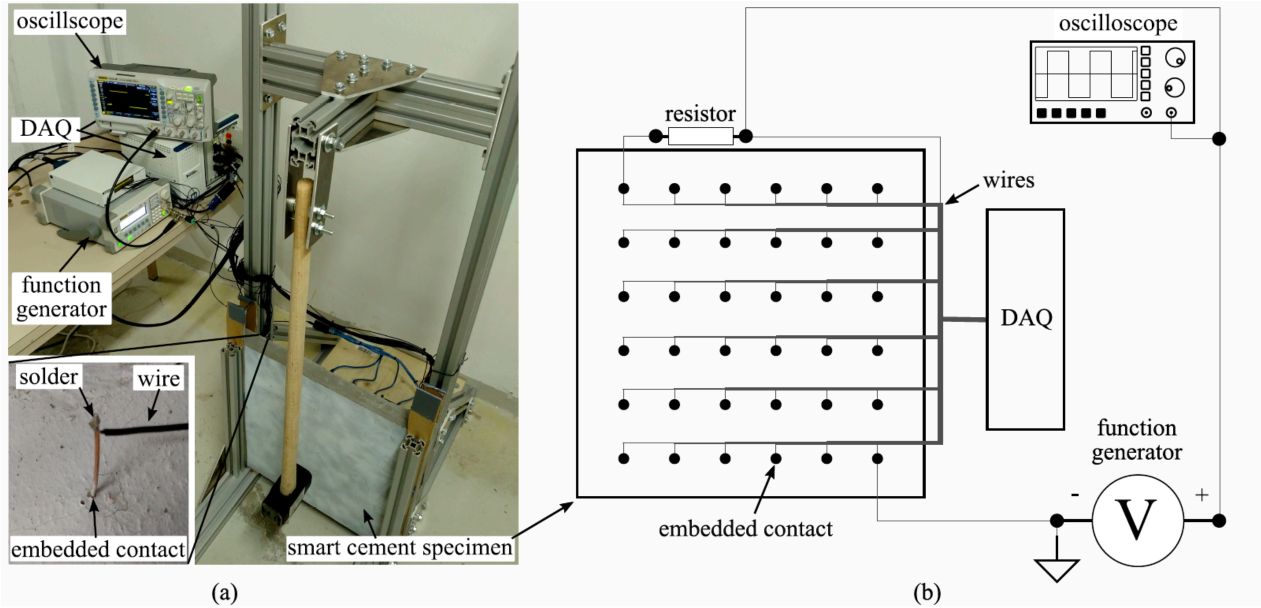
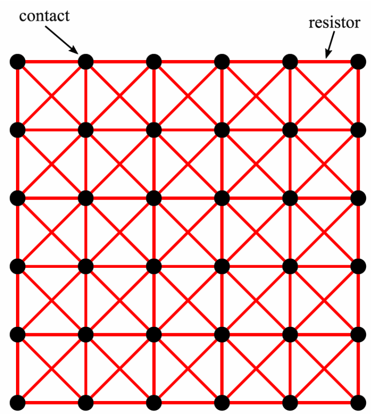
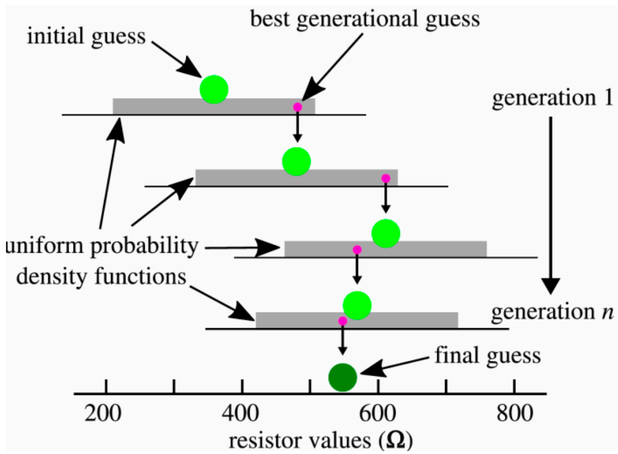
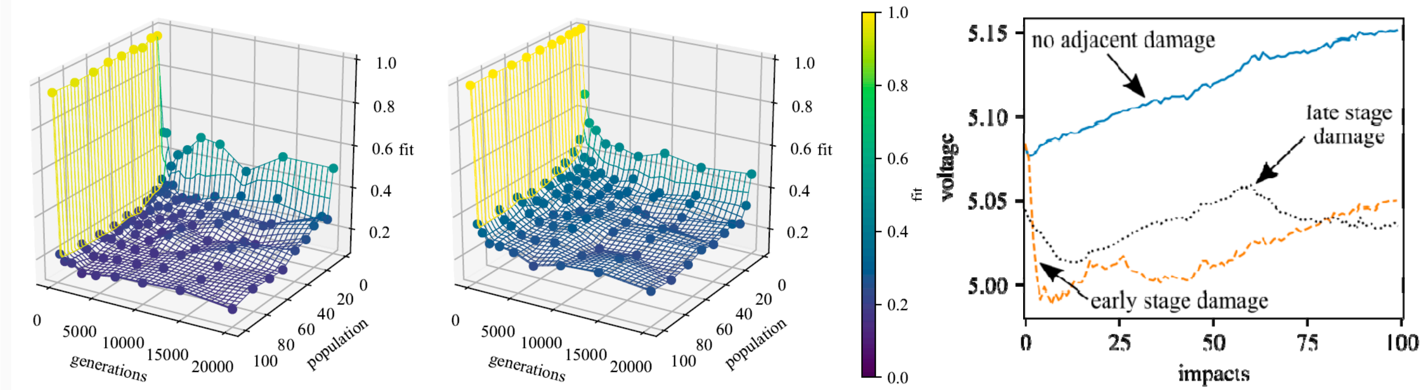
Smart Concrete: experiment on a smart RC plate

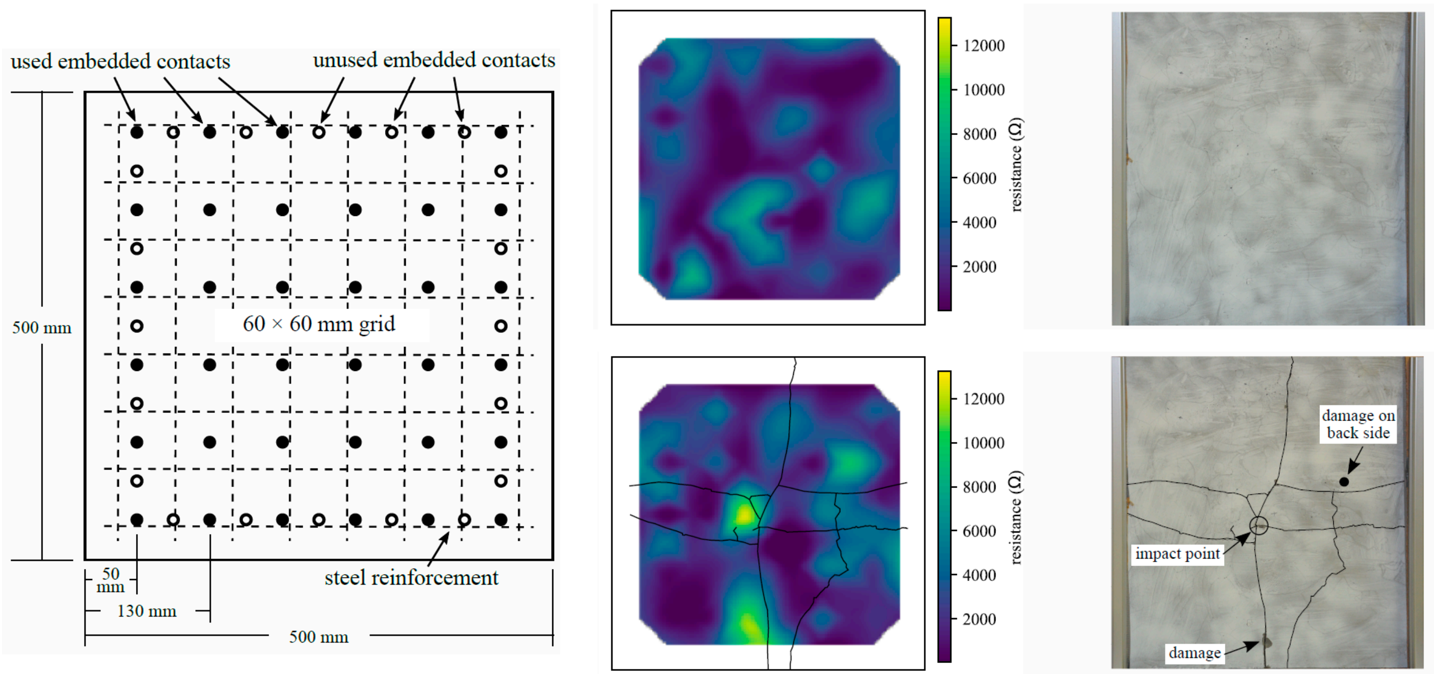




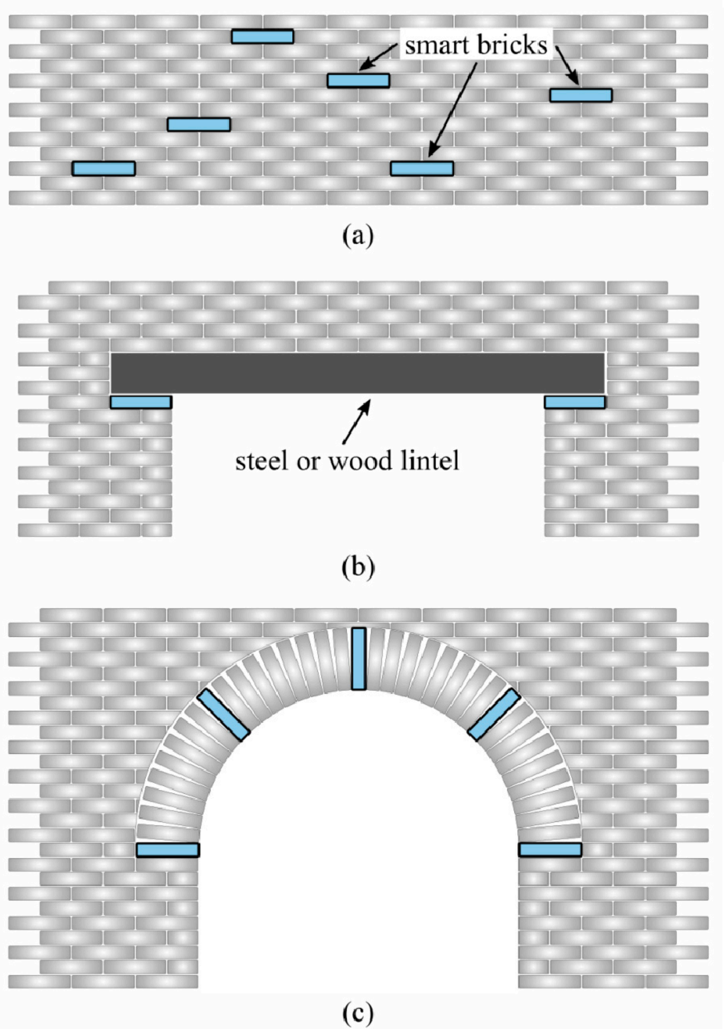


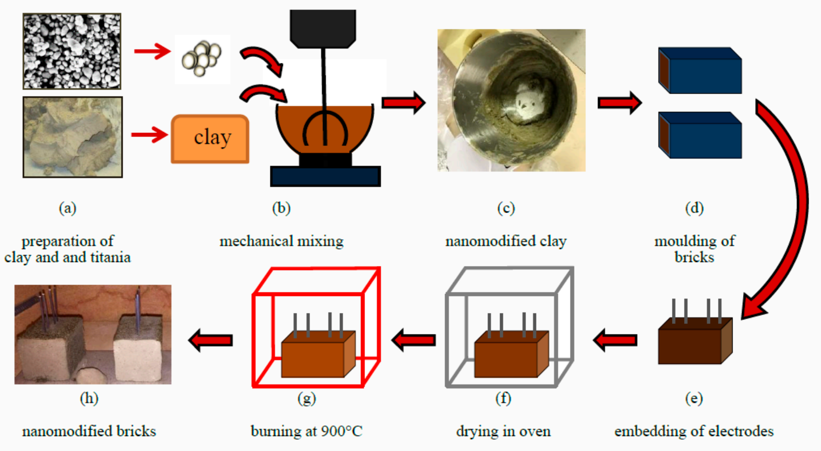
Smart Concrete: experiment on a smart RC plate

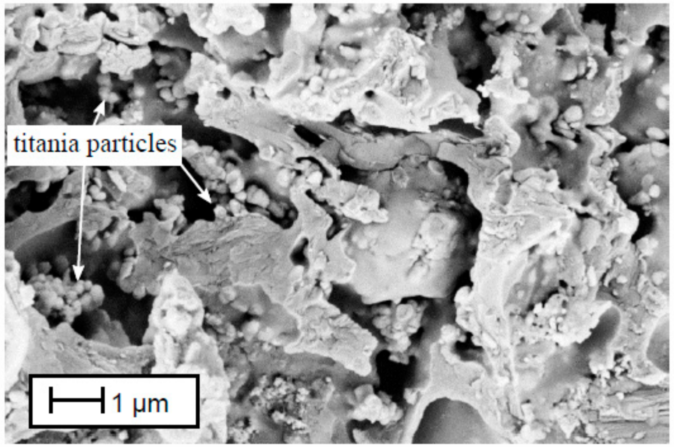




Smart Bricks: concept and fabrication







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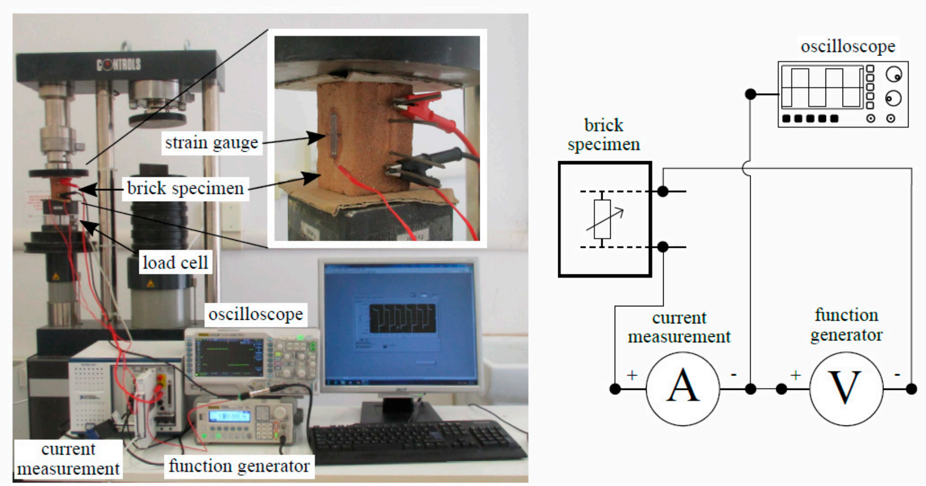
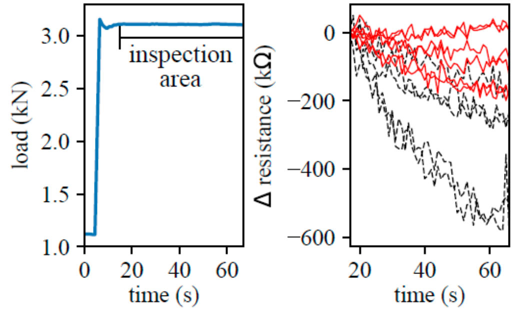
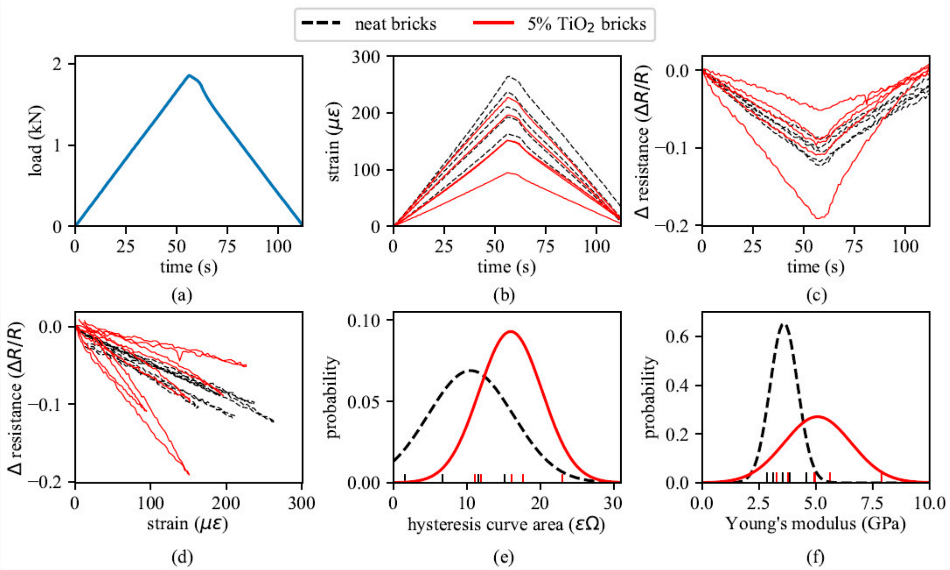
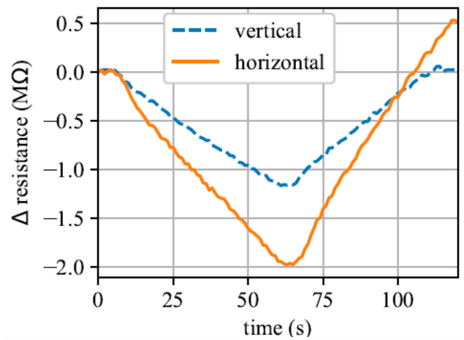
Smart Bricks: characterization in lab



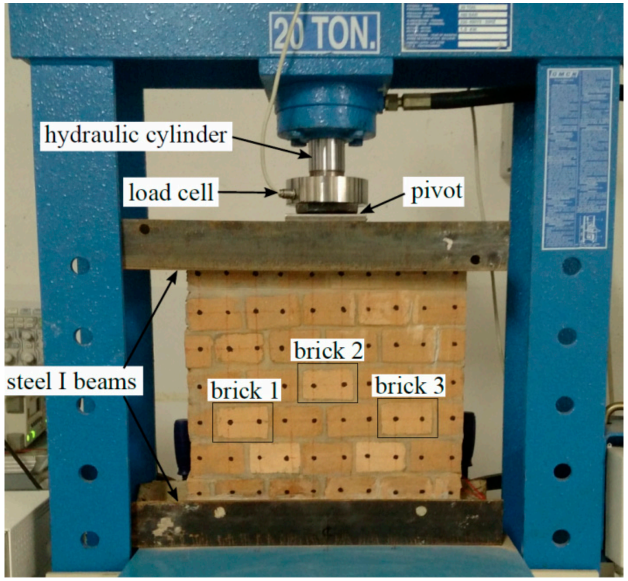


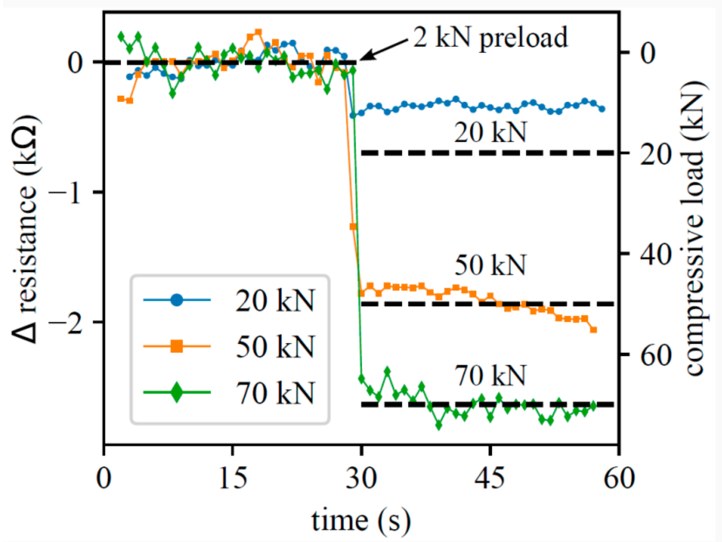


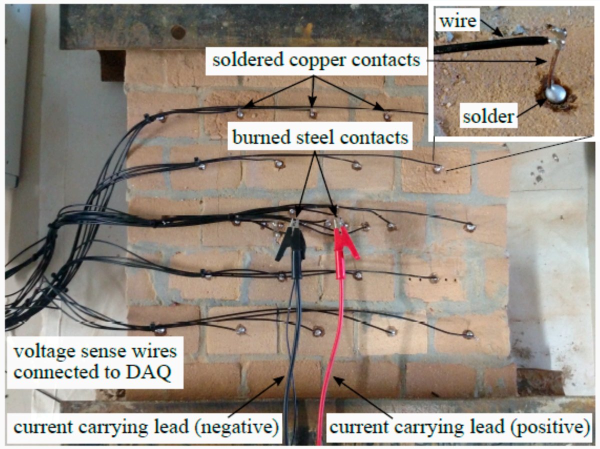


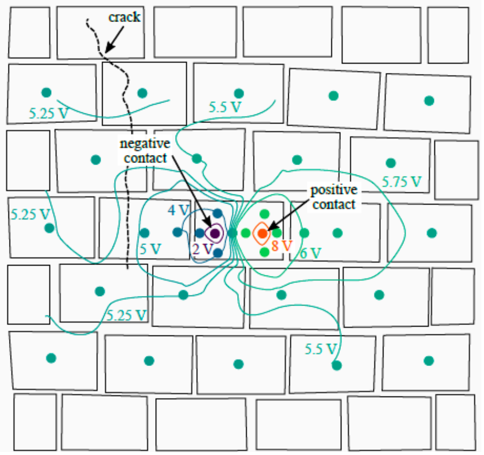
$$\frac{\Delta R}{R} = -\lambda \varepsilon_v = -\lambda(\varepsilon_x + \varepsilon_y + \varepsilon_z)$$

Smart Bricks: experiment on a laboratory wall









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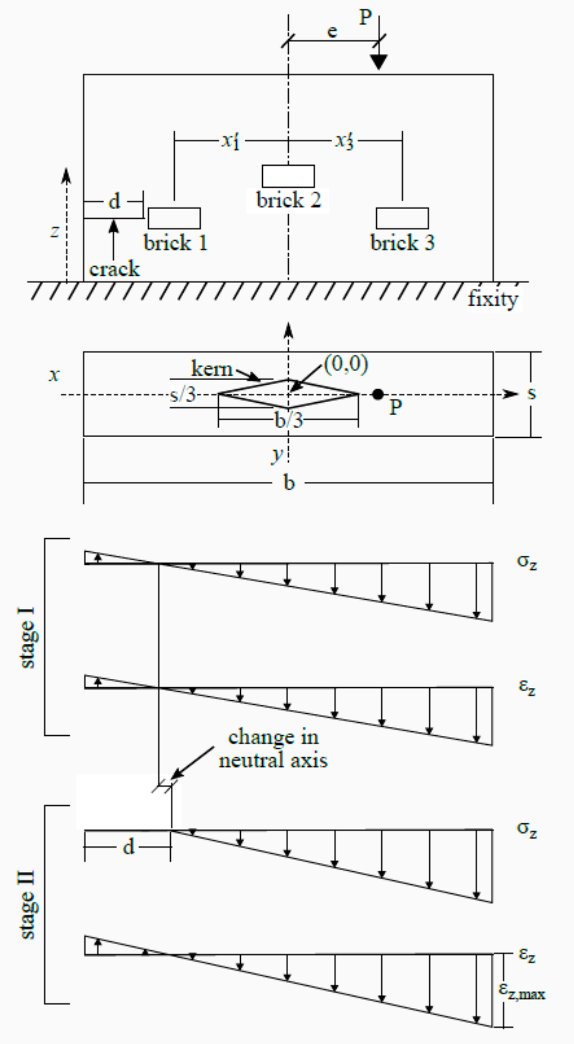
Smart Bricks: experiment on a laboratory wall



Uncracked elastic stage

$$\varepsilon_z(x) = \frac{P}{EA} + \frac{Pe}{EI}x$$

$$\frac{\Delta R(x)}{R} = -\lambda(1-2\nu)\left(\frac{P}{EA} + \frac{Pe}{EI}x\right)$$

$$\overline{\Delta R}(x) = \frac{\Delta R(x)}{\Delta R(x)|_{e=0}} = 1 + \frac{eA}{I}x = 1 + \frac{12e}{b^2}x$$

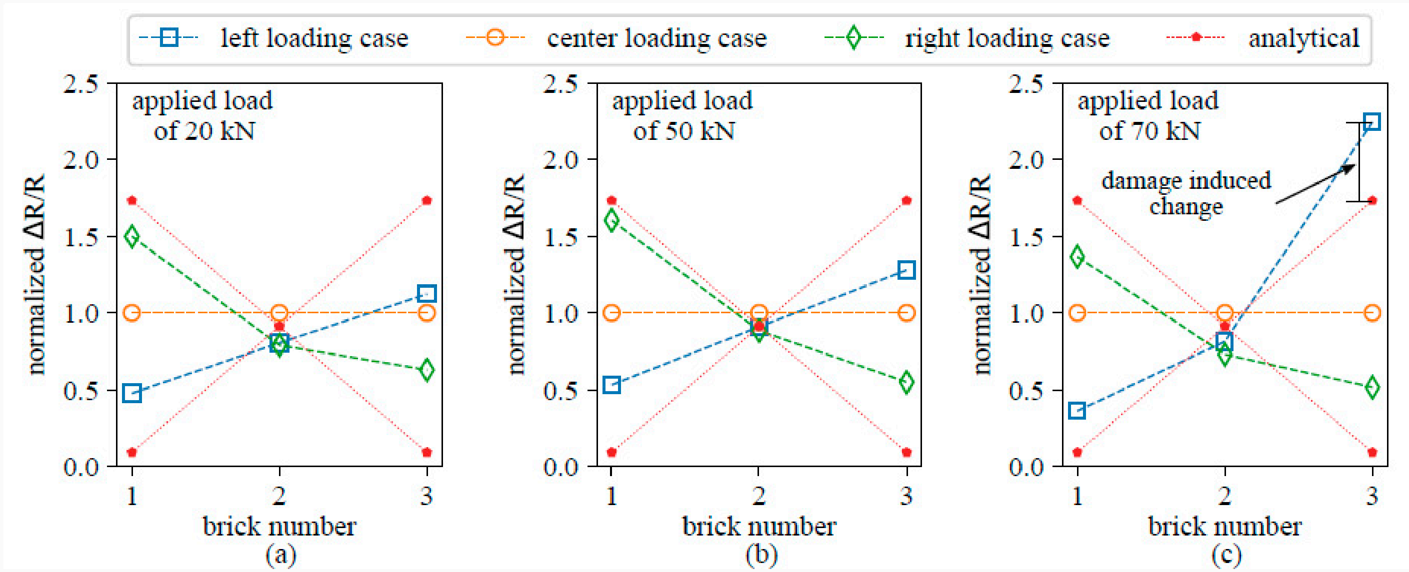
Cracked elastic stage

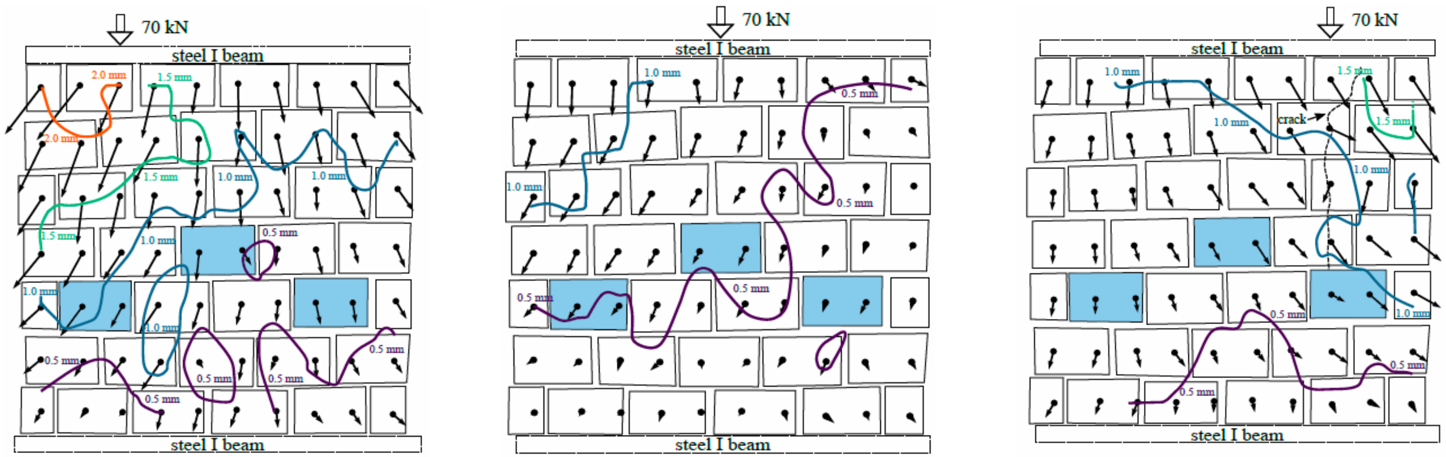
$$\varepsilon_z(x) = \frac{\varepsilon_{z,\max}}{b-d}\left(\frac{b}{2} - d + x\right)$$

$$\frac{\Delta R(x)}{R} = -\lambda(1-2\nu)\left(\frac{1}{E}\frac{2P}{(b-d)^2 s}\left(\frac{b}{2} - d + x\right)\right)$$

$$\overline{\Delta R}(x) = \frac{2b}{(b-d)^2}\left(\frac{b}{2} - d + x\right)$$

Smart Bricks: experiment on a laboratory wall





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Conclusions

- ❑ Embedded smart concrete sensors are a durable solution for strain monitoring in RC structures
- ❑ Micromechanics approaches and lumped circuit approaches represent effective modeling strategies for investigated smart materials and sensors
- ❑ Thanks to a new biphasic DC measurement method cracks can be detected in smart RC components through local changes in electrical properties
- ❑ Smart bricks allow strain monitoring and damage detection in masonry structures
- ❑ Smart concretes and smart bricks can potentially improve the current state of development of SHM technologies by overcoming some of the main limitations that impede their large-scale deployment to civil engineering structures

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Acknowledgements

PRIN SMARTBRICK

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Thank you for your attention!

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