Distributed fiber-optic sensing for subsurface vibration and deformation monitoring

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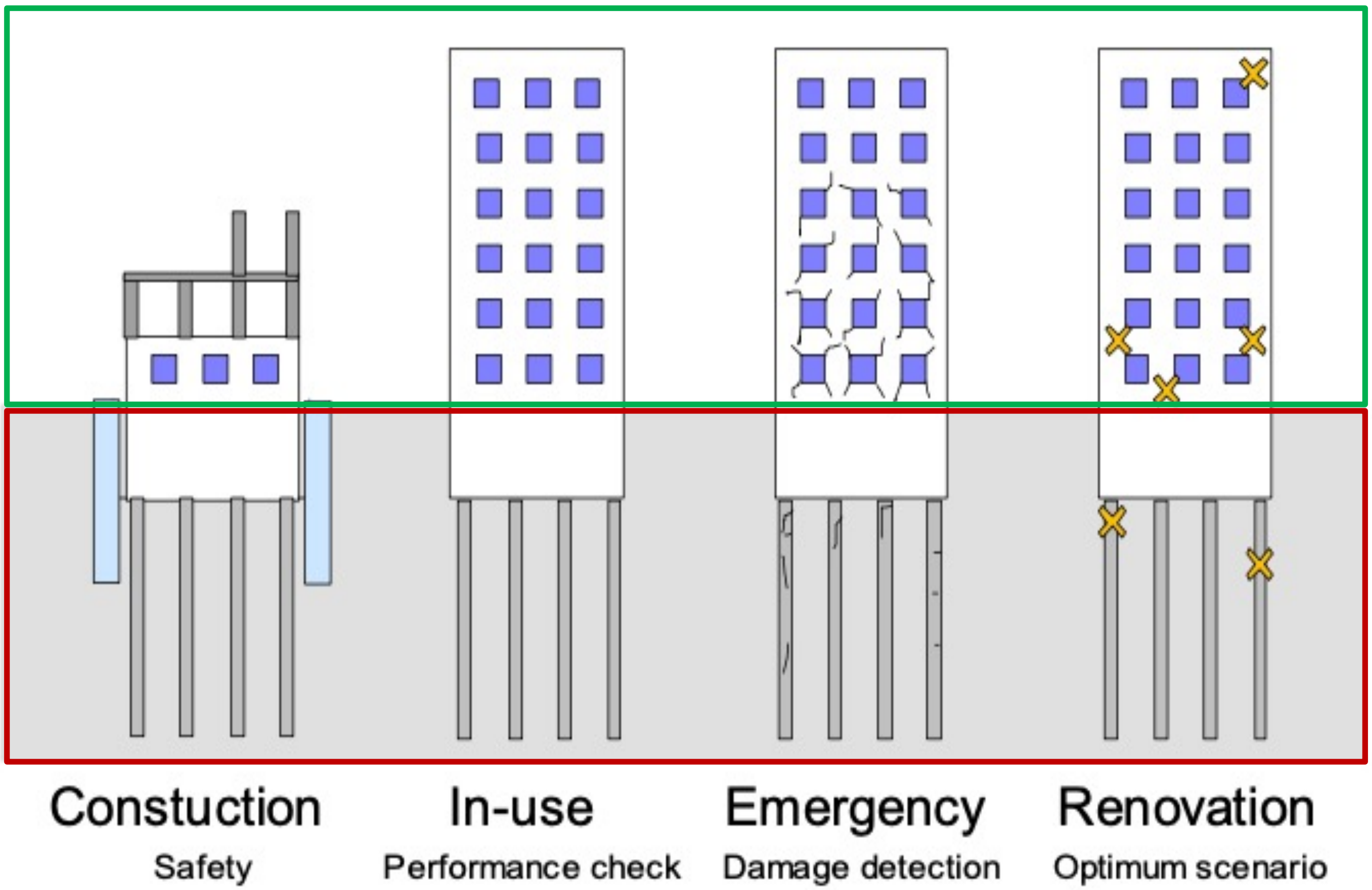
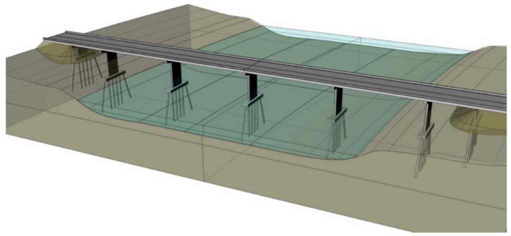
Outline

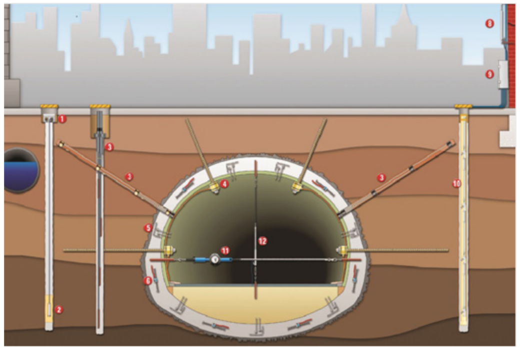
- Importance of subsurface monitoring
- Distributed fiber optic sensing
    - Distributed strain sensing applications
    - Distributed acoustic sensing applications
    - Lab-scale sand box testing on optical fiber cables
- **Soil box testing and modeling: A new opportunity to build confidence on using distributed fiber optic sensing for subsurface monitoring**
- Concluding remarks

Subsurface Monitoring



Mita (1999)





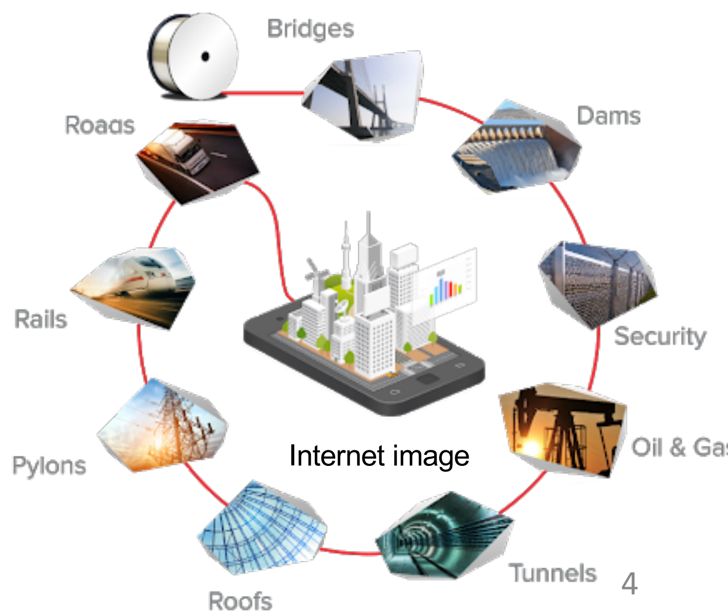
Internet images

Measurement Sparsity, Inference Uncertainty, and Inaccessibility

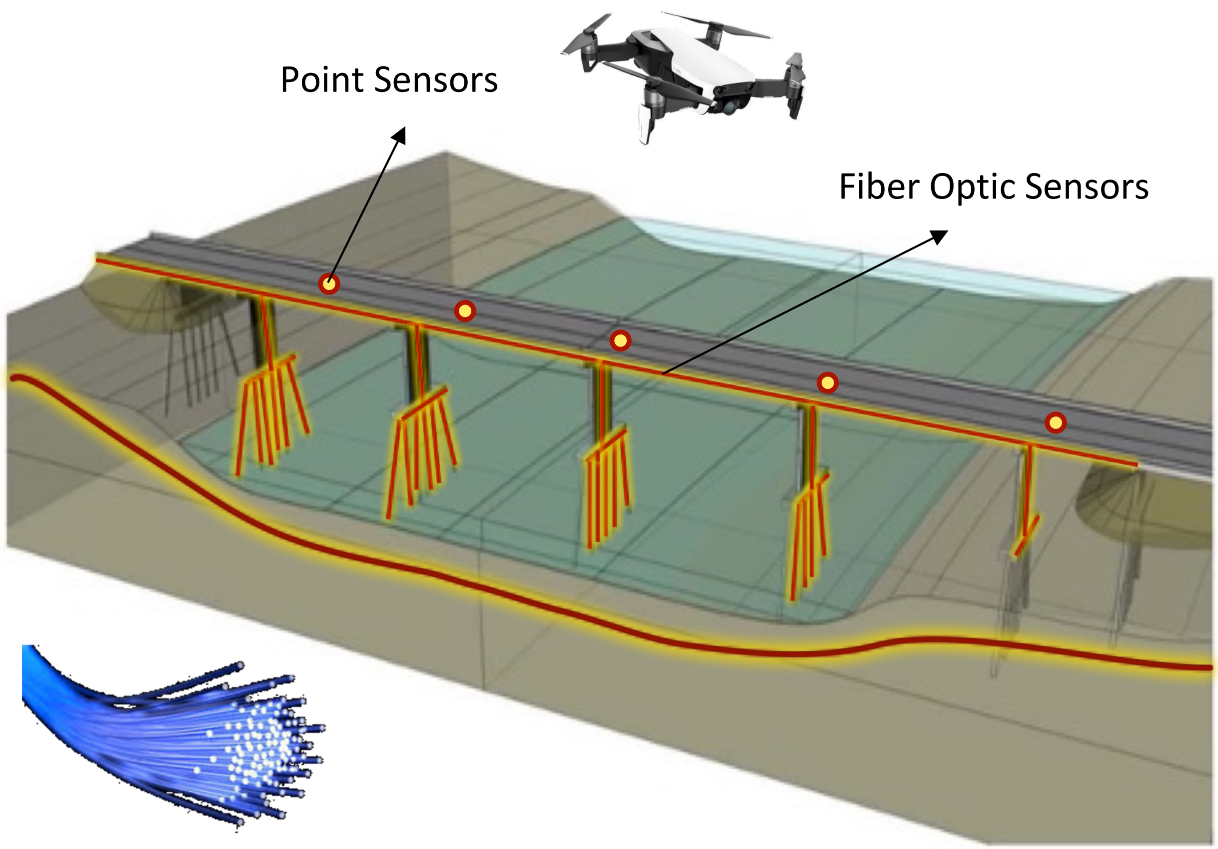
- Sparse **point sensors** (e.g., strain gauges, accelerometers) do not provide continuous field measurement, can result in large uncertainties, and are not optimized for long-term monitoring.

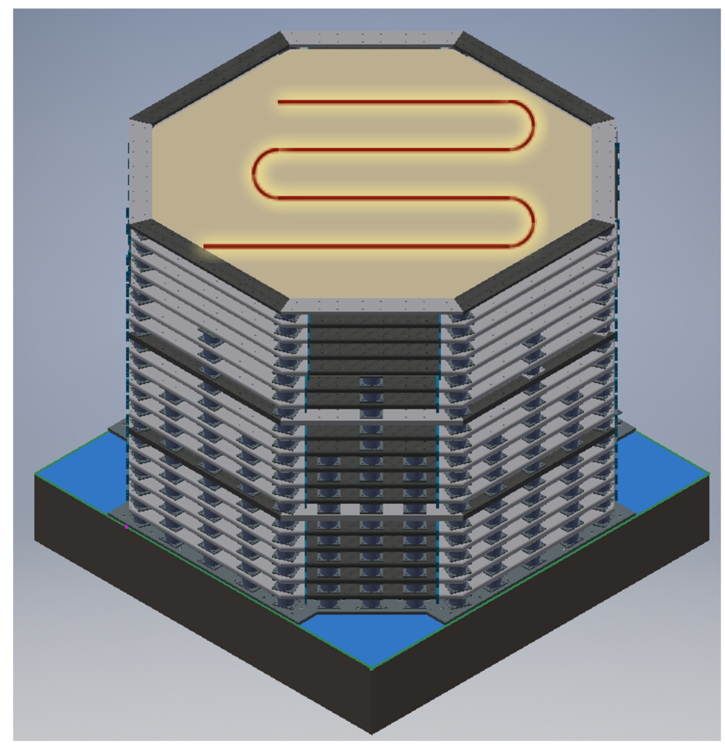
- **Vision and remote sensing-based methods** cannot help much with monitoring of inaccessible/deep subsurface infrastructure and subsurface monitoring.

- **Fiber optic sensing-based methods** have been long explored as a promising sensing candidate for health monitoring of civil infrastructure.



Can distributed fiber optic sensing provide robust solutions for subsurface monitoring?

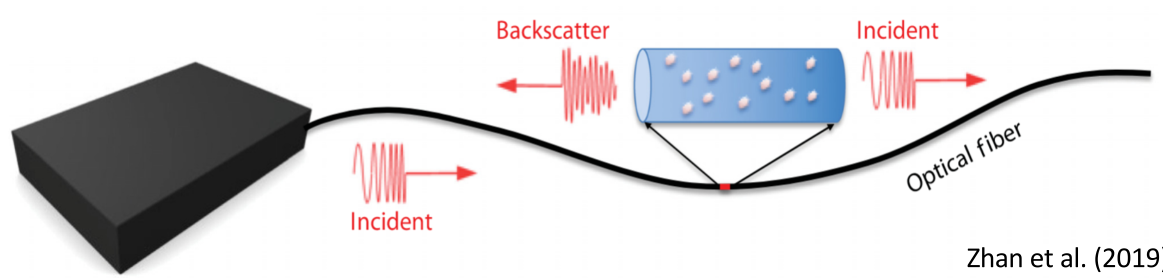




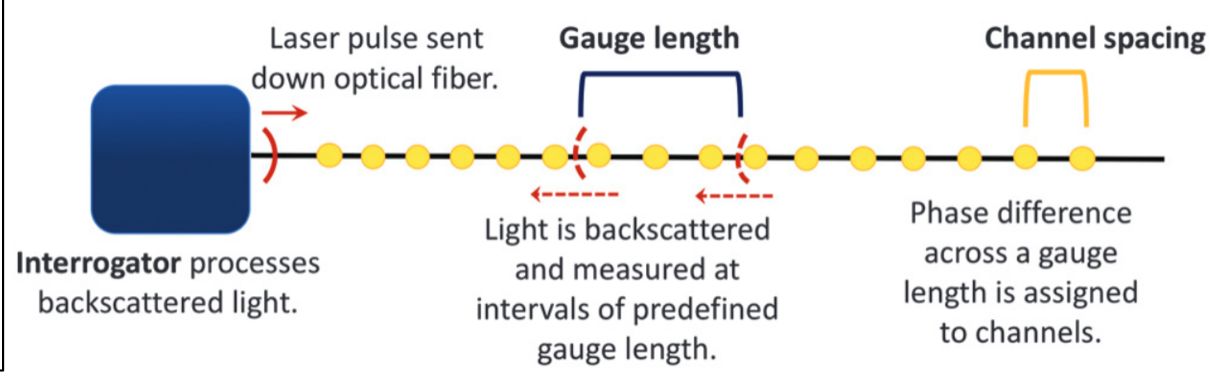
Distributed Fiber Optic Sensing

- Distributed fiber-optic sensing technologies measure **light backscattered from every point along a continuous fiber**
- Changes in the environment around the fiber (temperature, strain) will alter the scattering profile - <u>**The cable is the sensor**</u>

Distributed fiber-optic sensing converts conventional fiber-optic cables into massive arrays of strain, temperature and/or vibration sensors.



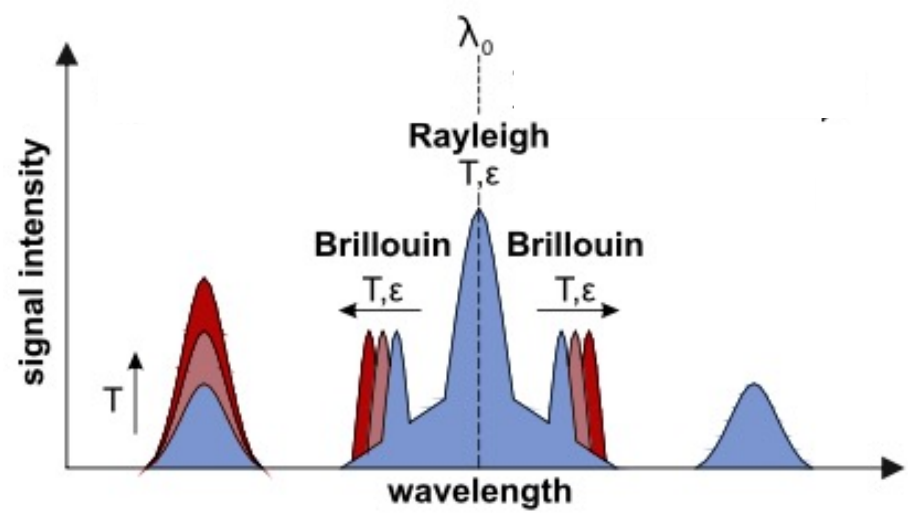
Zhan et al. (2019)



Stork et al. (2020)

Brillouin-Based and Rayleigh-Based Distributed Sensing

	Brillouin-Based Sensing	Rayleigh-Based Sensing
Measurement	Brillouin frequency shift	Rayleigh phase shift
Temporal Sampling	Typically, minutes	mHz to kHz
Sensitive to	**Strain** (and Temperature)	**Dynamic Strain** (and Temperature)
Gauge length (spatial averaging)	Typically, 1 m	Typically, 1 -10 m
Spatial Sampling	< 1 m	< 1 m



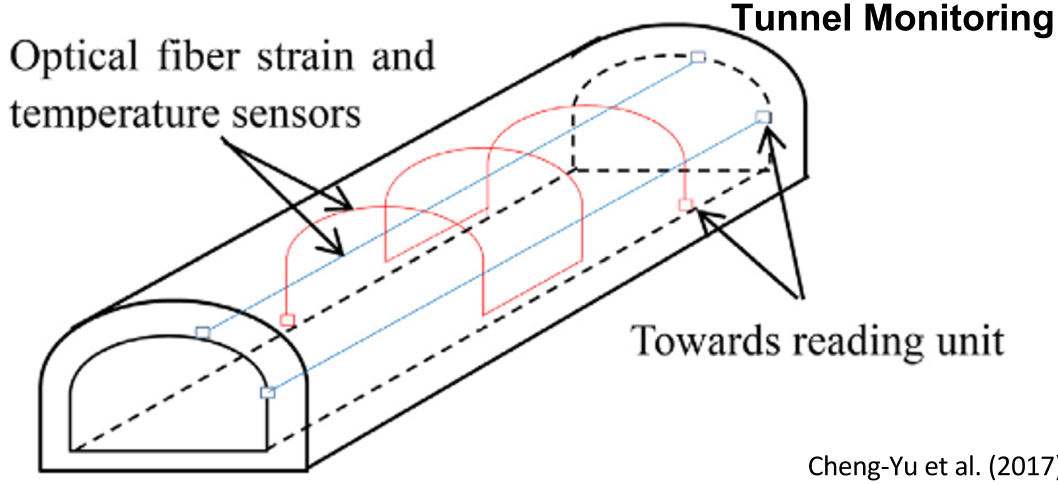
Monsberger et al. (2020)

DAS can provide:

- Increased sensitivity
- Increased temporal resolution >> possibility to measure **dynamic processes**

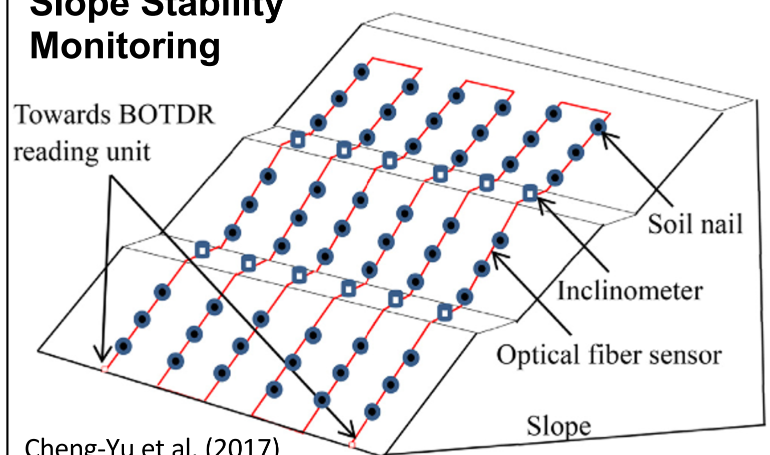
Brillouin-Based Distributed Strain Sensing Applications

Tunnel Monitoring



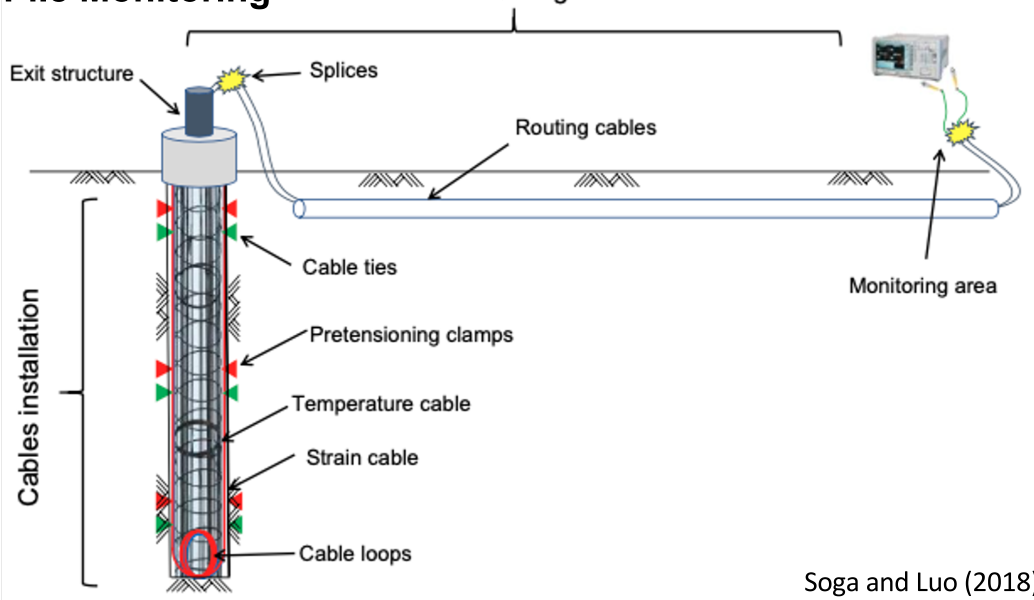
Cheng-Yu et al. (2017)

Slope Stability Monitoring



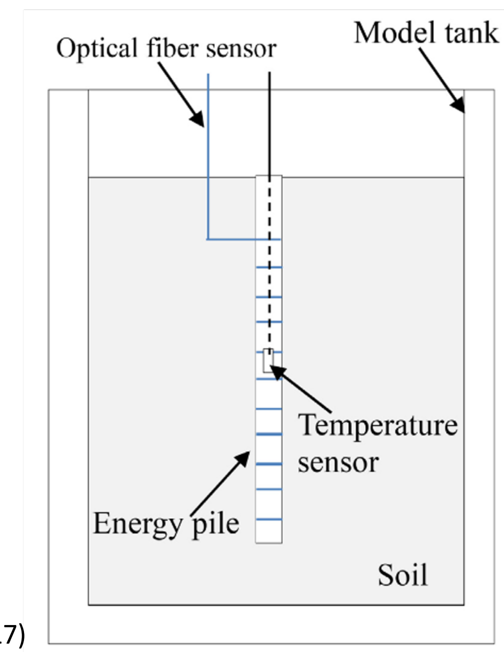
Cheng-Yu et al. (2017)

Pile Monitoring



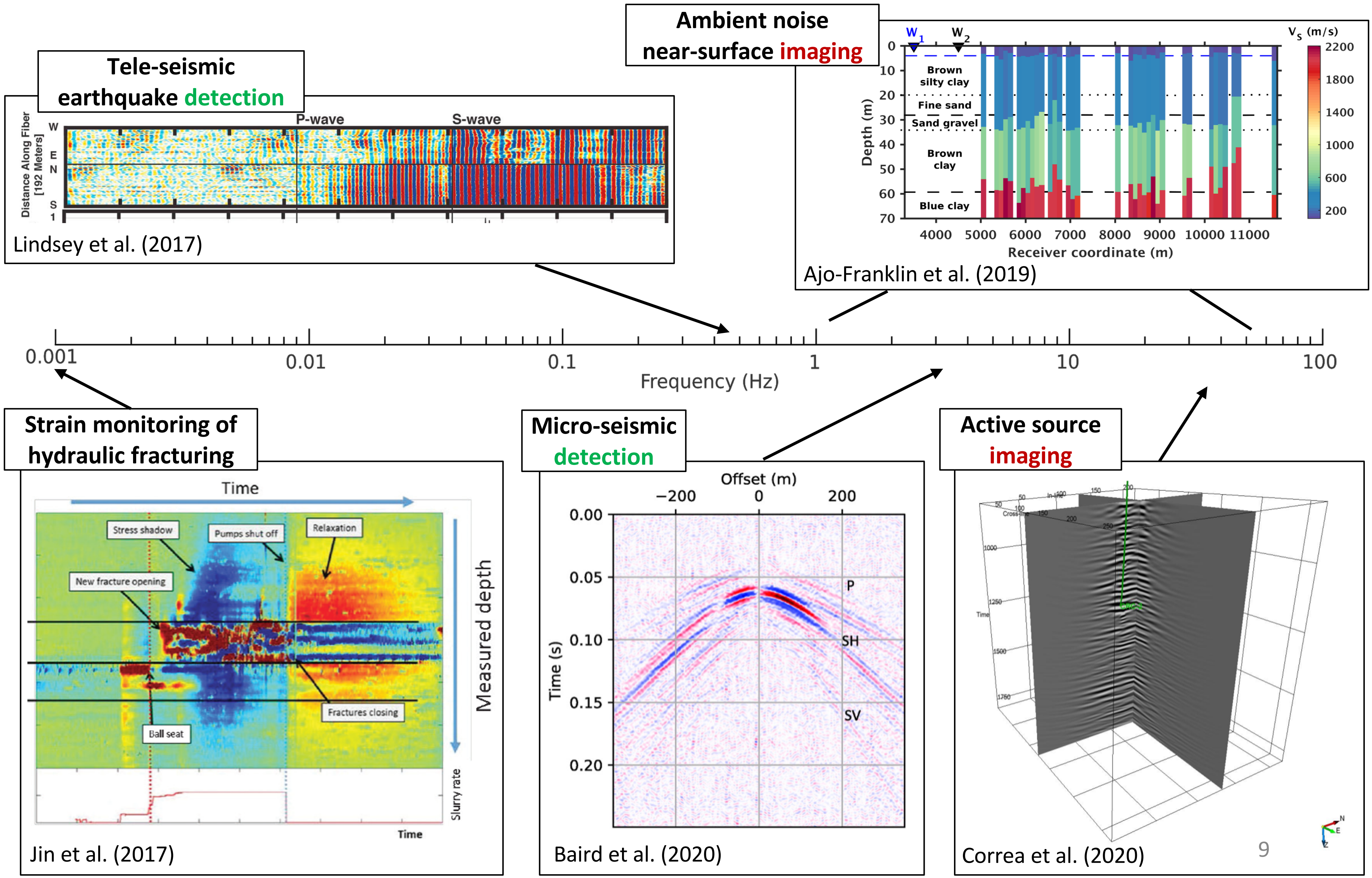
Soga and Luo (2018)

Temperature Monitoring

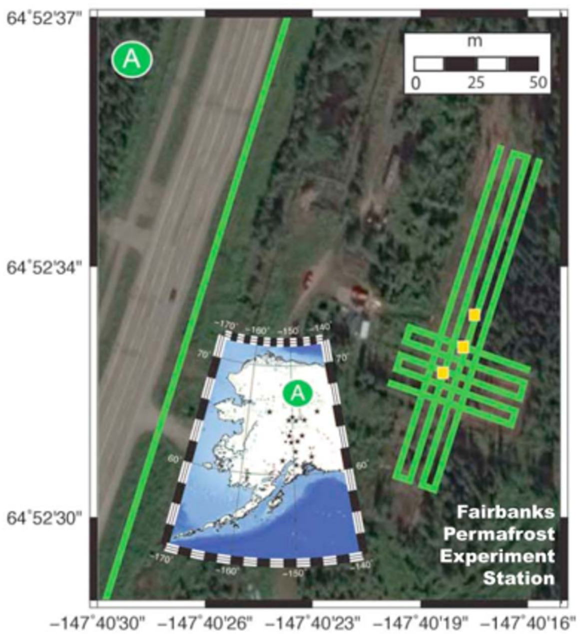


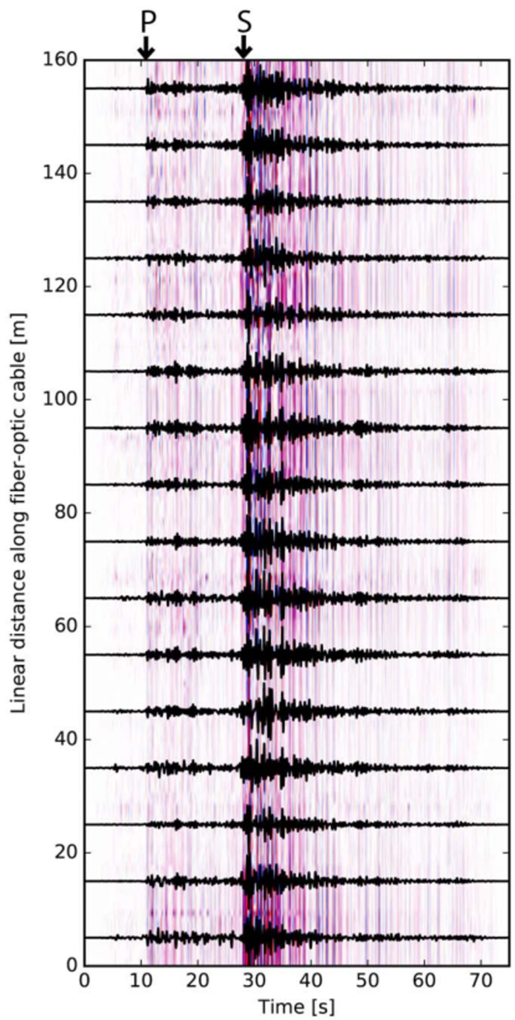
Cheng-Yu et al. (2017)

Rayleigh-Based Distributed Acoustic Sensing (DAS) Applications

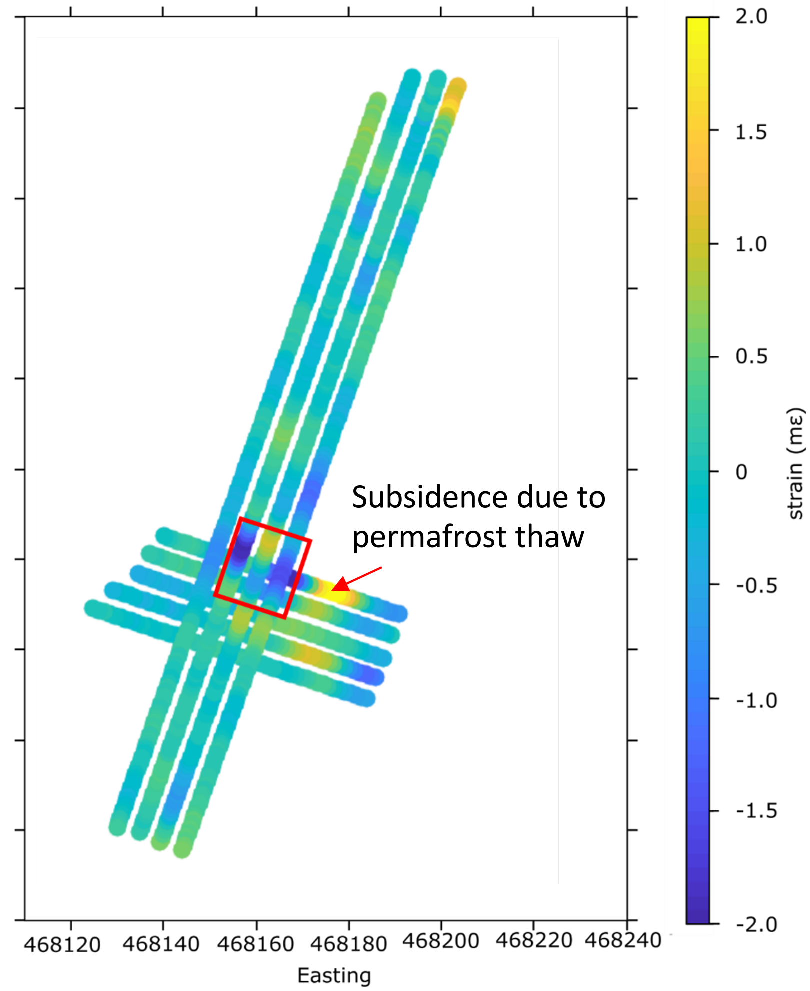


Earthquake & Deformation Monitoring Along the Same Array



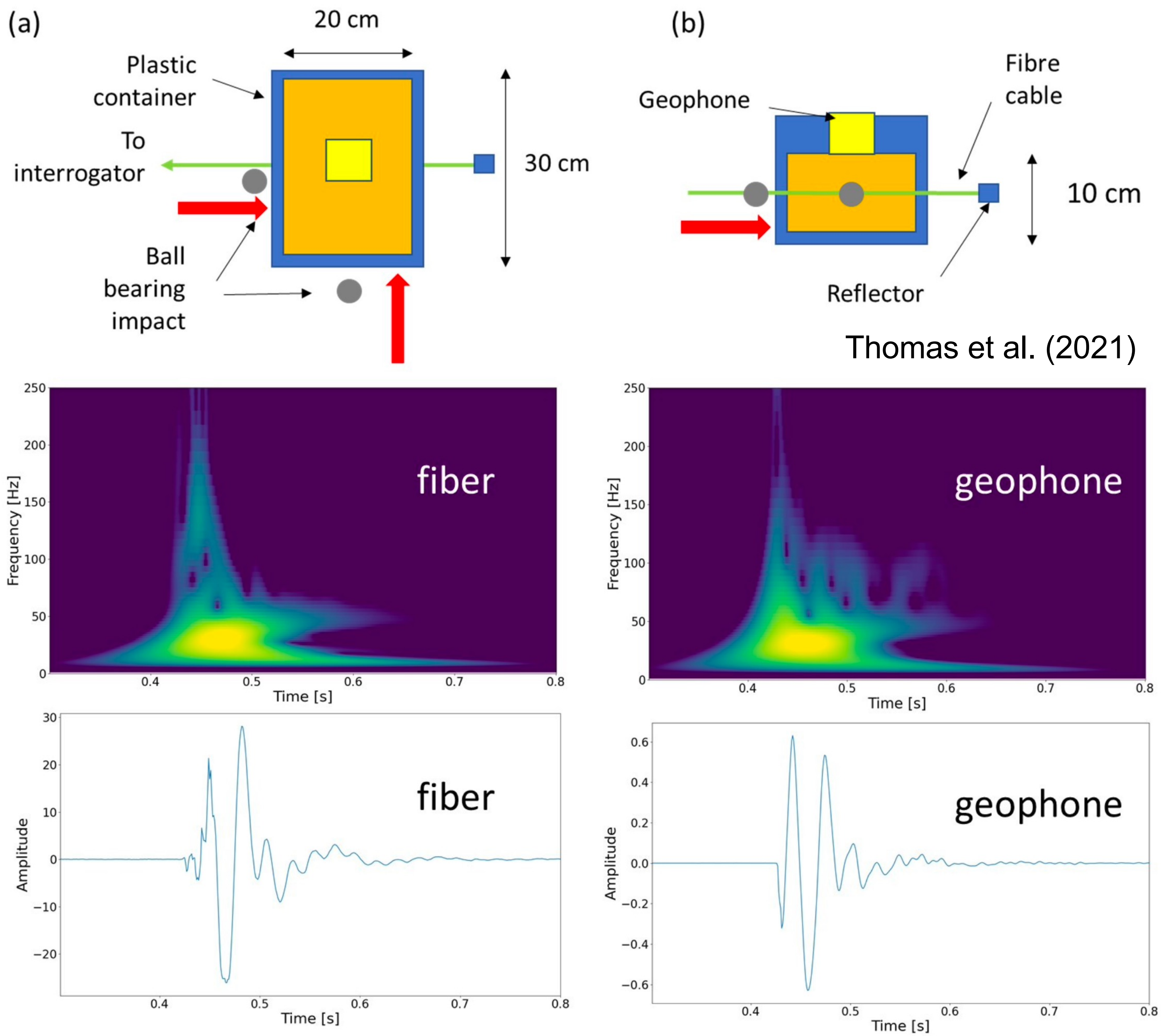


Lindsey et al. (2017)



Rodriguez Tribaldos et al. (2018)

Lab-scale Sand Box Testing on Optical Fiber Cables



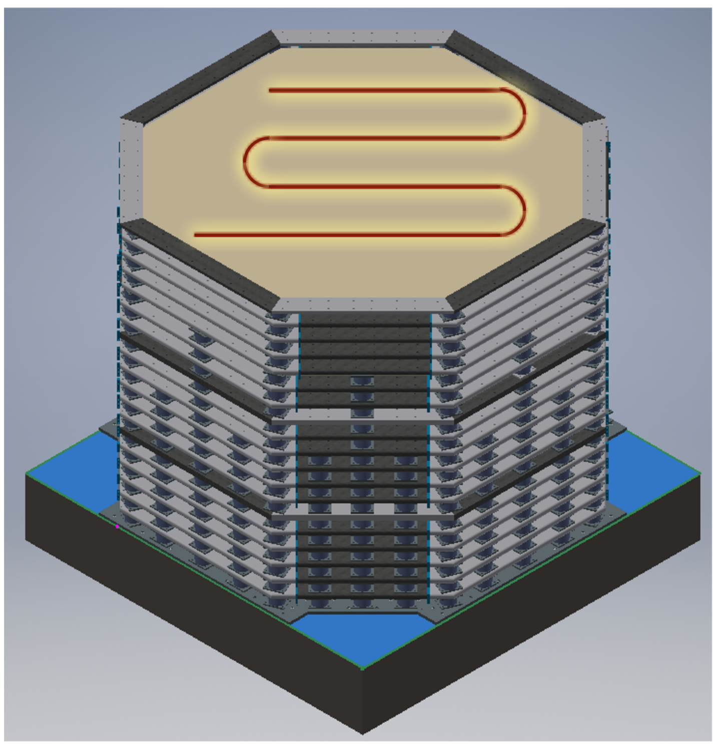
Soil Box Testing & Modeling: A New Opportunity to Build Confidence on Using Distributed Fiber Optic Sensing in Lab- and Real-scale Problems

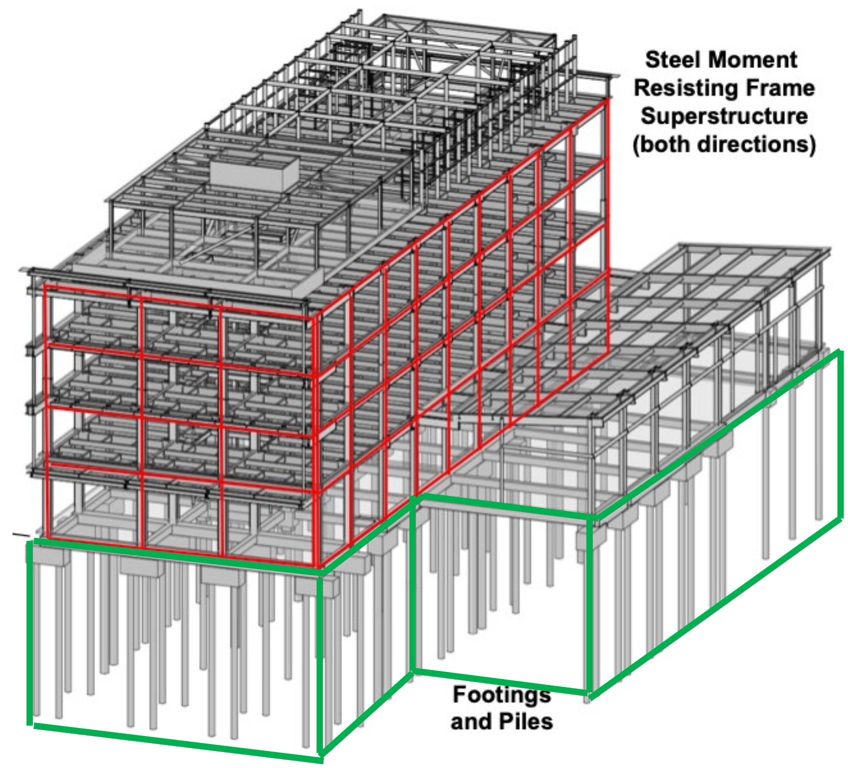
Objective 1

Advanced Instrumentation Solutions & Lab-Scale Subsurface Monitoring

Objective 2

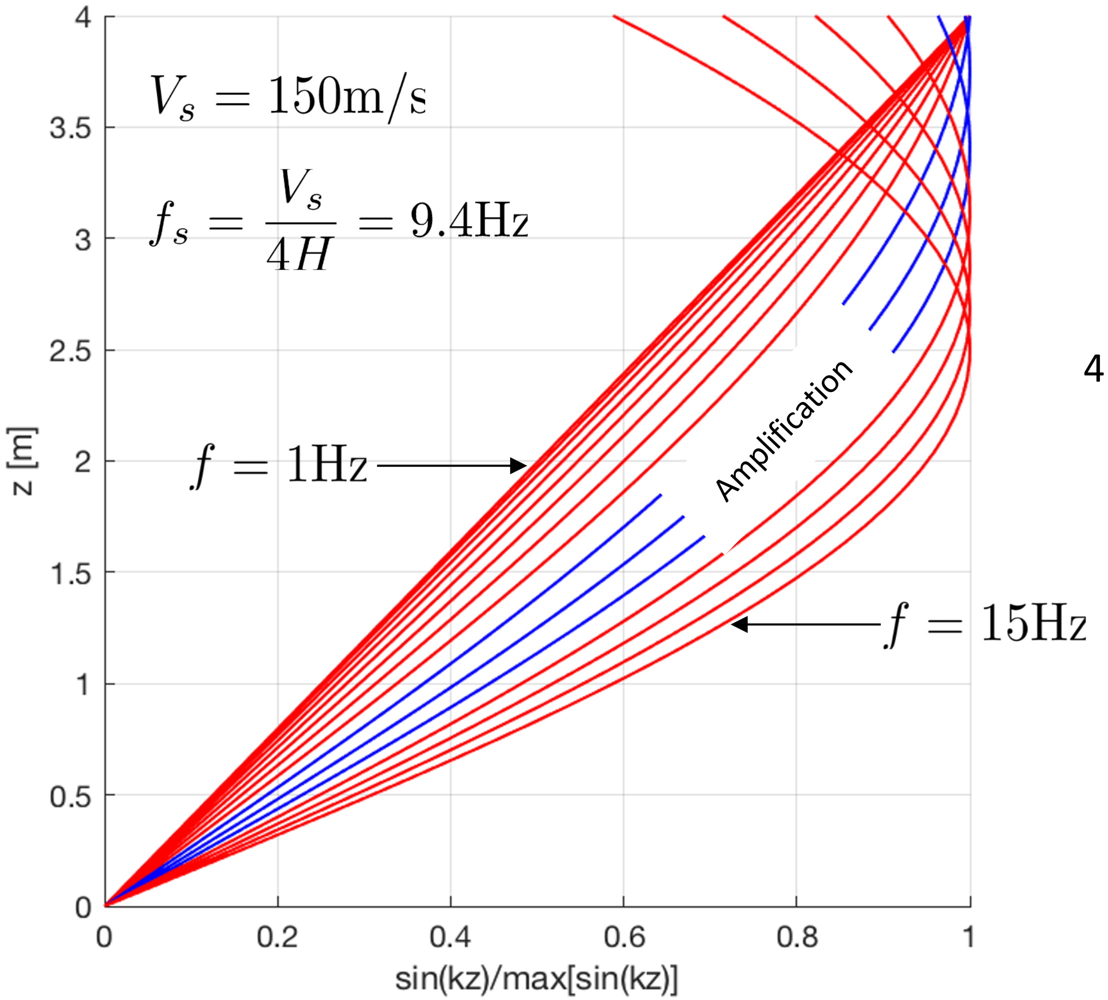
Real-Scale Subsurface Monitoring Solutions

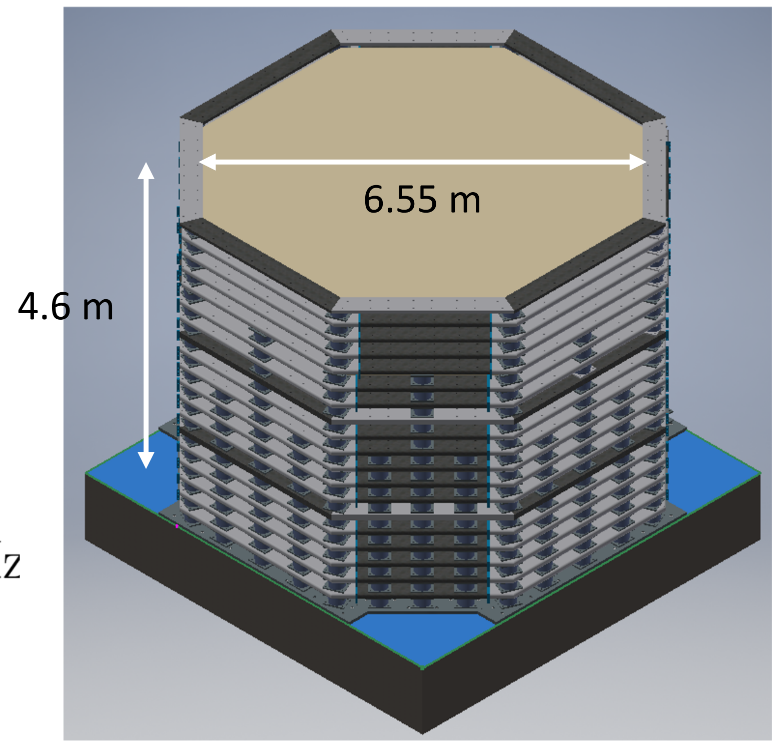




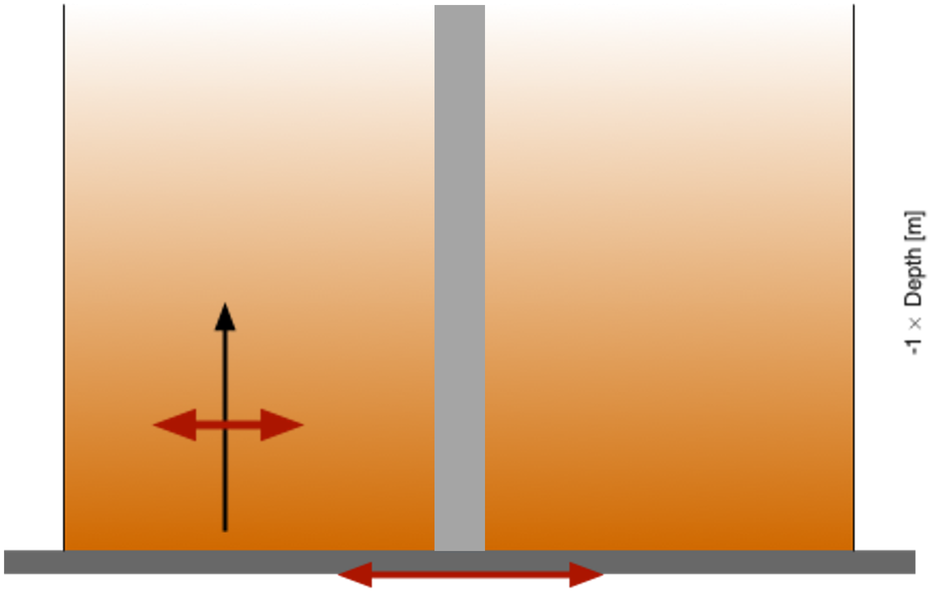
LBNL BioEPIC Building (Courtesy of David McCallen)

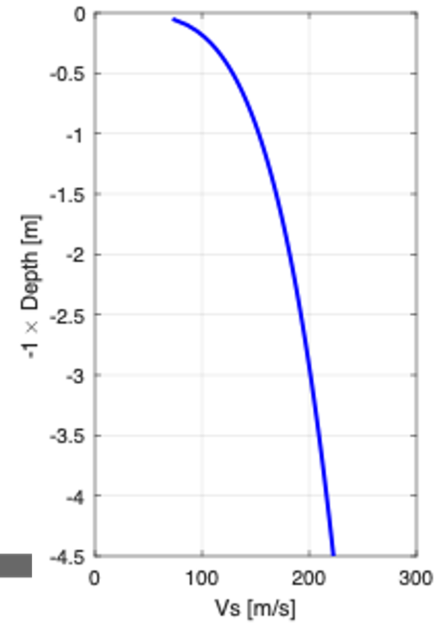
Soil Box Dynamic Characteristics

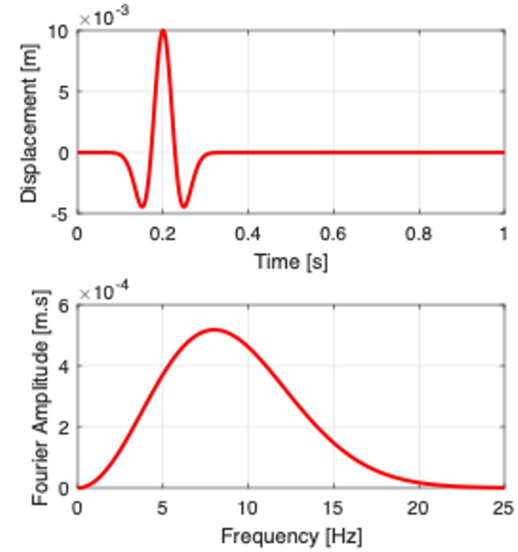




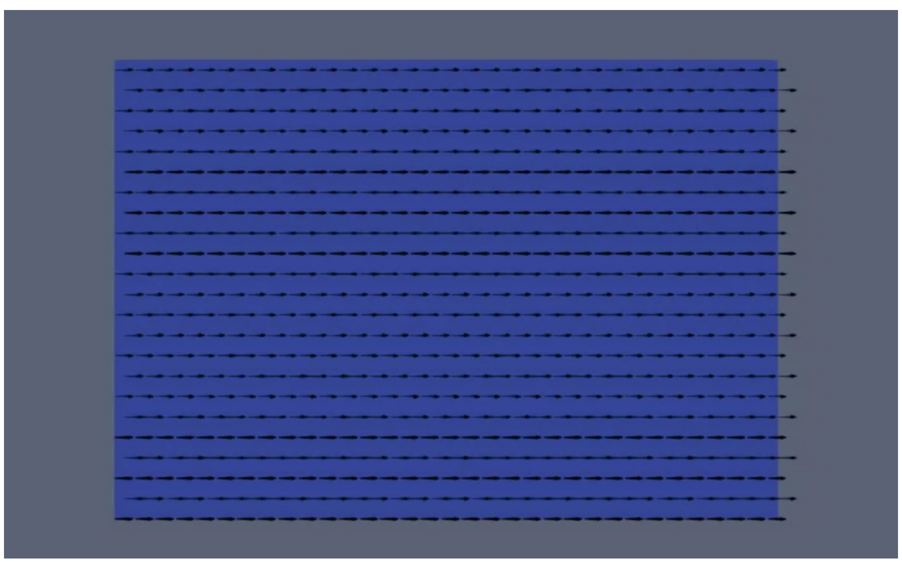
Soil Box Dynamic Characteristics (plane-strain approximation)



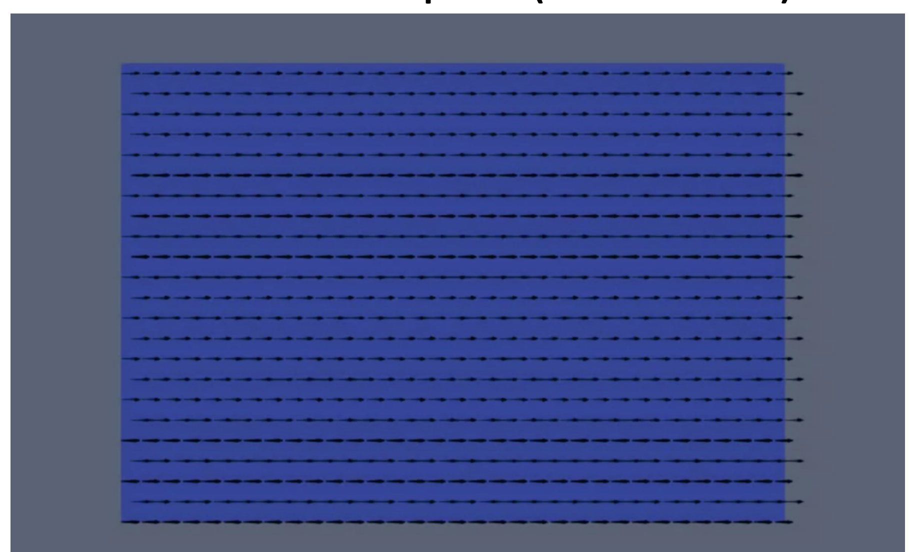




Free field response (no structure)



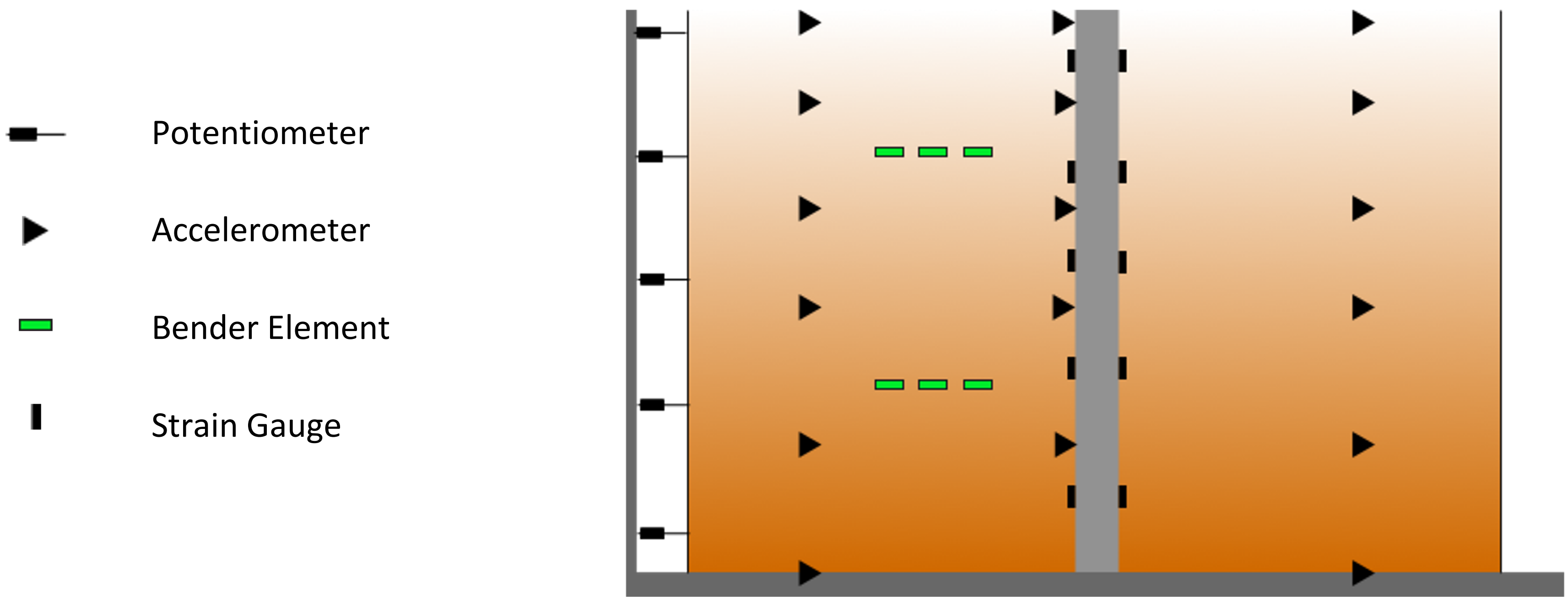
Scattered field response (with structure)



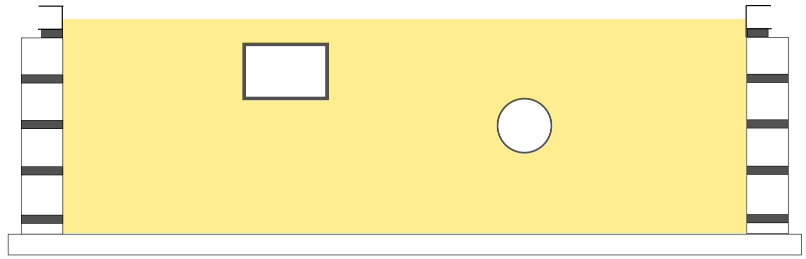
Typical Point Sensors for Lab-Scale Instrumentation of Soil-Structure Interaction Problems

Quantities of Interest:

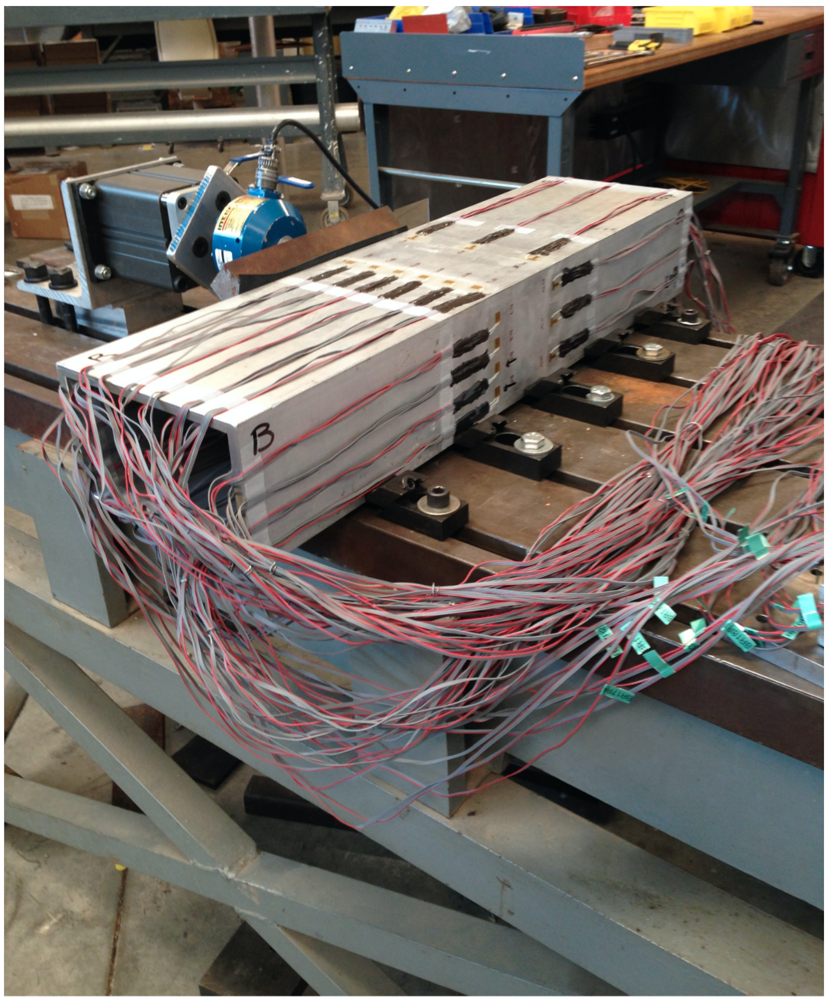
- Structure deformation and strain
- Soil deformation and strain
- Strain dependent soil properties
- Soil-structure interface characteristics

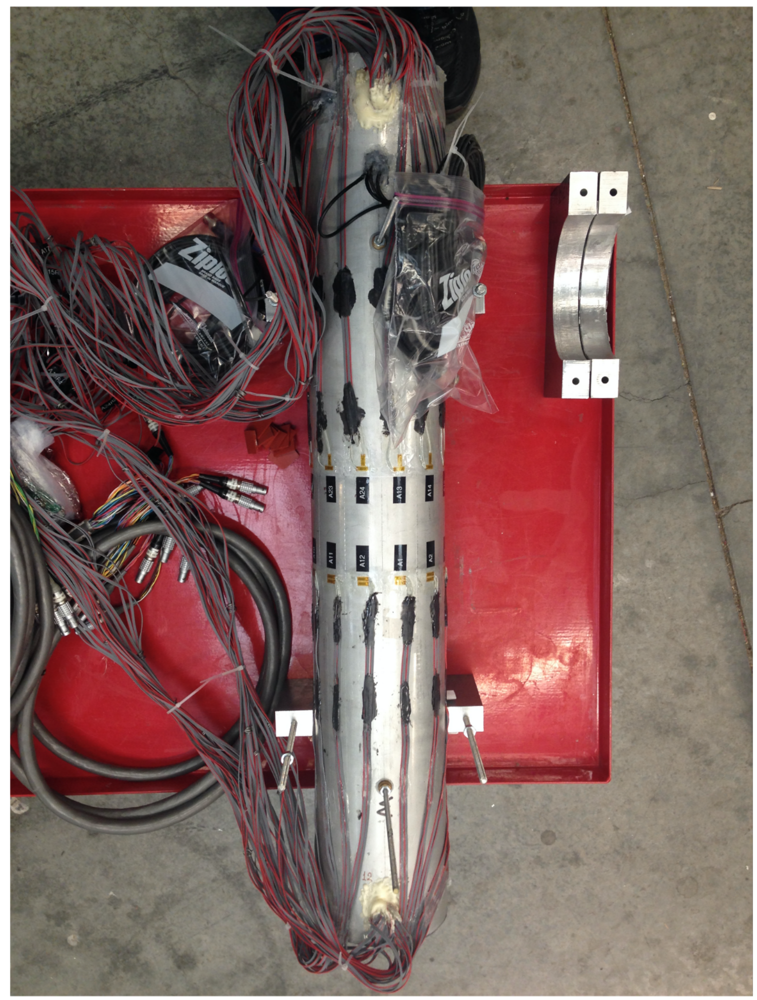


Exemplar Instrumentation (Centrifuge Testing)



Seylabi et al. (2016)





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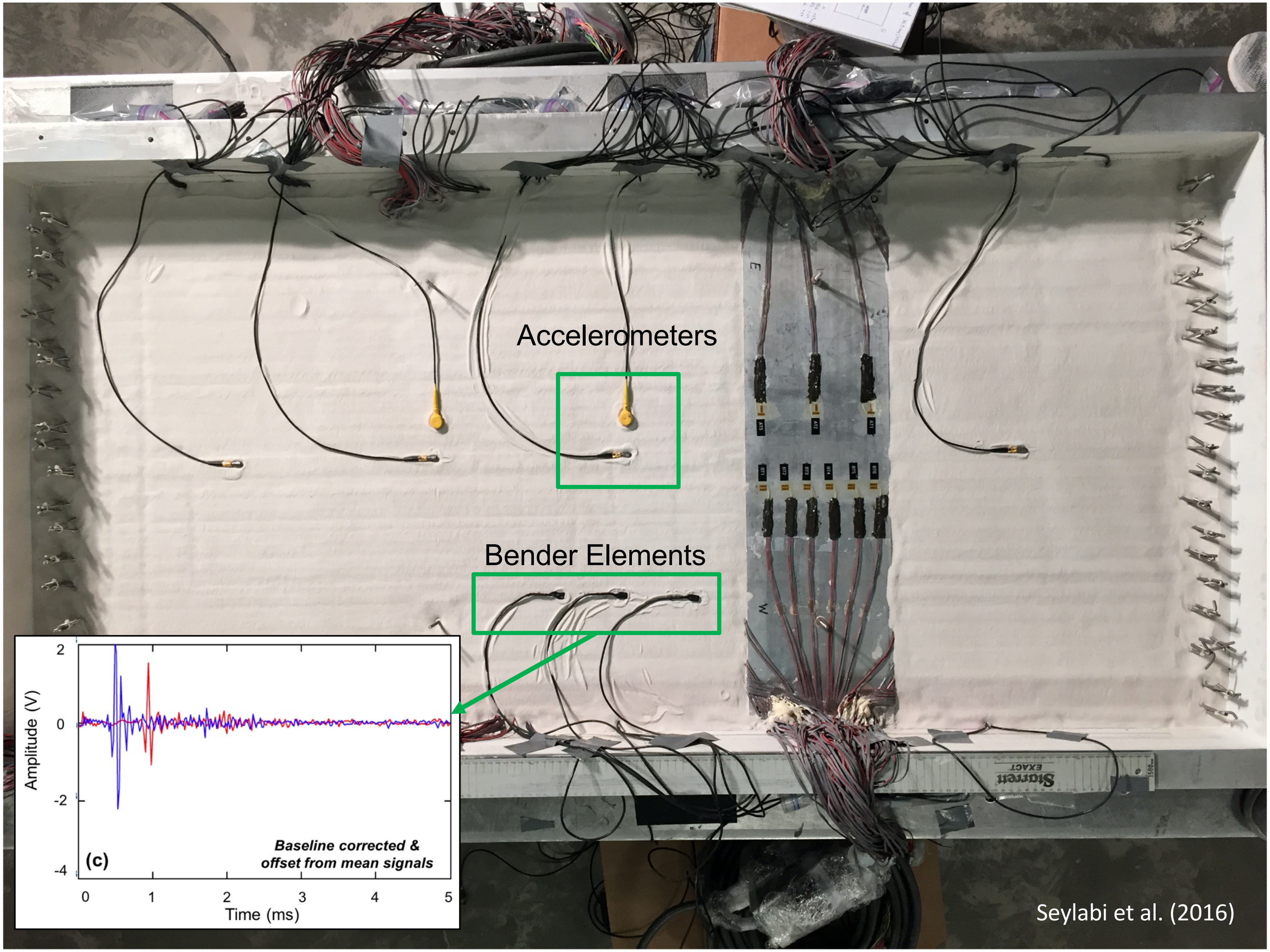
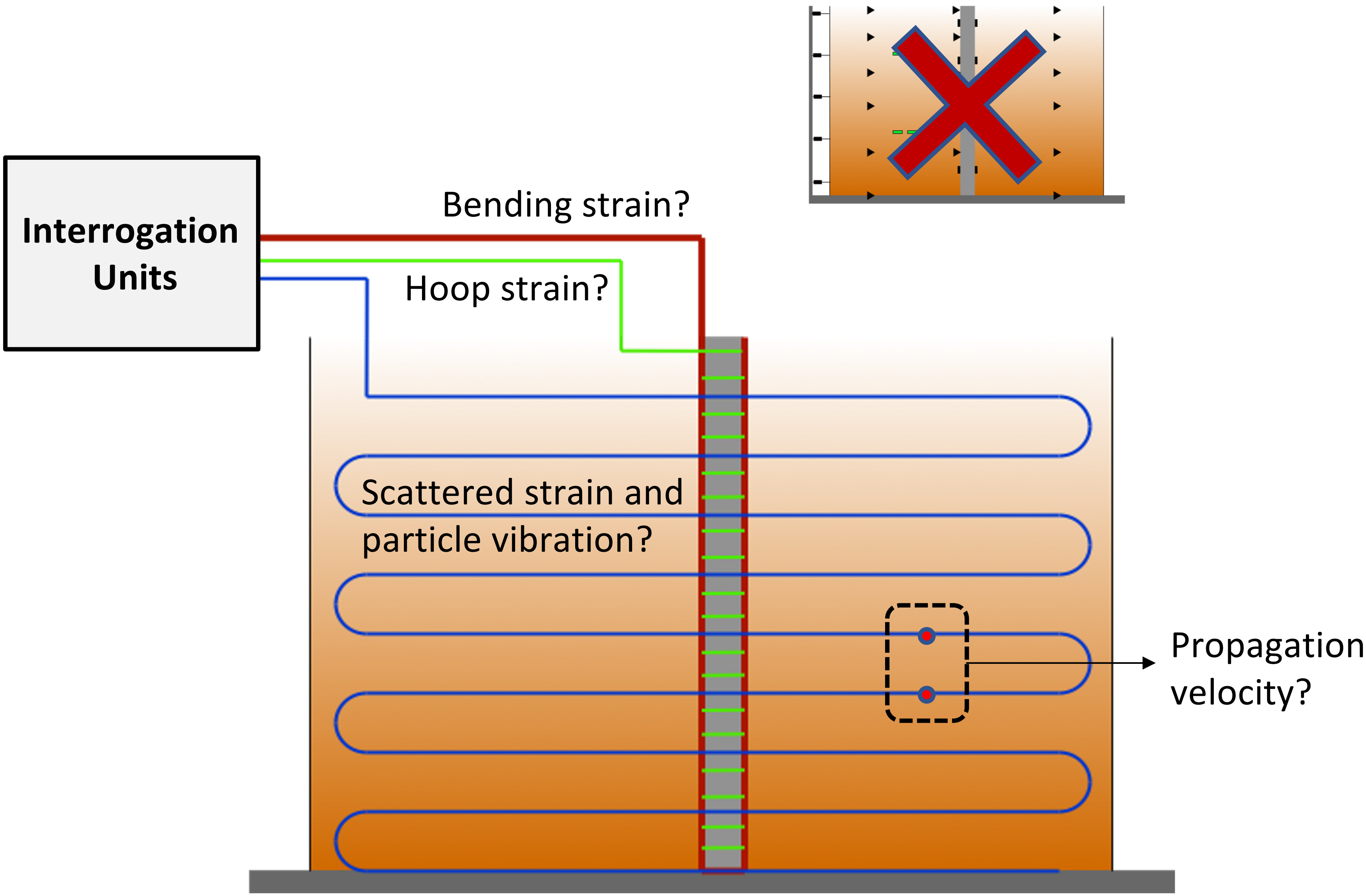


Seylabi et al. (2016)

Potential Fiber Optic Sensing Instrumentation Layout

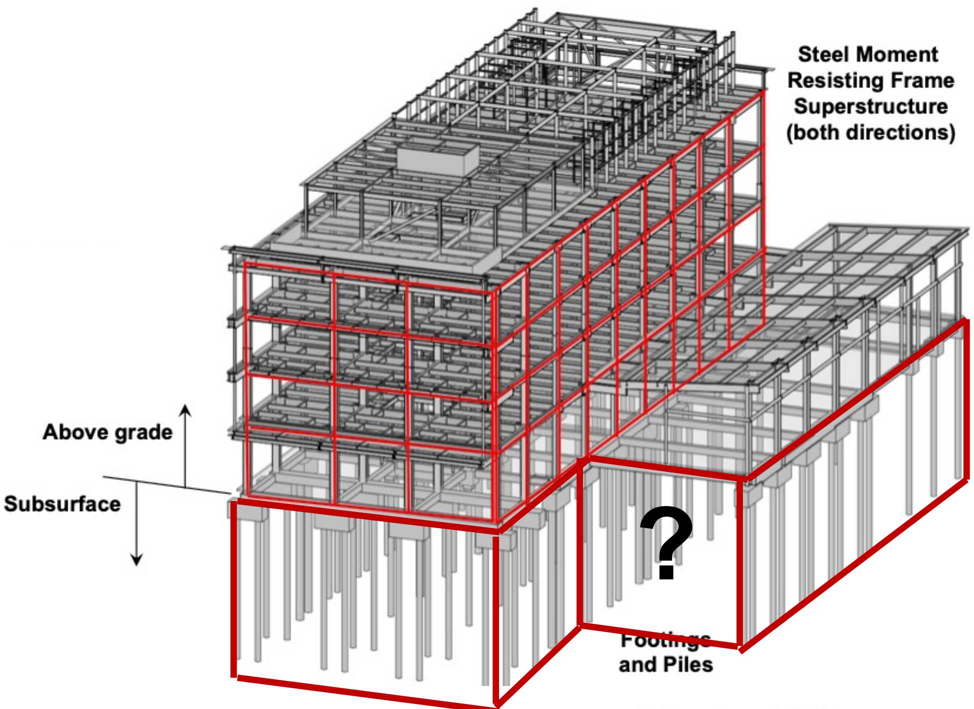


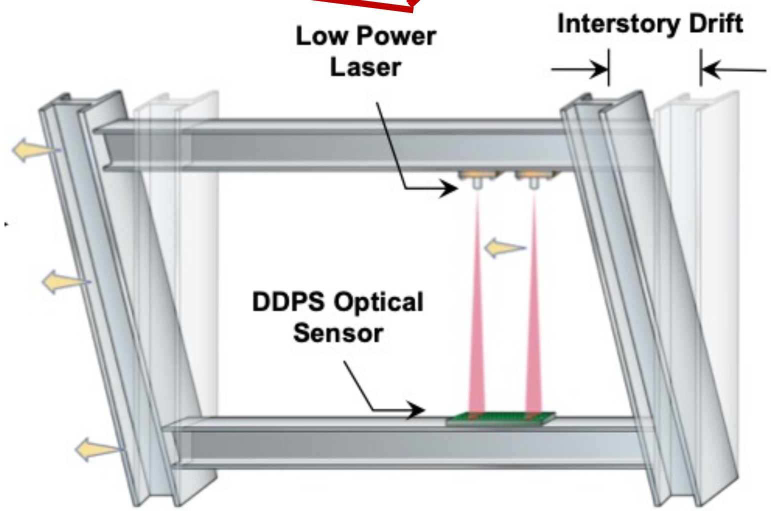
Research Questions

We need to perform systematic numerical and experimental feasibility studies to answer the following research questions:

- Spatial & temporal resolutions in different environments
- Possible designs to resolve different components of the strain tensor
- Consistency with point sensor measurements
- Soil-cable-structure coupling effects and strain transfer mechanisms
- Embedment, densification, and soil nonlinearity effects
- Integrity and resistance to large deformations and damages
- Required numerical modeling techniques
- Real-scale deployment challenges and opportunities for long-term/real-time monitoring

Concluding Remarks

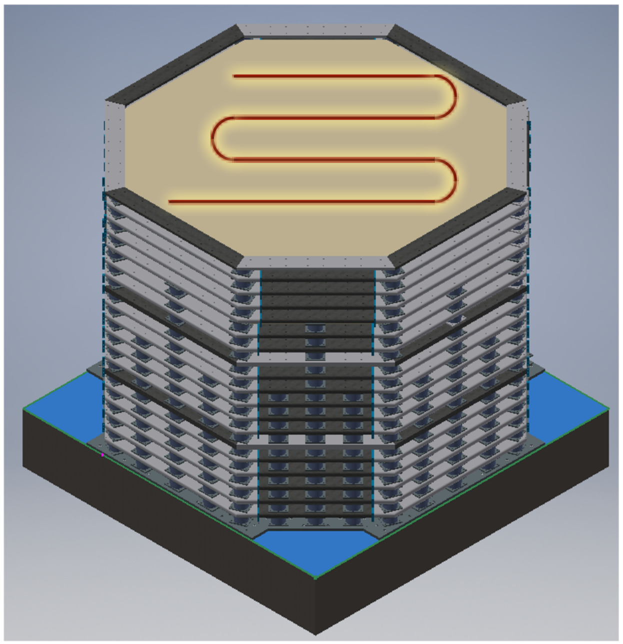


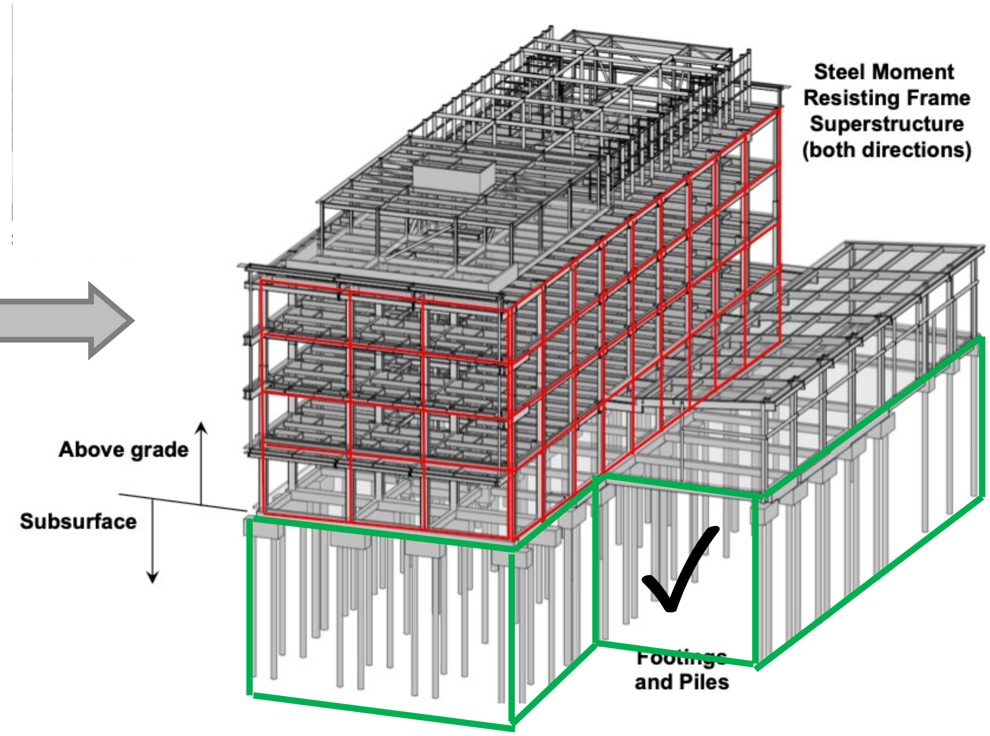


Courtesy of David McCallen

Concluding Remarks

Towards robust solutions for subsurface vibration and deformation monitoring





Thank you for your attention!