NORTH AMERICAN SOCIETY FOR TRENCHLESS TECHNOLOGY

STRUCTURAL HEALTH MONITORING OF UNDERGROUND INFRASTRUCTURE

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Graduate Student

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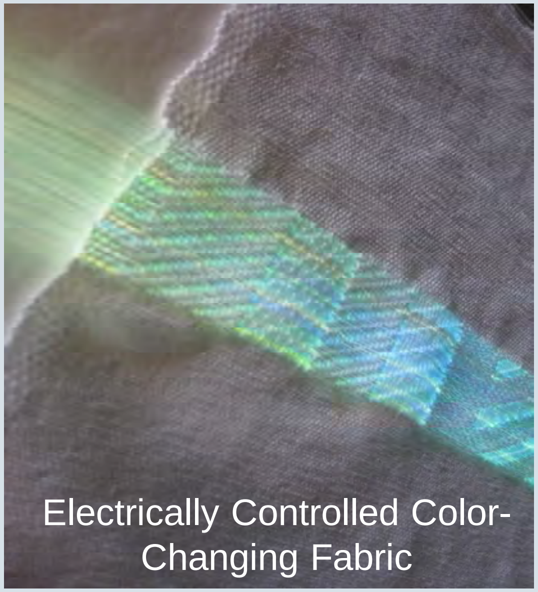
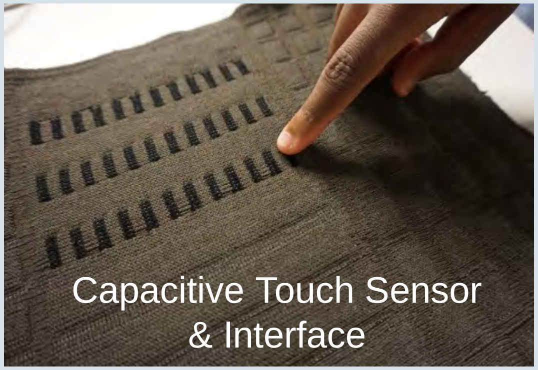
Advanced Functional Fabrics Of America (AFFOA)

- AFFOA funded the project title "**Sensing Textiles[Patent Pending] for Civil Infrastructure Monitoring**" in collaboration with ***Saint Gobain ADFORS.***

- AFFOA is a public-private partnership led by the Massachusetts Institute of Technology.

- It aims to deliver breakthroughs in fiber materials and manufacturing processes which will allow the design and wear of fabrics that see, hear, sense, communicate, store and convert energy, regulate temperature, monitor health and change color - heralding the dawn of a "fabric revolution."


Electrically Controlled Color-Changing Fabric

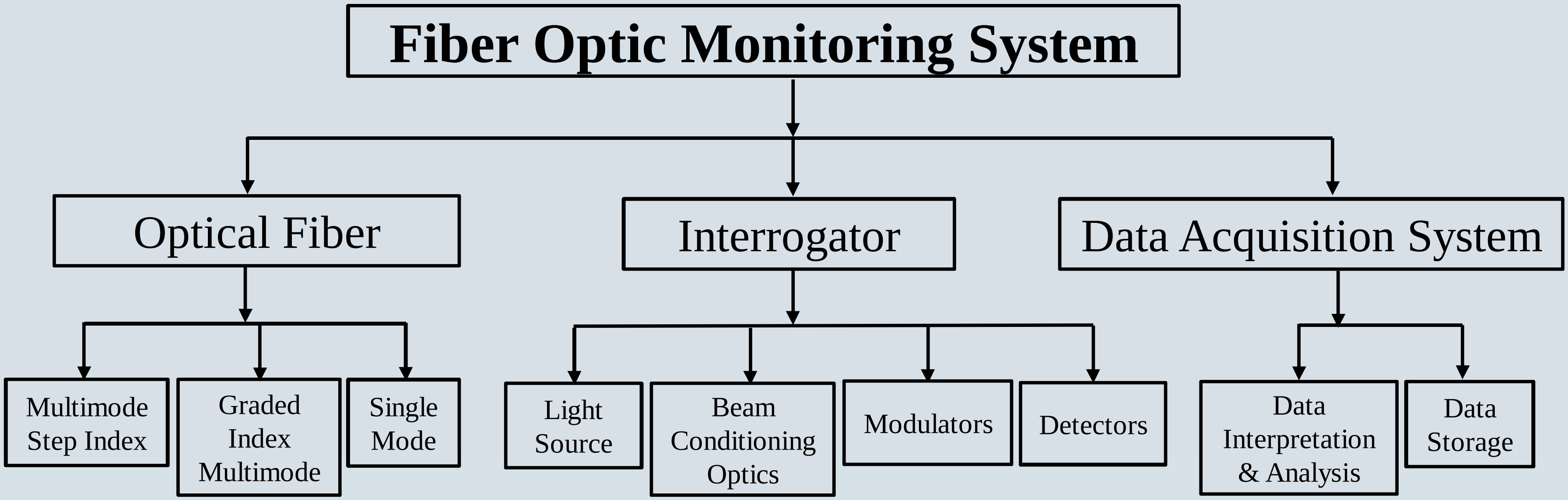

Capacitive Touch Sensor & Interface

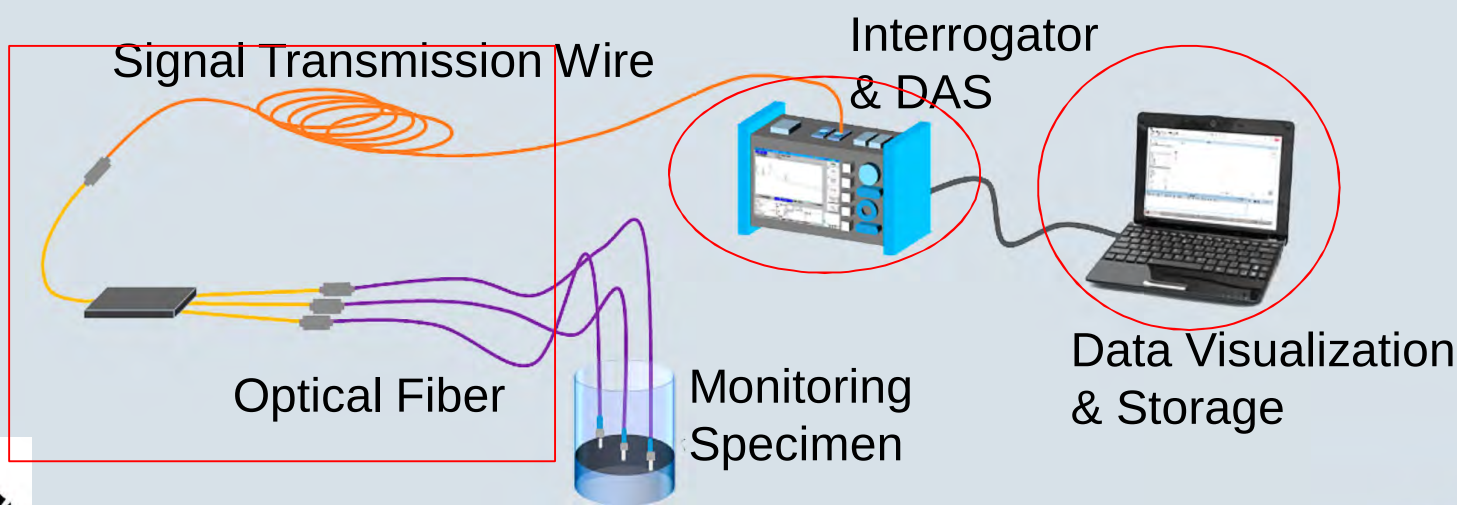
Scope of this Presentation

(Literature Review on Application of FOS in Underground Infrastructure)

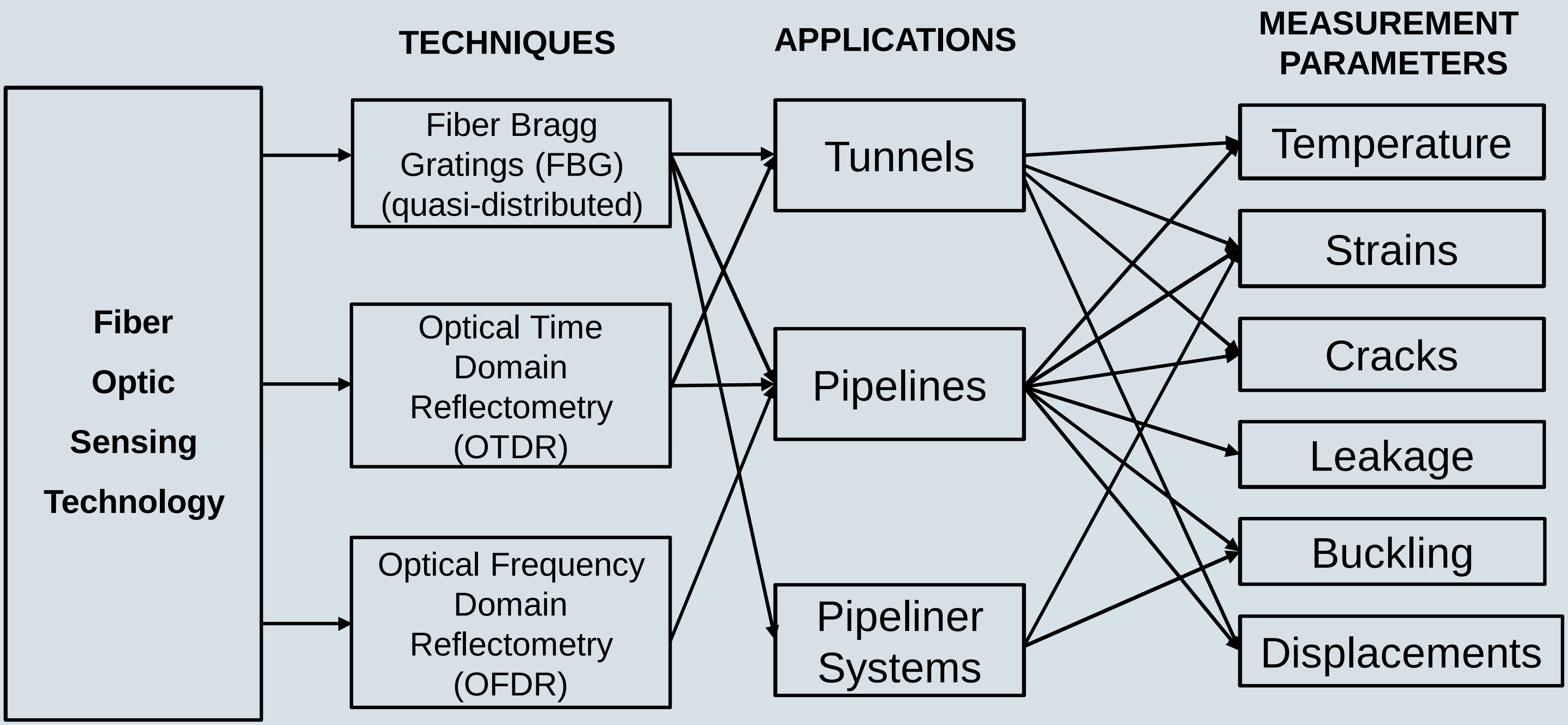
- Components of Fiber Optic Sensing Technology
- General discussion of available FOS Techniques
- Application of FOS for Monitoring Underground Infrastructure:
    - Tunnels
    - Pipelines
    - Pipe Liner Systems
- Sensing Textile & its Potential Application in Trenchless Technology

Essential Components of FOS Technology





Fiber Optic Sensing Techniques



Specifications of Commercial FOS Technology:

Spatial Resolution < 1m | Temperature Resolution: 0.1 - 0.2°C

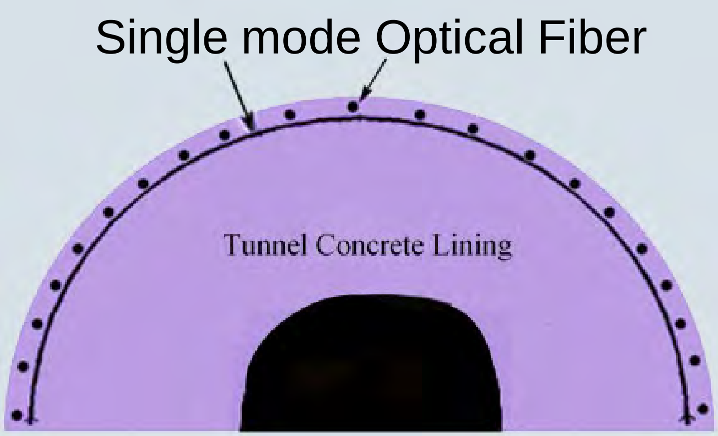
Strain Resolution: 30 με | Measurement Range: 30 km

Data Acquisition Time: 30 sec (200m) – 300 sec (12 km)

Application of FOS for Monitoring Underground Infrastructure

Tunnels

- Single mode telecommunication optical fibers attached using epoxy adhesive on the surface of a **concrete tunnel lining** to detect **strain** along the optical fiber.
- The **spatial resolution** of strain distribution in such a scenario is reported to be less than **100 mm**
- This approach is also suitable for **dynamic strain** monitoring at any arbitrary location, due to faster sampling rates.



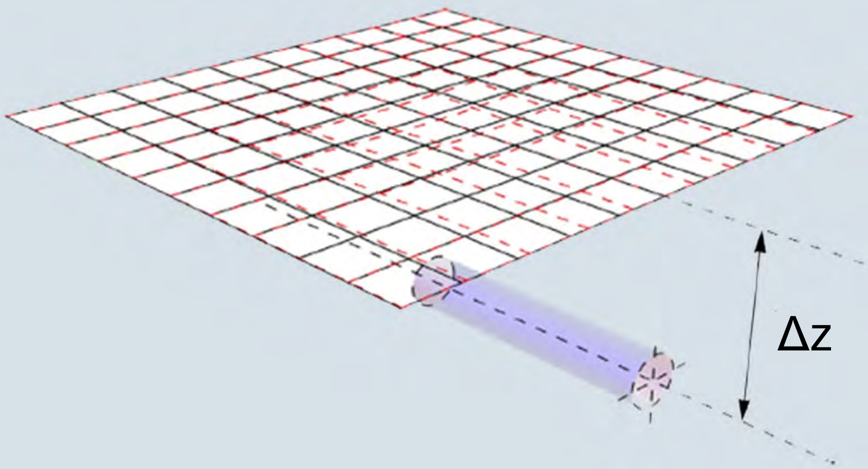
Application of FOS for monitoring a tunnel concrete lining (Revised from Leung, et al., 2013)

Induced Stresses and Displacements

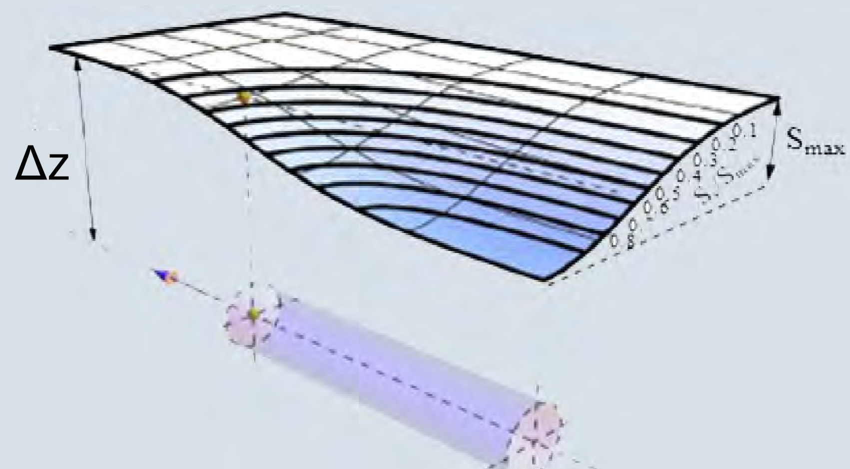
- Evaluate **<u>induced stresses</u>** and the **<u>displacements</u>** (vertical and horizontal) caused by disturbances or activities associated close to the underground tunnel.

- Calculate greenfield parameters such as the **<u>volume loss</u>** and the **<u>inflection point</u>** (associated with the settlement trough).

Horizontal displacements (3D Model)



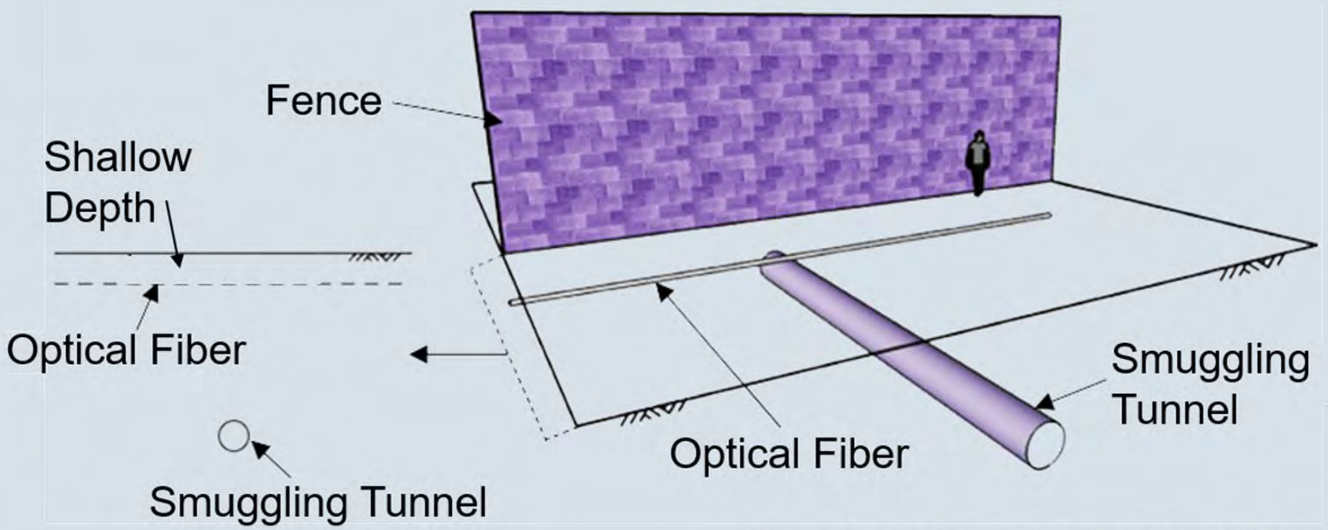
Vertical displacements (3D Model)



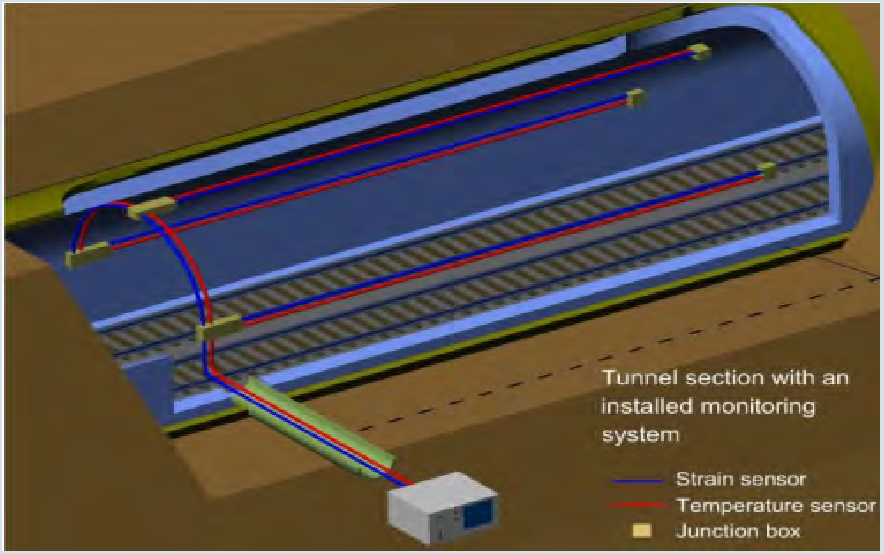
Vertical and Horizontal ground displacements (Revised from Klar et al., 2014)

Detection of Smuggler Tunnels

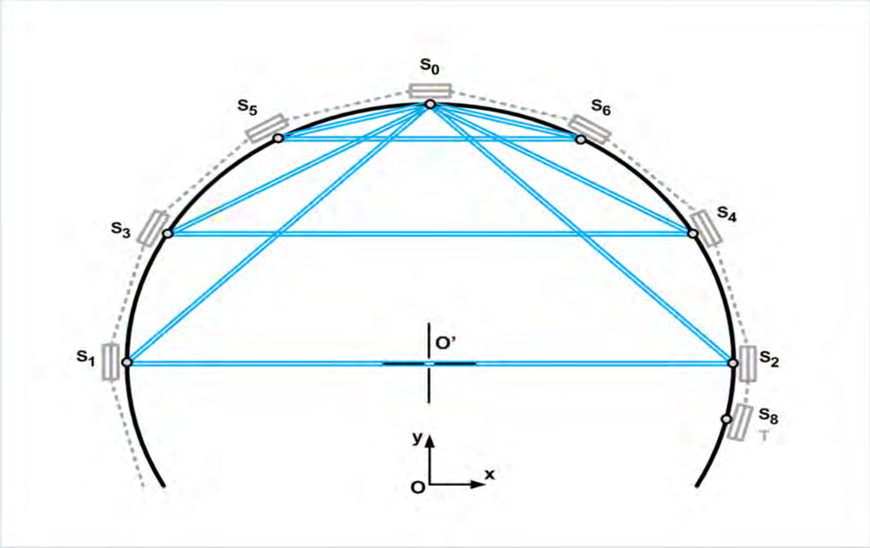
- Detection and characterization of **<u>cross-border smuggler tunnels</u>**.
- This is achieved by placing an optical fiber at a **<u>shallow depth</u>** under the surface throughout the **<u>length of the border</u>**. Sensors detect the **<u>disturbance</u>** caused by boring of a smuggler tunnel and alerts the appropriate agencies.
- Therefore, this technology can be useful to monitor impact in nearby structures due to Trenchless applications.



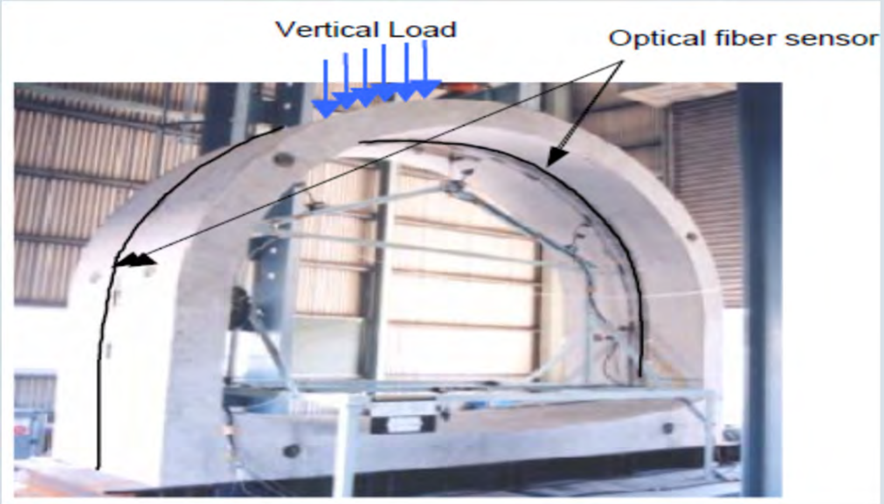
(Revised from Linker and Klar, 2013)



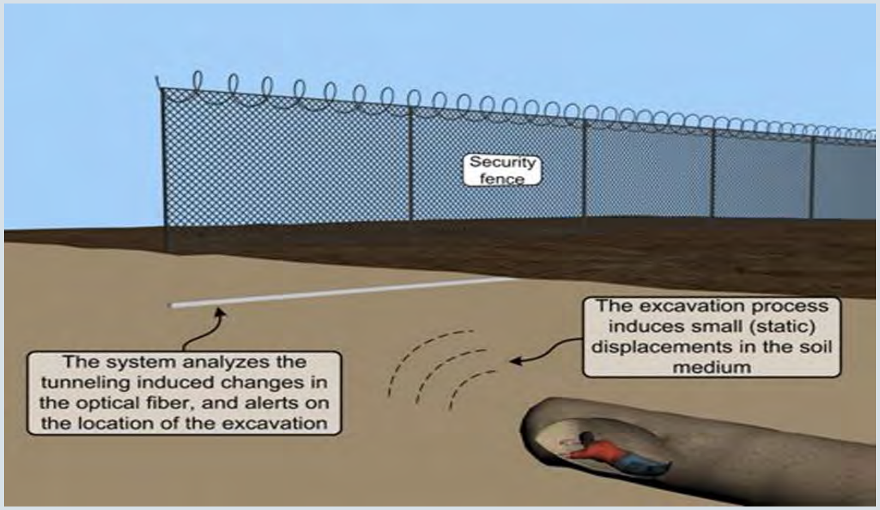
Mitigation measures to Tunnel Structures with Fiber Optic Monitoring System, http://lscom.ru/en_tunnel.html



HBM- Tunnel Monitoring with Optical Sensor Technology www.hbm.com/en/5854/tunnel-monitoring-with-fiber-bragg-sensors/



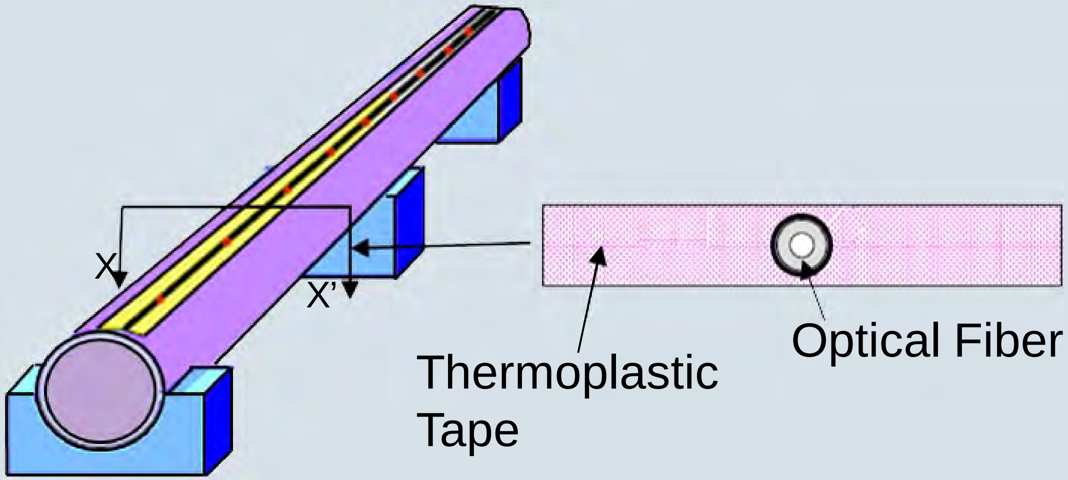
Tachibana, Kojima, Nakayama, Tunnel Monitoring System using the Optical Fiber Sensor or the Electric conductible Paint, 2014.



Locating Tunnel Excavations, http://thefutureofthings.com/ 3871-locating-tunnel-excavations/

Pipelines

- Conventionally, ***leak detection*** in pipelines is based on point sensors or the measurement of ***mass flow rate*** at certain points. However, these methods cannot be applied directly to ***detect exact location*** of leaks in the pipeline.



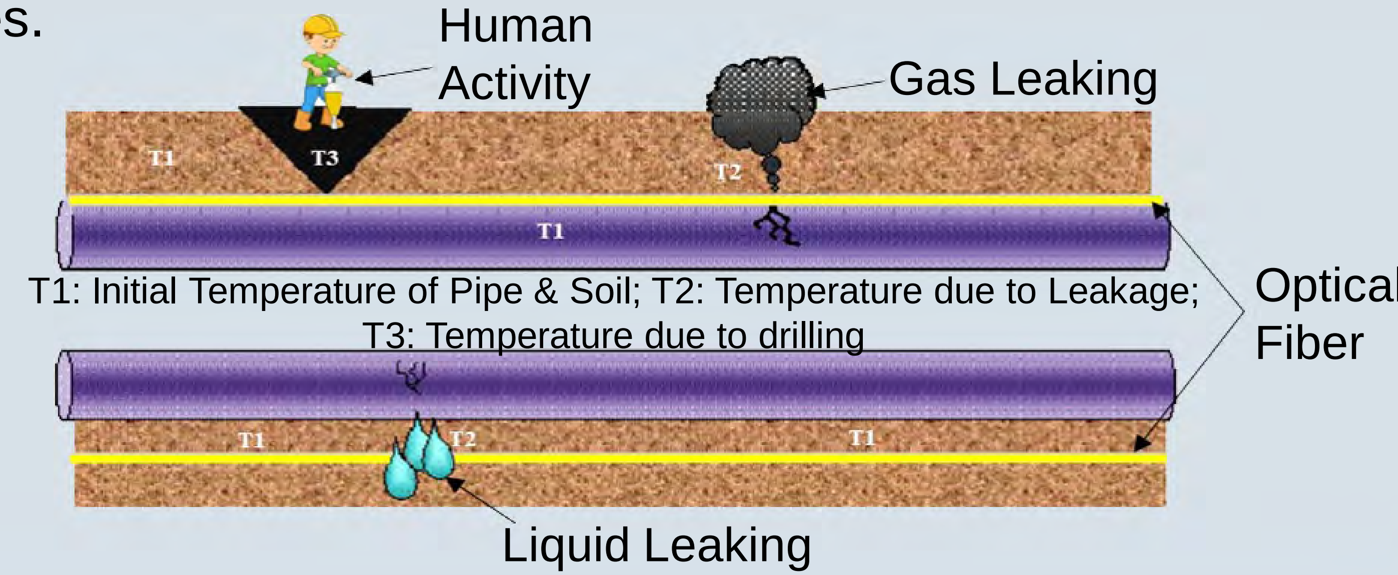
Cross- section and application of sensing tape (Revised from Inaudi and Glisic, 2007)

- The fiber optic sensors can be installed with the **thermoplastic tape** to monitor **deflections, strains and temperature changes** that could assist in the **detection of leakage** in pipelines.
- The strain and temperature resolution in such applications is reported to be in the range of **20 microstrains** and **1ºC**, respectively, with **spatial resolution up to 1.5 m**

Location of a Pipeline Leakage

- Significant **variation of temperature** along the pipeline helps in detecting the location of the leakage. In gas & liquid pipelines, a **local drop in temperature** along the pipeline can be observed. By FOS, the **precise location of temperature drop** can be identified in real-time.

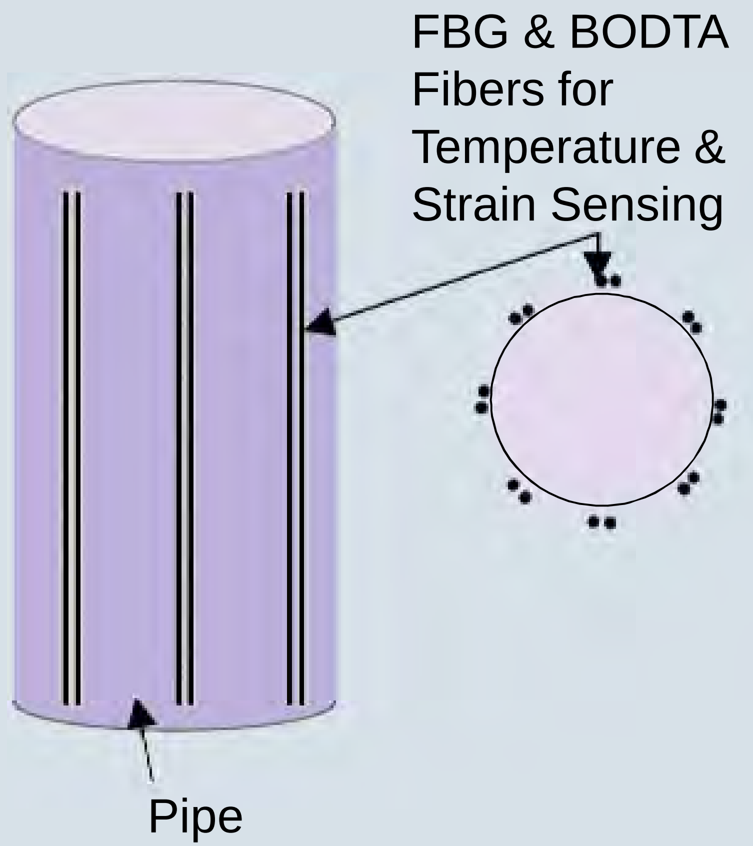
- The temperature sensing cable is placed in direct contact with the surface of the gas pipeline and installed below the pipeline for liquid pipelines.



(Revised from Inaudi and Glisic, 2007)

Pipeline Buckling

- In the case of **oil pipelines**, the fiber optic sensors are used in the investigation of pipeline **buckling**.
- When pipelines are subjected to ***sudden temperature change***, the large ***thermal induced compressive stress*** may cause buckling of pipe.
- The buckling locations could be identified by the **ripples of the strain distribution** before the pipeline rupture. The hoop strains can be calculated based on measured strains at different angular positions along the pipeline.



FBG and BOTDA fiber sensors attached along the longitudinal direction of the pipe for temperature and buckling detection (Revised from Leung et al., 2013)

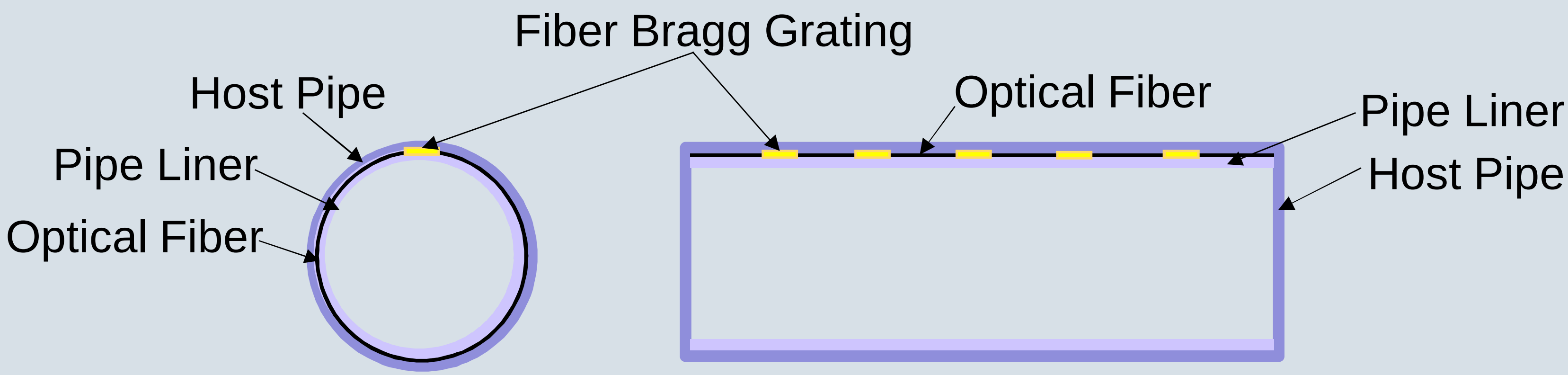
HBM- Fiber Optic Strain Sensors Monitor Pipeline Integrity, www.hbm.com/en/4577/fiber-optic-strain-sensors-monitor-pipeline-integrity/

Inaudi D, Glisic B. Long-Range Pipeline Monitoring by Distributed Fiber Optic Sensing. ASME. International Pipeline Conference

Inaudi D, Glisic B. Long-Range Pipeline Monitoring by Distributed Fiber Optic Sensing. ASME. International Pipeline Conference

Smartpipe Technologies, Smart Pipe: Embedded Fiber Optic Monitoring

Pipe Liner Systems



Schematics of FBG Sensors installed in pipe liner (Revised from Saber and Sterling, 2005)

- Fiber Bragg Grating (FBG) were embedded in a pipe liner system to monitor the **strains** in the repaired pipe liner.

- Experimental results showed that the **buckling loads** and **strain distribution** provided by the FBG sensors **do not correlate** with theoretical values, suggesting the challenges of theoretical calculation and the importance of in-situ monitoring systems.

Limitations of Existing FOS Technology

(Reported by Researchers in the Literature)

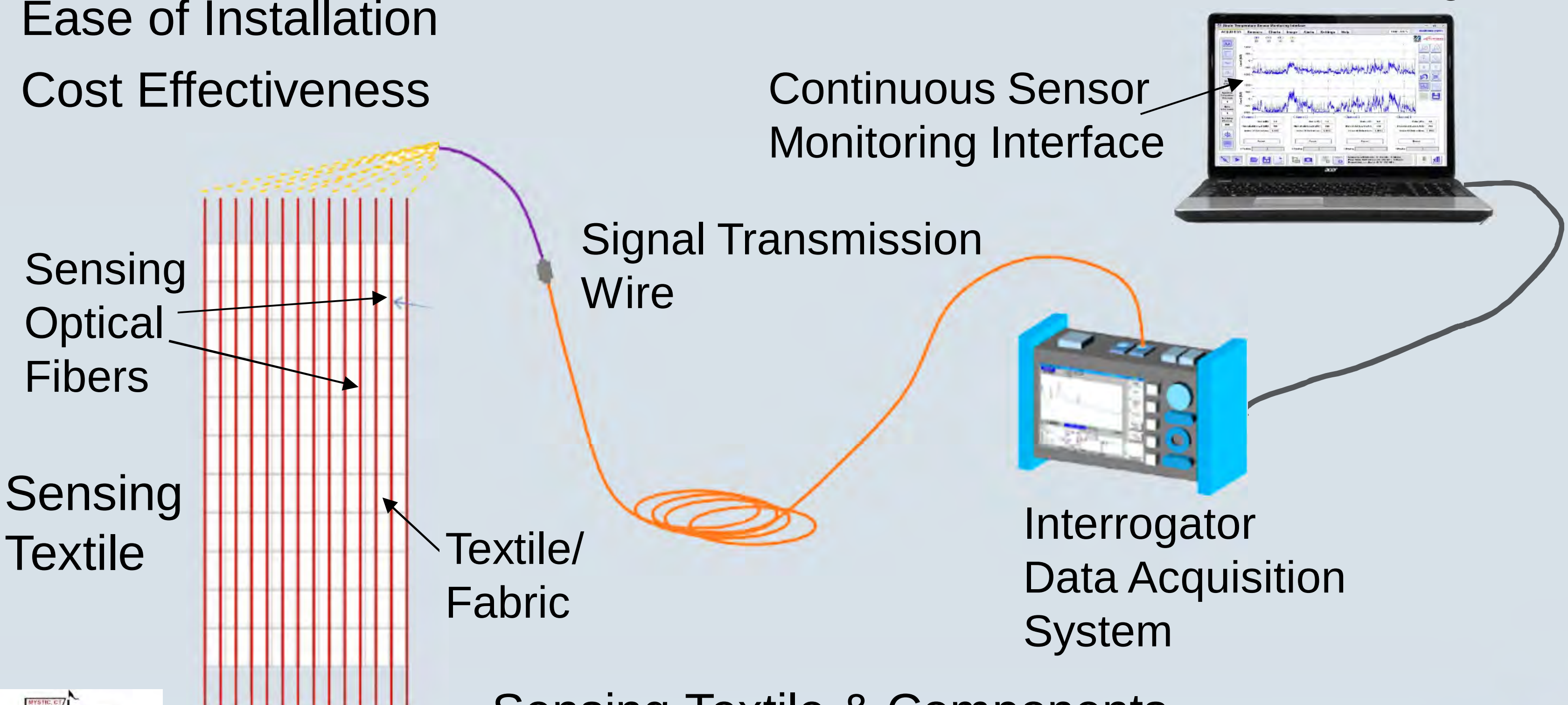
- Optical Fibers are ***fragile*** and ***difficult to handle***:
  - Hard to Install on Structures
  - May break or get damaged during its installation

- Limited number of optical sensors (2-3 fibers) to monitor structure which:
  - May not be effective in monitoring relatively huge structures with high accuracy
  - May overlook any defect/damage if a sensor is not available at that vicinity

Sensing Textiles for Civil Infrastructure Monitoring

Sensing Fabric Technology (Patent Pending) that provides:

- Sensing Redundancy
- Enhanced Resolution
- Designed in Robustness
- Ease of Installation
- Cost Effectiveness

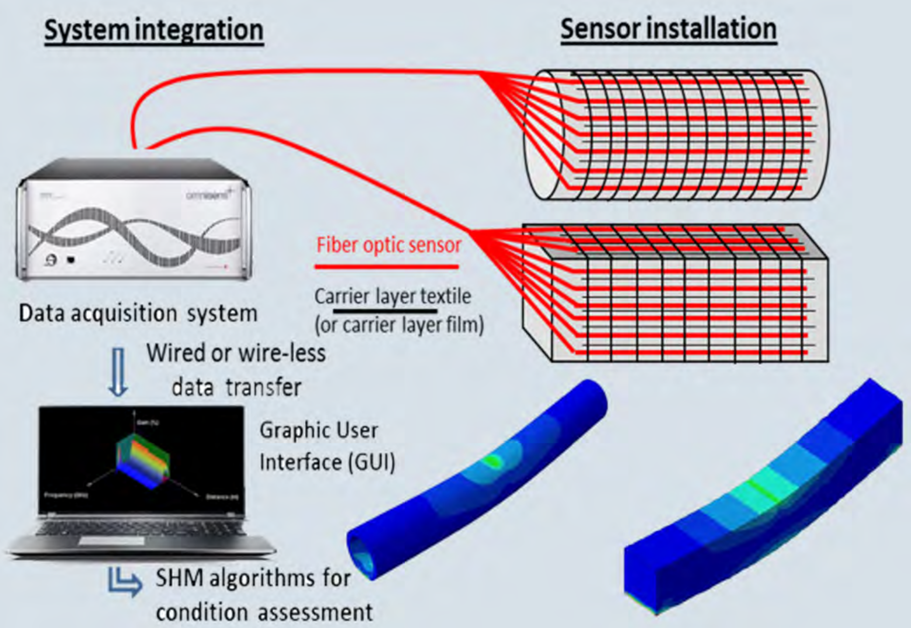


Sensing Textile & Components

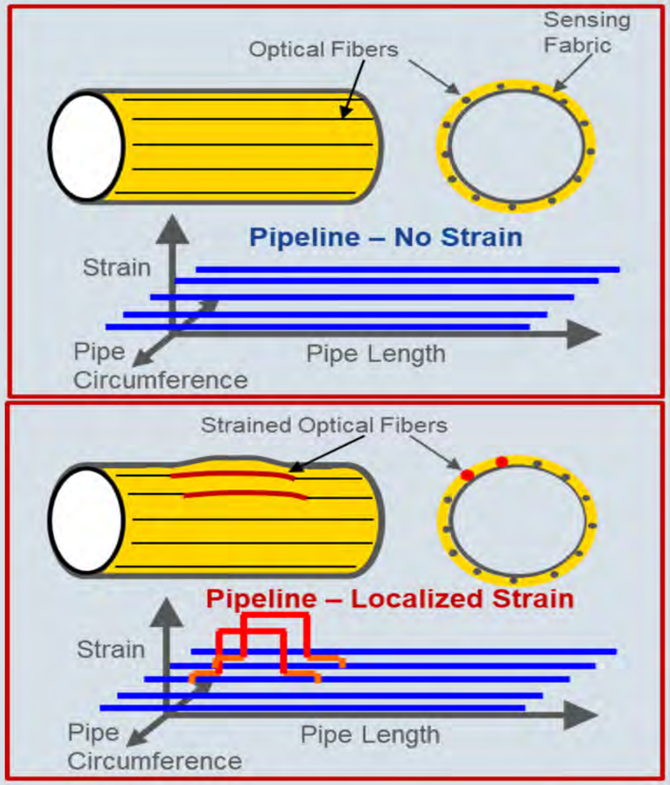
Enhanced Structural Reinforcement with Sensing

→ Quantitative Measurement & High Resolution

→ Proactive Infrastructural Health Assessment

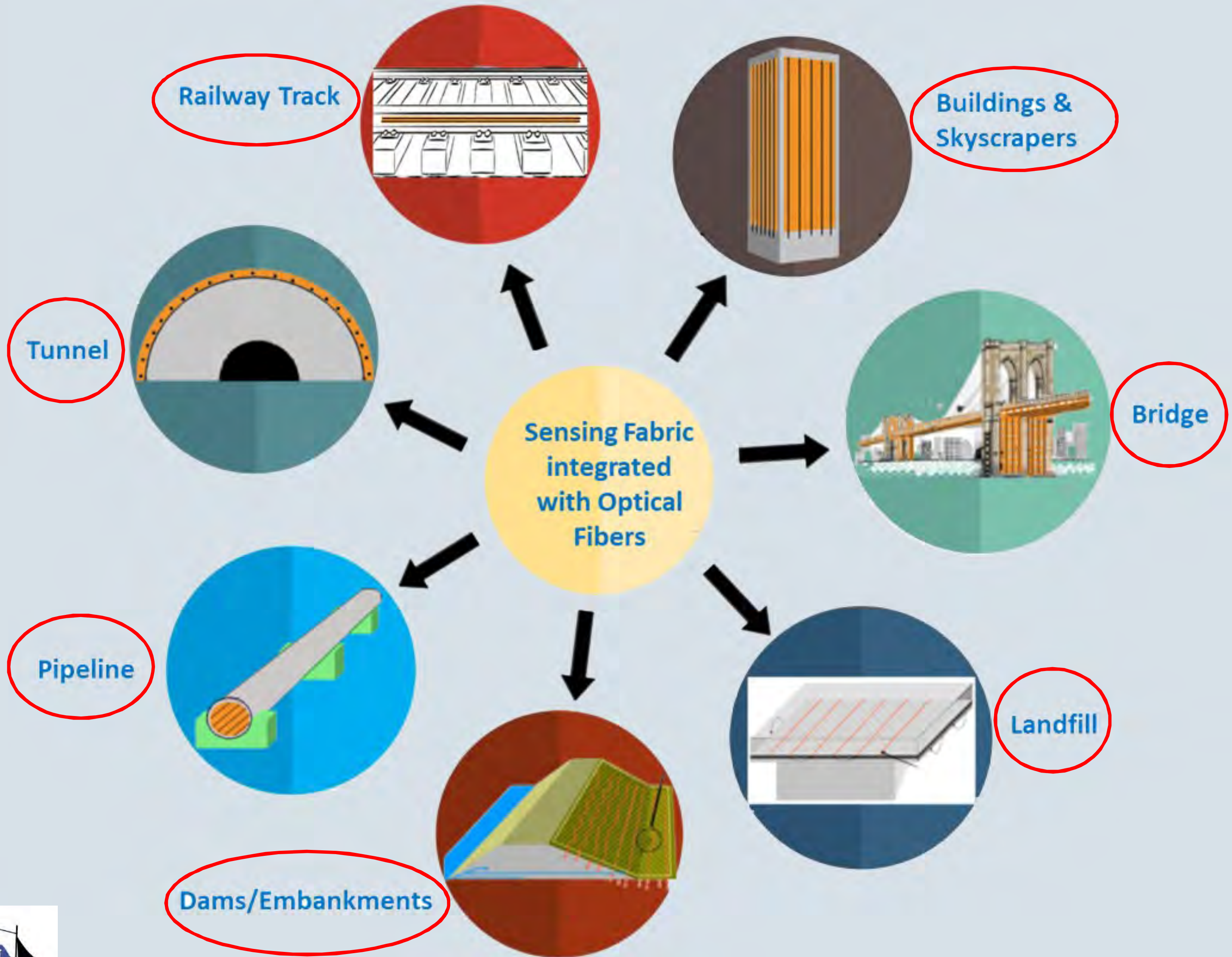


Sensing Textile Application & Numerical Simulation



Reduced Inconvenience & Improved Safety

Sensing Textiles Applications



Potential Application of Sensing Textile in Trenchless Technology

- **Pipe jacking joints**: measuring real time pressures in the joints, especially for curve microtunnels
- **Cured-in-place liners**: monitoring of curing using sensing textiles with temperature sensors
- **Soft tubes**: measuring stresses while insertion or inversion into host pipe
- **Nearby structures**: monitoring the impact during trenchless applications

Summary & Conclusions

- Fiber optic sensors offer unique advantages over other conventional techniques by:
  - long-term monitoring of underground infrastructure over large distances.
  - measuring physical quantities (such as displacements, stresses and strains) continuously distributed over the full length of the fiber.
  - helping early-stage detection of risks associated with the damage or failure of structures.

- The geometry and versatility of these sensors allow them to be effectively integrated into structures for monitoring strains that could assist in providing early warning signals related to timely detection of damage to prevent catastrophic failures.

- The simplicity, cost-effectiveness, and robust performance of this technology enable it to be employed as an effective monitoring approach.

THANK YOU

ANY QUESTION ?

Any Suggestions/Comments On Sensing Textiles ?