Distributed Fiber Optic Sensor Network for Real-time Monitoring of Pipeline Interactive Anomalies

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Sponsor and research team members

Sponsor: US Department of Transportation PHMSA

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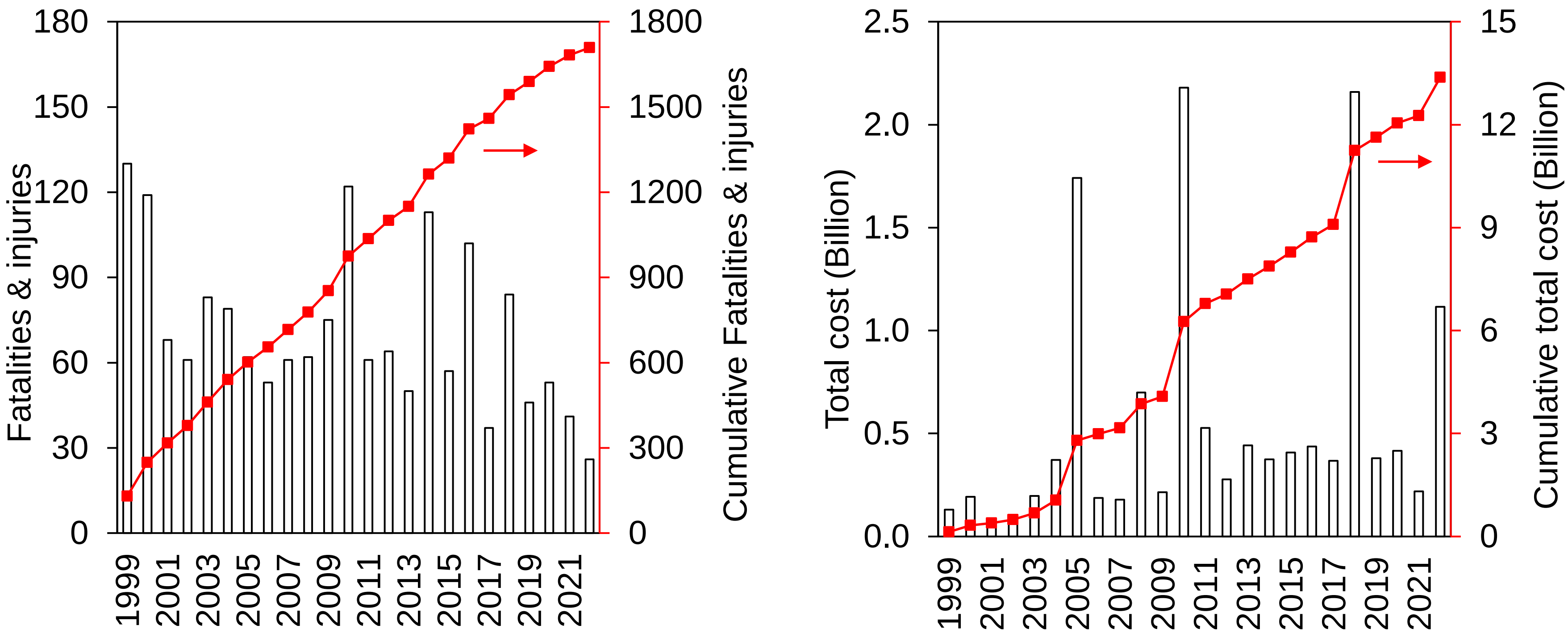
Background

Pipeline incidents continue occurring



Pipeline incidents in 1999-2022: (a) number of fatalities and injuries, and (b) costs

Data source: United States Department of Transportation, PHMSA. Data and Statistics Overview: https://www.phmsa.dot.gov/data-and-statistics/pipeline/data-and-statistics-overview

Problems address in this project

Pipelines are subjected to interactive risks

- Different types, or same type but multiple ones at the same position


Digging


Cracking


Dent

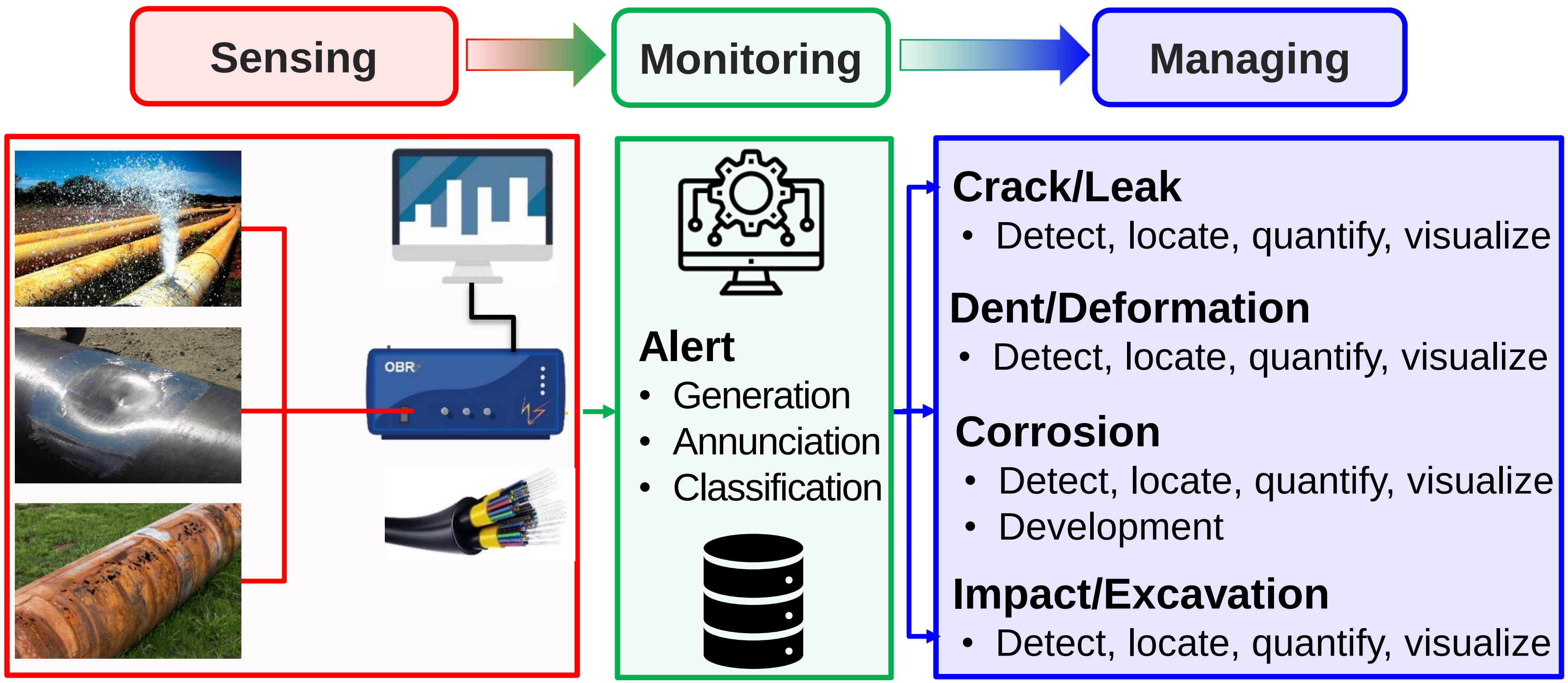

Corrosion

These risks interact with each other

- The development rate of anomalies are increased
- More difficult to detect and evaluate the anomalies
  - ➢ Measurement results are sensitive to multiple anomalies
  - ➢ Difficult to differentiate each type of anomaly

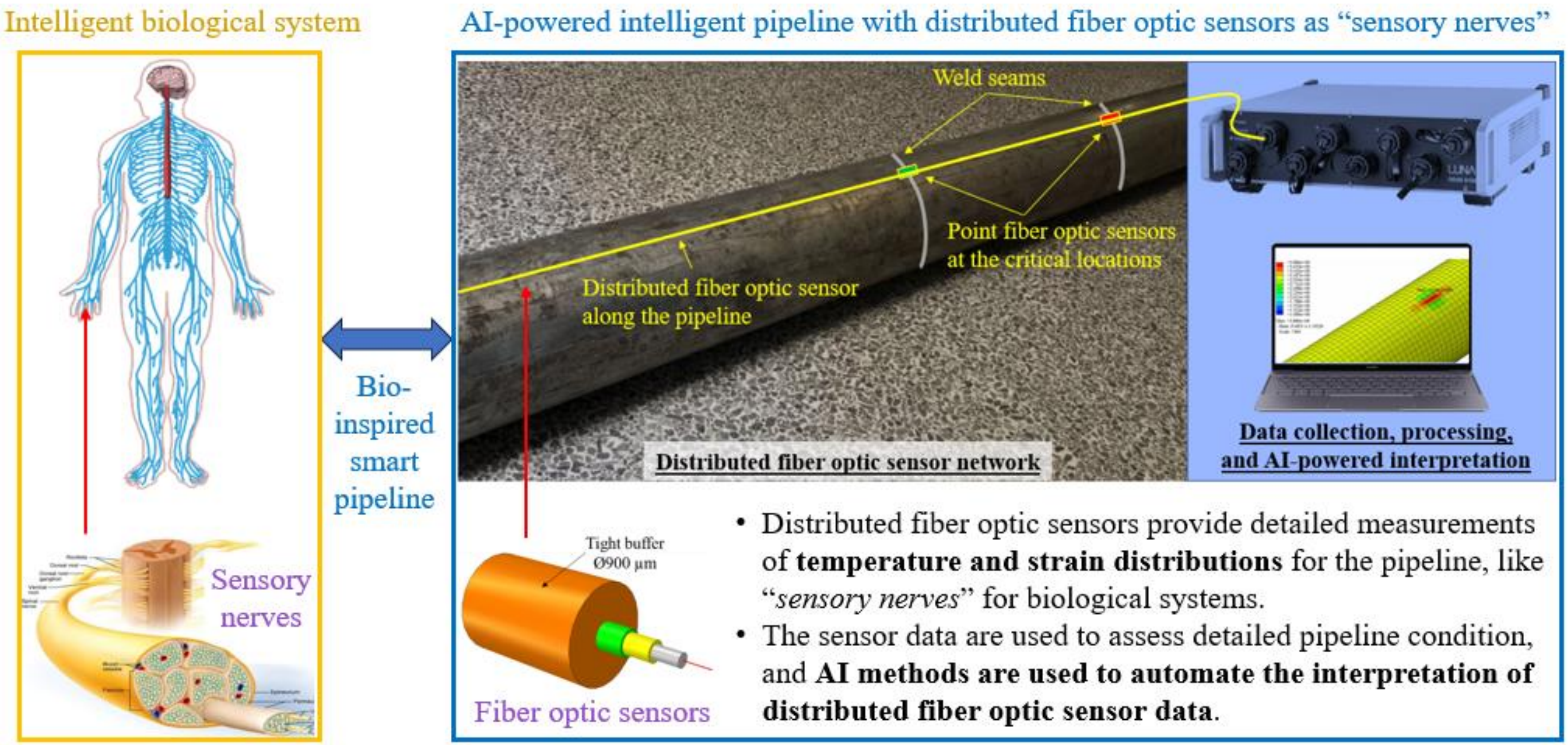
Research objective

Develop a distributed fiber optic sensor network for monitoring cracks, dents, corrosion, impact, and their interactive effects for pipelines



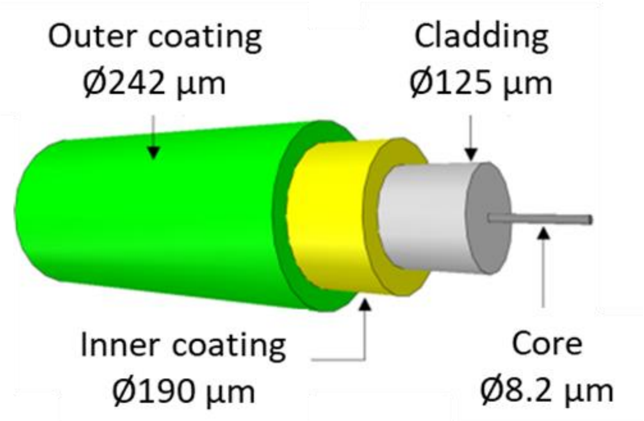
Distributed fiber optic sensor network

Integrate distributed sensor, point sensor, and AI

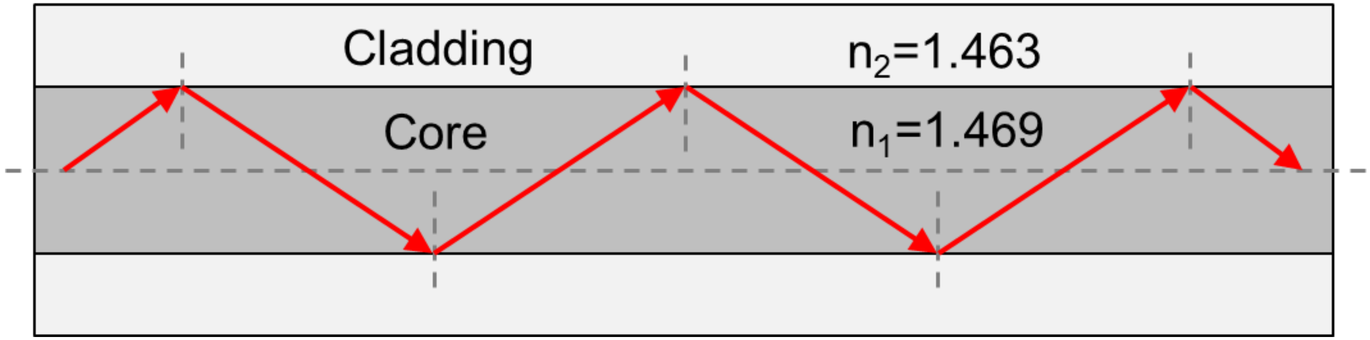


Optical fibers

- Telecommunication-grade single-mode optical fiber:
  - ➢ Core: high-purity fused silica, high refractive index
  - ➢ Cladding: high-purity fused silica, low refractive index
  - ➢ Coatings: mechanical protection

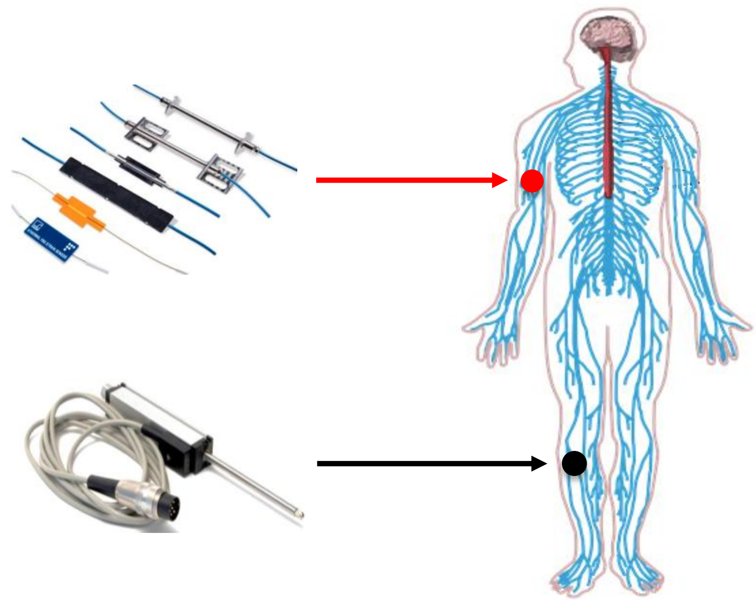


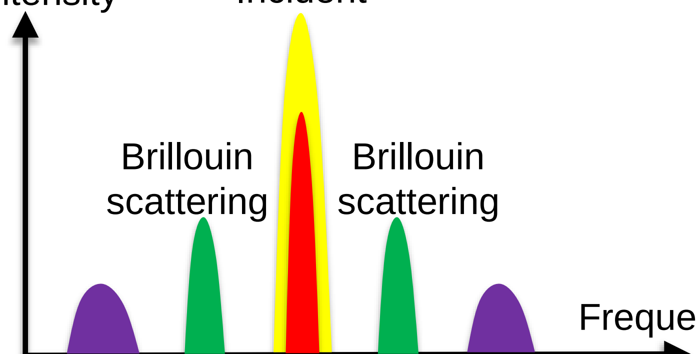
- Light wave is guided through total internal reflection at the core-cladding interface



Fiber optic sensors

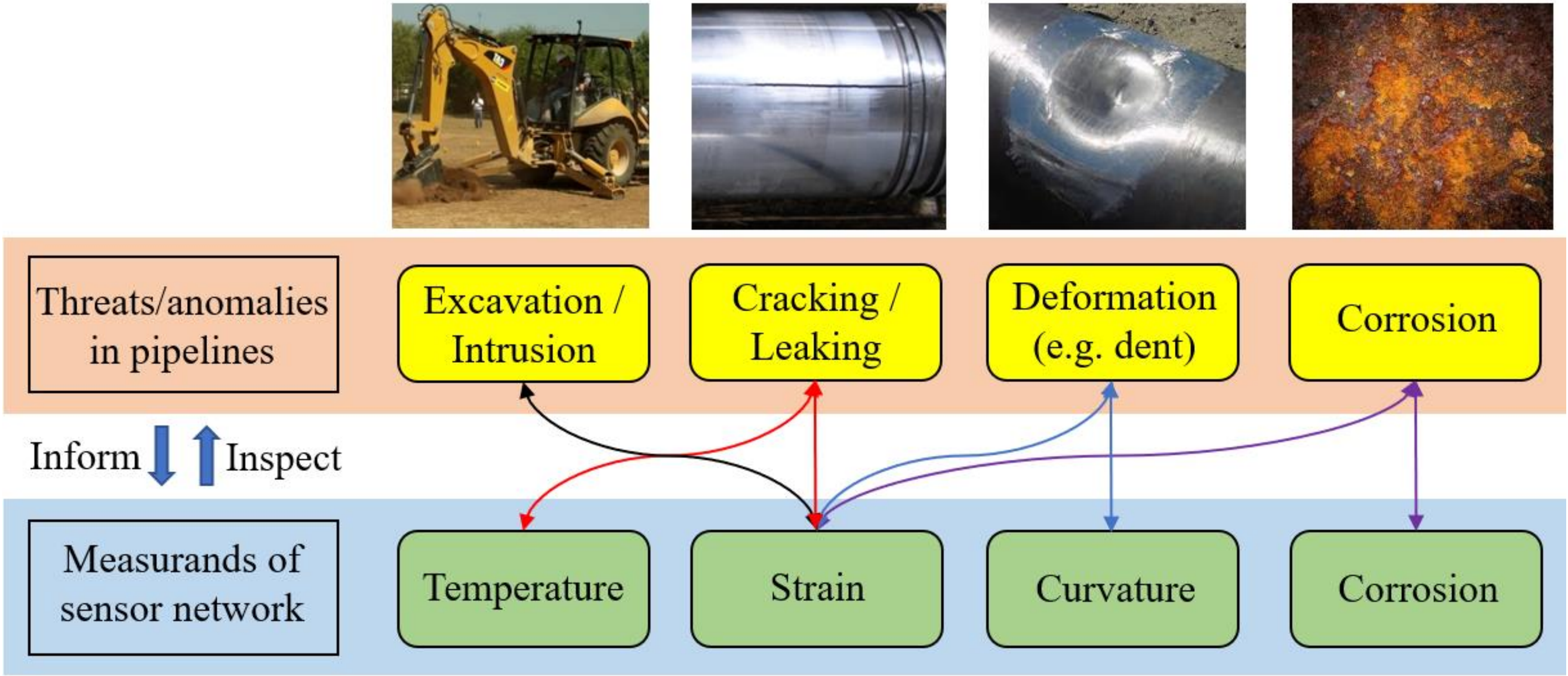
- Grating sensors
  - ➢ Single point measurement
- Interferometer sensors
  - ➢ Single point measurement
- Distributed sensors
  - ➢ Continuous measurement along optical fiber (~100 km), 1 sensing point at every 1 cm
  - ➢ Based on light scatterings in optical fiber





Proposed approach

Interactive anomalies are monitored using a distributed fiber optic sensor network that measures temperature and strain distributions



Tasks with total project funding (high level)

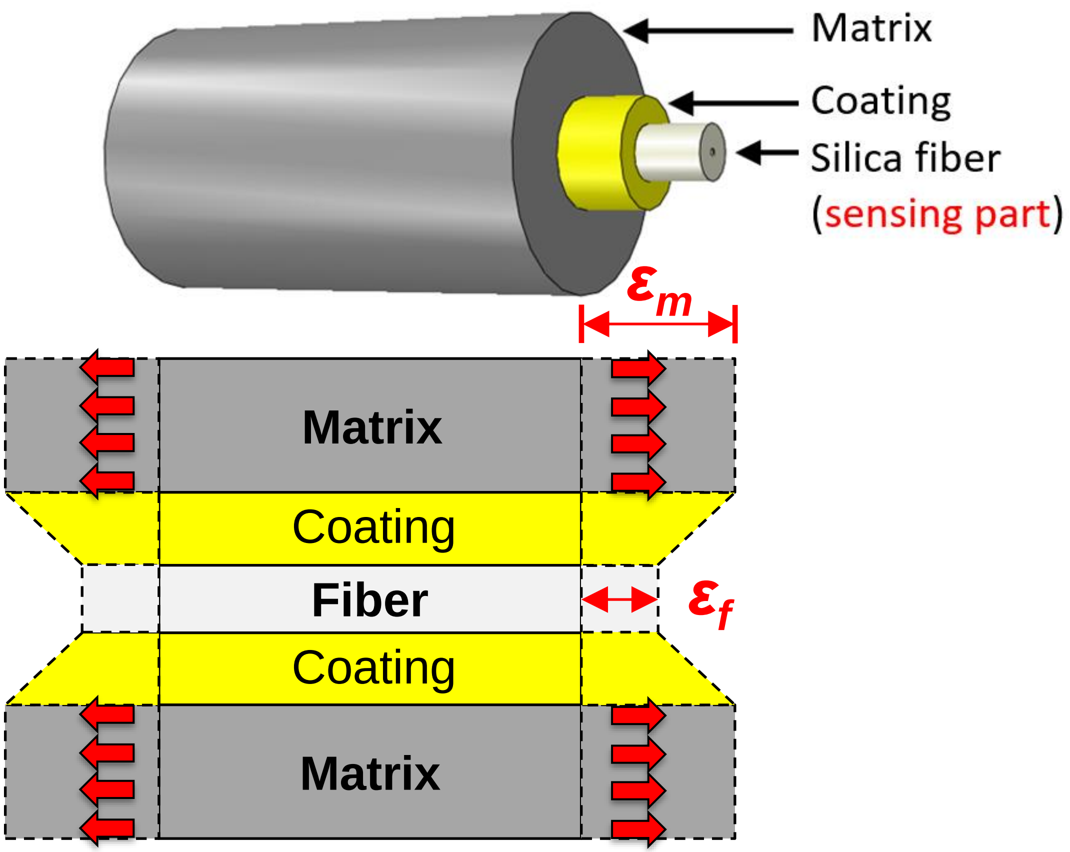
- Develop and demonstrate the distributed fiber optic sensor network for detecting, locating, characterizing, and quantifying individual and interactive anomalies
  - Individual anomalies (strain, bending, dent, crack, corrosion, impact)
  - Interactive anomalies
- Develop data processing and analysis programs for effective and efficient interpretation of sensor data
  - Analytical methods
  - Machine learning methods
- Train graduate and undergraduate students through conducting research on pipeline anomaly detection to prepare them for future careers in related industry
- Funding: $250,000 from PHMSA

Experiments

1. Measurement of arbitrary strain fields
2. Detection, localization, and quantification of cracks
3. Interfacial mechanics of distributed sensors undergoing debonding
4. Detection, localization, quantification, and visualization of buckling/dent
5. Detection, localization, quantification, and visualization of corrosion
6. Investigation of different types of fiber optic cables and installation methods
7. Detection of excavation induced impacts on pipelines
8. Measurement of **interactive** deformations and cracks
9. Measurement of **interactive** dent and corrosion
10. Measurement of **interactive** deformations and dent
11. Measurement of **interactive** impact loads and corrosion
12. Measurement of **interactive** deformations, dent, crack, and corrosion

Theme 1: Measurement of arbitrary strain fields

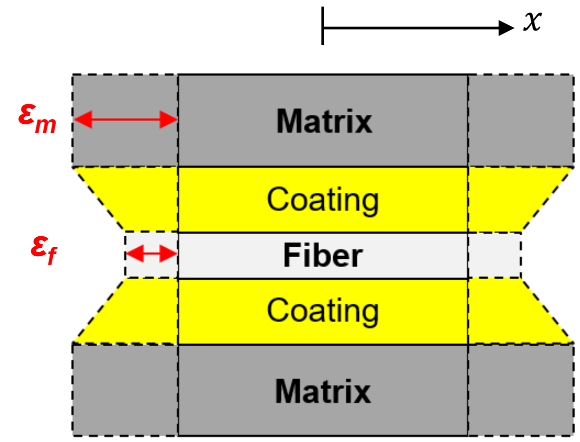
- When a fiber optic sensor is embedded in a matrix, does the sensor always sense the same strain as the host matrix?
- The relationship between ε_m and ε_f must be determined.



Mechanical study

- Governing equation

$$\varepsilon_f''(x) - k^2\varepsilon_f(x) + k^2\varepsilon_m(x) = 0$$



where

$$k^2 = \frac{2}{E_f r_f^2 [\frac{In(r_i/r_f)}{G_i} + \frac{In(r_o/r_i)}{G_o}]}$$

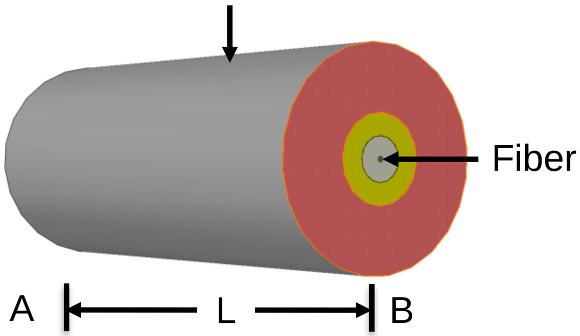
- Strain in fiber (ε_f) is solved, given the strain field (ε_m) in the matrix

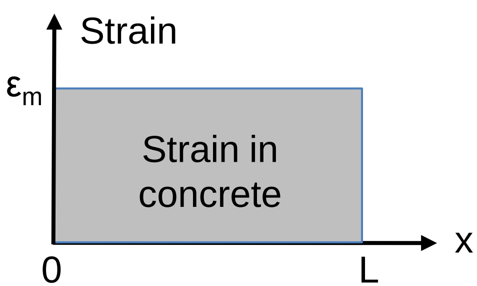
$$\varepsilon_f(x) = C_1\cosh(kx)+C_2\cosh(kx) + \varepsilon^p(x)$$

- Different strain fields (ε_m) have been studied.

Case 1: Uniform strain field in matrix

Concrete cylinder under uniform compression

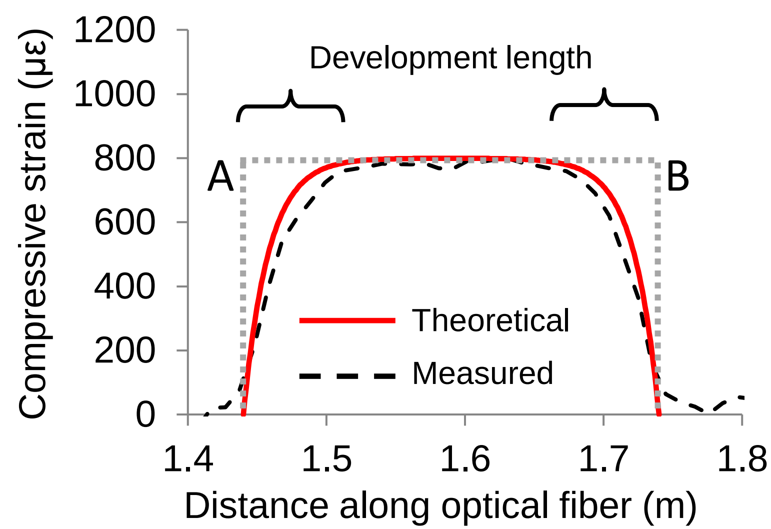




Strain in fiber is calculated:

$$\varepsilon_f(x) = \varepsilon_m[1 - \cosh(kx) + \tanh(kL/2)\sinh(kx)]$$

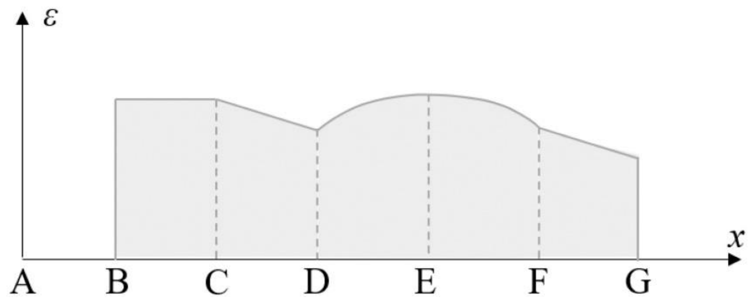
Plot in red color



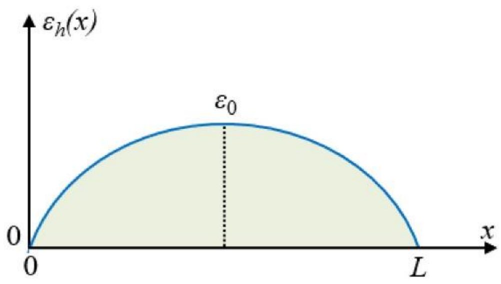
Strain measurement results should be corrected using the calibrated relationship between ε_f and ε_m

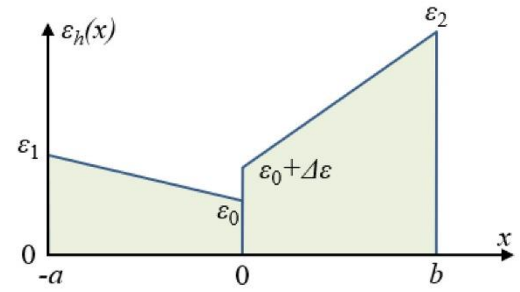
Case 2: Non-uniform strain fields in matrix

- Distributed fiber optic sensors are usually subjected to non-uniform strain fields due to the long length



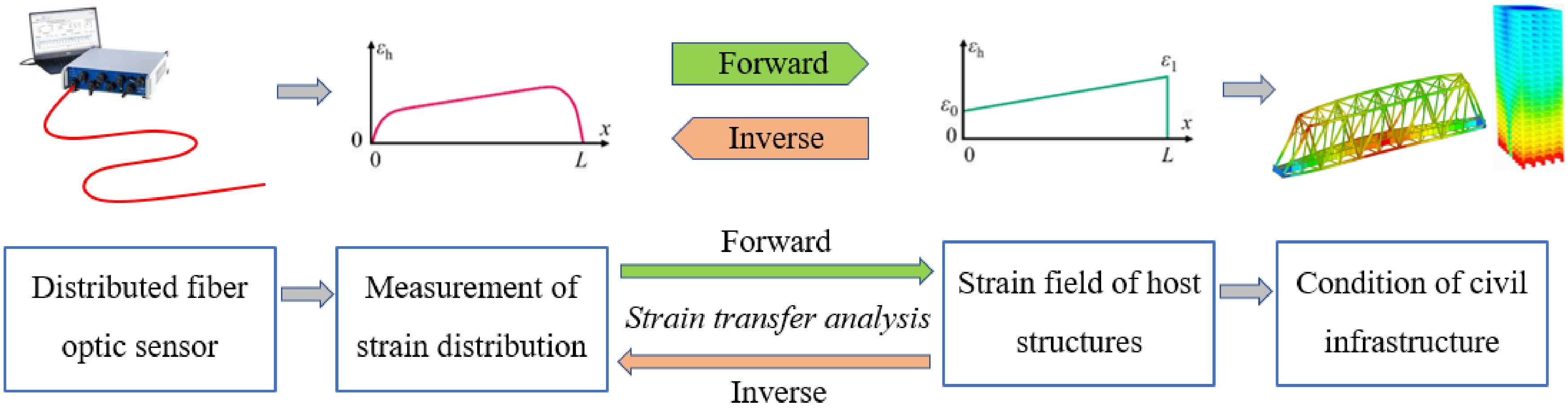
This original work enables accurate interpretation of sensor data for measuring strain distributions.





Strain transfer analysis

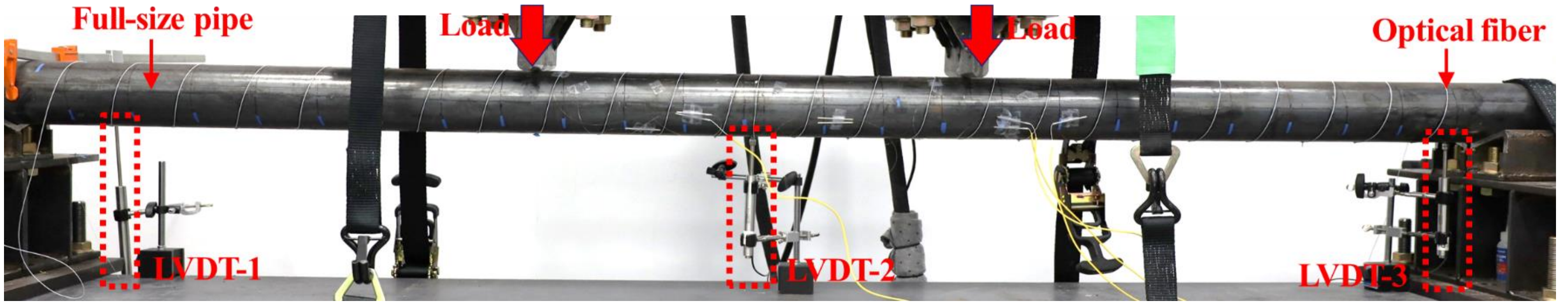
- An approach to perform forward and backward (inverse) strain transfer analysis has been developed in recent research
- Measurement from distributed sensors can be corrected to eliminate the strain transfer effect

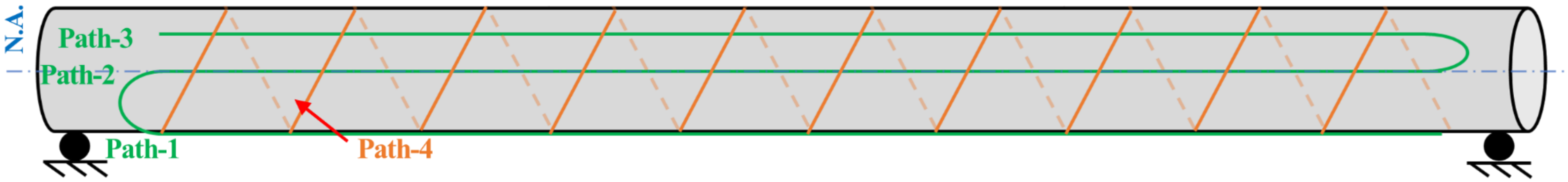


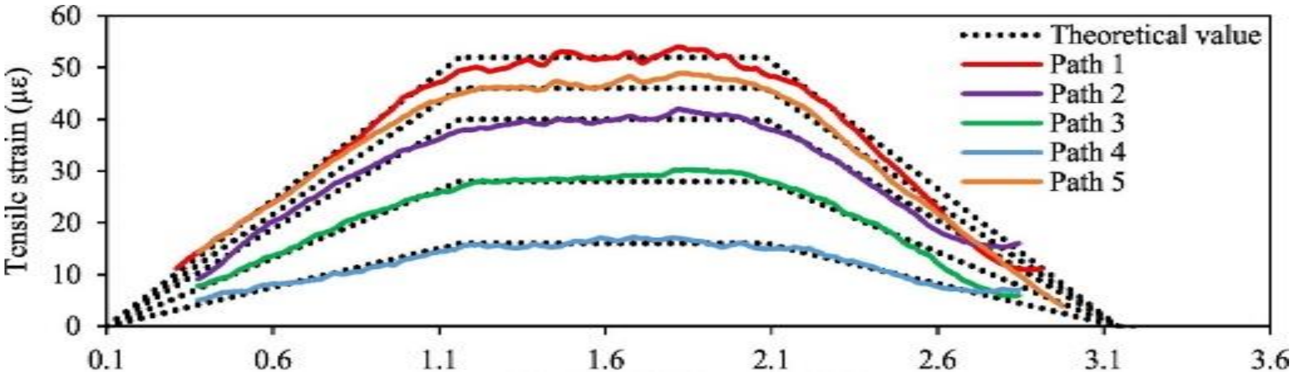
Tan, X., **Bao, Y.***, Zhang, Q., et al., 2021. Strain transfer effect in distributed fiber optic sensors under an arbitrary field. *Automation in Construction*, 124, p.103597.
Mahjoubi, S., Tan, X. and **Bao, Y.***, 2022. Inverse analysis of strain distributions sensed by distributed fiber optic sensors subject to strain transfer. *Mechanical Systems and Signal Processing*, 166, p.108474.
Yan, M., Tan, X., Mahjoubi, S. and **Bao, Y.***, 2022. Strain transfer effect on measurements with distributed fiber optic sensors. *Automation in Construction*, 139, p.104262.

Pipeline deformation

- Detailed strain distributions were measured

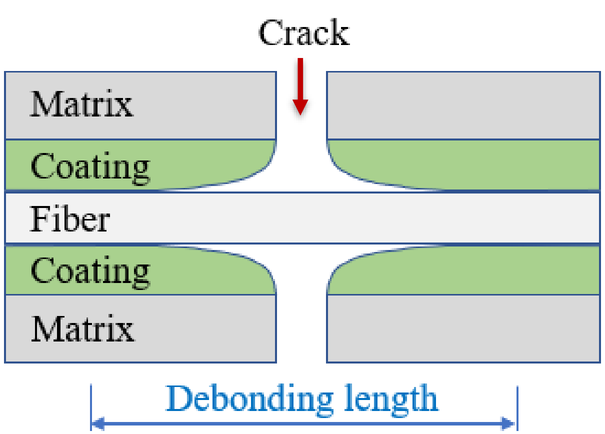


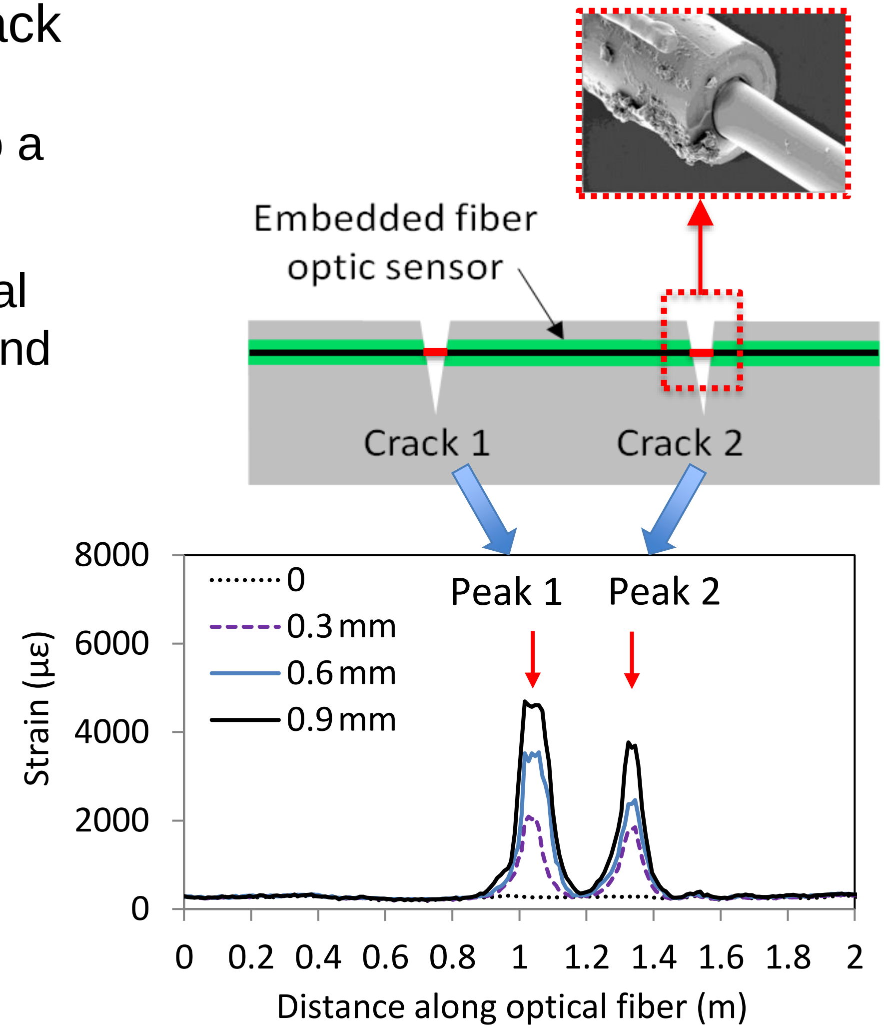




Theme 2: Detection, localization, and quantification of cracks

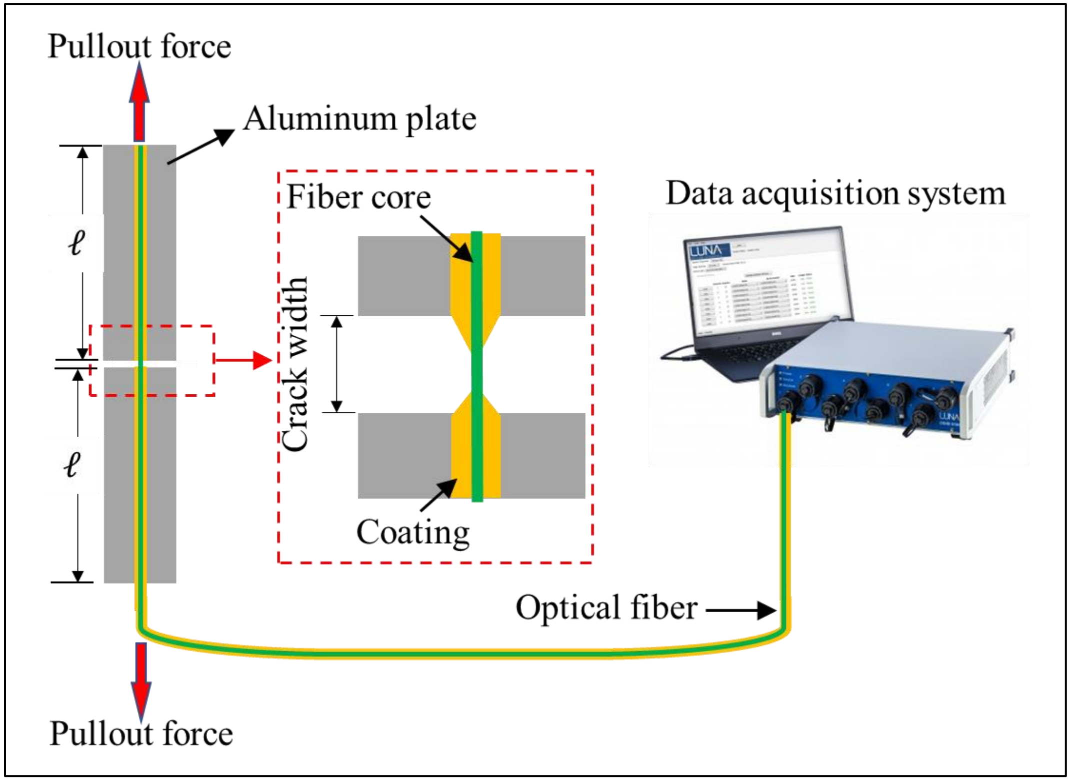
- When an optical fiber passes a crack
  - the optical fiber will be stretched to a high strain level,
  - debonding will happen in the optical fiber to delay the rupture of fiber, and
  - the strain peaks indicate the locations of cracks.



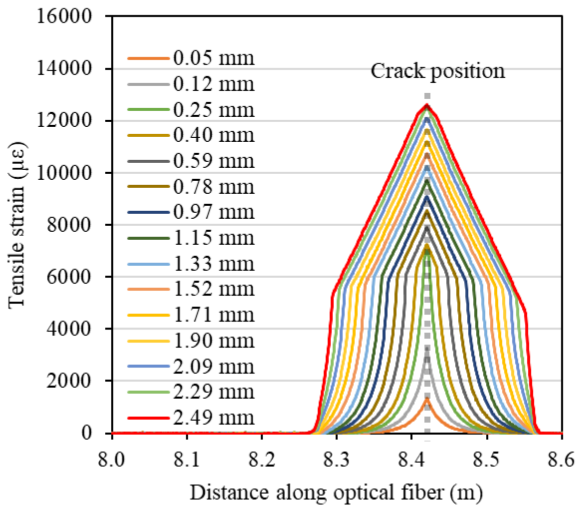


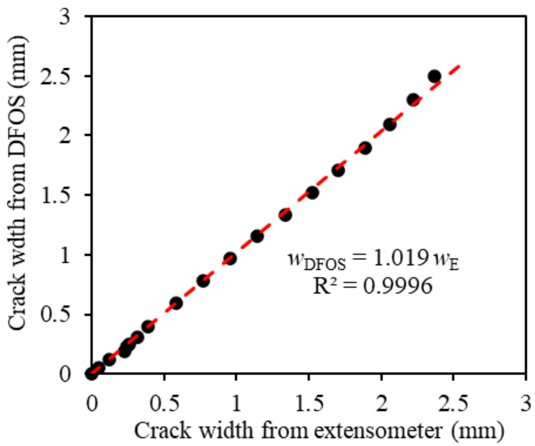
Methods for crack width quantification

Theoretical support of the empirical crack width correlation



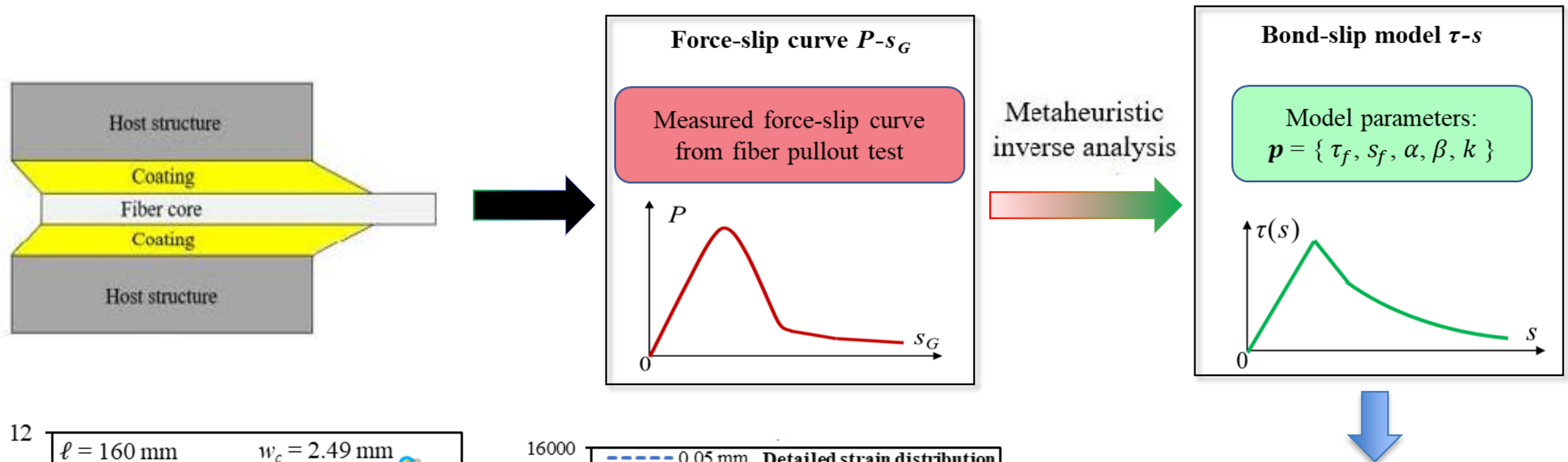
$$w = 2\int_0^{\ell} \varepsilon_f(x)dx$$

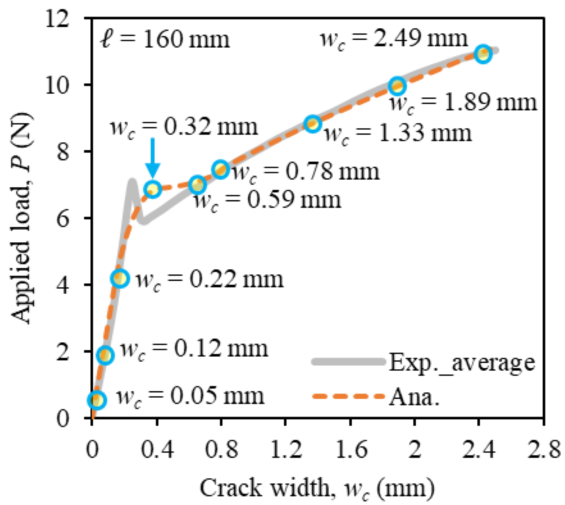




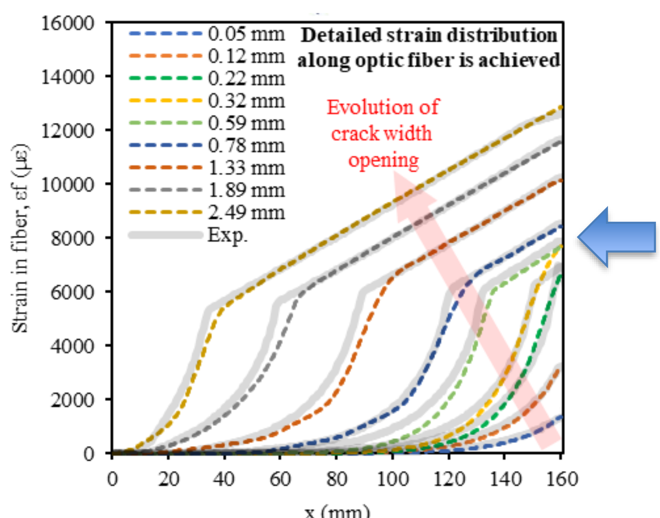
Tan, X. and **Bao, Y.*** (2021). Measuring crack width using a distributed fiber optic sensor based on optical frequency domain reflectometry. *Measurement*, 172, p.108945.

Theme 3: Interfacial mechanics of distributed sensors undergoing debonding

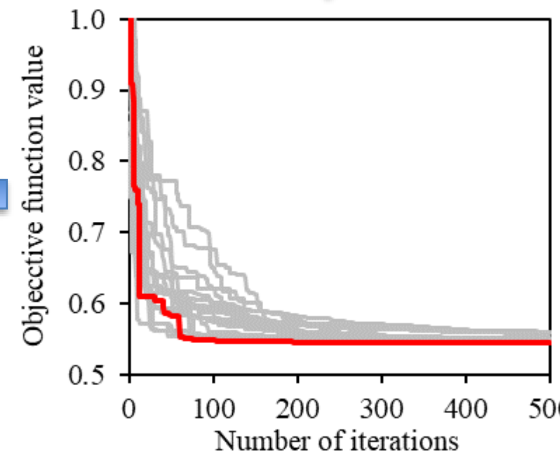




Comparison of the analytical and experimental results



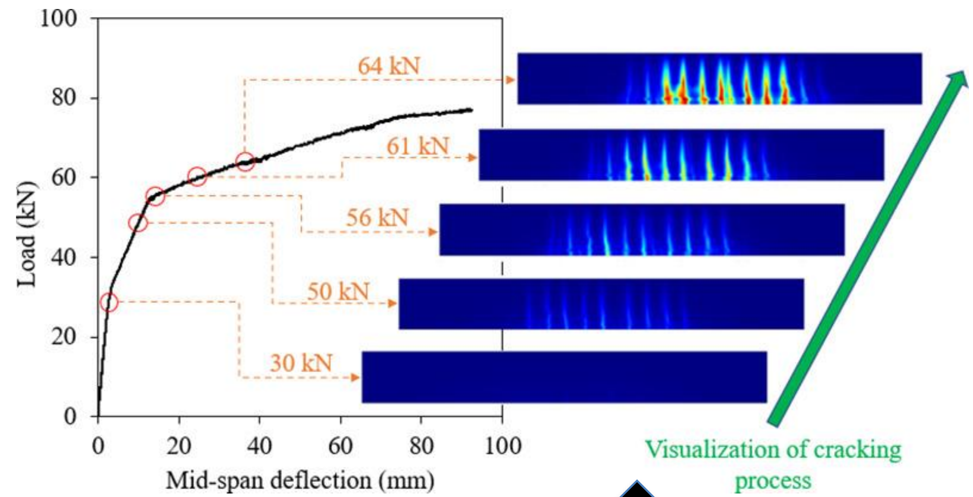
Strain distributions

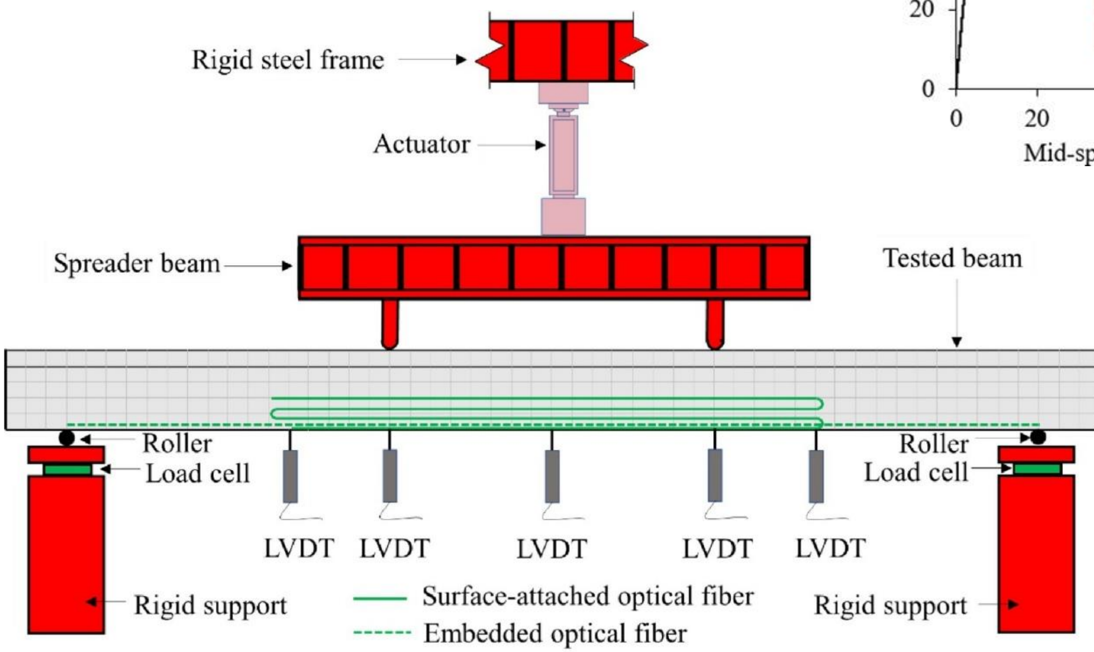


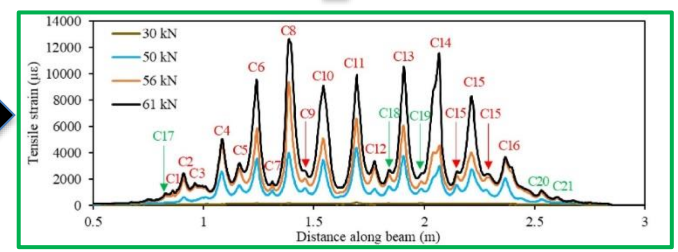
Convergence curves

Application 1: Flexural testing

- Four-point bending tests

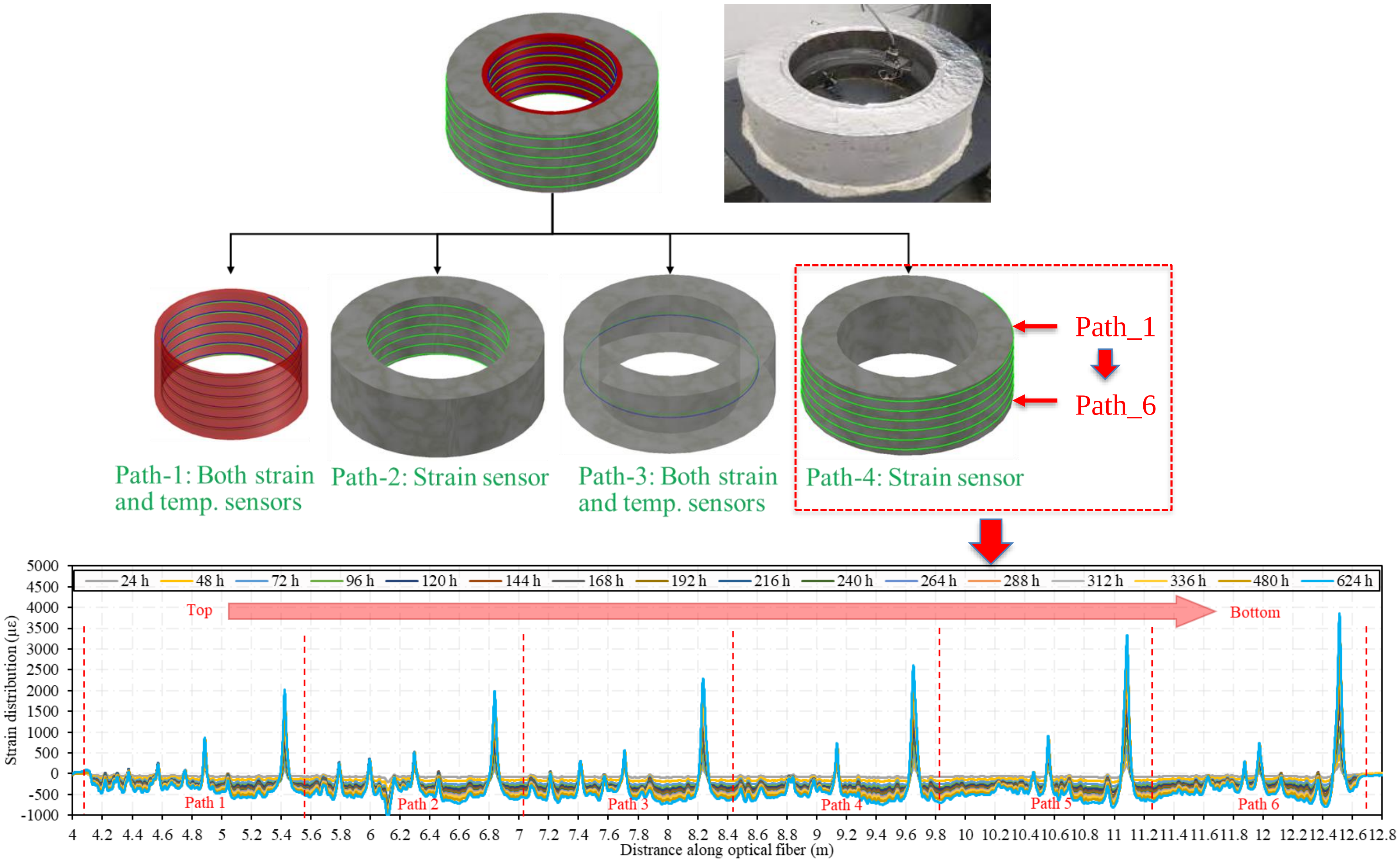




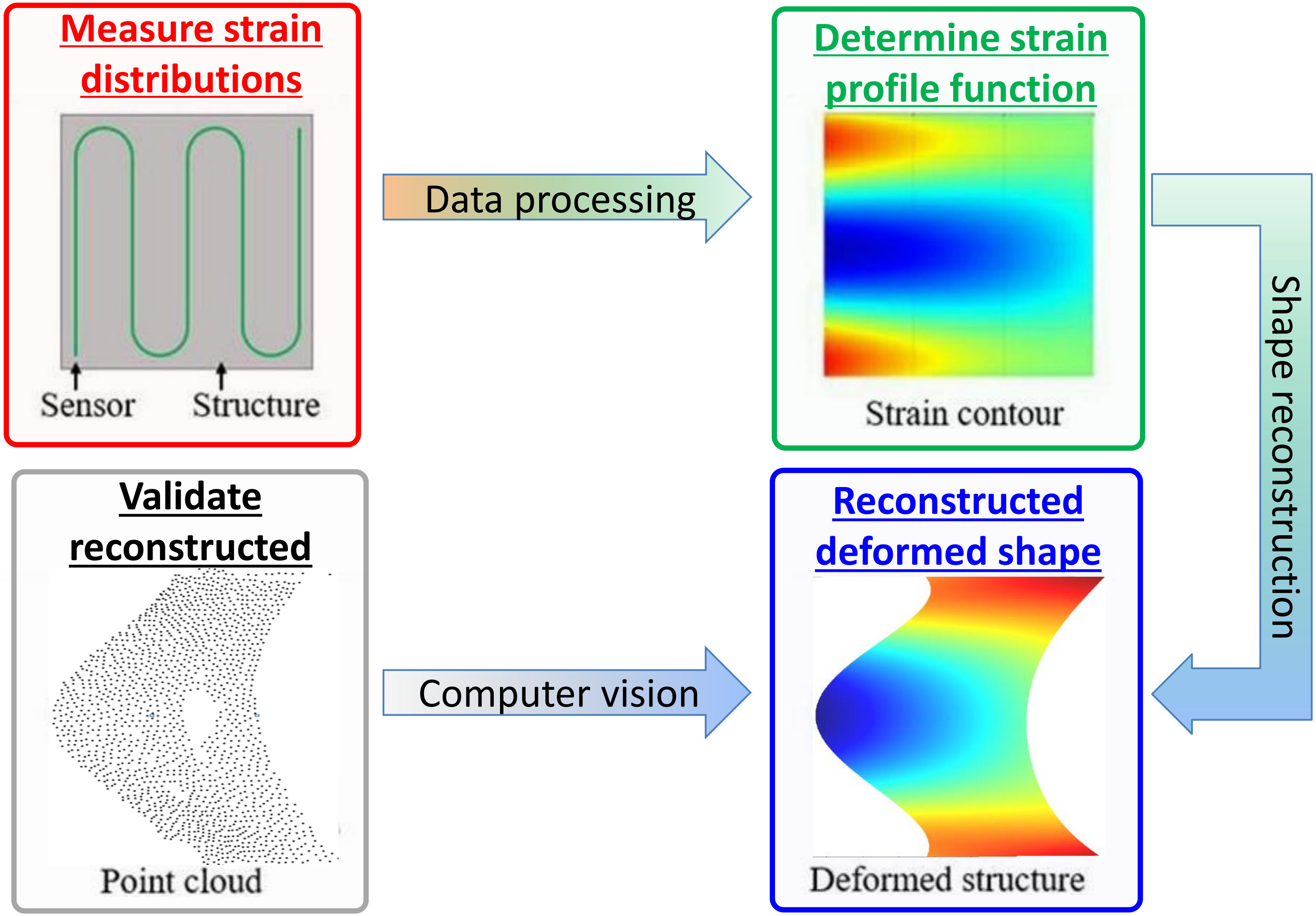


Tan, X., Abu-Obeidah, A., Bao, Y.*, Nassif, H., and Nasreddine, W. (2021). Measurement and visualization of strains and cracks in CFRP post-tensioned fiber reinforced concrete beams using distributed fiber optic sensors. Automation in Construction, 124, p.103604.

Application 2: Steel-concrete pipe crack



Theme 4: Detection, localization, quantification, and visualization of buckling/dent



Shape reconstruction algorithm

- For both 1D and 2D problems

Governing equations:

$$\varepsilon_p(x,y) = \sum_i \sum_j m_{ij} x^i y^j = \boldsymbol{F}^{\varepsilon} \boldsymbol{m}^{\varepsilon}$$

$$\Phi^{\varepsilon} = \min\left\{\left[\boldsymbol{\varepsilon}_p - \boldsymbol{F}^{\varepsilon}\boldsymbol{m}^{\varepsilon}\right]^T \boldsymbol{W}^R \left[\boldsymbol{\varepsilon}_p - \boldsymbol{F}^{\varepsilon}\boldsymbol{m}^{\varepsilon}\right]\right\}$$

$$\boldsymbol{W}^R = \mathrm{diag}\left[W_1^R \cdots W_i^R \cdots W_N^R\right]$$

$$W_i^R = \begin{cases} 1, & \text{Point } i \text{ at straight sensor lengths} \\ 0, & \text{Point } i \text{ at curved sensor lengths} \end{cases}$$

$$\varepsilon_p(x,y) = -z\frac{\partial^2 v_p(x,y)}{\partial p^2}, (p = x \text{ or } y)$$

Boundary conditions:

$$v_x(x=0, y_i) = v_x(x=L, y_i) = 0$$

$$\left.\frac{dv_x(x,y_i)}{dx}\right|_{x=0} = \left.\frac{dv_x(x,y_i)}{dx}\right|_{x=L} = 0$$

$$\left.\frac{d^2v_x(x,y_i)}{dx^2}\right|_{x=0} = \left.\frac{d^2v_x(x,y_i)}{dx^2}\right|_{x=L} = 0$$

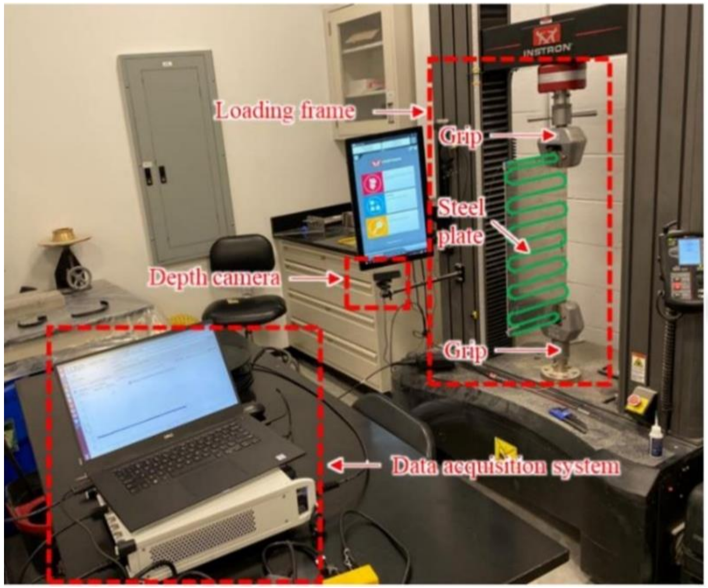
Analytical solution:

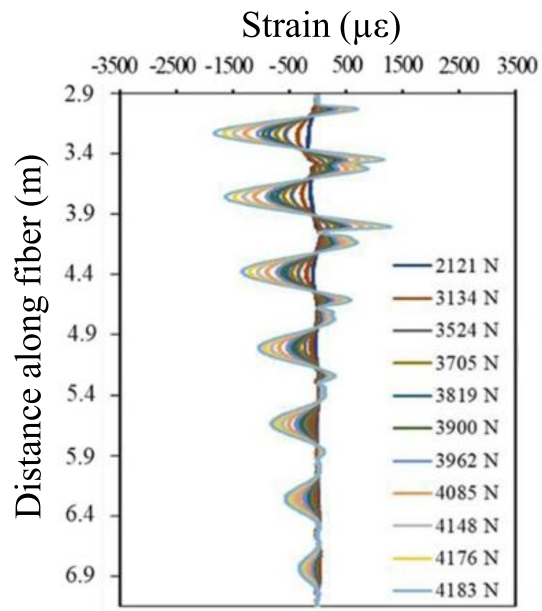
$$v_x(x,y_i) = \sum_i \sum_j M_{ij} x^{i+2} {y_i}^j \qquad M_{ij} = -\frac{1}{z}\frac{m_{ij}}{i(i-1)}$$

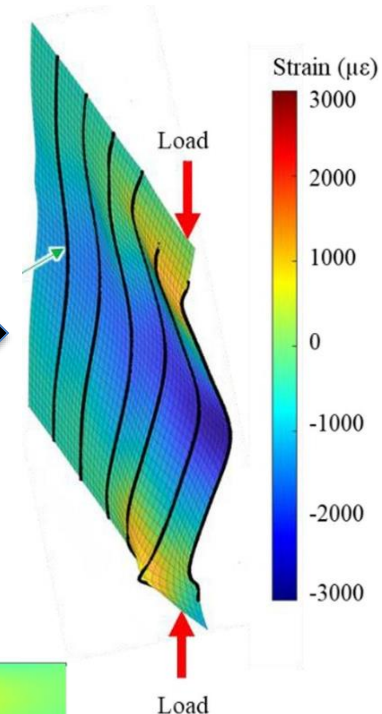
Tan, X., Guo, P., Zou, X., & **Bao, Y.** * (2022). Buckling detection and shape reconstruction using strain distributions measured from a distributed fiber optic sensor. *Measurement*, 200, p.111625.

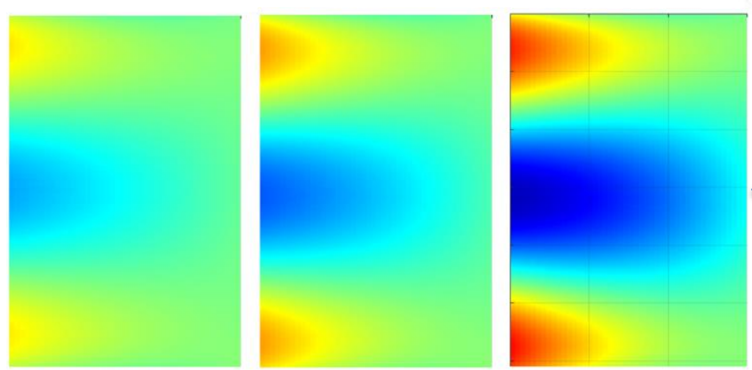
Application: Eccentrical buckling

- Coordinate transform and strain profile interpolation



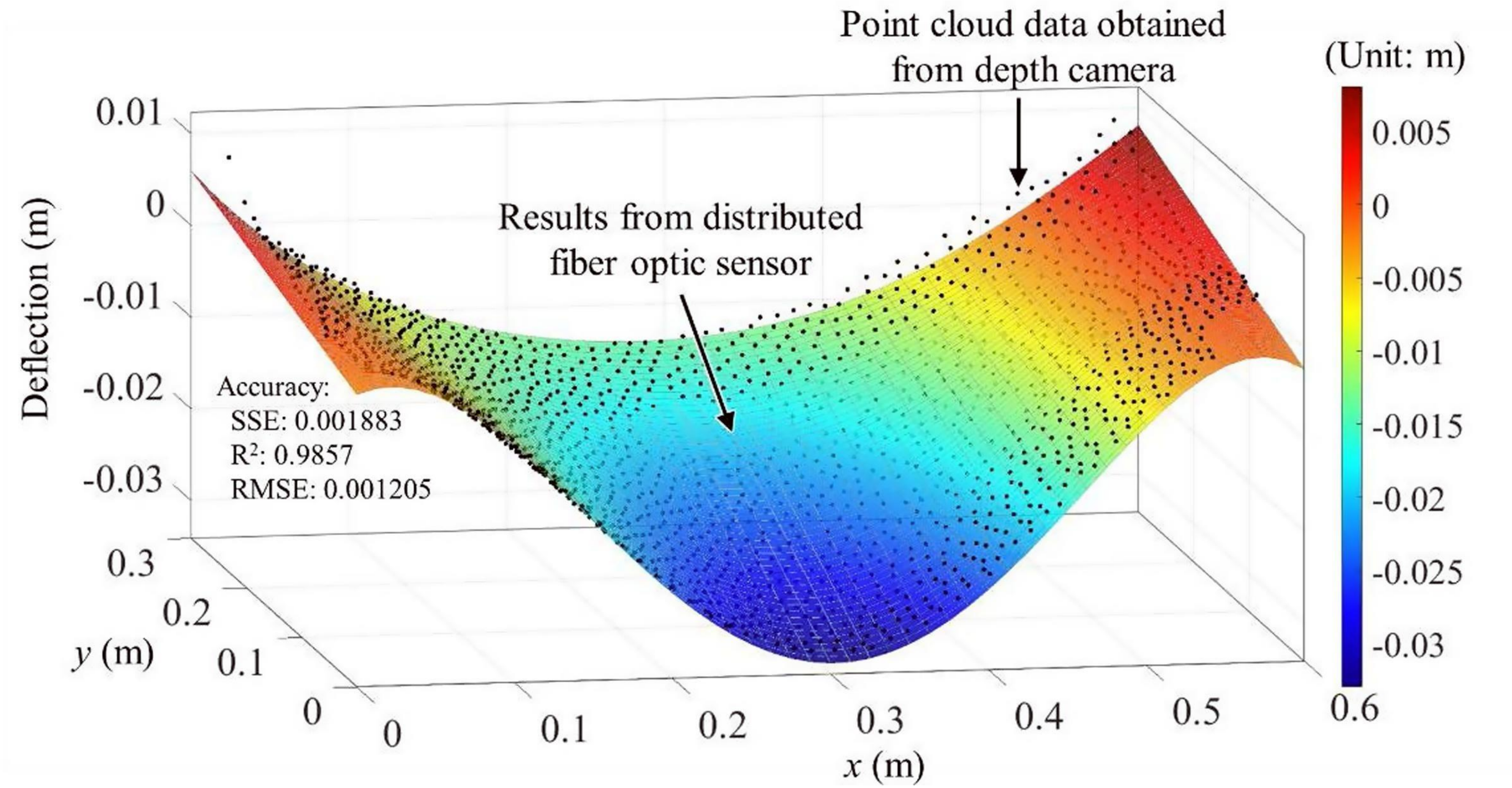






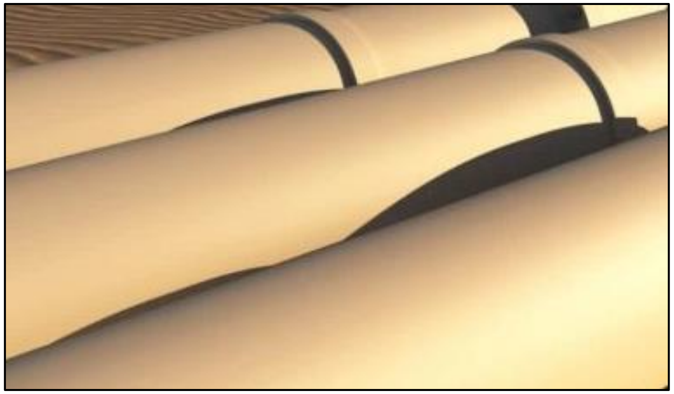
Increase of load

- Computer vision result (point cloud) for validation



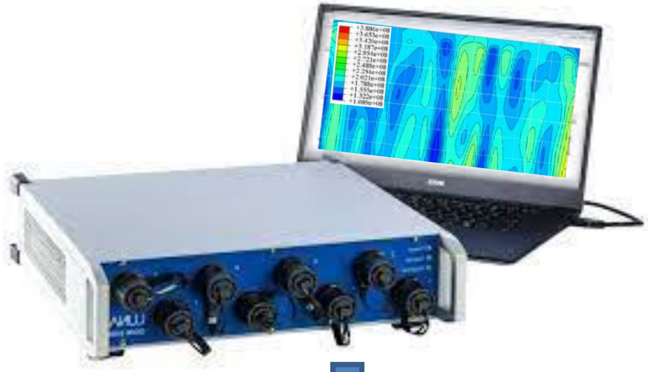
Theme 5: Detection, localization, quantification, and visualization of corrosion

1. "Smart pipes" instrumented with a distributed fiber optic sensor



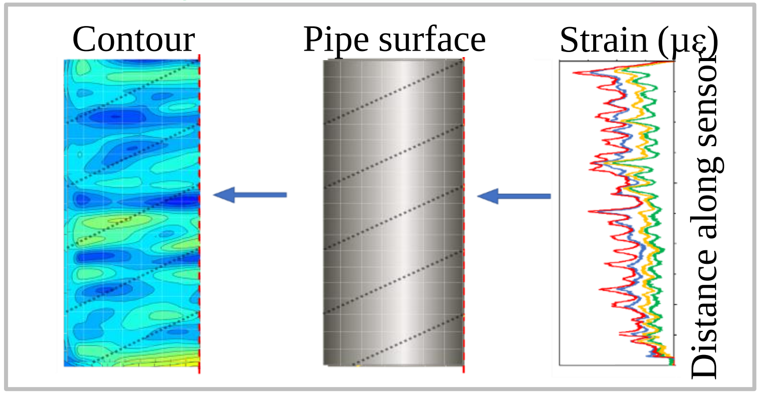
Input

2. Real-time data acquisition from the distributed sensor



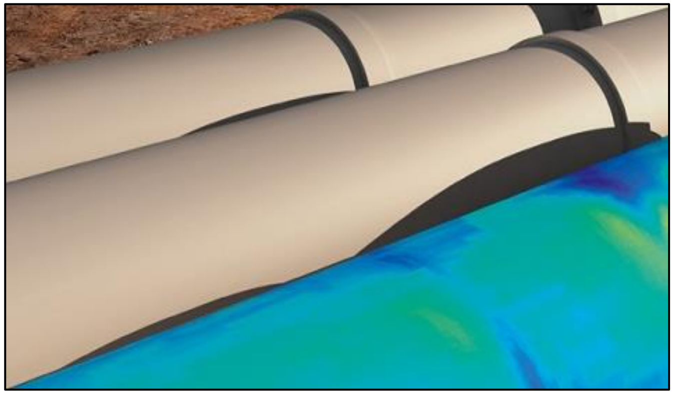
Analysis

3. Real-time data processing and analytics of distributed sensor data



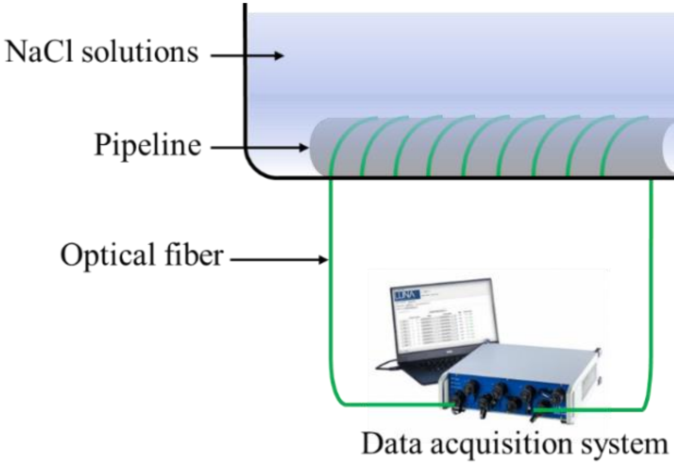
Output

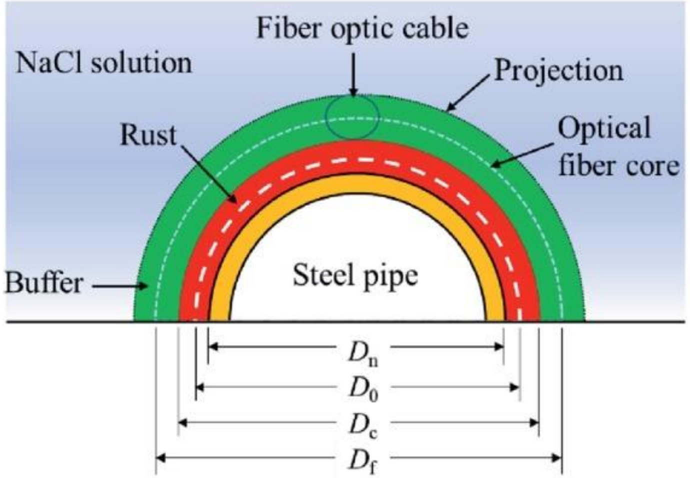
4. Detection, localization, visualization, and quantification of corrosion

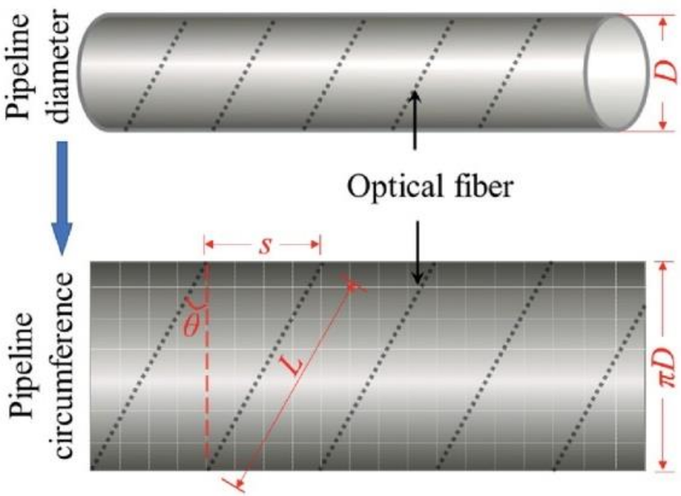


Corrosion mass loss model

- Meso-scale corrosion model







$$\Delta m = \frac{\pi \rho L {D_0}^2}{4(k-1)}[(1+\alpha^2)(2\varepsilon+\varepsilon^2)]$$

$$k = \frac{V_r}{V_p} = \frac{{D_c}^2 - {D_n}^2}{{D_0}^2 - {D_n}^2}$$

$$\alpha = \frac{s}{\pi D_0}$$

Tan, X., Fan, L., Huang, Y., & Bao, Y. (2021). Detection, visualization, quantification, and warning of pipe corrosion using distributed fiber optic sensors. Automation in Construction, 132, p.103953.

Corrosion severity evaluation

- Calibrated corrosion mass loss model

$$\Delta m \approx \frac{\pi \rho L {D_0}^2}{2.328}\left[(1+\alpha^2)(2\varepsilon+\varepsilon^2)\right]$$

where $k = 1.582$

- Corrosion severity evaluation model

$$\boxed{CR = \frac{\Delta m \times 365 \times 1000}{AT\rho}}$$

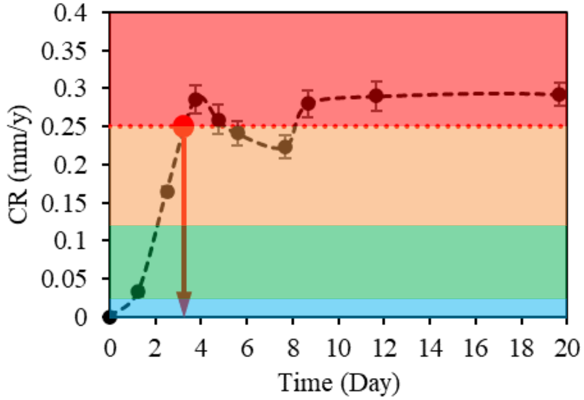
where CR is average corrosion rate (unit in mm/y = millimeter per year);

Δm is the mass loss (g);

A is the initial exposed surface area (mm^2);

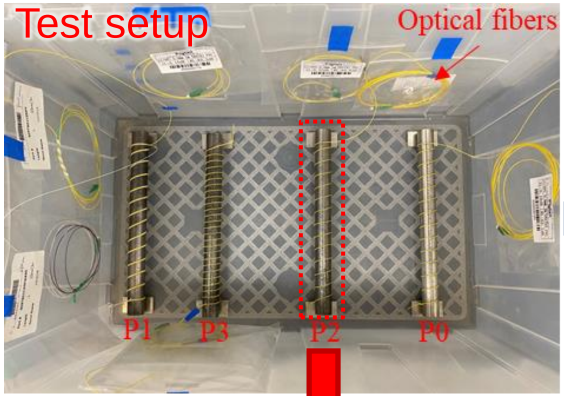
T is exposure time (days); and

ρ is density of metal (g/cm^3).

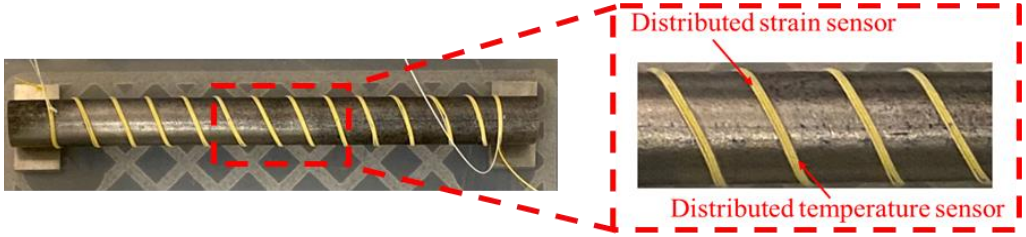


$0 < CR \le 0.025$	Low
$0.025 < CR \le 0.12$	Moderate
$0.12 < CR \le 0.25$	High
$0.25 < CR$	Severe

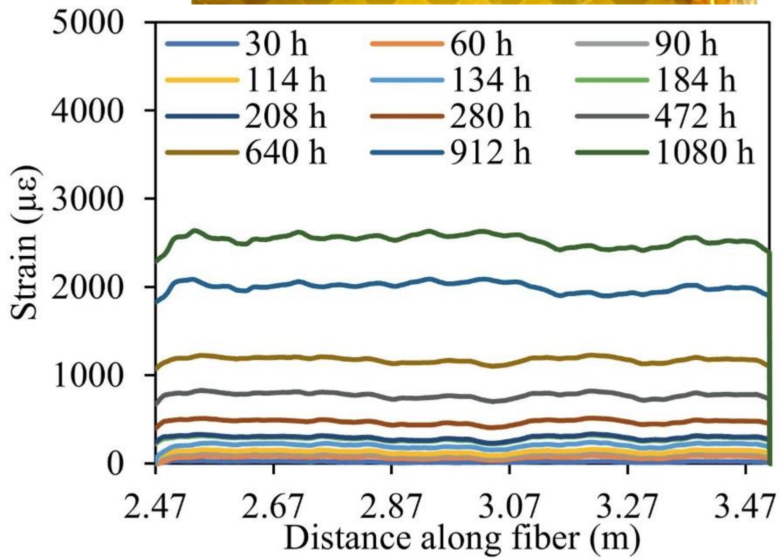
Application: Corrosion mass loss calculation



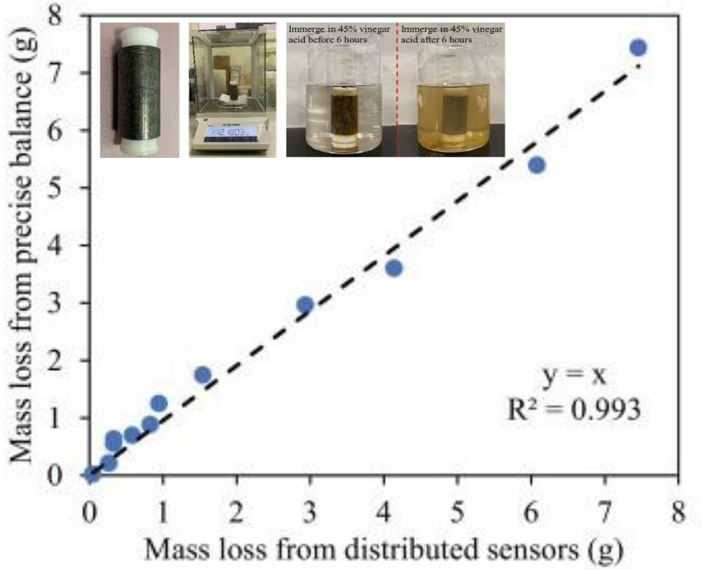
Instrumentation of pipes



P2



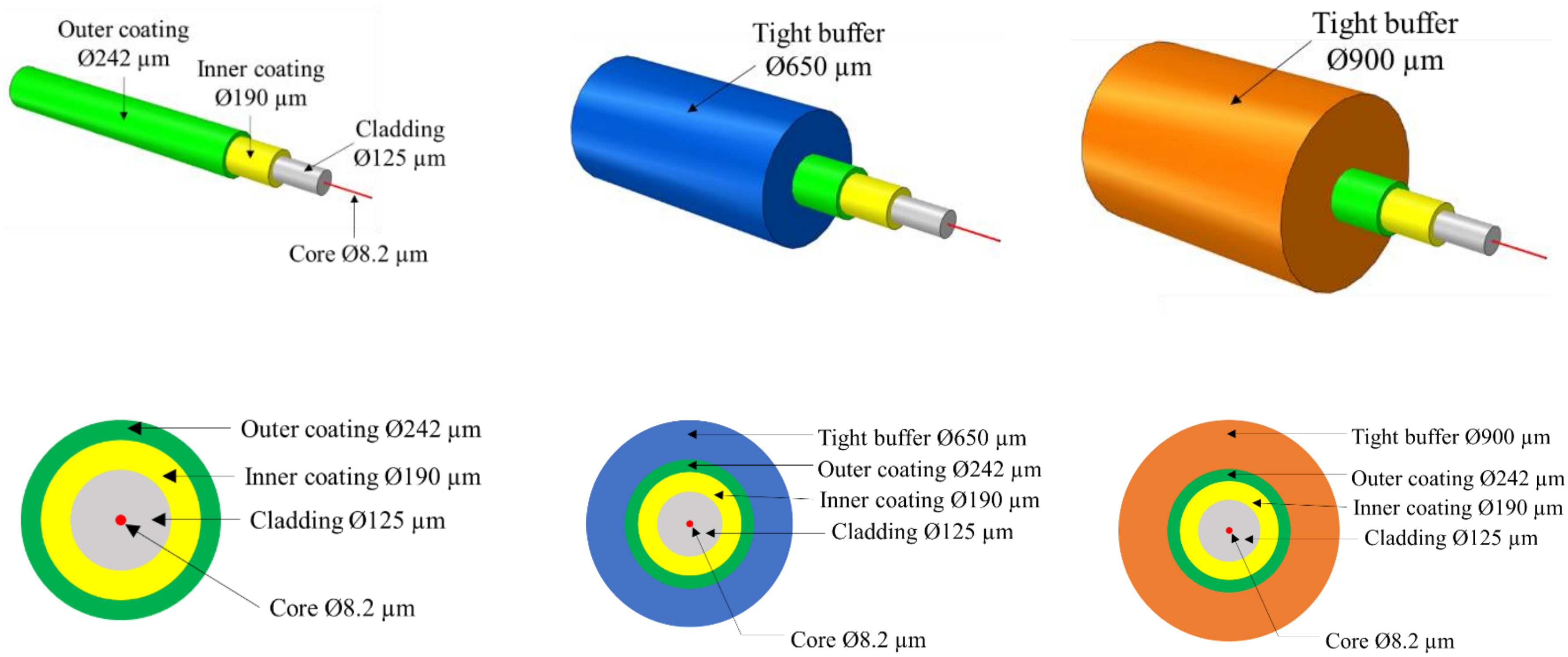
Calibration



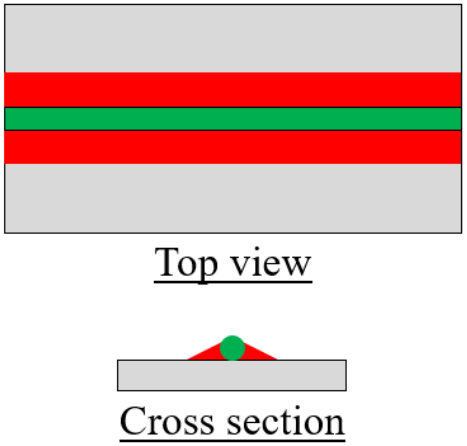
Comparison results

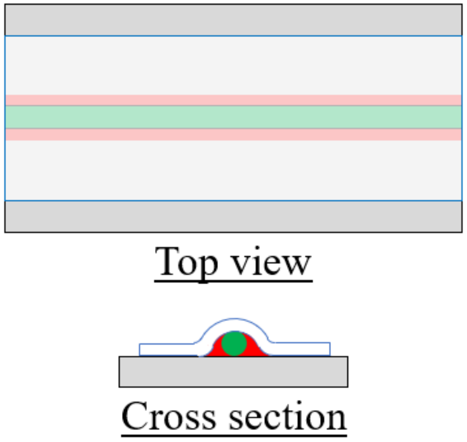
Theme 6: Different types of fiber optic cables and installation methods

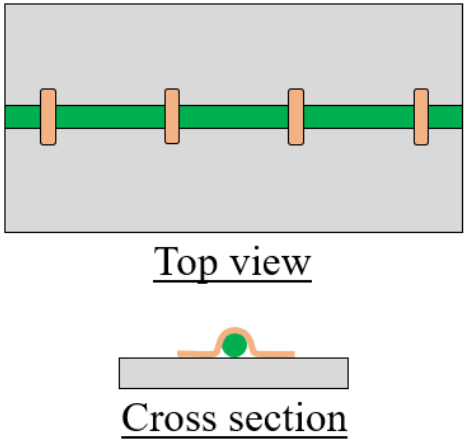
- Three types of fiber optic cables



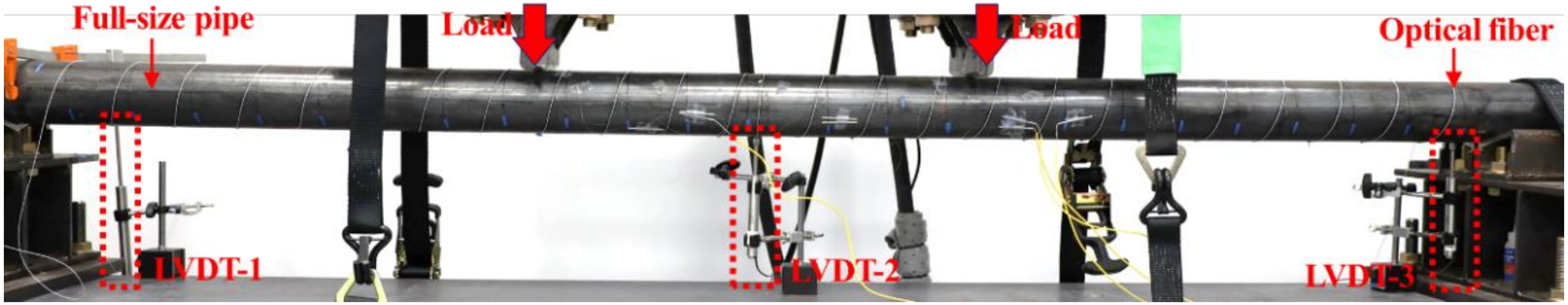
- Three sensor installation methods

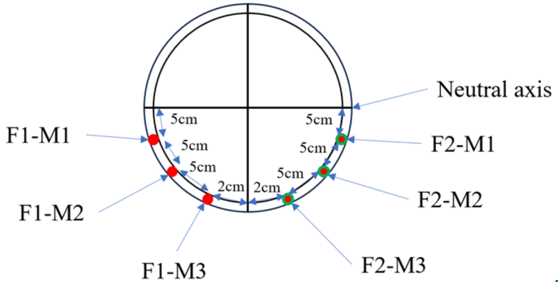




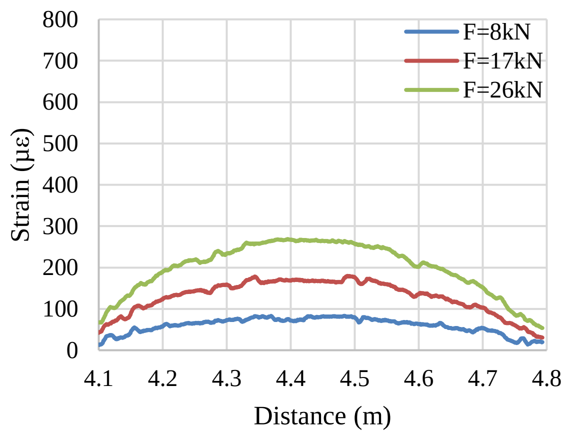


- Mechanical testing of a steel pipe

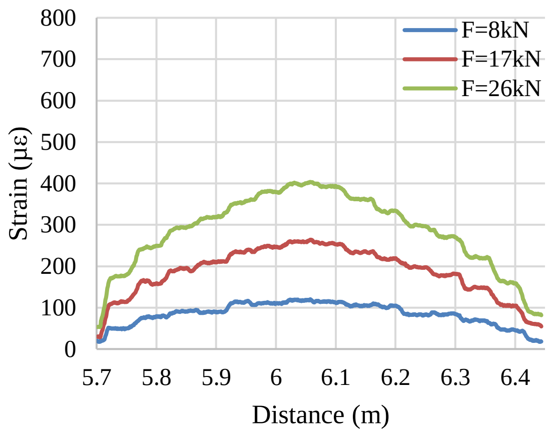




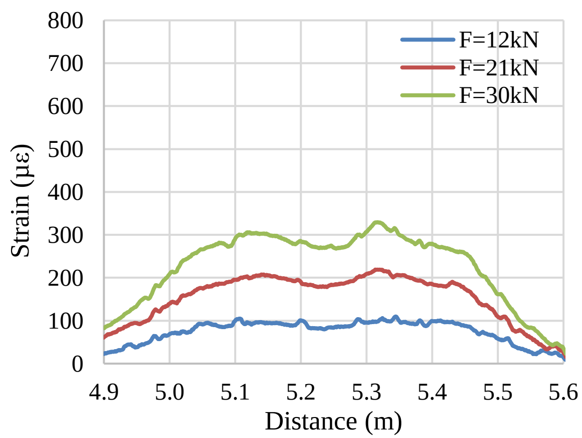
- Three sensor installation methods



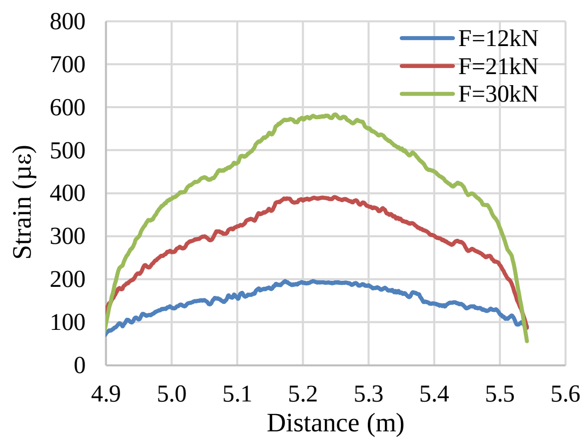
F1-M1



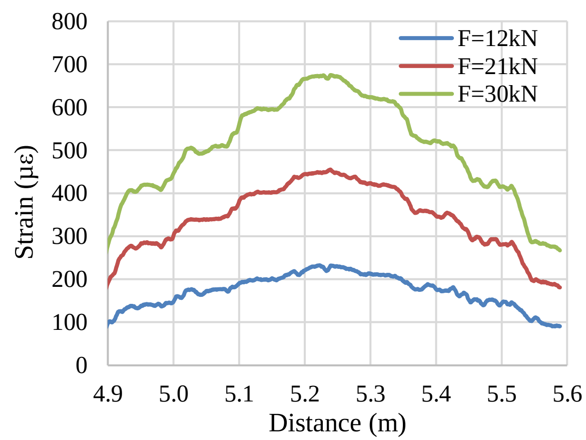
F1-M3



F2-M1



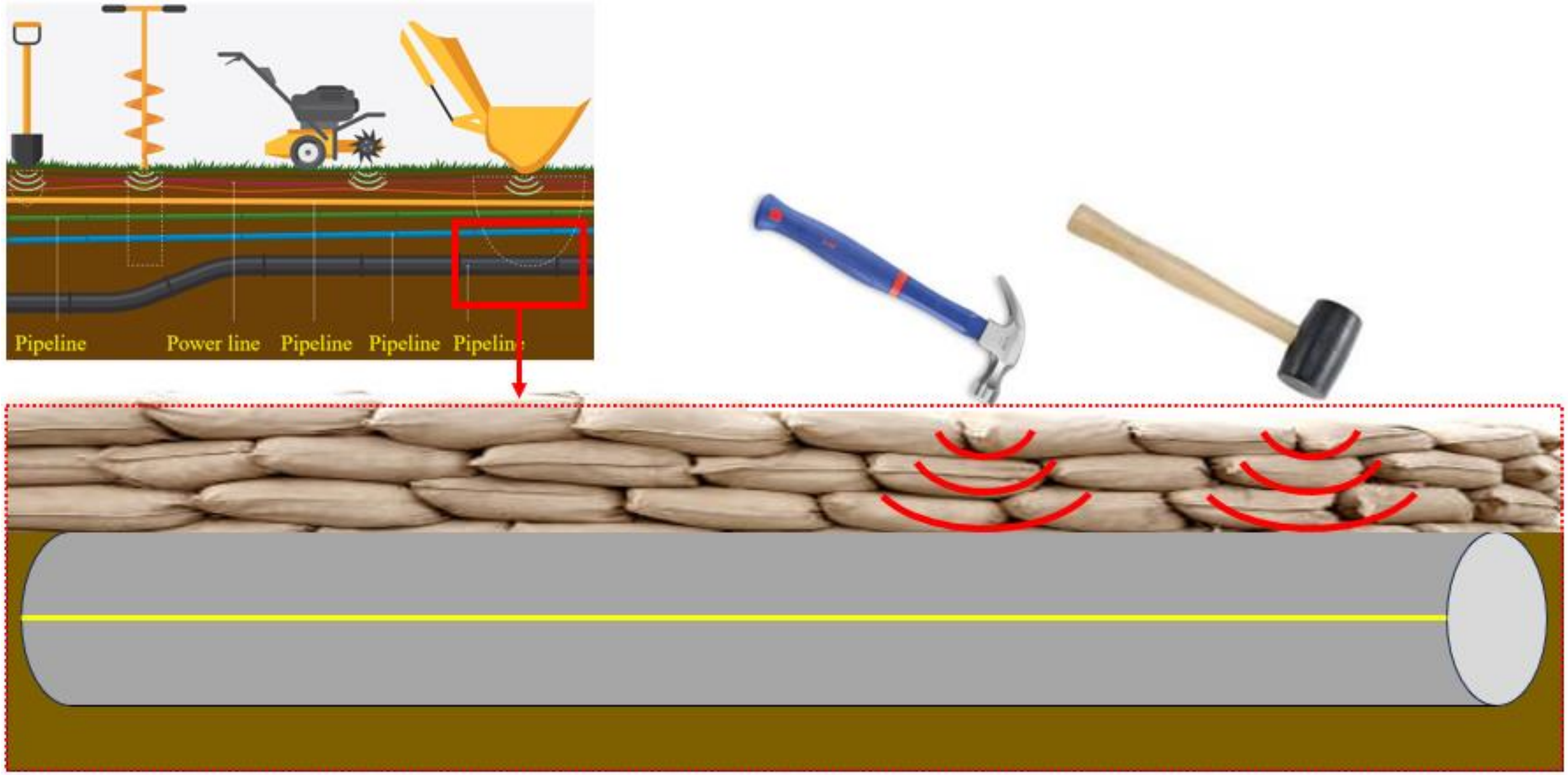
F2-M2



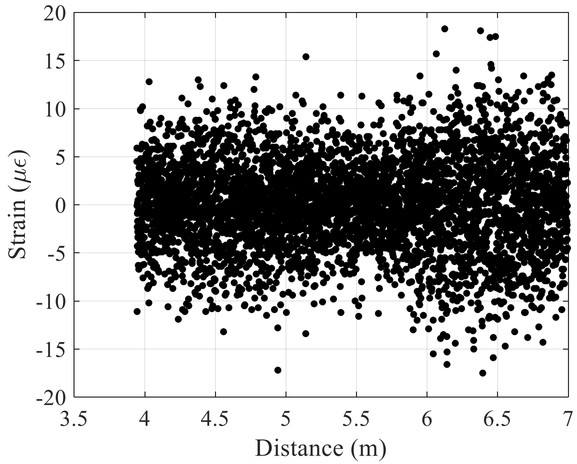
F2-M3

Theme 7: Detection of excavation induced impacts on pipelines

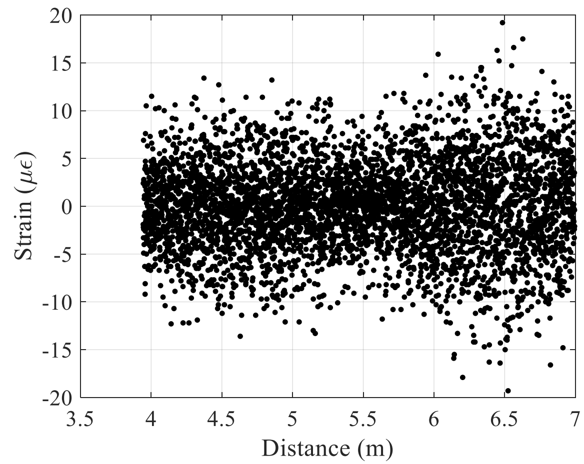
- Impact detection is challenging for underground pipelines which are unseen to excavation crews
- This project developed a strain-based method to detect impact effects using distributed fiber optic sensors



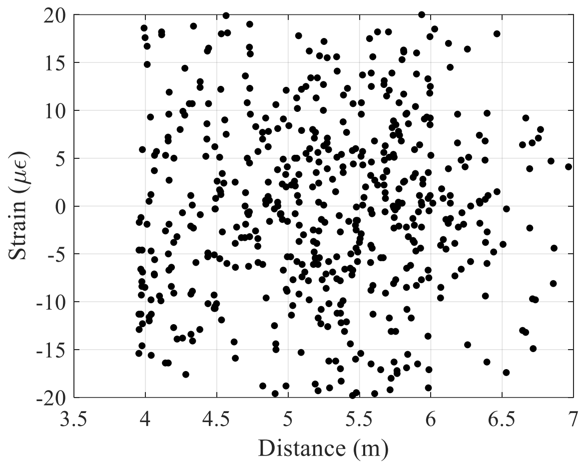
- When an impact load was applied, the sensor showed high sensitivity



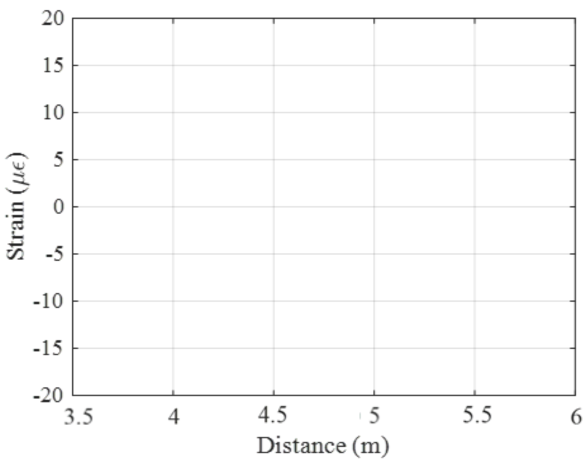
t=46.6 s



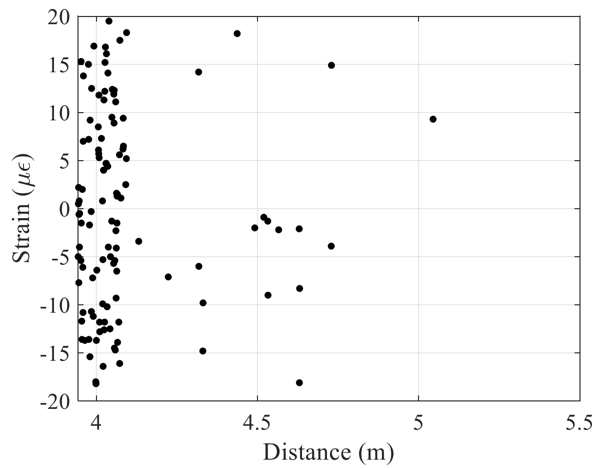
t=47.0 s



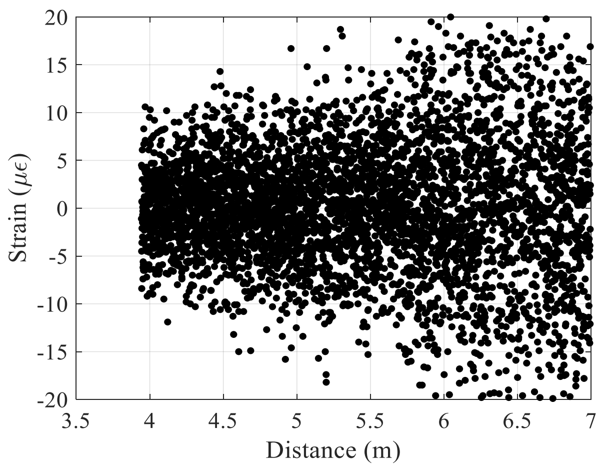
t=47.003 s



t=47.004 s

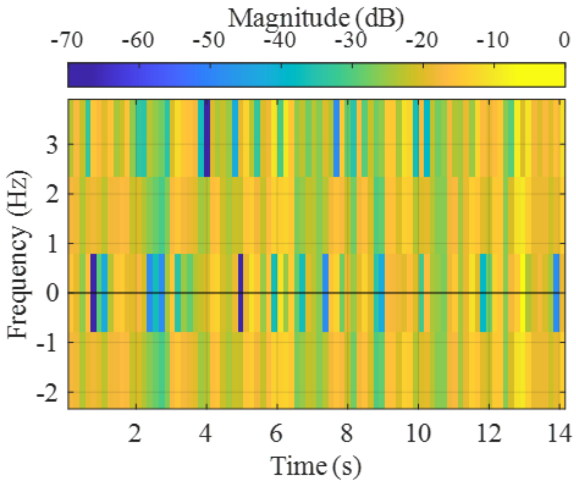


t=47.008 s

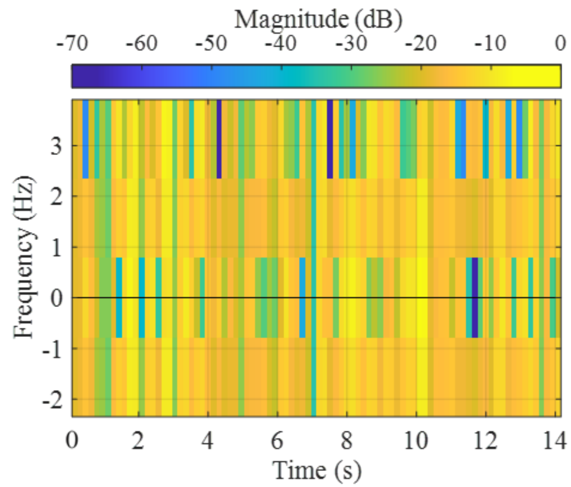


t=47.012 s

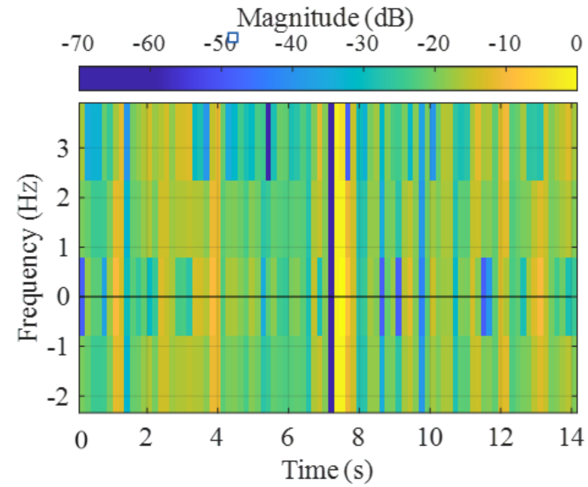
- A time-frequency analysis was conducted to monitor the impact load



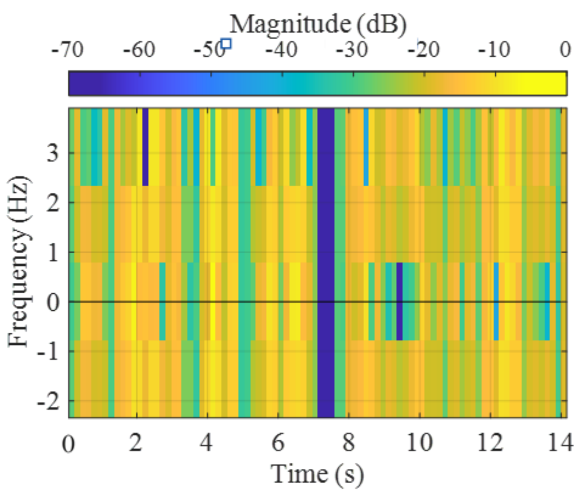
x=0.5m



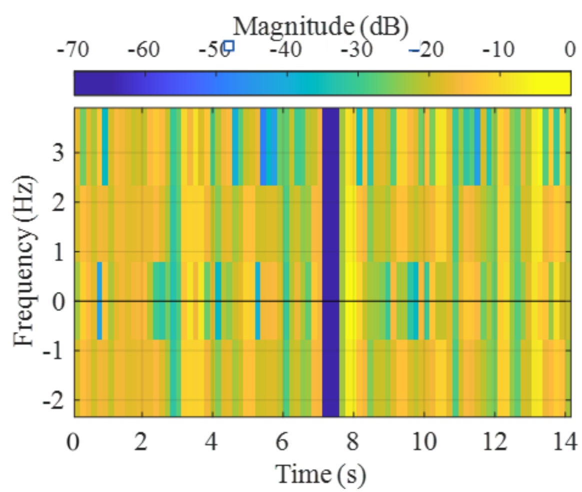
x=1m



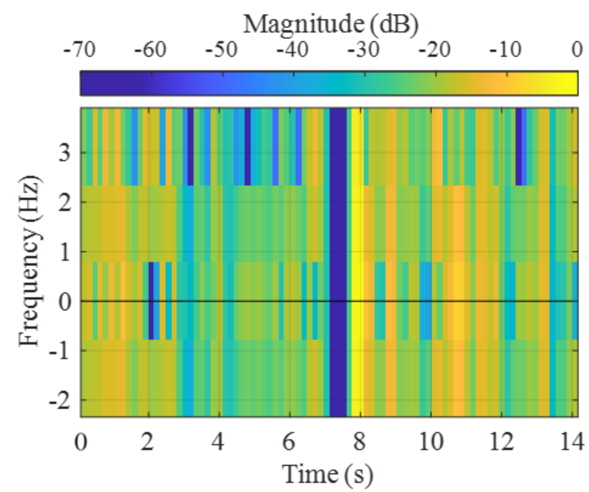
x=1.5m



x=2m



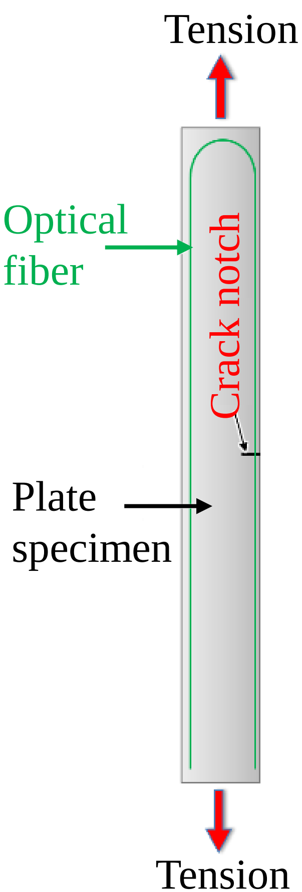
x=2.5m

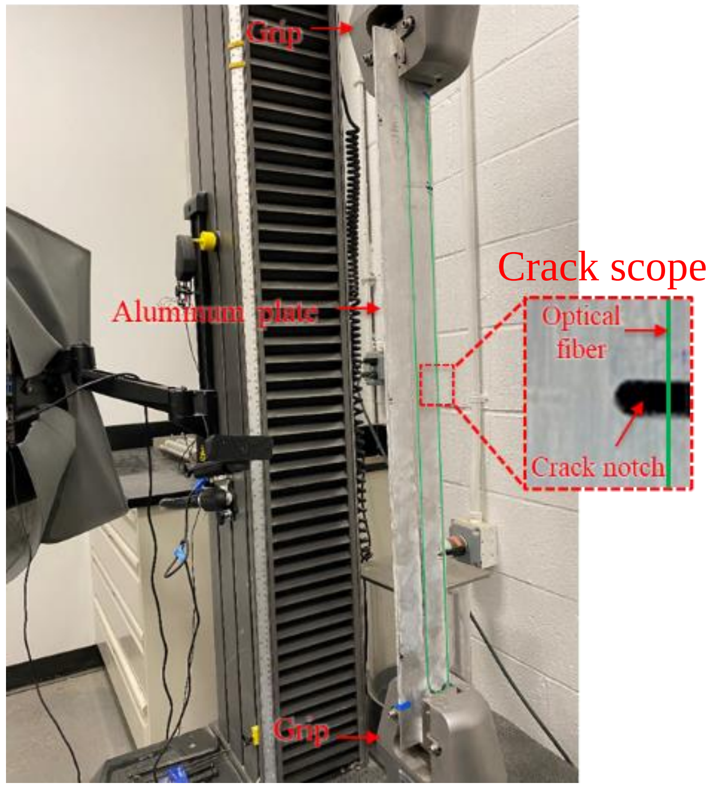


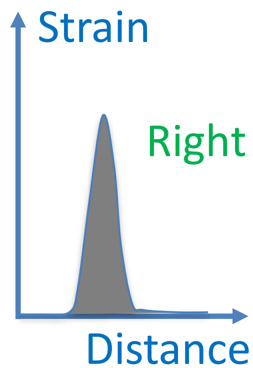
x=3m

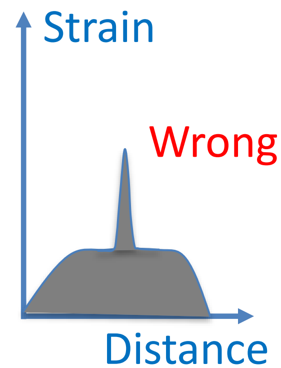
Theme 8: Measurement of interactive deformations and cracks

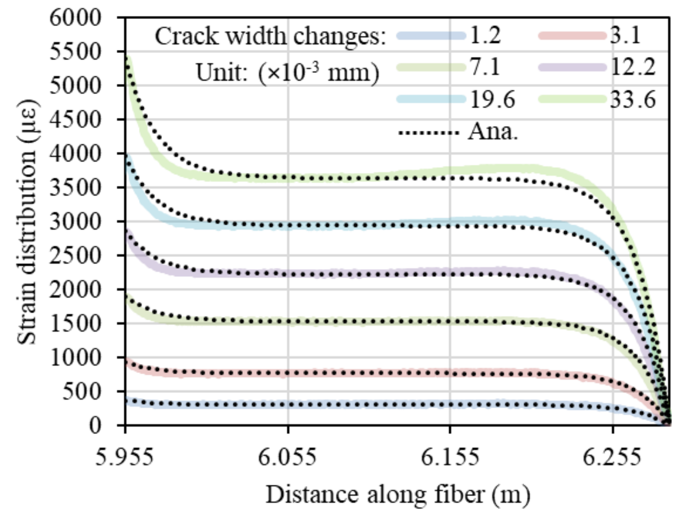
- Direct integration of strains becomes unavailable





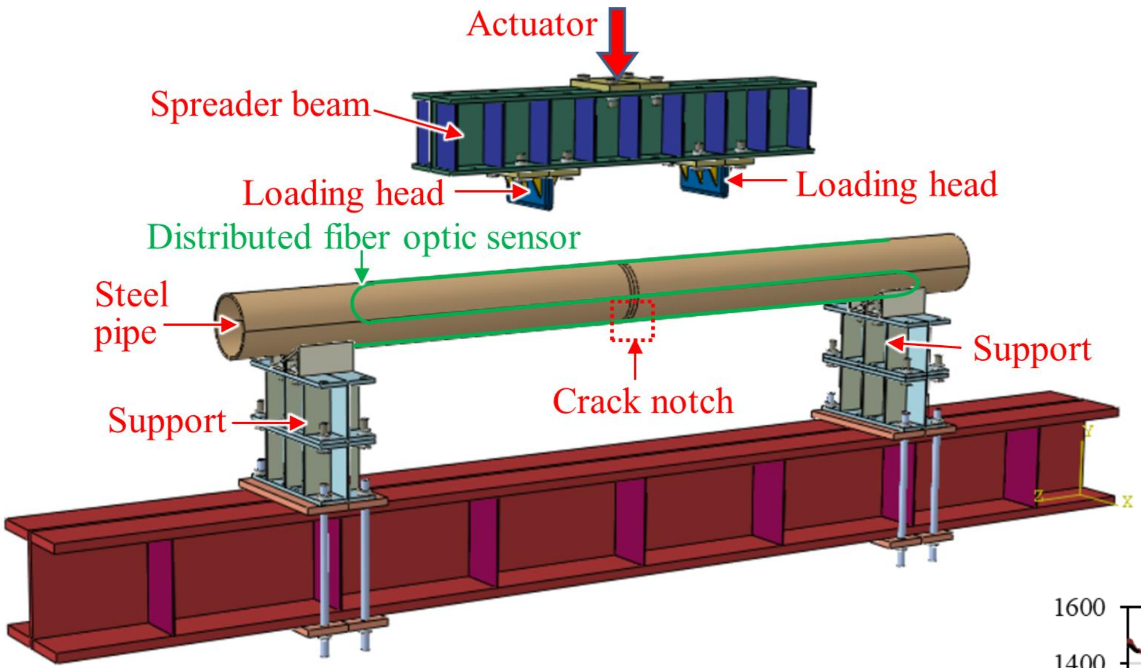




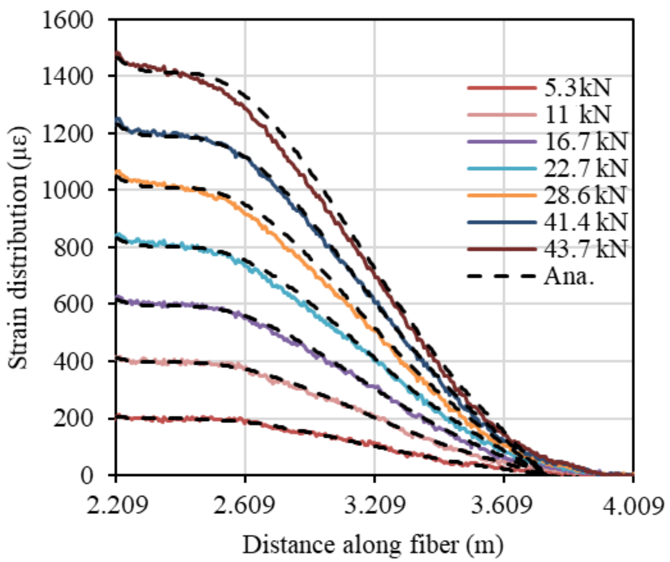


$$u_h(x) = \int_0^x \varepsilon_h(x)\,dx + \delta = \varepsilon_0 x + \delta$$

Full-size steel pipe under four-point bending

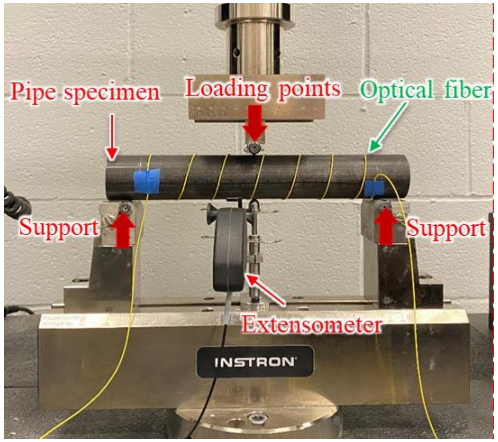


$$u_h(x) = \int_0^x \varepsilon_h(x)\,dx + \delta = \begin{cases} \varepsilon_0 x + \delta, & 0 \le x < a \\ \frac{1}{2}\varepsilon_0 \left(\frac{L-x}{L-a}\right)^2 + \delta, & a \le x \ge L \end{cases}$$

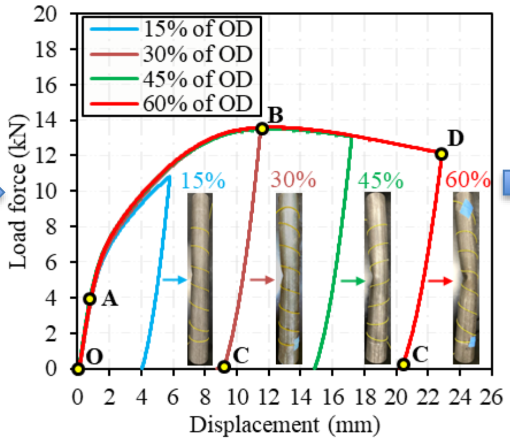


Theme 9: Measurement of interactive dent and corrosion

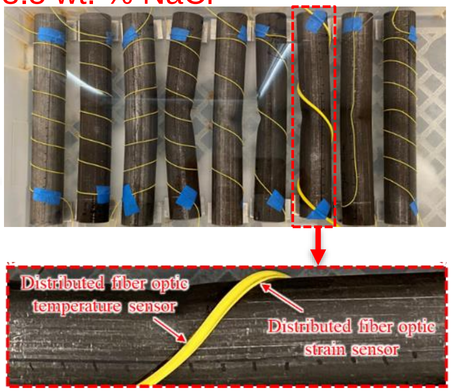
- Monitoring of dent effect to corrosion

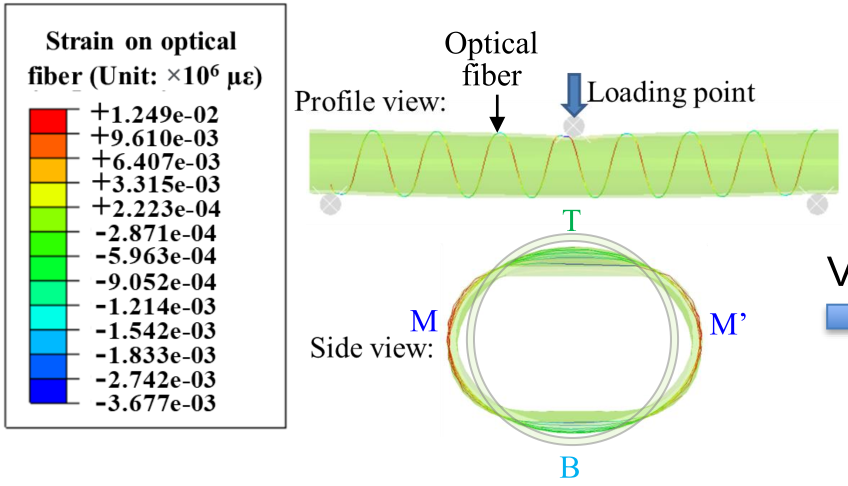


Test setup of dent

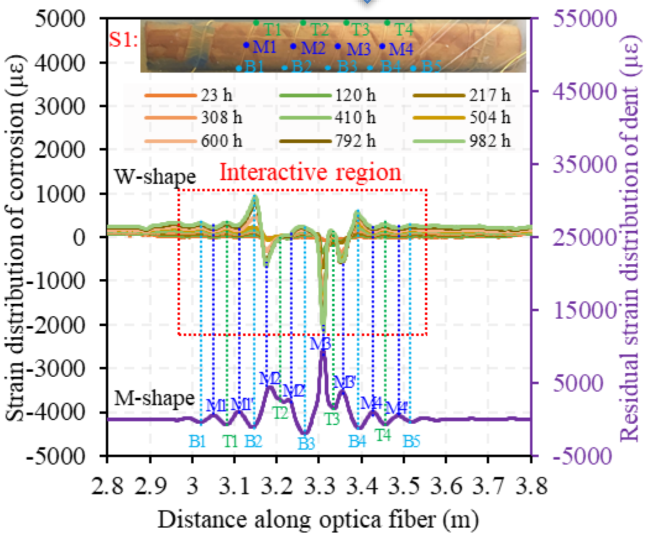


Loading and unloading



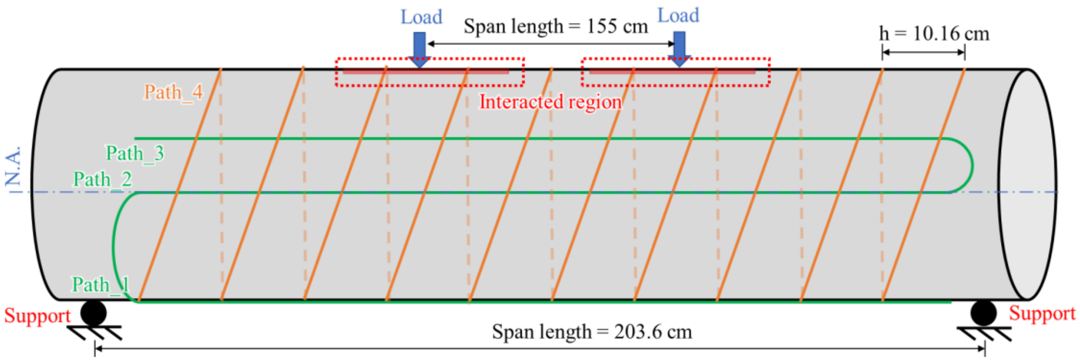


Validation

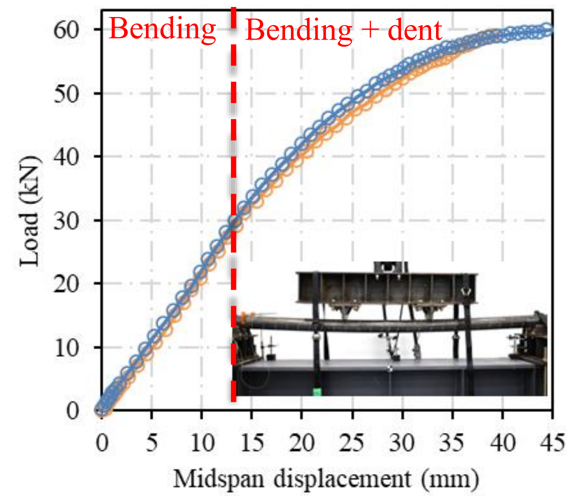


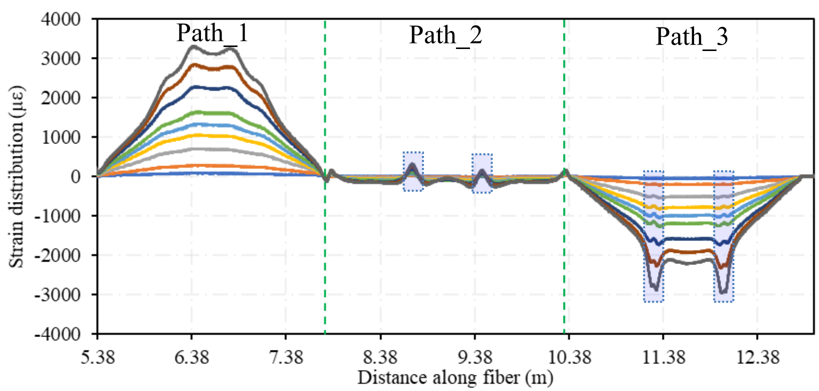
Theme 10: Measurement of interactive dent and bending

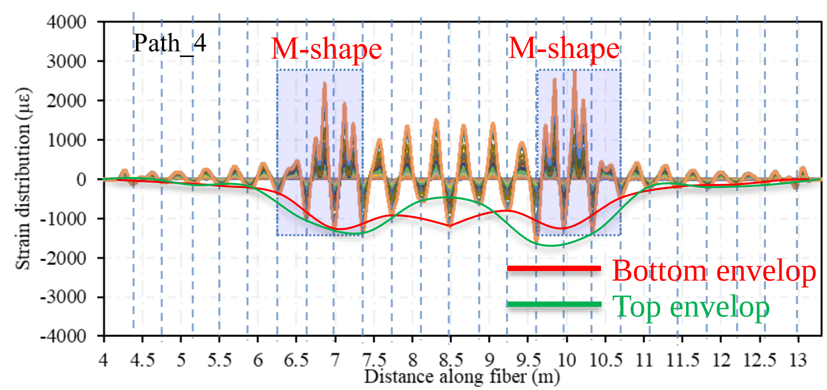
- Monitoring of dent effect to bending



Distributed fiber optic network

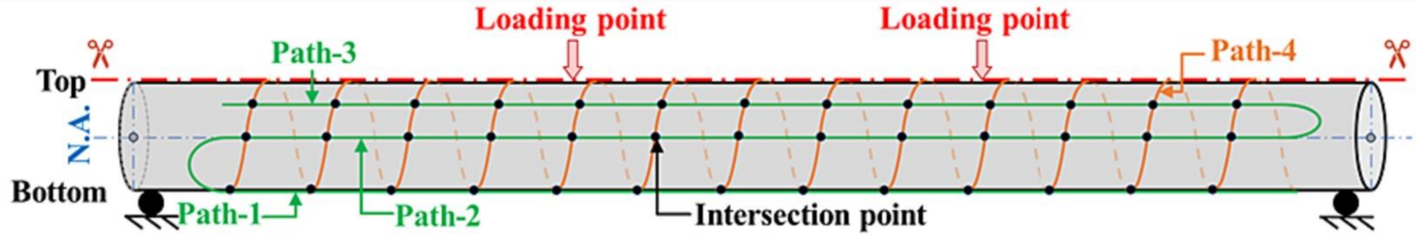






Tan, X., Poorghasem, S., Huang, Y., Feng, X. and **Bao, Y.***, 2024. Monitoring of pipelines subjected to interactive bending and dent using distributed fiber optic sensors. *Automation in Construction*, *160*, p.105306.

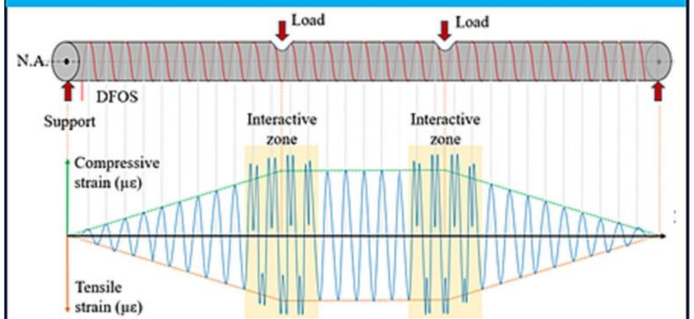
Distributed fiber optic sensors installed on pipes with different paths



Discrimination of dent and bending

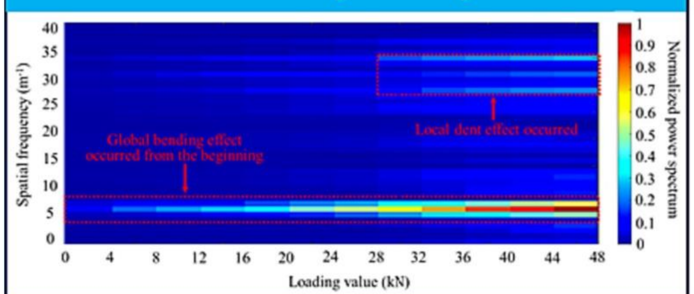
Assessment of dent and bending

Interactive deformation model



Fast Fourier transform

Normalized power spectra



Calculation of deformations

- **Calculation of bending**

$$w_n = \frac{s_d}{4\left(R + \frac{t}{2}\right)} \begin{bmatrix} (2n-3)\varepsilon_{x1}^b + \varepsilon_{xn}^b \\ +4\sum_{i=2}^{n-1}(n-i)\,\varepsilon_{xi}^b \end{bmatrix}$$

- **Evaluation of dent**

$$R_{\varepsilon_{eq}} = max\left\{\frac{\varepsilon_{eq}}{6\%}, 0\right\}$$

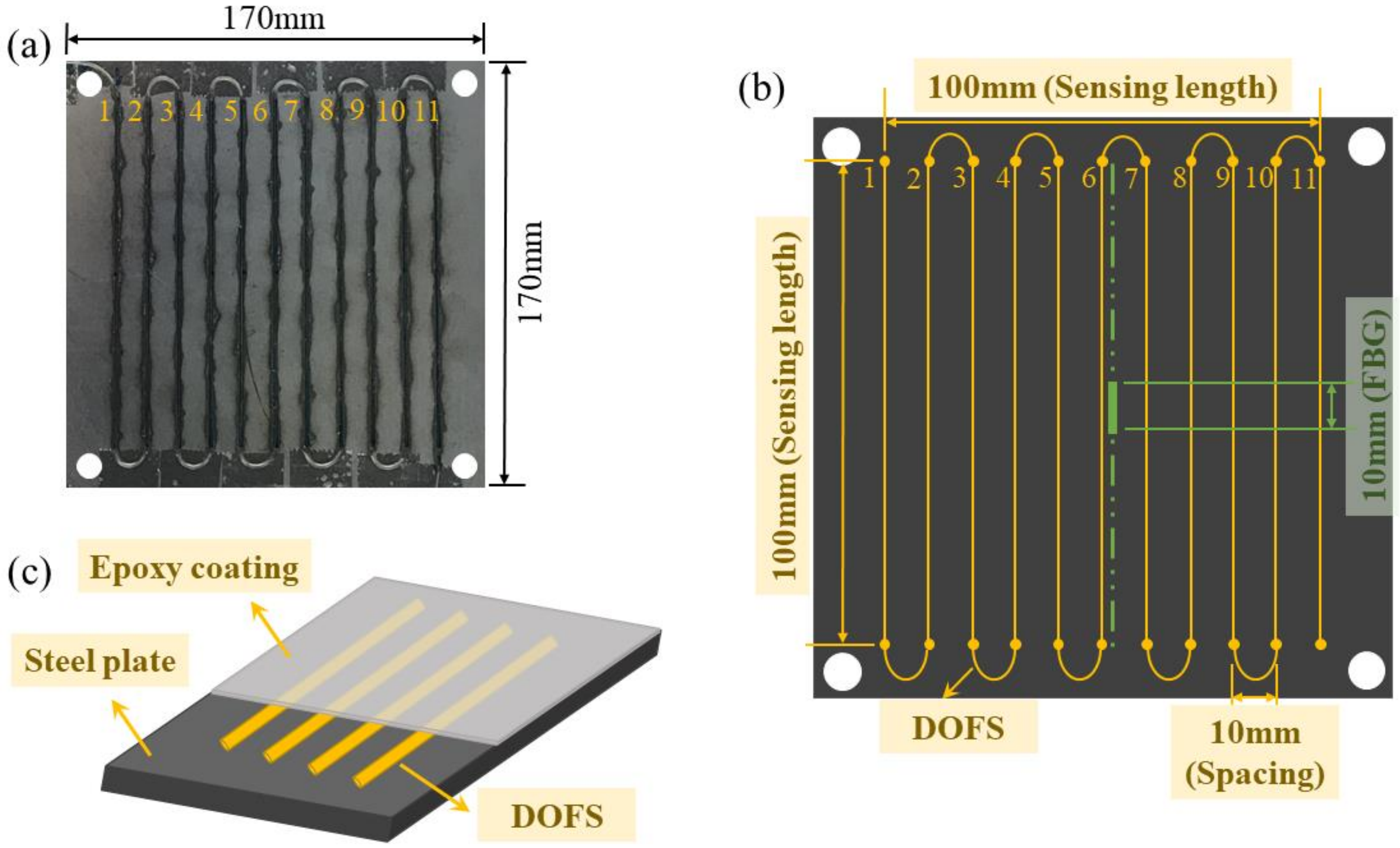
$$\varepsilon_{eq} = \frac{2}{\sqrt{3}}\sqrt{{\varepsilon_x}^2 + \varepsilon_x\varepsilon_y + {\varepsilon_y}^2}$$

$$\varepsilon_y = \frac{\varepsilon_{f_4}}{\sqrt{1+\alpha^2}}$$

$$\alpha = \frac{s}{\pi(2R + t + r_f)}$$

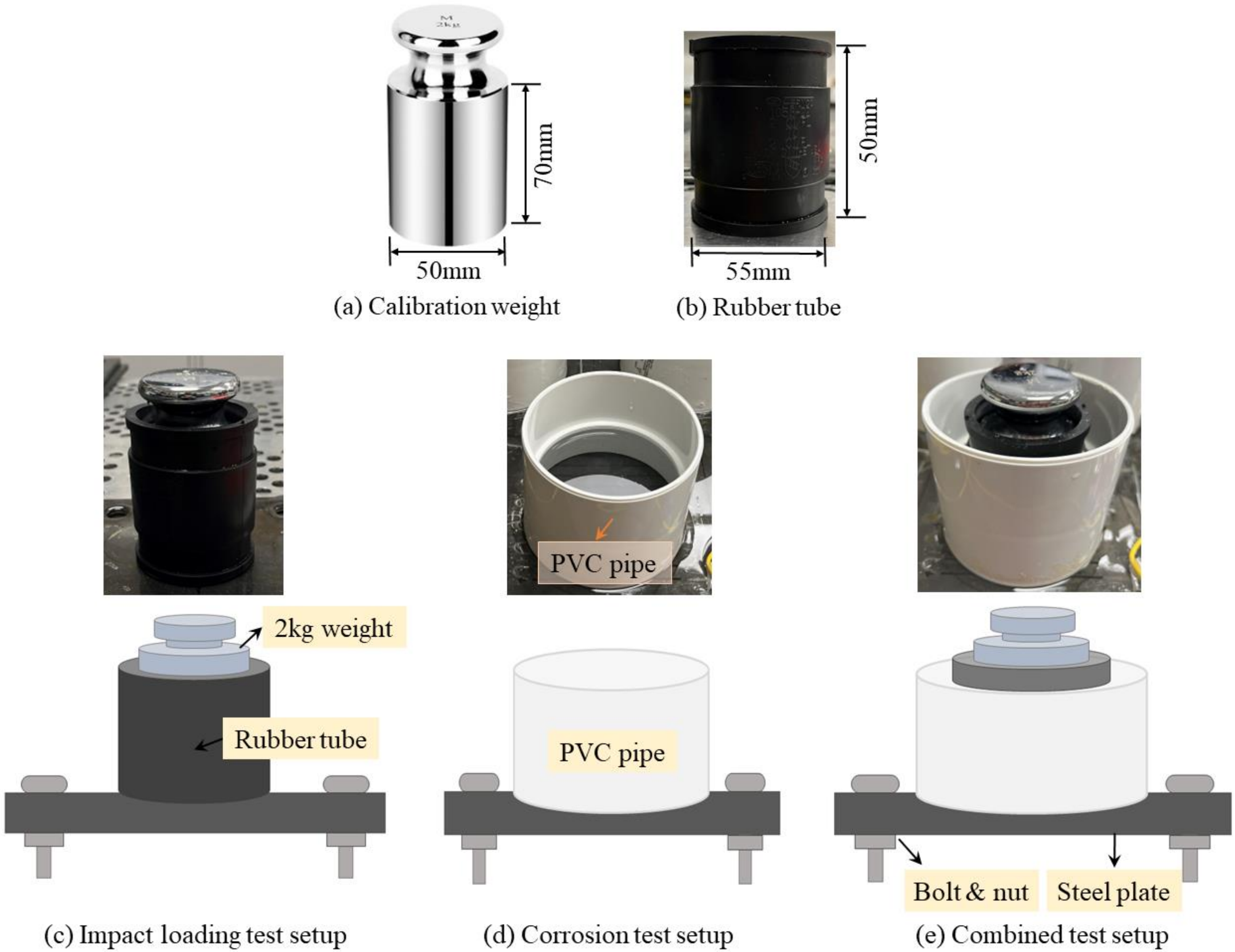
Theme 11: Measurement of interactive impact loads and corrosion

- Monitoring of impact loads and corrosion



Test specimens and sensors: (a) a test specimen, (b) schematic of the sensors, (c) schematic of a specimen.

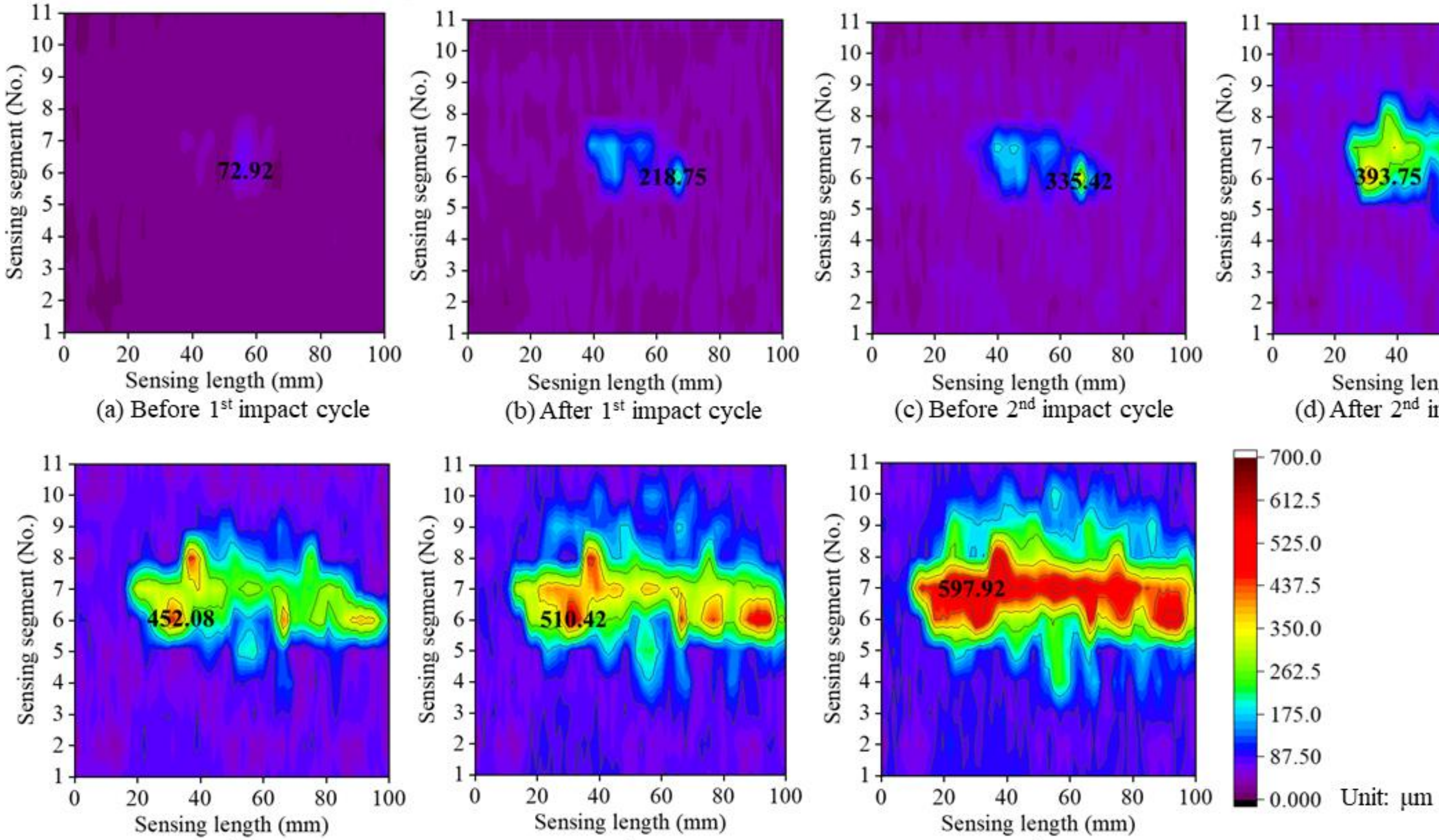
- Test setup



(a) Calibration weight (b) Rubber tube

(c) Impact loading test setup (d) Corrosion test setup (e) Combined test setup

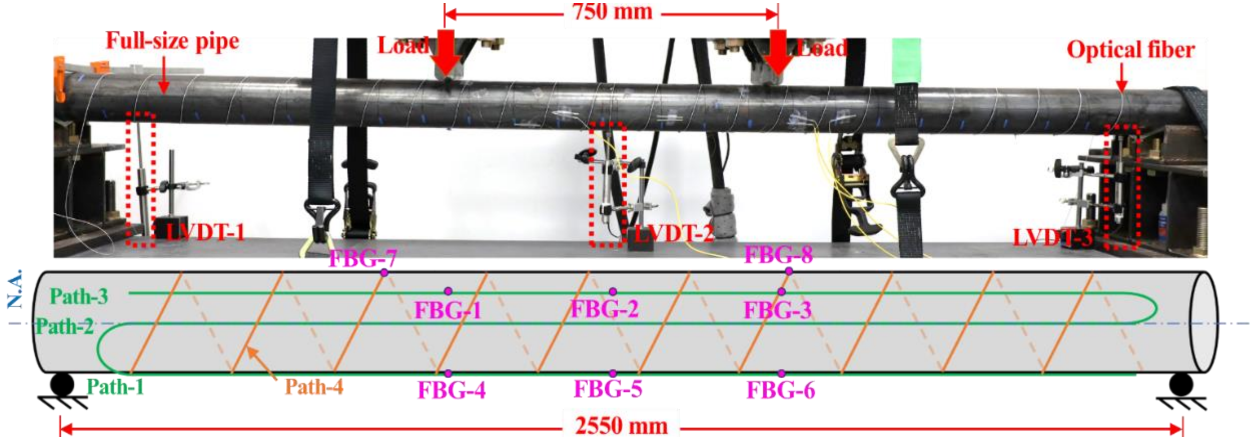
- Representative results

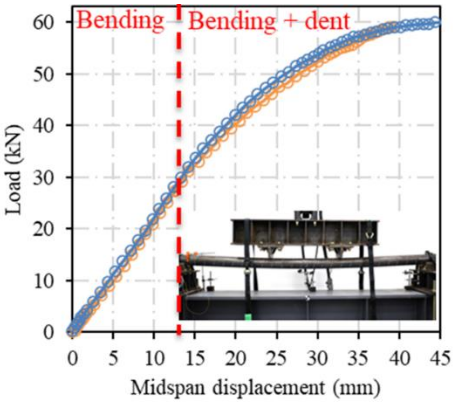


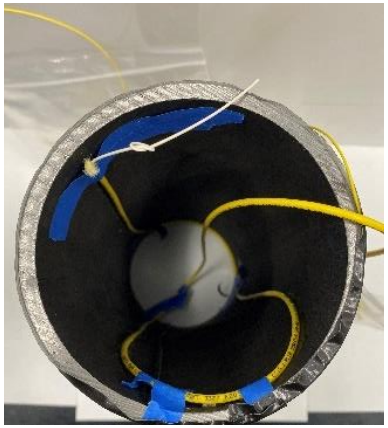
(a) Before 1st impact cycle
(b) After 1st impact cycle
(c) Before 2nd impact cycle
(d) After 2nd impact cycle
(e) Before 3rd impact cycle
(f) After 3rd impact cycle
(g) Before 4th impact cycle

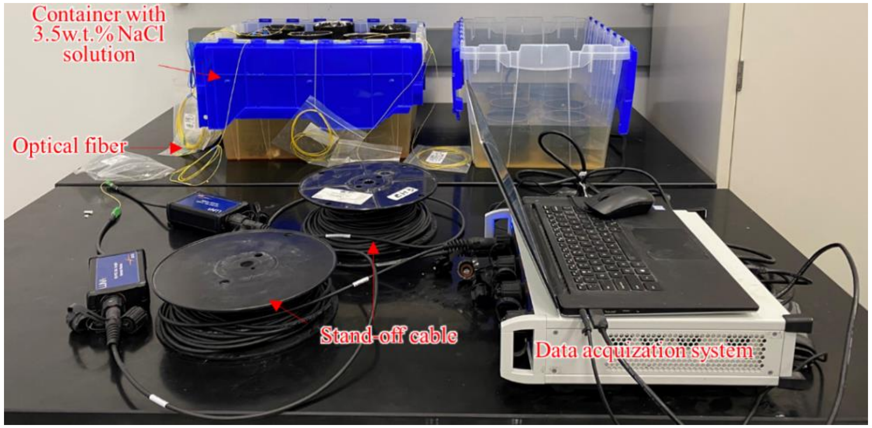
Theme 12: Measurement of interactive deformations, dent, crack, and corrosion

- Monitoring of deformations, dent, crack, and corrosion

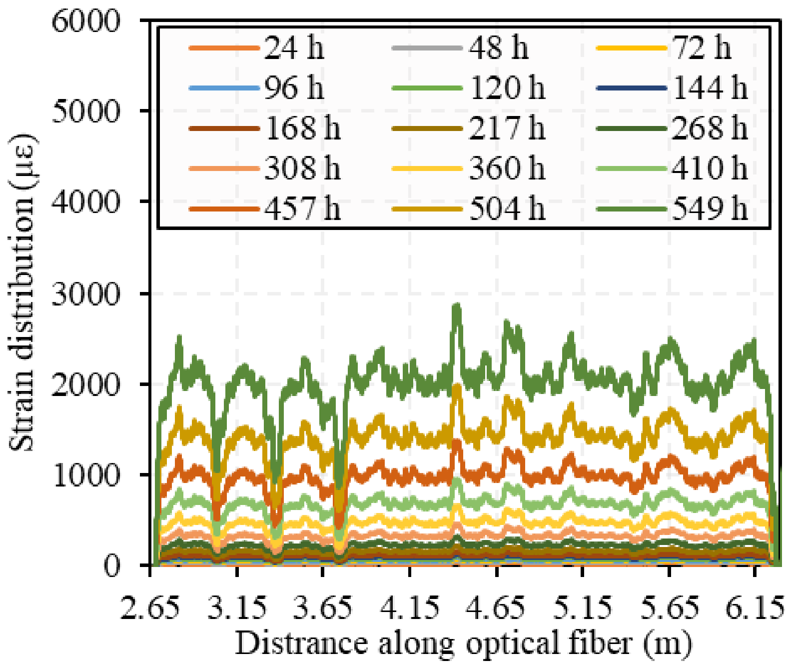




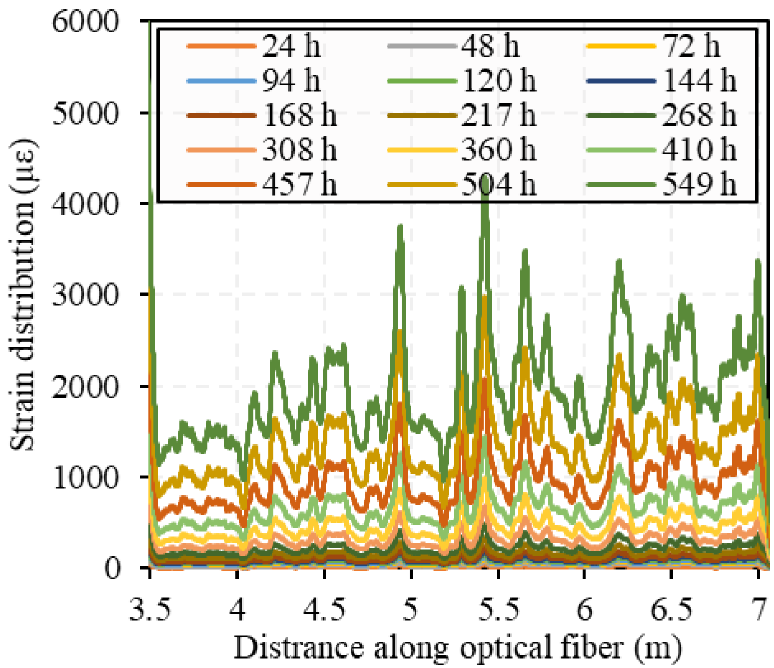




- Representative results measured from distributed fiber optic sensors
  - ➢ The strain distributions measured from the pipes with dent show higher spikes and deeper valleys than the pipes without any dent because dent caused residual strains in the steel pipes and modified the microstructures of the pipes.
  - ➢ The presence of the notch accelerated the corrosion, as shown by higher spikes.



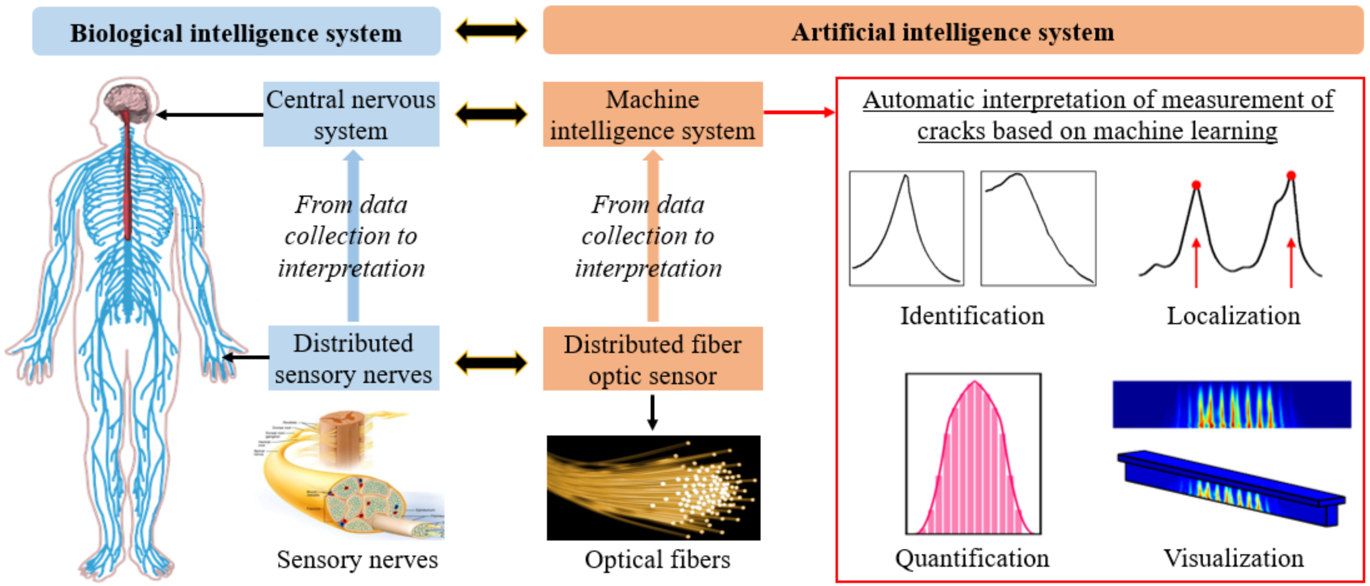
Corrosion + Dent

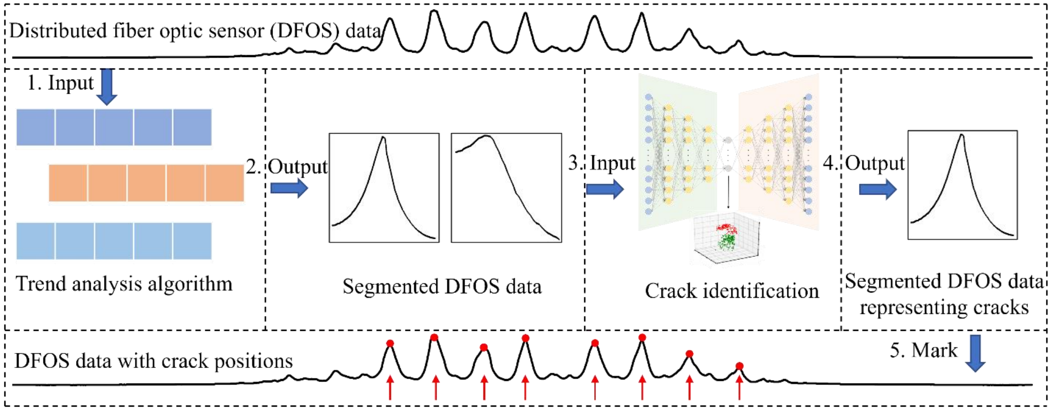


Corrosion + Dent + Notch

Develop a machine learning approach

- To enable automatic monitoring of anomalies based on distributed sensor data





Conclusions

- Measurement of 3D arbitrary strain fields of pipelines.
- Detection, localization, quantification, and visualization of cracks in pipelines.
- Detection, localization, quantification, and visualization of pipeline buckling/dents.
- Detection, localization, quantification, visualization, and warning of pipeline corrosion.
- Detection and monitoring of impacts applied to pipelines. The impacts can be applied by third-party excavation or digging.
- Detection and discrimination of interactive anomalies of pipelines. The investigated cases of interactive anomalies included: (1) global and local deformations (bending and dents); (2) deformations and cracks; (3) deformations and corrosion; (4) deformations, impacts, and corrosion; and (5) deformations, cracks, and corrosion.
- Machine learning-based methods for automatic data interpretation.

Journal Papers (21 journal papers published, 1 paper under review)

[1] Liu, Y. and Bao, Y.* (2024), "Intelligent monitoring of corrosion using distributed fiber optic sensors assisted by deep learning." Measurement. 226, 114190. https://doi.org/10.1016/j.measurement.2024.114190 (JCR: Q1, IF: 5.6)

[2] Xu, L., Shi, S., Huang, Y., Yan, F., Yang, X. and Bao, Y. (2024). "Corrosion monitoring and assessment of steel under impact loads using discrete and distributed fiber optic sensors." Optics & Laser Technology, 174, p.110553. https://doi.org/10.1016/j.optlastec.2024.110553 (JCR: Q1, IF: 5)

[3] Liu, Y. and Bao, Y.*, (2023). "Intelligent monitoring of spatially-distributed cracks using distributed fiber optic sensors assisted by deep learning." Measurement, 220, p.113418. https://doi.org/10.1016/j.measurement.2023.113418 (JCR: Q1, IF: 5.6)

[4] Liu, Y. and Bao, Y., (2023). "Automatic interpretation of strain distributions measured from distributed fiber optic sensors for crack monitoring." Measurement, 211, p.112629. https://doi.org/10.1016/j.measurement.2023.112629 (JCR: Q1, IF: 5.6)

[5] Tan, X., Mahjoubi, S., Zou, X., Meng, W. and Bao, Y., (2023). "Metaheuristic inverse analysis on interfacial mechanics of distributed fiber optic sensors undergoing interfacial debonding." Mechanical Systems and Signal Processing, 200, p.110532. https://doi.org/10.1016/j.ymssp.2023.110532 (JCR: Q1, IF: 8.4)

[6] Xu, L., Shi, S., Yan, F., Huang, Y. and Bao, Y., (2023). "Experimental study on combined effect of mechanical loads and corrosion using tube-packaged long-gauge fiber Bragg grating sensors." Structural Health Monitoring, p.14759217231164961. https://doi.org/10.1177/14759217231164 (JCR: Q1, IF: 8.4)

[7] Liu, Y. and Bao, Y., (2023). "Real-time remote measurement of distance using ultra-wideband (UWB) sensors." Automation in Construction, 150, p.104849. https://doi.org/10.1016/j.autcon.2023.104849 (JCR: Q1, IF: 10.3)

[8] Xu, L., Zhang, D., Huang, Y., Shi, S., Pan, H. and Bao, Y., (2022). "Monitoring epoxy coated steel under combined mechanical loads and corrosion using fiber Bragg grating sensors." Sensors, 22(20), p.8034. https://doi.org/10.3390/s22208034 (JCR: Q2, IF: 3.9)

[9] Yan, M., Tan, X., Mahjoubi, S. and Bao, Y.* (2022), "Strain transfer effect on measurements with distributed fiber optic sensors." Automation in Construction, 139, p.104262. https://doi.org/10.1016/j.autcon.2022.104262 (JCR: Q1, IF: 10.3)

[10] Mahjoubi, S., Tan, X. and Bao, Y.* (2022), "Inverse analysis of strain distribution sensed by distributed fiber optic sensor subject to strain transfer." Mechanical Systems and Signal Processing, 166, p.108474. https://doi.org/10.1016/j.ymssp.2021.108474 (JCR: Q1, IF: 8.4)

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Next steps

- Evaluation of the developed sensors and analytical tools for other types and sizes of pipes. It is important to test the sensor installation methods and data analysis methods in further experiments using large pipe specimens and in field testing.
- Development, evaluation, and implementation of machine learning methods for automatic interpretation of data provided by distributed fiber optic sensor network deployed on pipes subject to interactive anomalies.
- Development, evaluation, and implementation of methods for efficient installation of fiber optic cables on the surfaces of pipelines. It is important and urgent to develop effective and efficient methods for installing fiber optic cables. Robots are promising solutions for the installation of fiber optic cables as distributed sensors for pipeline applications.
- Development, evaluation, and implementation of an Internet of Things (IoT) platform for automatic generation and utilization of digital twins of smart pipelines instrumented for improved asset management.
- Education and training of students and pipeline professionals for developing the next-generation workforce for the pipeline industry. It is important to develop courses and certificate programs to support the vision for smart pipelines.

Project's public page

- The final report has been posted on the project's public page

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Distributed Fiber Optic Sensor Network for Real-time Monitoring of Pipeline Interactive Anomalies

Main Objective

The main objectives in this project include: (1) the development, calibration, and validation of an innovative distributed fiber optic sensor network for detection, localization, characterization, and quantification of cracking, deformation (dent), material degradation (corrosion), and excavation along the pipelines, and their interactions in between these different anomalies; (2) the development and validation of a data processing programs for real-time sensor data analysis to identify interactions between different anomalies for effective and efficient pipeline management; and (3) the training offered to graduate and undergraduate students through the research on pipeline anomaly detection to prepare them for future careers in related industry.

Public Abstract

A transportation pipeline network of about 2.6 million miles delivers the energy products that the American public needs, in order to keep its homes and businesses running. While various measures have kept the pipeline failure rate low, incidents continue occurring and causing fatality, injures, and significant revenue loss. Recent investigations conducted by National Transportation Safety Board (NTSB) have shown that interactive threats and anomalies play important roles in pipeline incidents. There is an urgent need to develop effective nondestructive evaluation technologies to detect and analyze interactive anomalies.
The current practice of pipeline anomaly detection mainly relies on the use of smart pigs that are only performed as scheduled or needed, which may have delayed actions to anomalies, operation downtime, and significant revenue loss. An alternative to monitor a pipeline in real time is to use field sensors installed on pipelines, such as ultrasonic or point fiber optic sensors. However, the use of point sensors requires a large quantity of sensors for a long distance, resulting in high cost and intensive labor efforts for long-term condition monitoring.
The overarching goal of this research is to pave a path which may transform the current pipeline anomaly detection technologies to a distributed fiber optic sensor network for real-time detection, localization, and quantification of interactive anomalies of pipelines, thus improving the pipeline safety and management. The distributed fiber optic sensor network will seamlessly integrate multifunctional distributed and point fiber optic sensors and provide fully distributed measurement along the pipeline. A continuous optical fiber will serve as both the transmission line and distributed sensor based on light scatterings in the optical fiber. Along the pipeline, the location of an event is determined by measuring the time of flight of the backscattered light signal. Point fiber optic sensors (e.g. fiber Bragg grating sensors) will be incorporated at critical locations for improving the measurement accuracy and reliability of the distributed fiber optic sensor network. Both the distributed and point fiber optic sensors will measure multiple pipeline anomalies and their interactions that are associated with the integrity of the pipeline. To exemplify the functionality of the proposed sensor network, this project will demonstrate the sensor network in monitoring the spatial distribution of cracks, dents, corrosion, and excavation along the pipeline. The sensor network will be characterized under individual anomaly type and tested under interactive anomalies. Data processing programs will be developed for real-time sensor data analysis. Different co-existing anomalies will be distinguished by analyzing the sensor data using the data processing programs. Anticipated outcomes will improve not only the safety but also the management of pipelines through providing real-time information of the locations, types, and severity of the anomalies.

Fast Facts	
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Downloads of Project Reporting	
Since Jan 1, 2017	6496
Financial and Status Data	
Project Status:	Completed
Start Fiscal Year:	2019 (09/30/2019)
End Fiscal Year:	2022 (09/29/2022)
PHMSA $$ Budgeted:	$250,000.00

FINAL REPORT

Final Report

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Q & A

Thank you!

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