



Real-time monitoring of far-field cracks in concrete bridge decks using distributed acoustic sensing technique

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Background

Importance of infrastructure monitoring

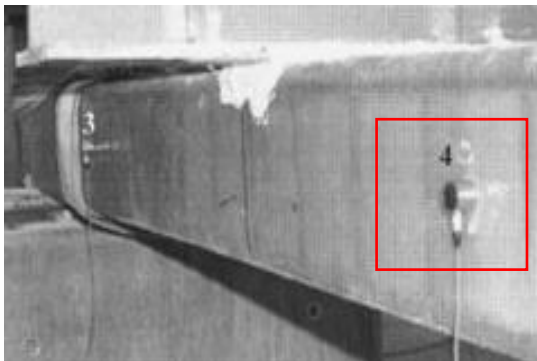
- According to the 2025 Infrastructure Report Card, the America's infrastructure is C overall.
- The bridges in the country with an average age of about 47 years, that serve as vital connections throughout the transportation system.
- Many bridges are approaching or have exceeded the 50-year life they were designed for.
- To ensure continued safety and serviceability, regular crack monitoring and maintenance are required.



2025 Report card, Photo: Brent Spence Bridge Corridor Project
(<https://infrastructurereportcard.org/cat-item/bridges-infrastructure/>)

Existing crack monitoring techniques

- Acoustic emission
 - Disadvantages : Expensive, incapable of long-distance monitoring
 - Localization requires multiple sensors
- Distributed fiber optic sensing
 - Disadvantages : only suitable for near-field monitoring
- Robot-assisted inspection
 - Disadvantages : only suitable for surface, visible cracks



Gostautas, et al. 2005



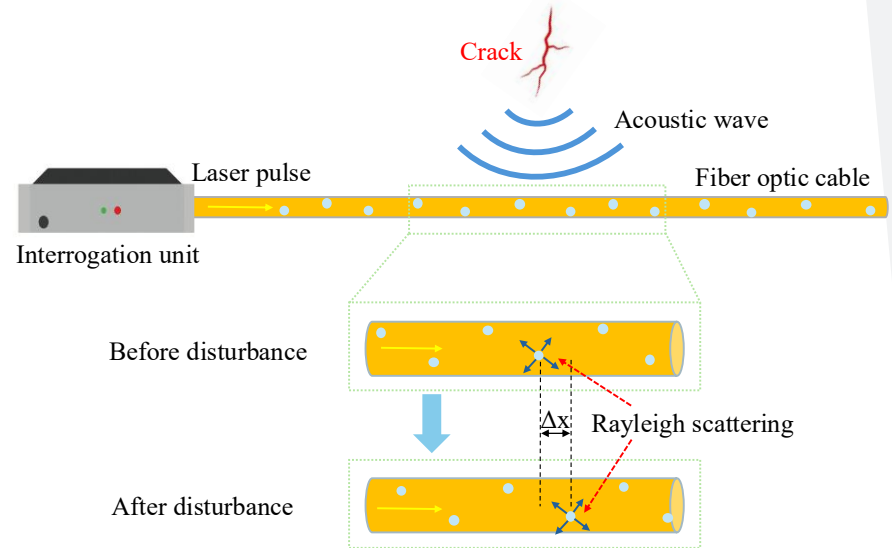
Poorghasem, et al. 2025



Metni, et al. 2007

Distributed acoustic sensing

- Far-field monitoring
- Real-time monitoring
- Long-distance monitoring
- Internal Crack Monitoring
- Cost - effective



Cheng, et al. (2019).

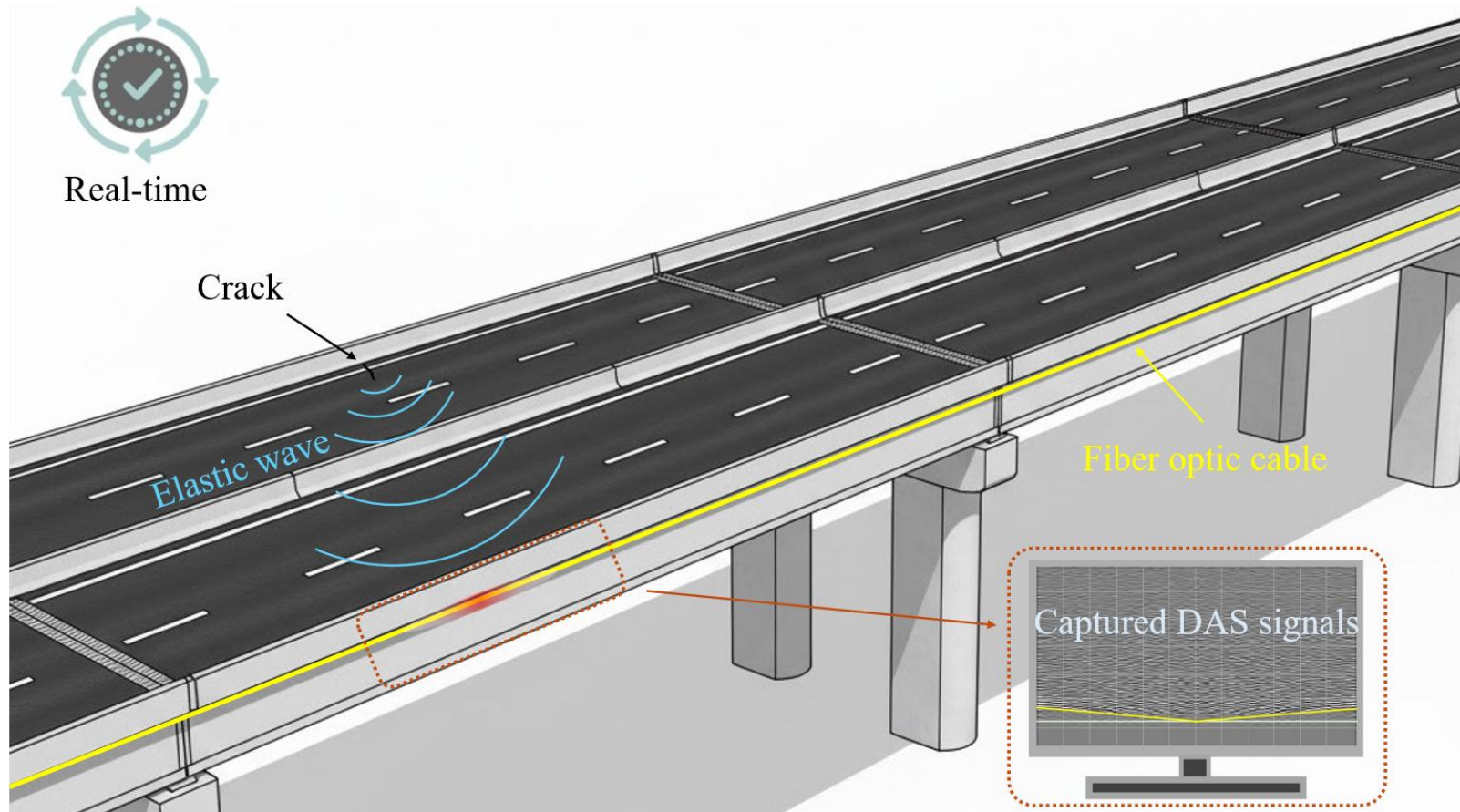


Truong, et al. (2024).



Methods

Proposed monitoring approaches



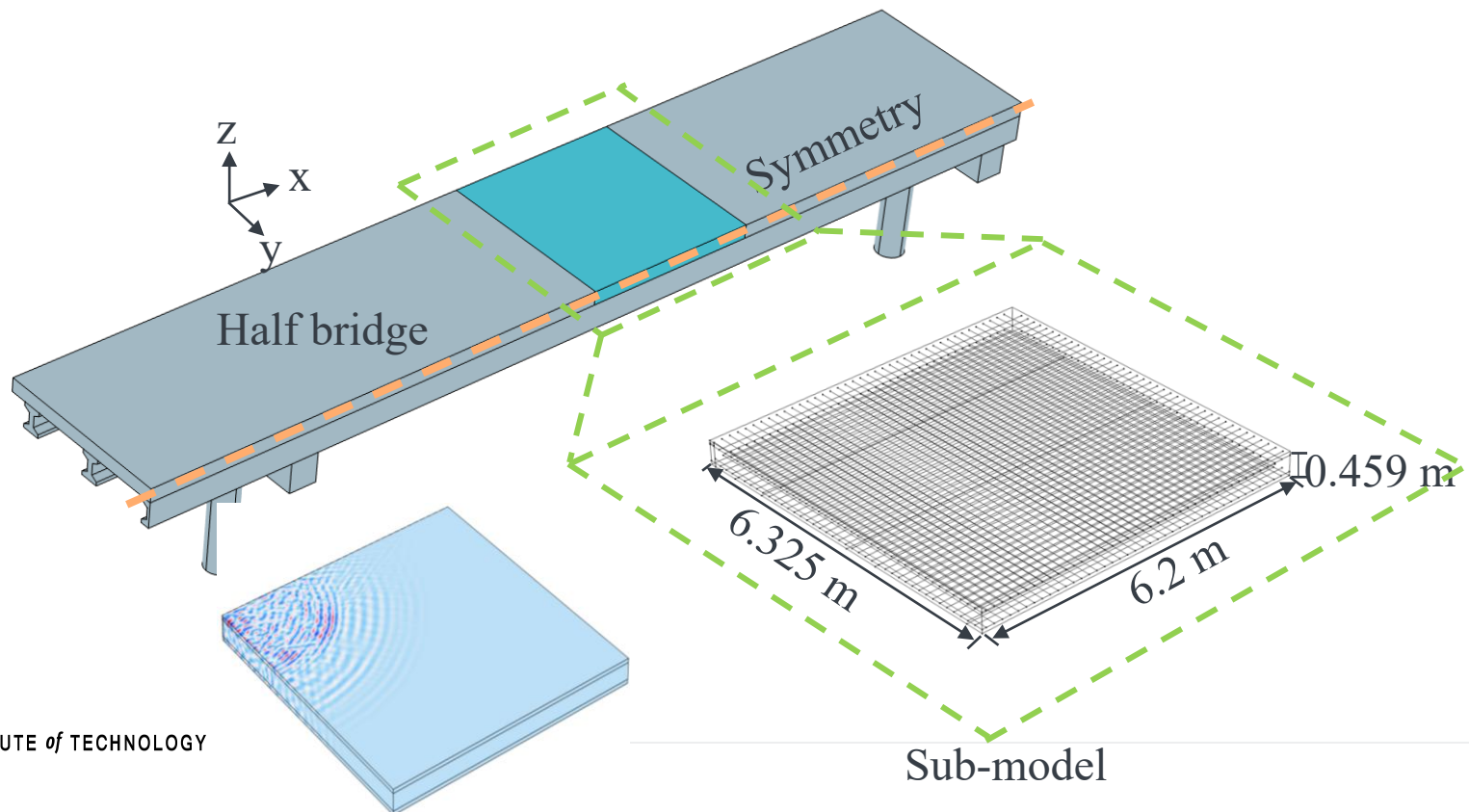
Multiphysics finite element analysis

Software : COMSOL Multiphysics

Model prototype: A highway bridge

Cracking simulation : 1 MPa-amplitude Tone burst wave

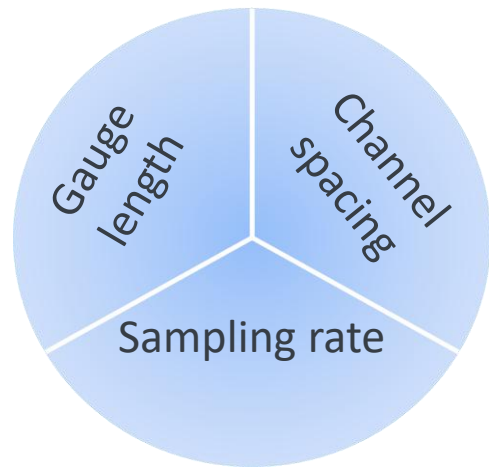
Validation : Through a FHWA report (Kennedy, et al.2008)



Data processing

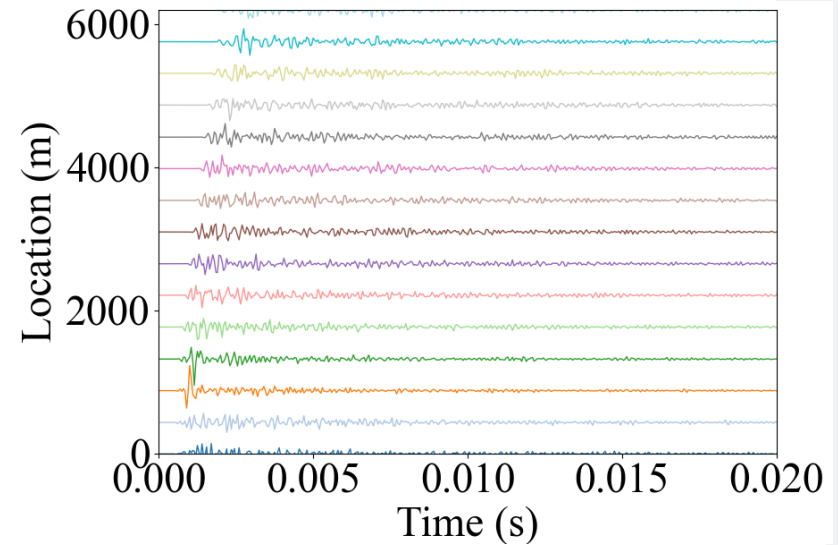
Translate the simulation results to DAS signals

- Cleaning
- Moving average
- Spatial down-sampling
- Temporal down-sampling

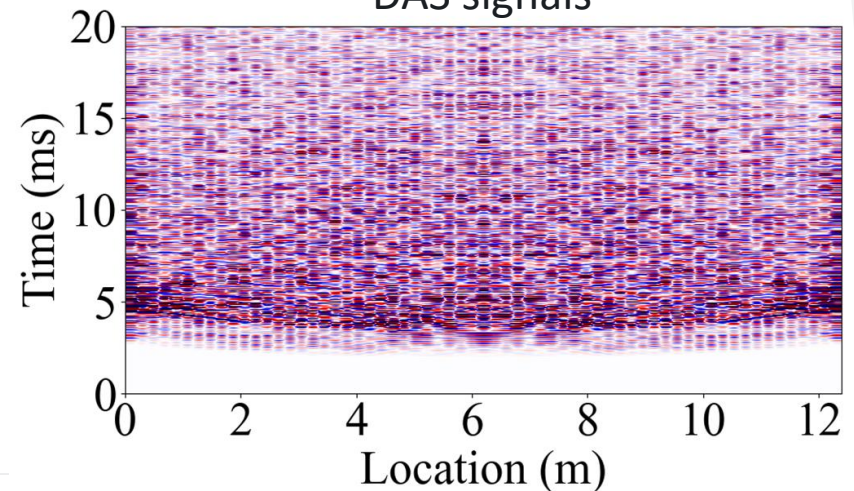


DAS system configurations

Simulation results



DAS signals

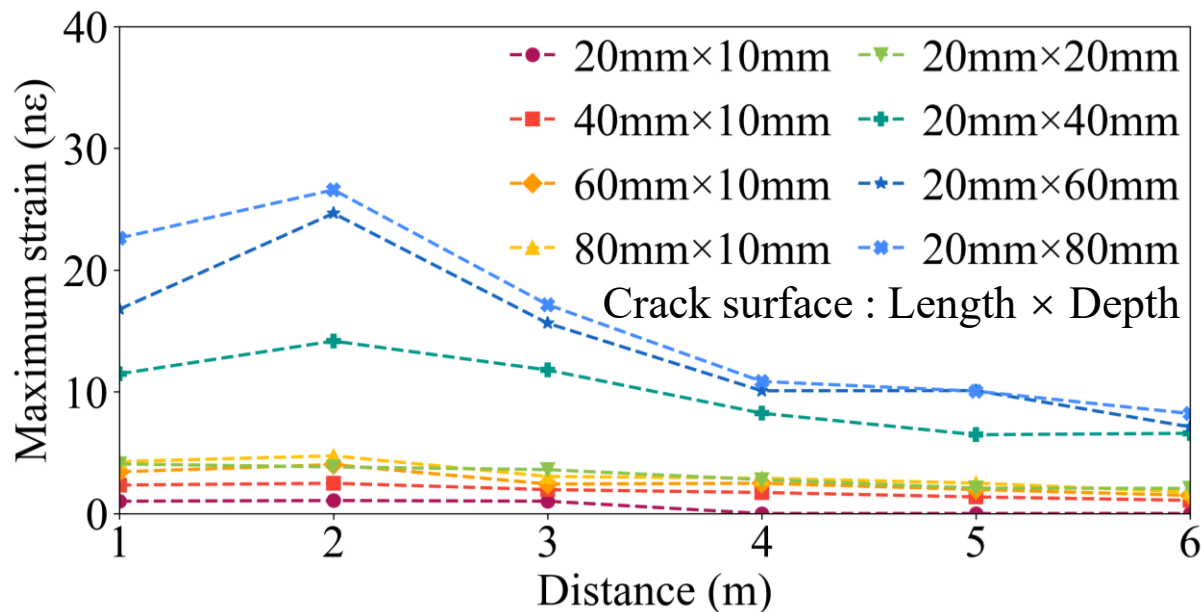




Feasibility

Whether crack can be monitored?

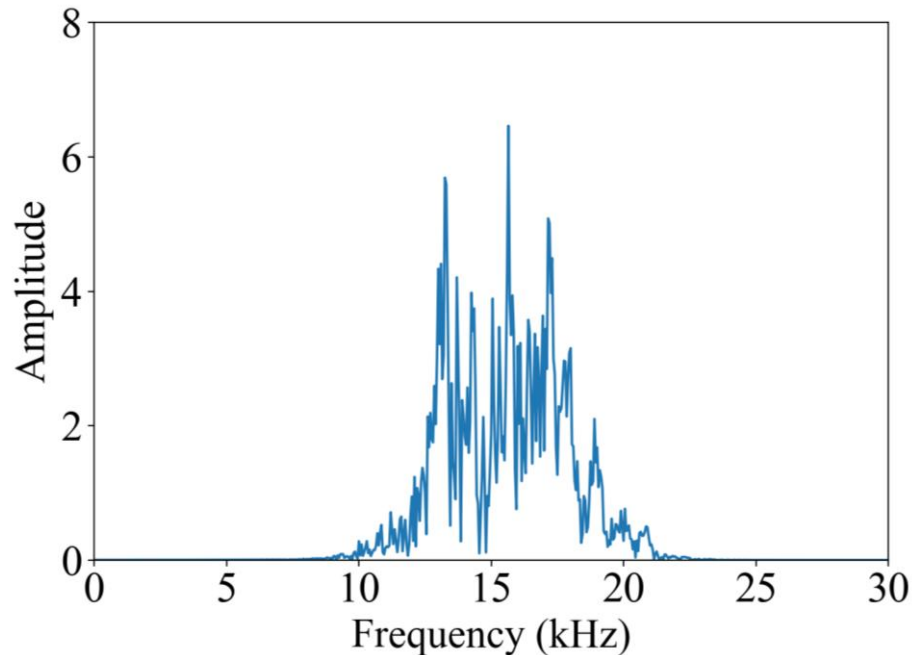
- Feasibility : exceed DAS's sensitivity (nanostrain $\text{n}\epsilon$)
- Crack larger than 20 mm $\times$ 20 mm can be monitored at 6 m away.
- Fiber optic cable layout under the bridge deck are more sensitive to deep crack.



Whether crack can be distinguished?

The primary frequency of crack : 15.4 kHz, 52 kHz, more than 100 kHz [xx]

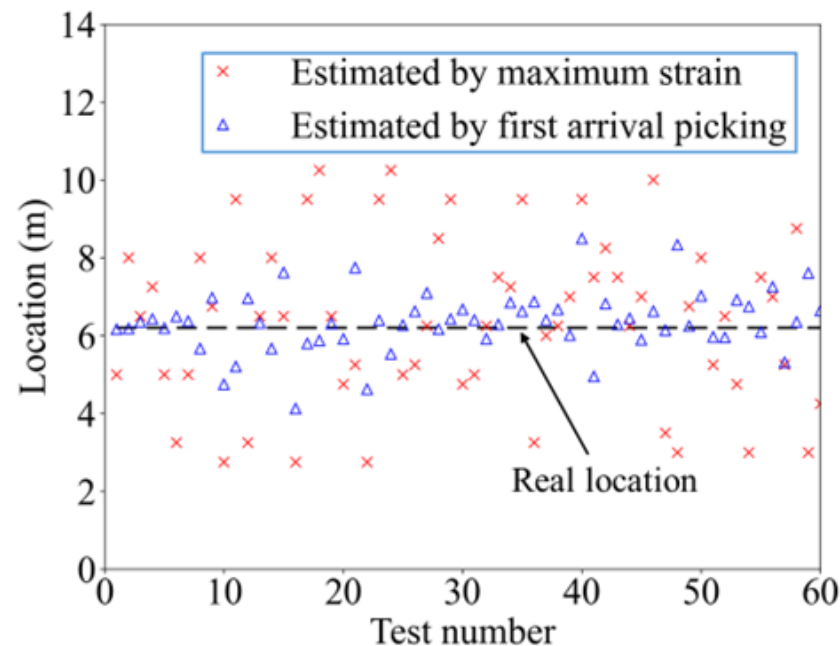
When a 15.4 kHz pulse was applied as the cracking wave, the frequency spectrum of the signal, captured 6 m horizontally and 0.459 m vertically, still exhibited frequency components exceeding 10 kHz. This frequency is significantly higher than the low-frequency band associated with vehicular traffic and pedestrian activities.



Whether crack can be located?

60 sets data with different crack and distance are tested for localization performance.

- Maximum strain method : The position that exhibits the maximum measured strain.
 - Root mean squared error : 2.13 m
- First arrival picking method : The position derived from the first arrival times.
 - Root mean squared error : **0.79 m**



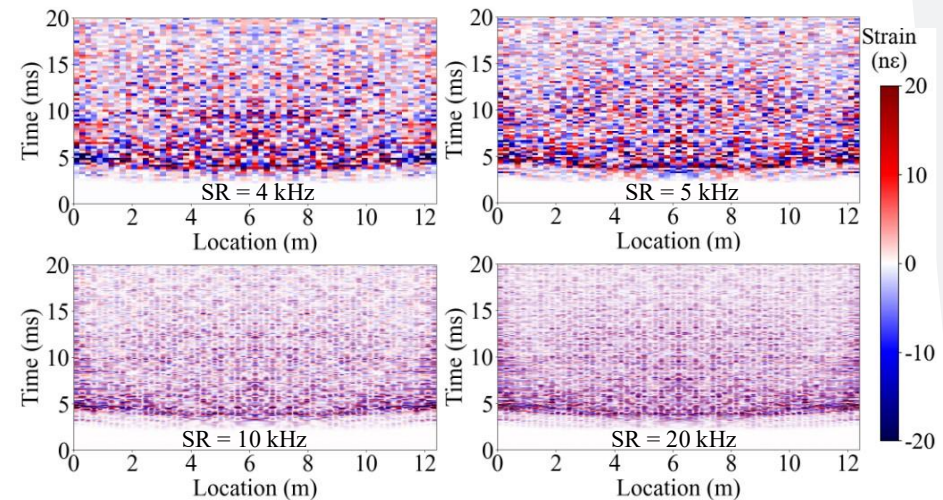
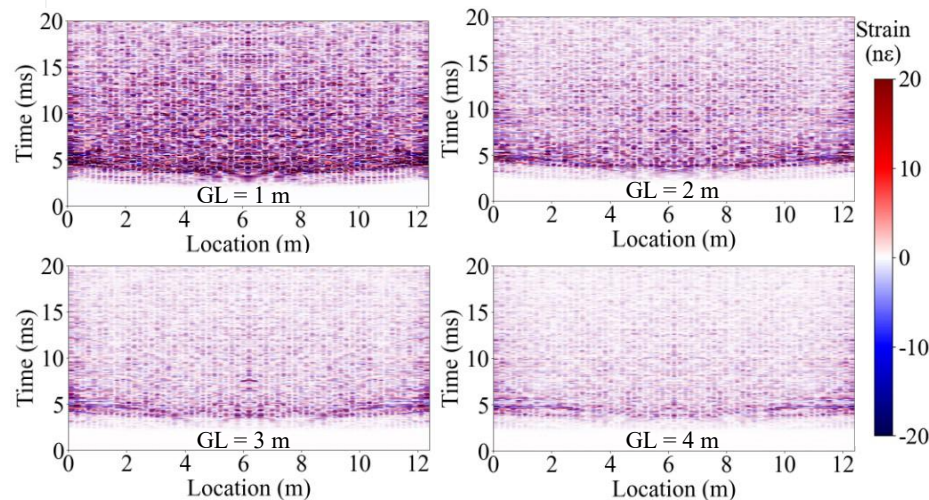
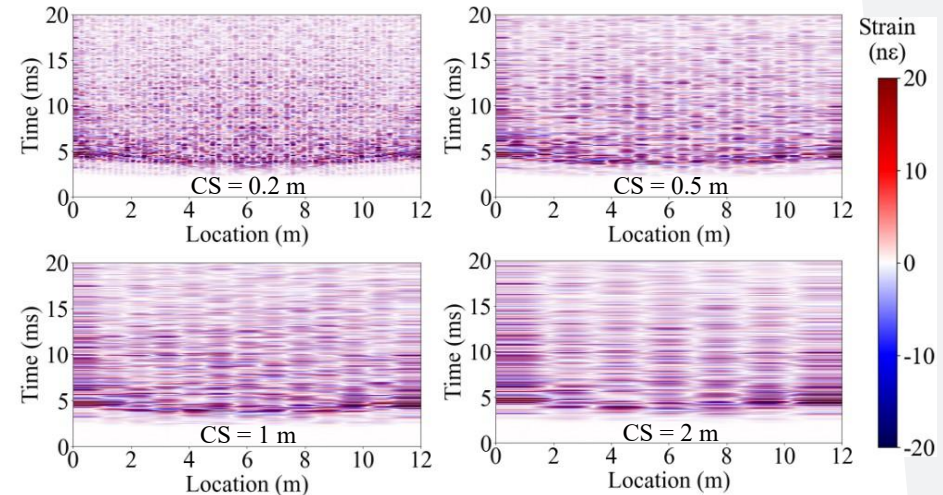


Influencing factors

Factors : system configurations

Primary DAS system configurations:

- Gauge length (GL)
- Channel spacing (CS)
- Sampling rate (SR)



Factors : system configurations

- Coarser gauge length or lower sampling rates lead to underestimation of maximum strain values, resulting in underestimation of crack severity.
- Among the configuration parameters of the DAS system, channel spacing exhibited the most significant impact on localization performance.

No.	Crack location (m)	Gauge length (m)	Channel spacing (m)	Sampling rate (kHz)	Absolute maximum strain ($\mu\epsilon$)	Estimated crack location (m)
1	6.2	1	0.2	20	73	6.2
2	6.2	2	0.2	20	35	6.2
3	6.2	3	0.2	20	25	6.2
4	6.2	4	0.2	20	17	6.2
5	6.2	2	0.5	20	32	5.3
6	6.2	2	1	20	28	9
7	6.2	2	2	20	24	4
8	6.2	2	0.2	4	25	6.2
9	6.2	2	0.2	5	25	6.2
10	6.2	2	0.2	10	35	6.2



Other factors

- Acoustic source
 - Concrete materials and crack types
- Propagation
 - Paths and the properties of the propagation medium
- Noise
 - Environmental noise and traffic-induced vibrations
- Temperature
 - $0.2 \mu\epsilon/^{\circ}\text{C}$



Comparative evaluation

Performance

- Monitoring performance

- Sensitivity : Acoustic emission > DAS (nε) > static DFOS (mε)
- Distance : DAS (km) > static DFOS (m-km) > Acoustic emission(m)

- Localization performance

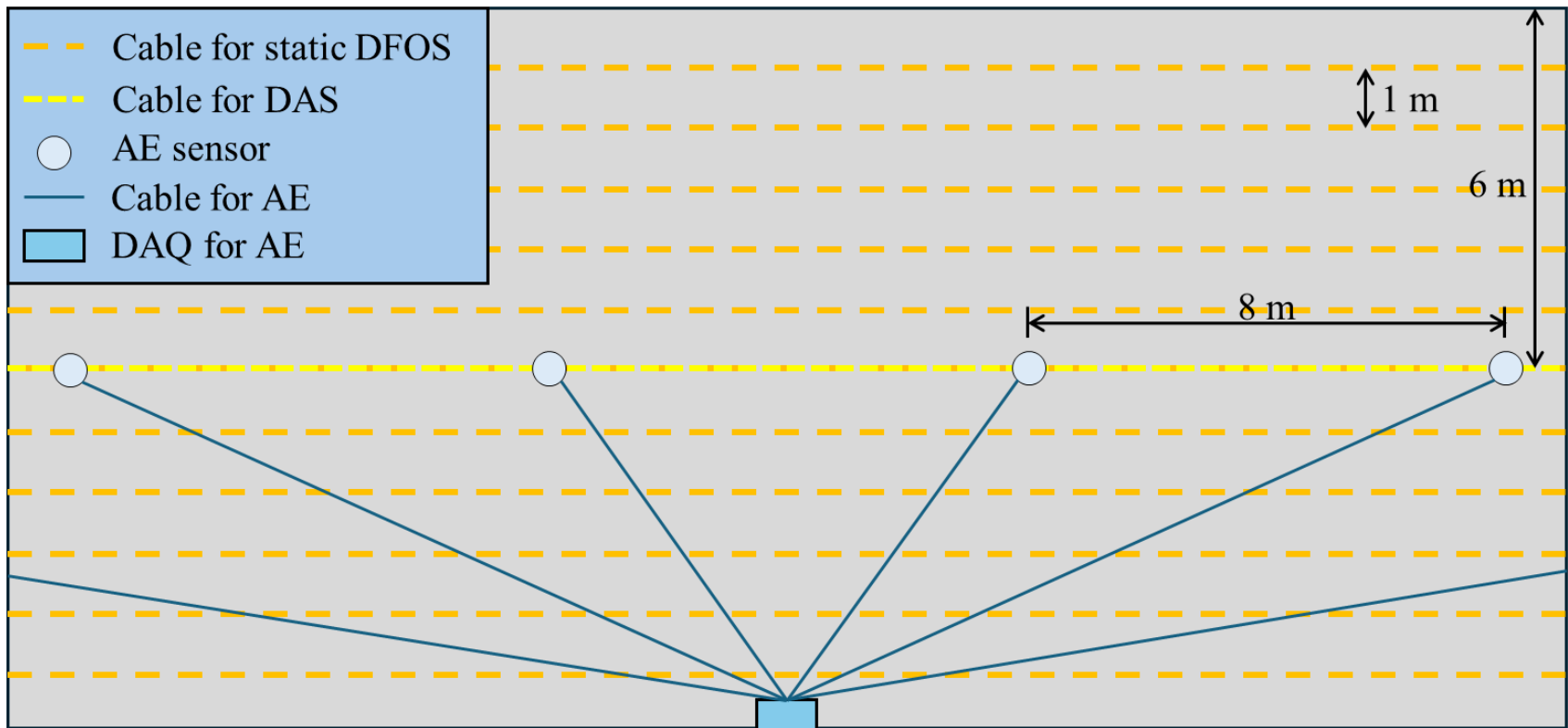
- Accuracy : static DFOS > DAS > Acoustic emission
- Long-distance localization : DAS > static DFOS > Acoustic emission
 - Notice: The localization of Acoustic emission need 3 sensors to form a sensing array.

Economic analysis

Background :

20 km-long and 12 m-wide reinforced concrete sea-crossing bridge.

AE sensor are assumed to integrated with pre-amplifier.



Economic analysis

By comparing the capital costs of the three techniques for a 20 km-long and 12 m-wide reinforced concrete bridge, DAS is found to be more **cost-effective**.

- The capability of DAS: perform long-distance, far-field monitoring using single fiber optic cables and single DAQ.

Cost	AE		DFOS		DAS	
categories	Unit cost	Quantity	Unit cost	Quantity	Unit cost	Quantity
Design	Price on request	1	N.A.	N.A.	N.A.	N.A.
Sensor	\$600	2500	\$0.18/m	220,000	\$0.18/m	20,000 m
Cable	\$195/m	2067 m		m		
DAQ	\$10,000 (32 channels)	79	\$300,000 (Estimated)	2	\$500,000 (Estimated)	1
Summary	\$2,693,065		\$639,600		\$503,600	



Conclusion

Conclusion

- The DAS-based approach was validated to be effective in monitoring far-field crack. The elastic wave emitted by cracks measuring 20 mm in length and 20 mm in depth, located 6 meters away.
- Using first arrival picking method, high-accuracy crack localization with an overall RMSE of 0.942 m was achieved.
- Coarser gauge length or lower sampling rates lead to underestimation of maximum strain values, resulting in underestimation of crack severity. Channel spacing exhibited significant impact on localization performance.
- For large-scale structures crack monitoring, DAS is an efficient and cost-effective solution.



References

- ASCE's 2025 Infrastructure Report Card. <https://infrastructurereportcard.org>.
- Gostautas, R.S., Ramirez, G., Peterman, R.J. and Meggers, D., 2005. Acoustic emission monitoring and analysis of glass fiber-reinforced composites bridge decks. *Journal of bridge engineering*, 10(6), pp.713-721.
- Poorghasem, S., Liu, Y. and Bao, Y., Machine Learning-Powered Automatic Detection and Prediction of Crack and Corrosion Using Spatiotemporal Measurement from Distributed Fiber Optic Sensors. *Available at SSRN 5189560*.
- Truong, K., Eidsvik, J. and Rørstadbotnen, R.A., 2024. Edge computing in distributed acoustic sensing: An application in traffic monitoring. arXiv preprint arXiv:2410.16278.
- Cheng, L., Jansen, R., Burggraaf, H., Jong, W.D., Toet, P. and Doppenberg, E., 2019, August. Dynamic load monitoring of a concrete bridge using a fiber optic distributed acoustic sensing (DAS) system. In *Proceedings of the 5th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures*, Potsdam, Germany (pp. 27-29).
- Kennedy, T.C., Lovejoy, S.C. and Blomberg, J.E., 2008. Finite element modeling of wave propagation in concrete (No. FHWA-OR-RD-09-06). Oregon. Dept. of Transportation. Research Unit. <https://rosap.ntl.bts.gov/view/dot/21828>.
- Thirumalaiselvi, A. and Sasmal, S., 2021. Pattern recognition enabled acoustic emission signatures for crack characterization during damage progression in large concrete structures. *Applied Acoustics*, 175, p.107797. <https://doi.org/10.1016/j.apacoust.2020.107797>.
- Miller, D.E., Coleman, T., Zeng, X.F., Patterson, J.R., Reinisch, E.C., Cardiff, M.A., Wang, H.F., Fratta, D., Trainor-Guitton, W. and Thurber, C.H., 2018, February. DAS and DTS at Brady Hot Springs: Observations about coupling and coupled interpretations. In *Proceedings of the 43rd workshop on geothermal reservoir engineering*, Stanford, CA, USA (pp. 12-14). <https://geoscience.wisc.edu/feigl/porotomo/>.
- Sidenko, E., Pevzner, R., Tertyshnikov, K. and Lebedev, M., 2021, March. Effects of temperature on DAS measurements. In *EAGE GeoTech 2021 Second EAGE Workshop on Distributed Fibre Optic Sensing* (Vol. 2021, No. 1, pp. 1-5). European Association of Geoscientists & Engineers. <https://doi.org/10.3997/2214-4609.202131018>.





Thanks!