Structural health monitoring and condition assessment for offshore wind turbines

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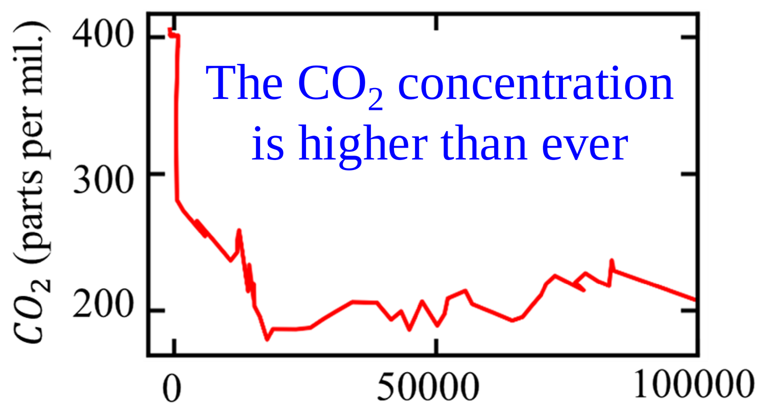
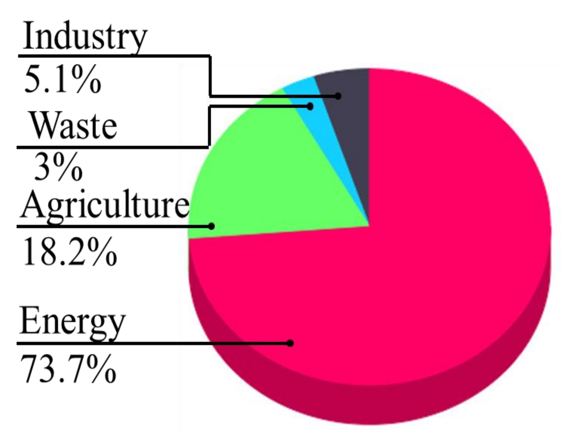
Introduction

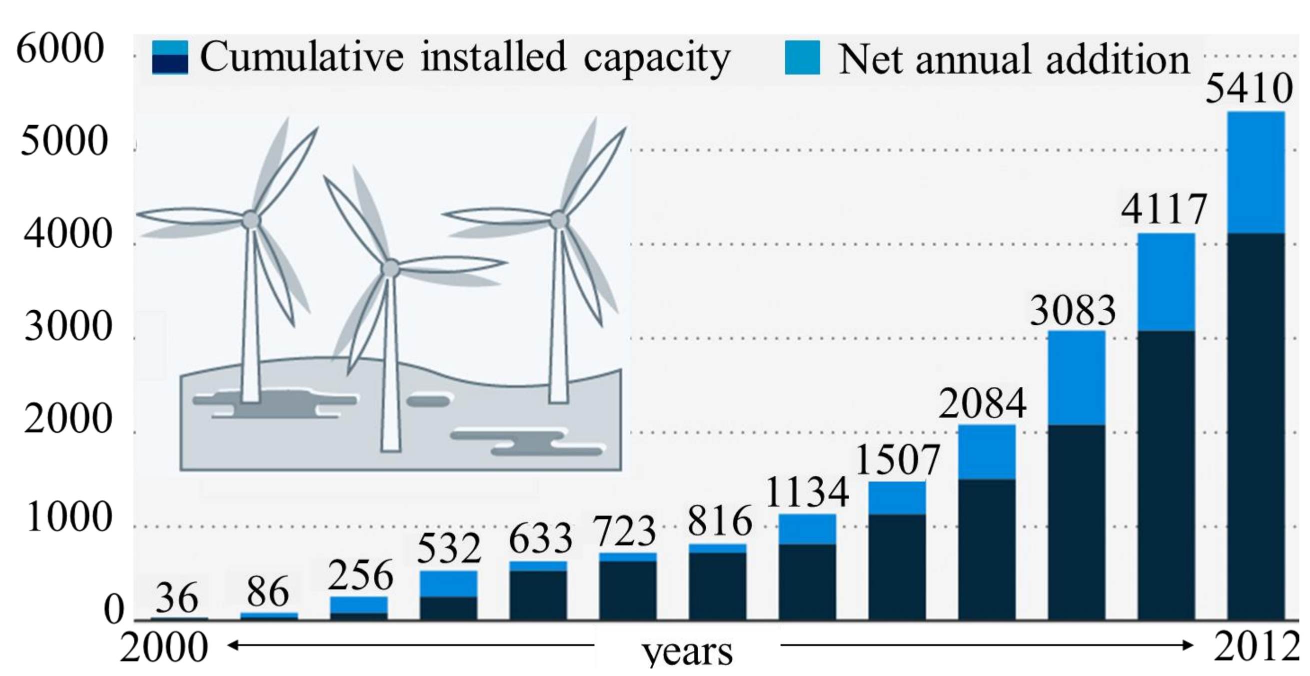
Climate change:

- Energy sector has high contributions to carbon emissions.





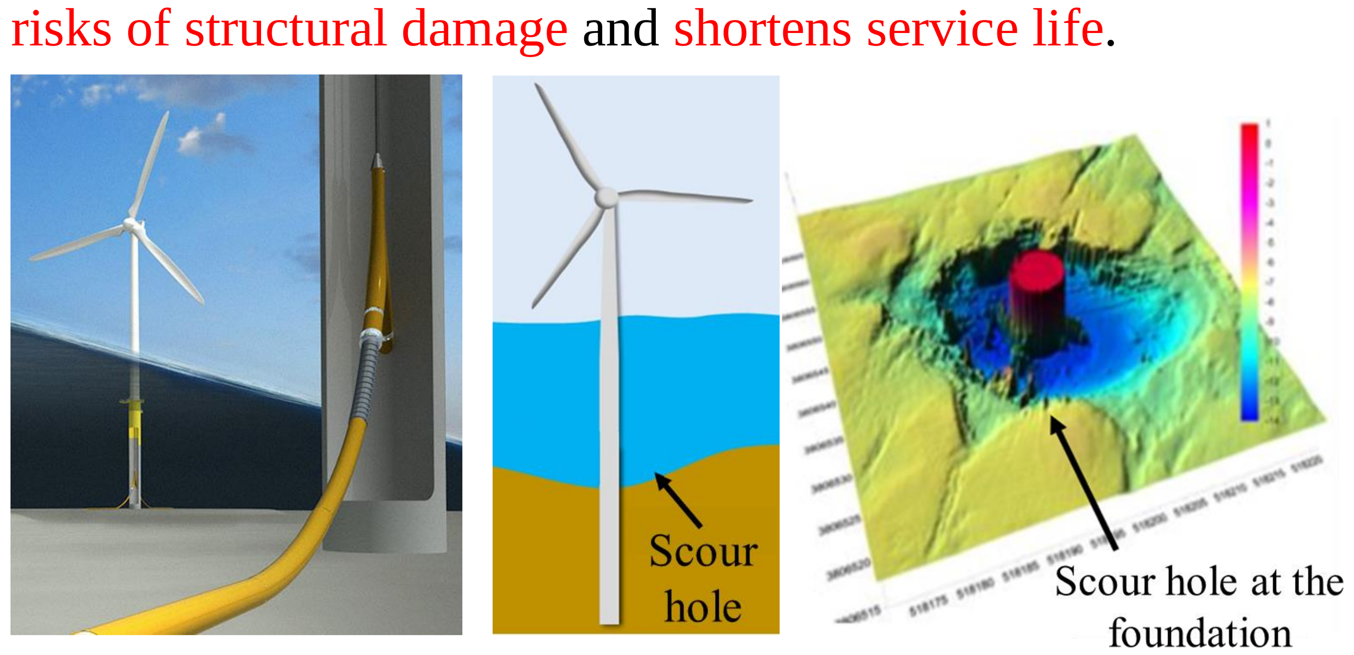
- In 2021, offshore wind energy reached a mainstream status with a total installed capacity of 54.0 GW.



Number of offshore wind turbine has increased

Challenges:

- The scouring of foundations and underwater cables causes risks of structural damage and shortens service life.

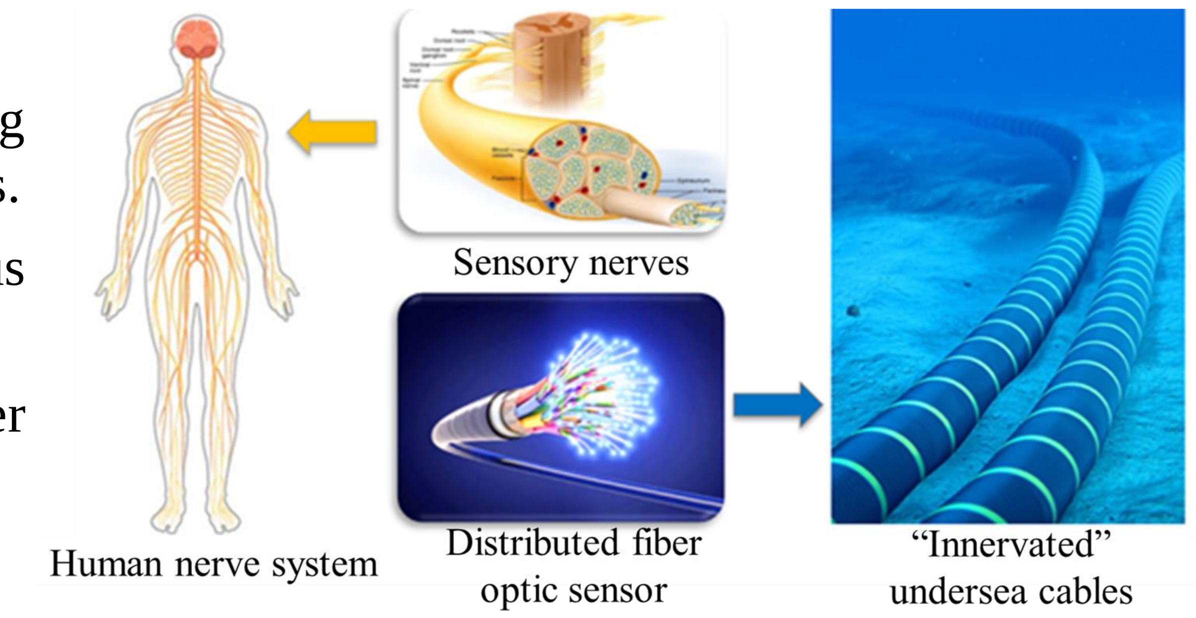


- Existing inspection methods for scouring based on visual inspection, sonar, or conventional sensors have limitations:
  - ➢ expensive
  - ➢ time-consuming
  - ➢ low accuracy
  - ➢ low precision

Methodology

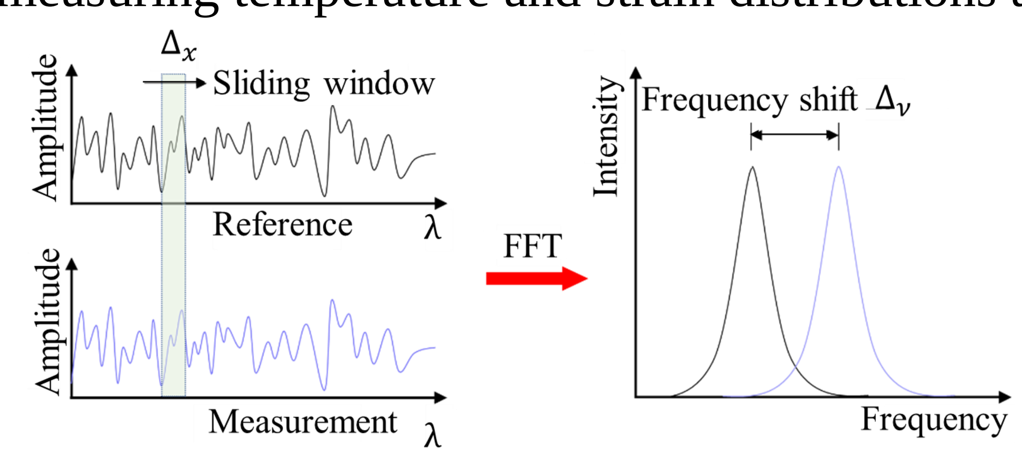
Proposed technology:

- Distributed fiber optic sensors for monitoring the scouring condition of foundations and cables.
- Distributed fiber optic sensors offer continuous measurements along the entire cable length.
- The continuous monitoring length can be longer than 100 miles.

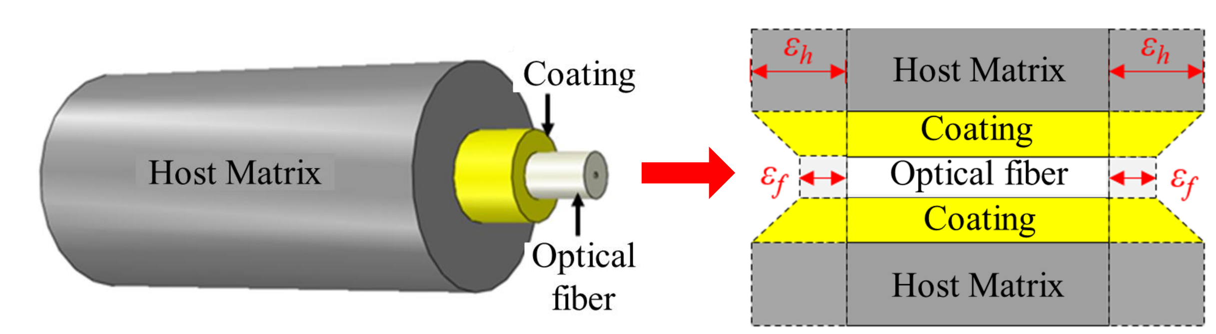


Distributed fiber optic sensor:

- A single-mode fiber optic cable is utilized as both the transmission line and a distributed sensor for measuring temperature and strain distributions along the cable length in real time.



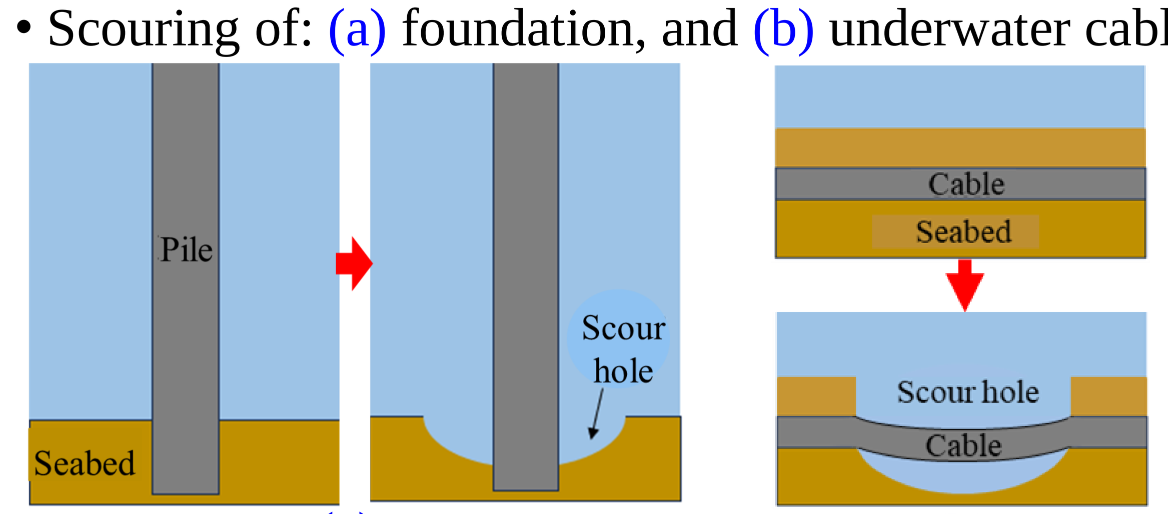
The sensor is sensitive to temperature and strain.



The fiber optic cable has protective coatings which introduce strain transfer effects.

Monitoring scour holes:

- Scouring of: (a) foundation, and (b) underwater cable



(a) (b)

- Formulate the relationship between strain and out-of-plane deformation:

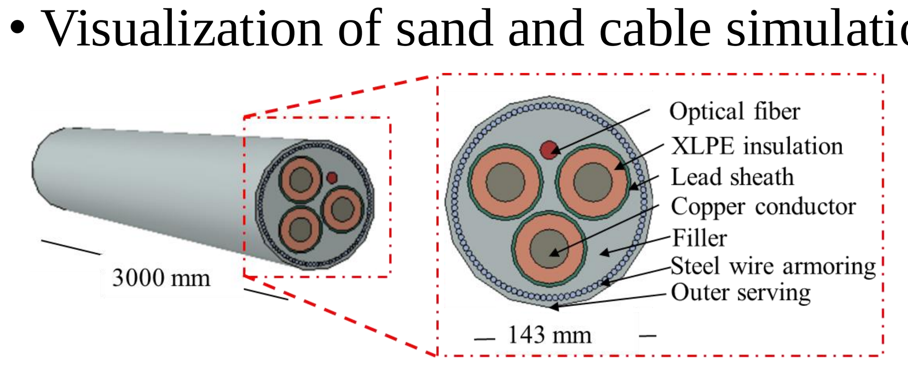
$$\varepsilon_p(x,y) = -z\frac{\partial^2 v_p(x,y)}{\partial p^2}, (p = x \text{ or } y)$$

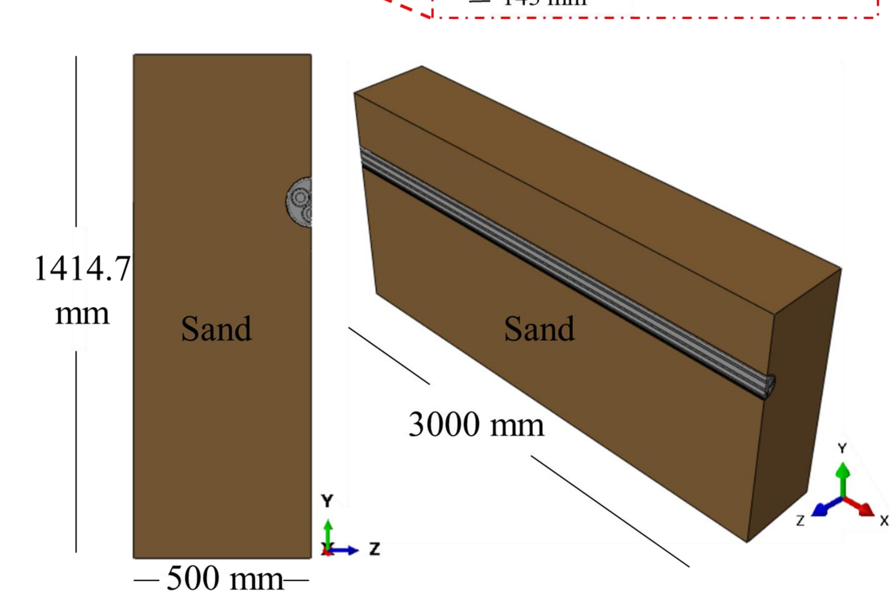
$$\varepsilon_p(x, y_i) = -z\frac{d^2 v_x(x, y_i)}{dx^2}$$

Numerical simulations

Finite element analysis:

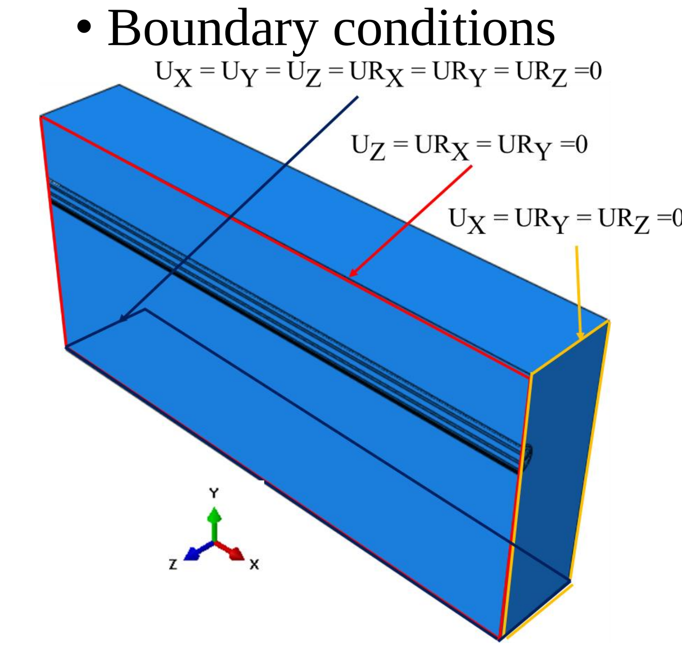
- Visualization of sand and cable simulation:



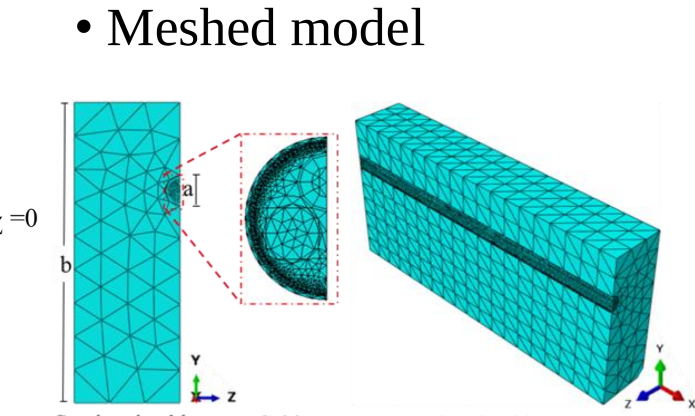


Material properties				
Density (kg/m^3)	Young's modulus (MPa)	Poisson's ratio	Friction angle	Dilation angle
1025	25	0.3	36	7.5

- Boundary conditions



- Meshed model

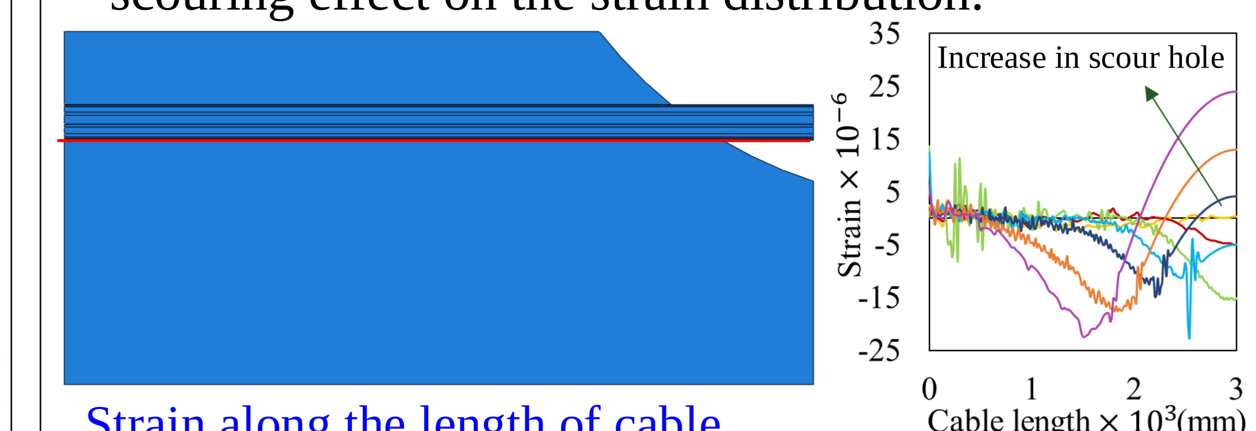


A mesh sensitivity analysis was conducted

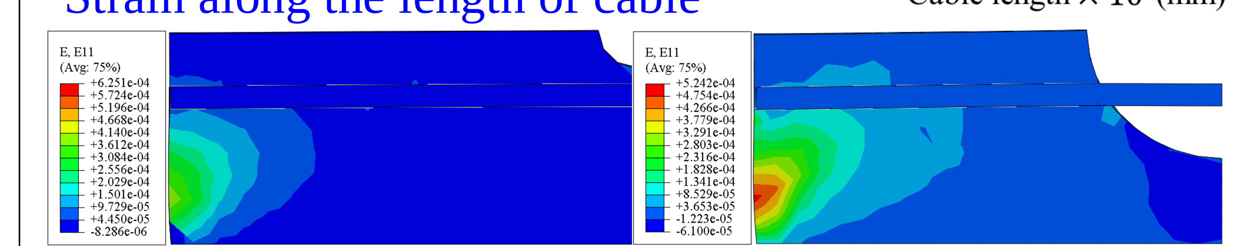
Results

Parametric study

- Six ABAQUS models were considered to study the scouring effect on the strain distribution.



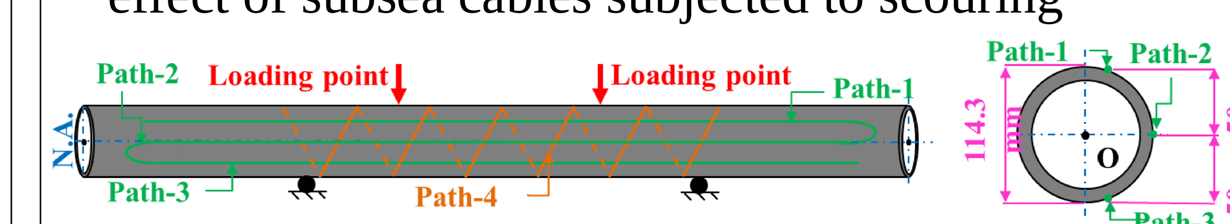
Strain along the length of cable



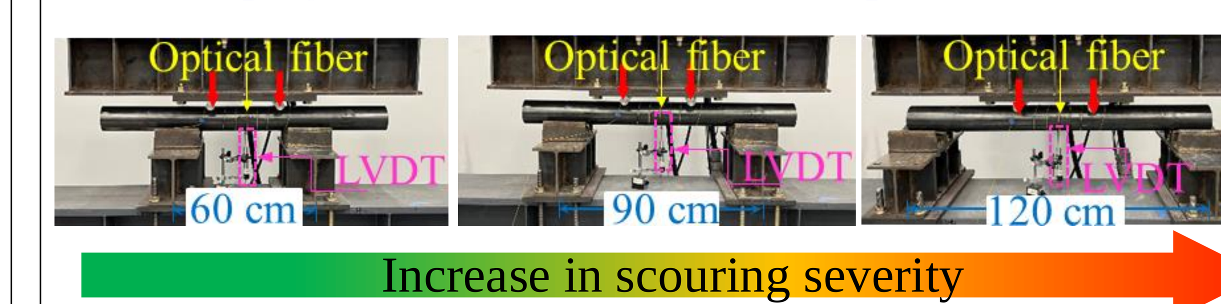
Visualization of strain distribution

Experimental study

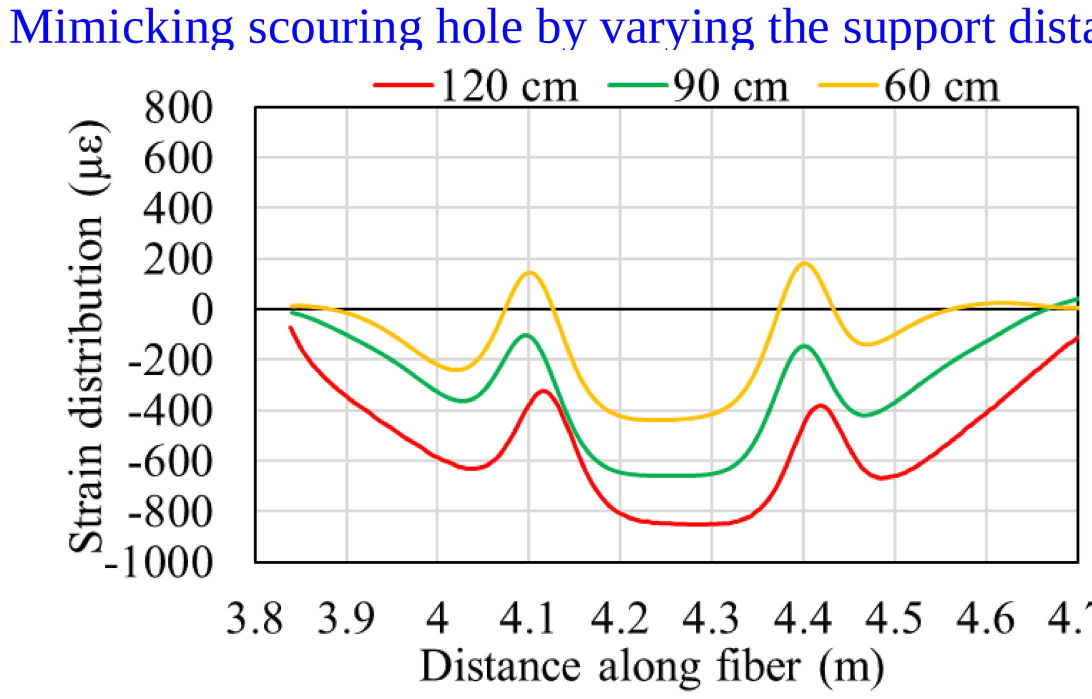
- Four-point bending tests used to mimic the bending effect of subsea cables subjected to scouring



Deployment of distributed fiber optic sensors



Mimicking scouring hole by varying the support distance



Strain distributions measured by DFOS

Conclusions

- ➢ It is feasible to monitor the scouring condition of the foundations and underwater cables of offshore wind turbines using distributed fiber optic sensors.
- ➢ The tensile strain of underwater cables is increased by about 20-30 με due to the scouring effect of underwater cables.
- ➢ The tensile strains along the length the underwater cables increase with the diameter of the scour hole.