Berkeley Center for Smart Infrastructure

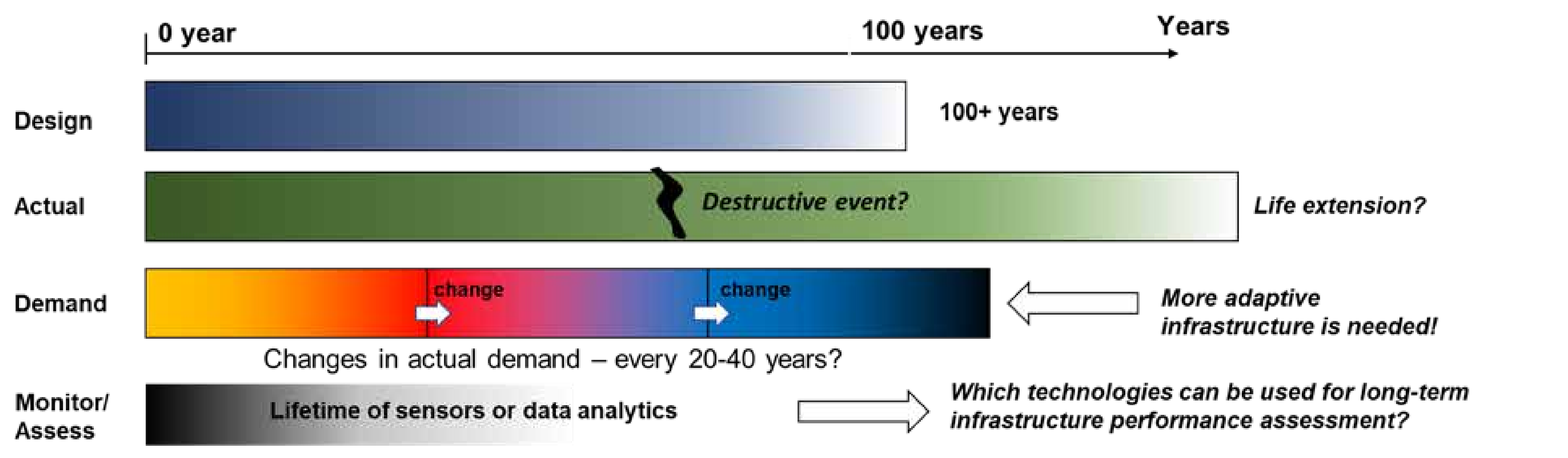
https://smartinfrastructure.berkeley.edu/

The Role of Emerging Technologies in Realizing Smart Infrastructure

Kenichi Soga

Berkeley University of California

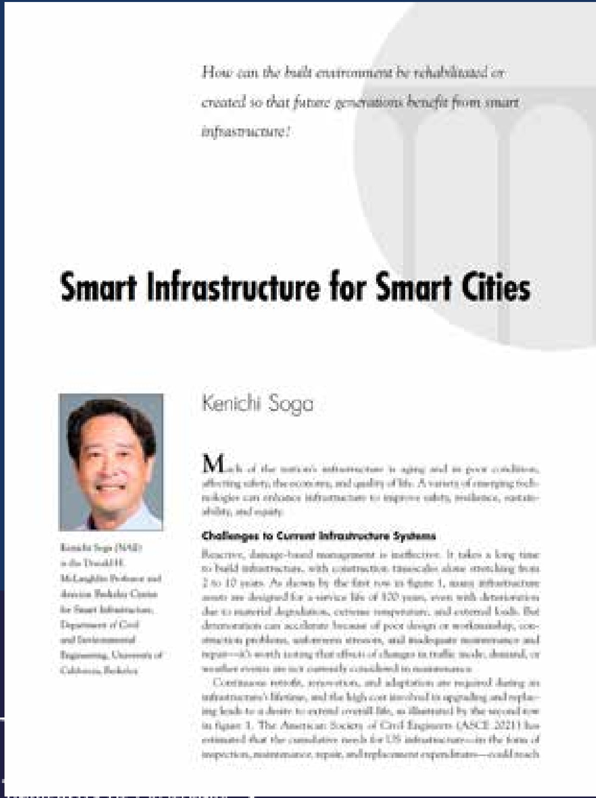
Challenges in Infrastructure – Differences in time scale



No More Aging Infrastructure for Future Generations?

Berkeley
UNIVERSITY OF CALIFORNIA

How can the built environment be rehabilitated or created so that future generations benefit from smart infrastructure?

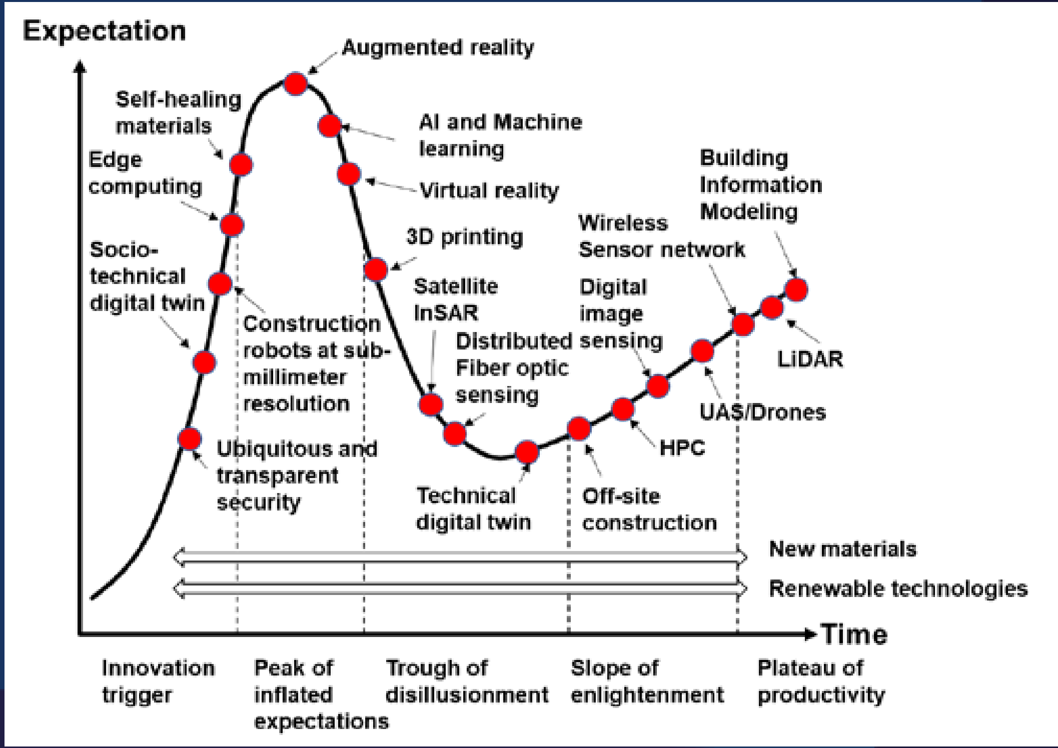


How can the built environment be rehabilitated or created so that future generations benefit from smart infrastructure?

Smart Infrastructure for Smart Cities

Kenichi Soga

Challenges to Current Infrastructure Systems



Soga, K. 2023. "Smart Infrastructure for Smart Cities", Spring issue, Bridge, National Academy of Engineering, pp.22-29

What is the Center for Smart Infrastructure?

Partnership between infrastructure owners, academia, industry, and regulators to address our most pressing challenges such as

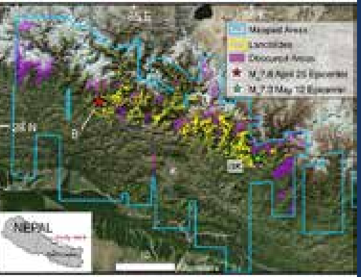
- Aging infrastructure
- Climate change
- Water supply and natural resources
- Emergency and community preparedness

The collaboration will use a holistic approach to develop ***resilient*** systems through

- State of the art lab and field testing equipment
- Smart sensors and robotics
- Big data and machine learning
- Multi-scale computer modeling and simulation

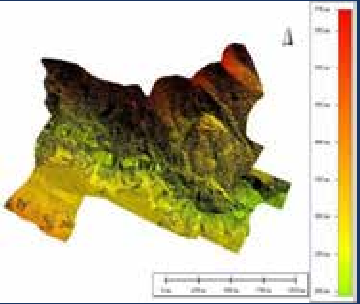
Berkeley
UNIVERSITY OF CALIFORNIA

SATELLITES



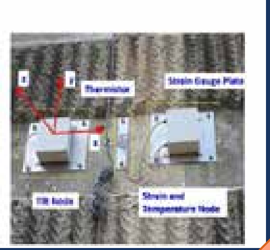
>100 km^2
>0.5 m
days

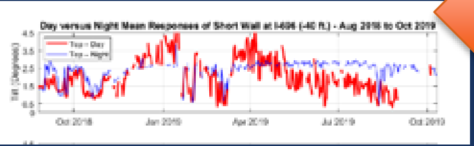
UNMANNED AERIAL VEHICLES

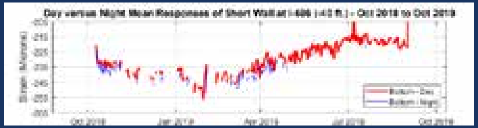


1-100 km^2
>1 cm
hrs

SENSORS/AMI







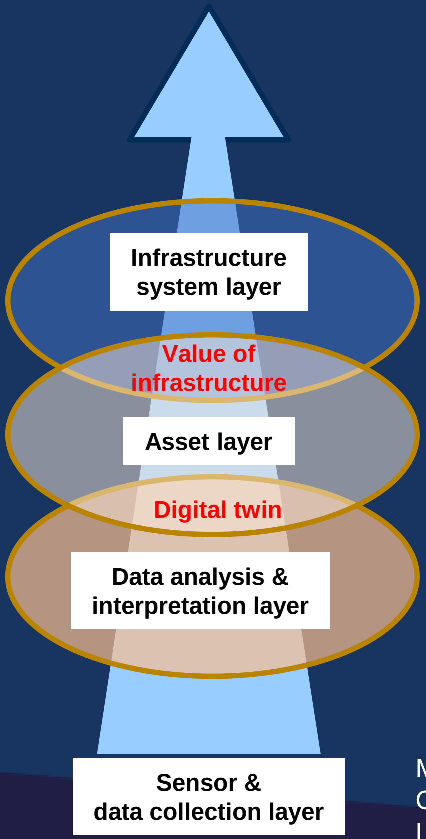
<1 km^2
local
sec

Pipeline network

100k joints, 100k pipes (EBMUD)

1.4 million customers
14 people/pipe segment

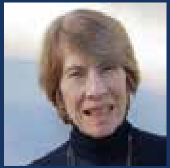
Berkeley
UNIVERSITY OF CALIFORNIA



Service Performance

Multi-scale Simulations and Interpretation

Alison Post
Smart City Technology Lead



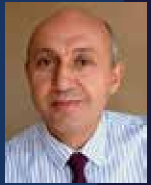
Louise Comfort
Community Resilience & Equity Lead

Matthew DeJong
Simulation Lead
Co-Director

SimCenter NHERI
Center for Computational Modeling and Simulation

Large scale test beds – Field and Lab

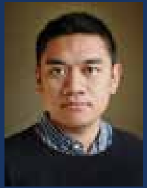
James Wang
Field Testing Lead



Shakhzod Takhirov
CSI Lab lead

Michael Riemer
Geotechnical Sensing Lead

Robert Kayen
Remote Sensing Lead



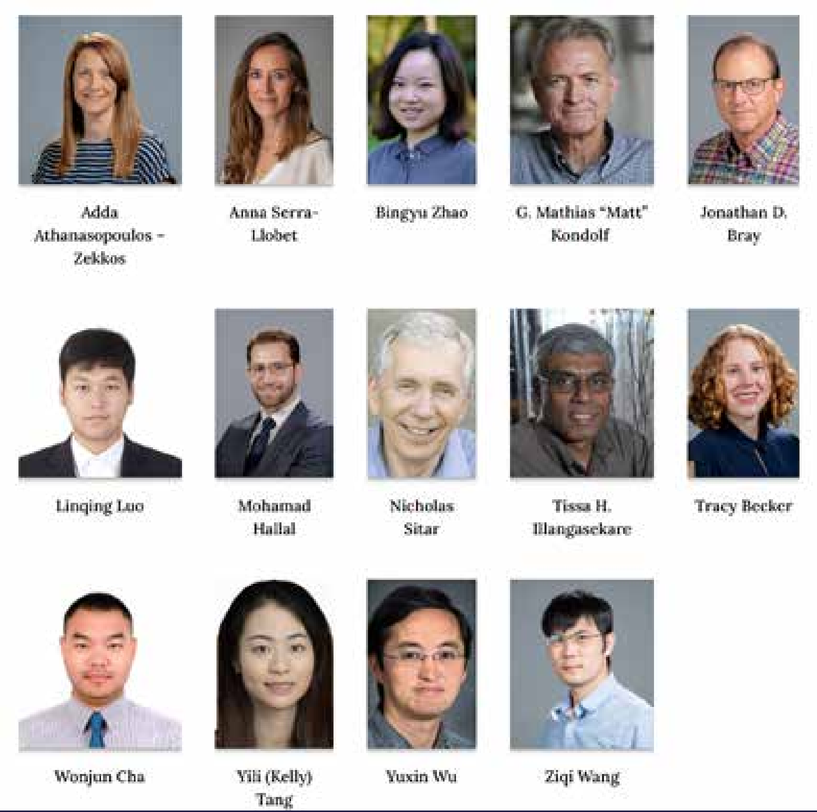
Dayu Apoji
Data Analytics & Machine Learning Lead

Dimitrios Zekkos
Sensor & Robotics Lead
Co-Director

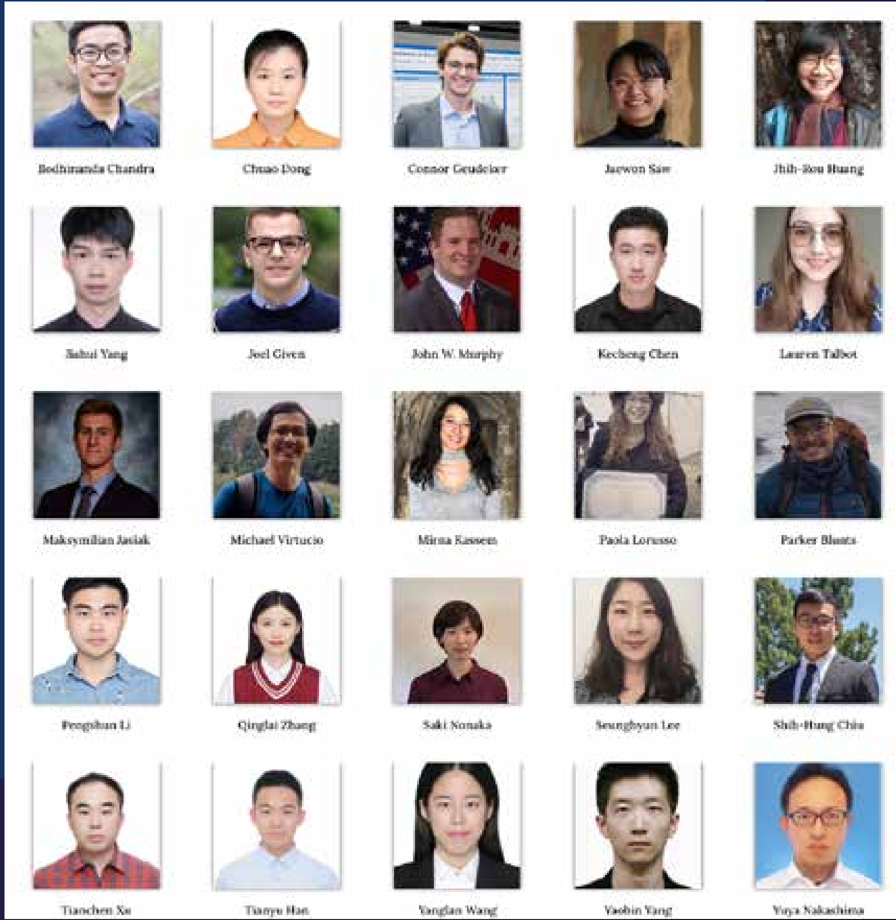
Multi-scale Observations

Asset Performance

Affiliated academics

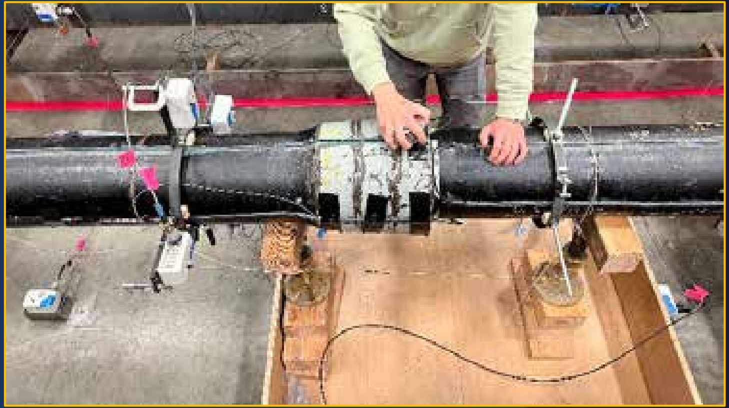


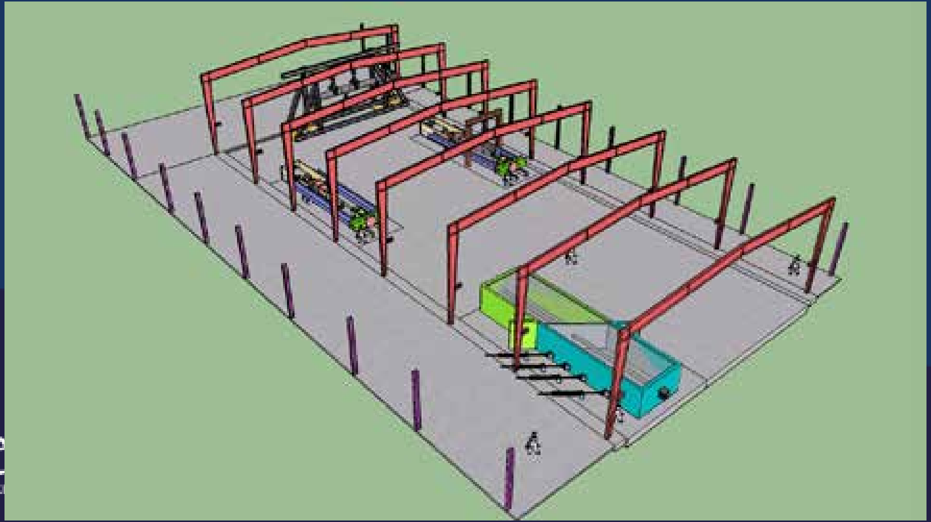
Researchers

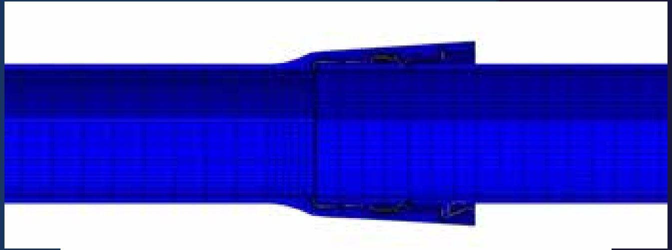


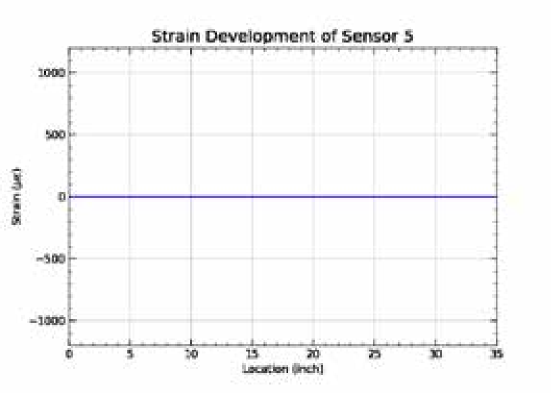
Berkeley
UNIVERSITY OF CALIFORNIA

Pipeline Testing









Be
UNIVERS

8 inch ERDIP

8 inch iPVC

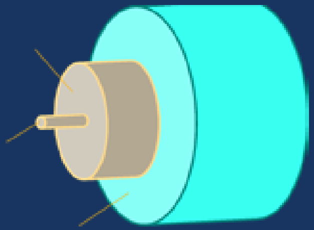
24 inch ERDIP

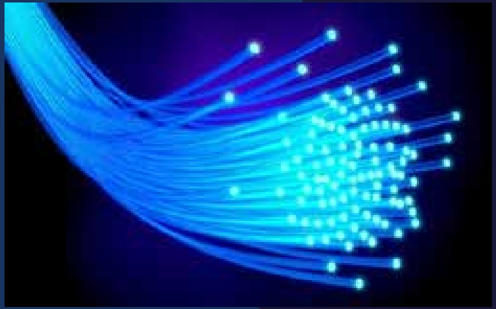
48 inch DIP

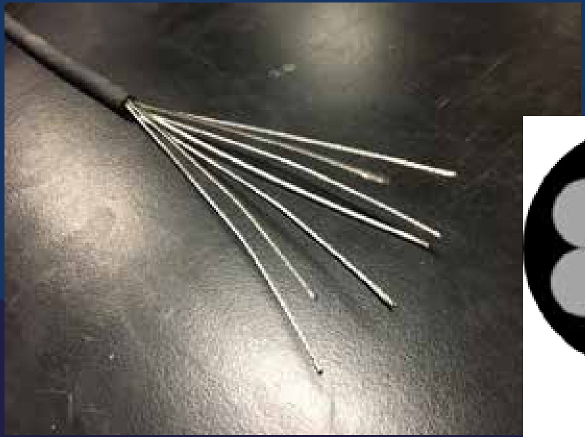
Distributed fiber optic sensing

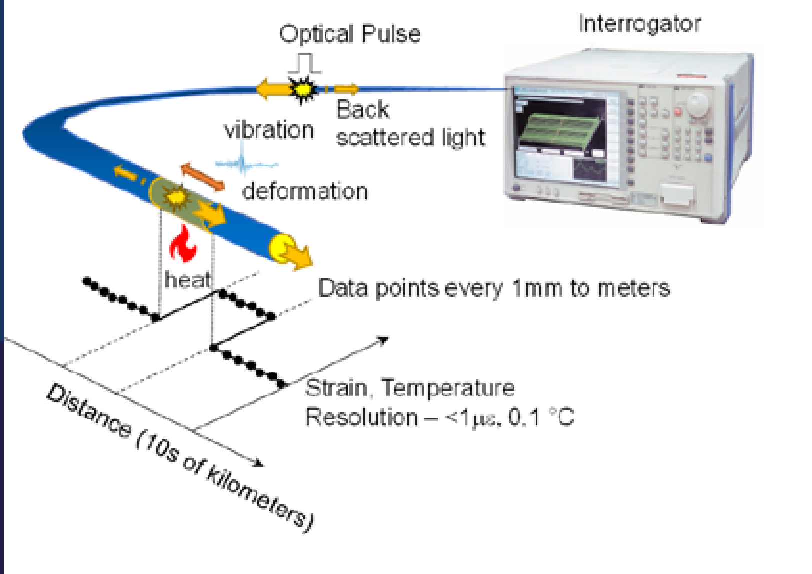
"Continuous Strain/temperature/vibration Profile" along the fibre optic cable

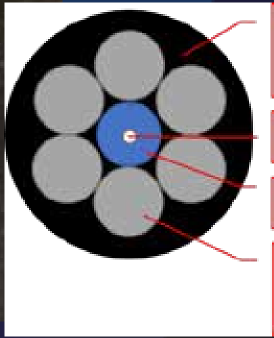
- Distributed Temperature Sensing (DTS)
- Distributed Strain Sensing (DSS)
- Distributed Acoustic/Vibration Sensing (DAS/DVS)

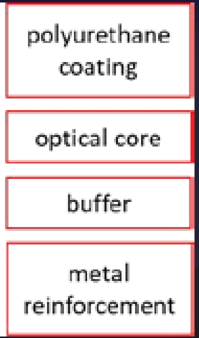




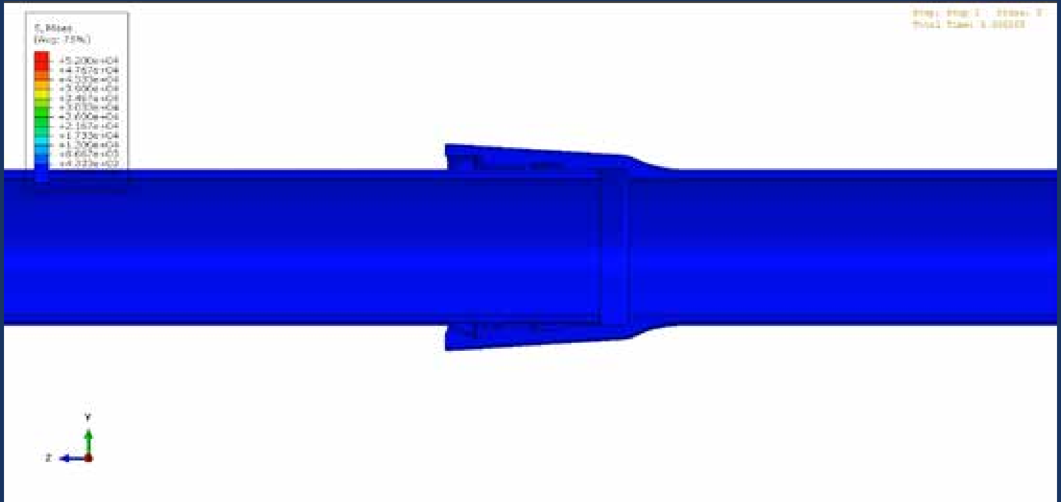


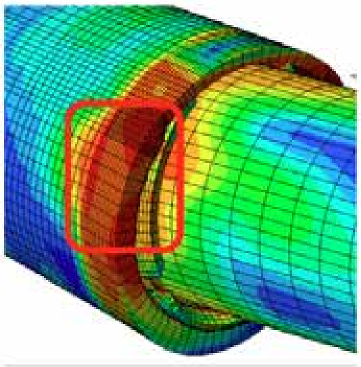




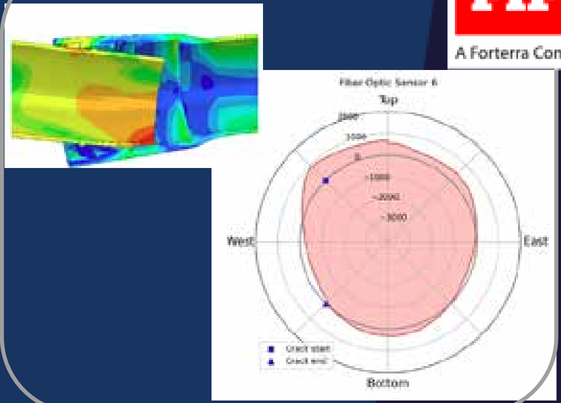


8” DIP Bi-axial Tension Test

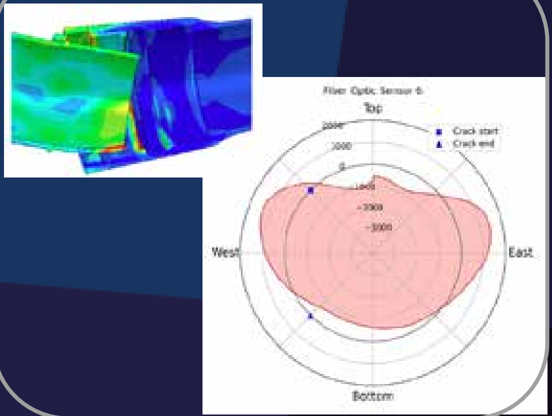




Push Down



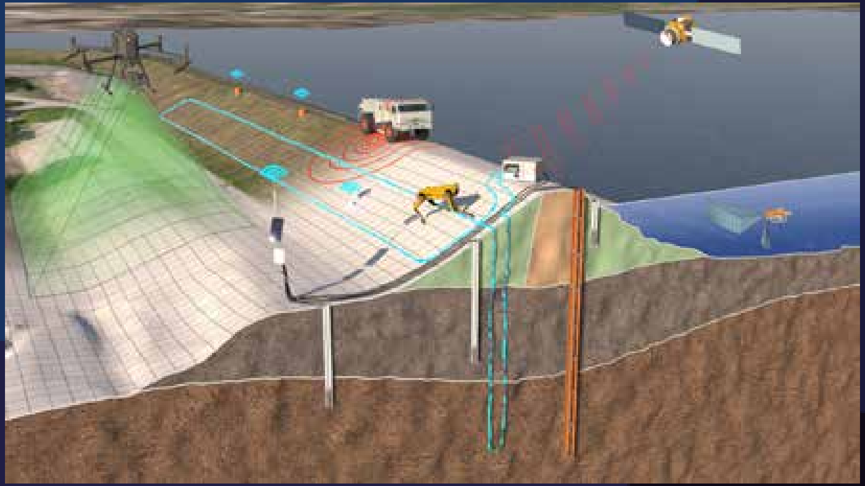
Pull



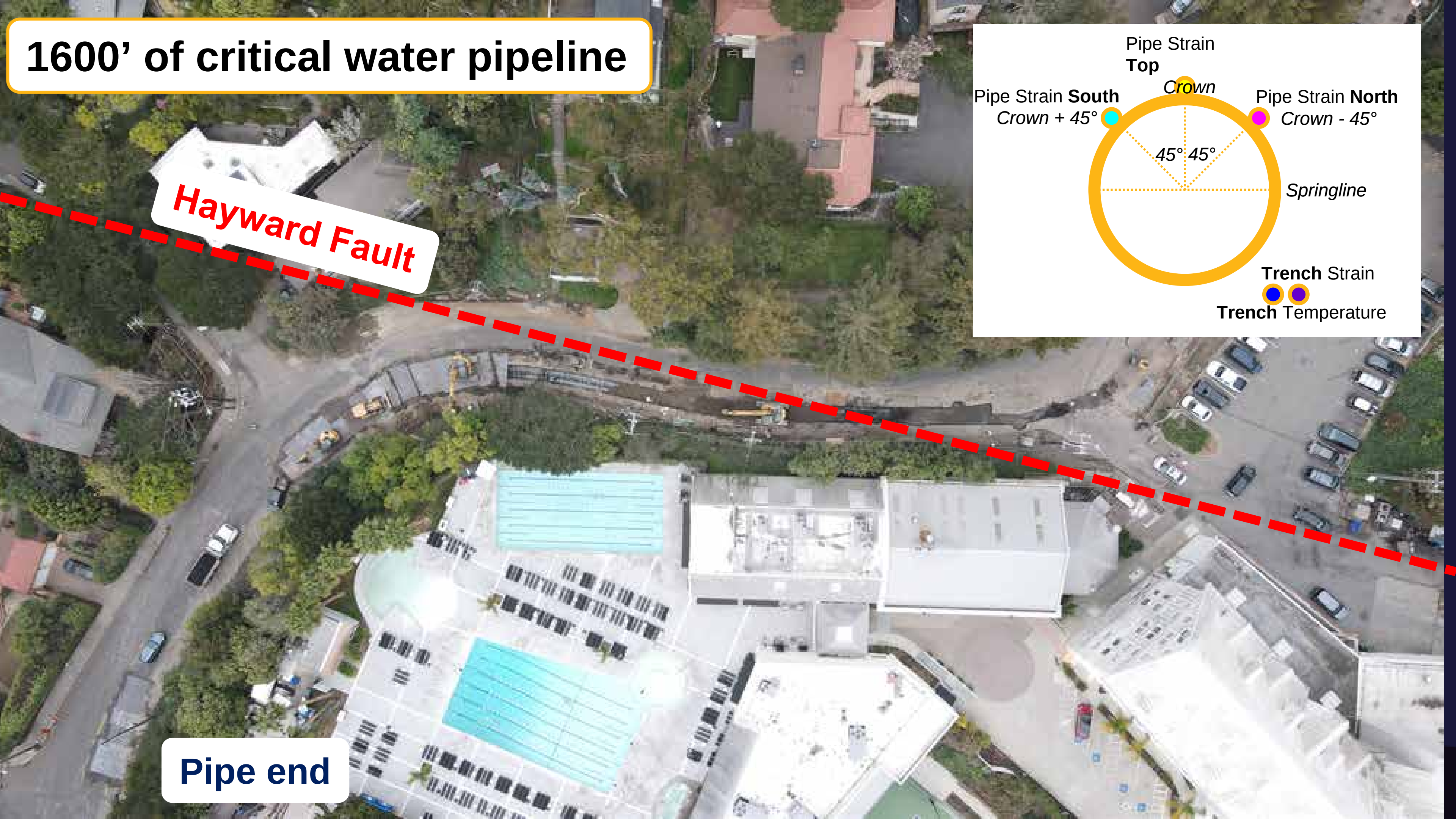
ET-1: Distributed sensors and network
(Satellite, fiber optics, wireless sensor network, etc)
Sensors everywhere with 5G/IoT, creating hyperconnected networks

ET-2: In-field Autonomy
(inspection, construction and maintenance)
Autonomy using drones, humanoids and super large robots.

ET-3: Off-site Autonomy at sub-millimeter resolution
3D printing to self-assembly and operation at sub-millimeter resolution.

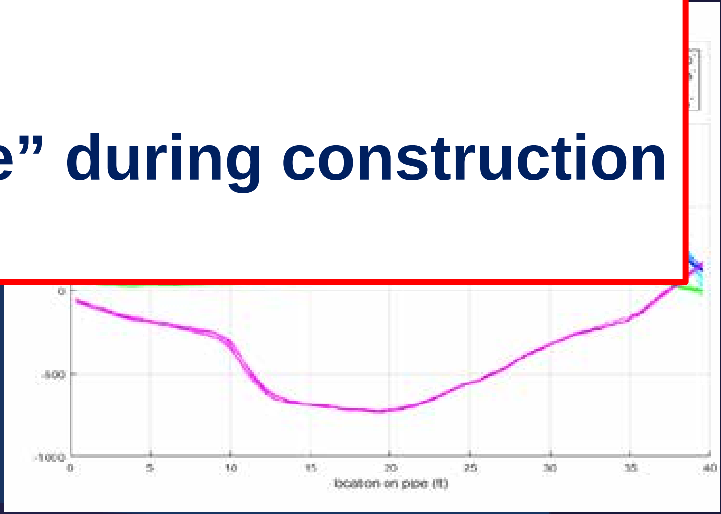


1600’ of critical water pipeline

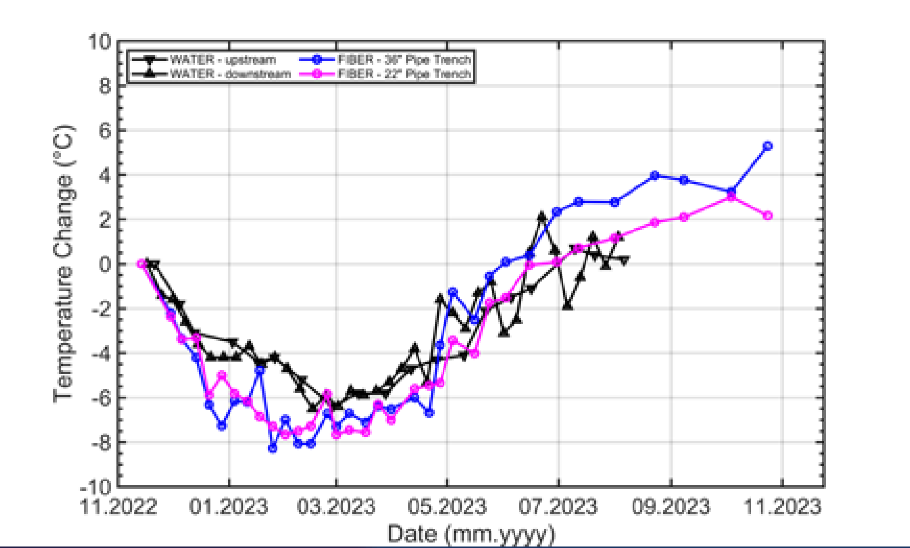


Once we bury a pipeline, we are not going to see it for the next 100 years.

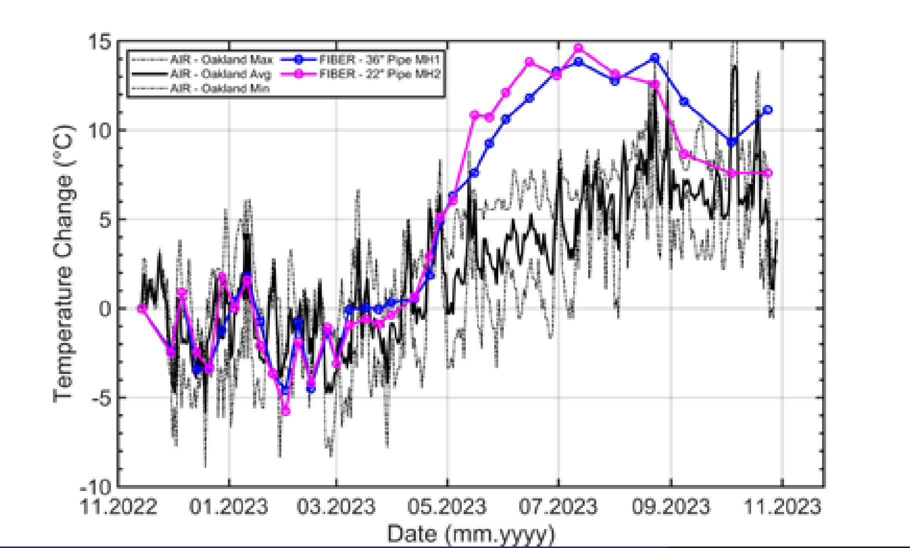
Why not embed “intelligence” during construction for future generations?

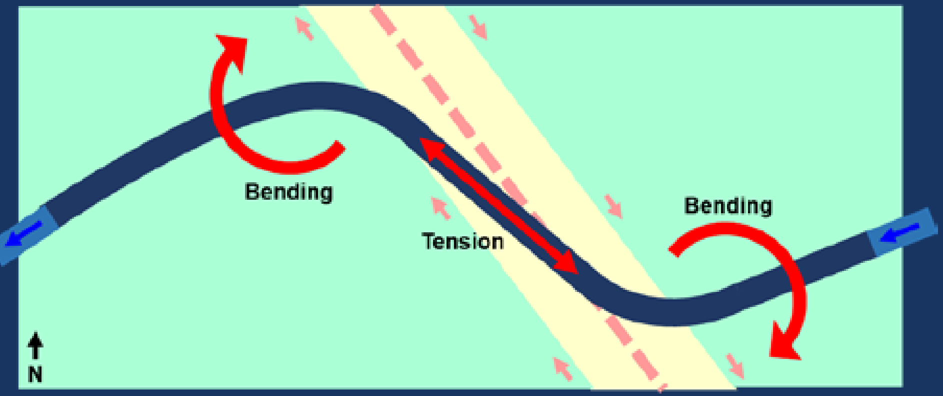


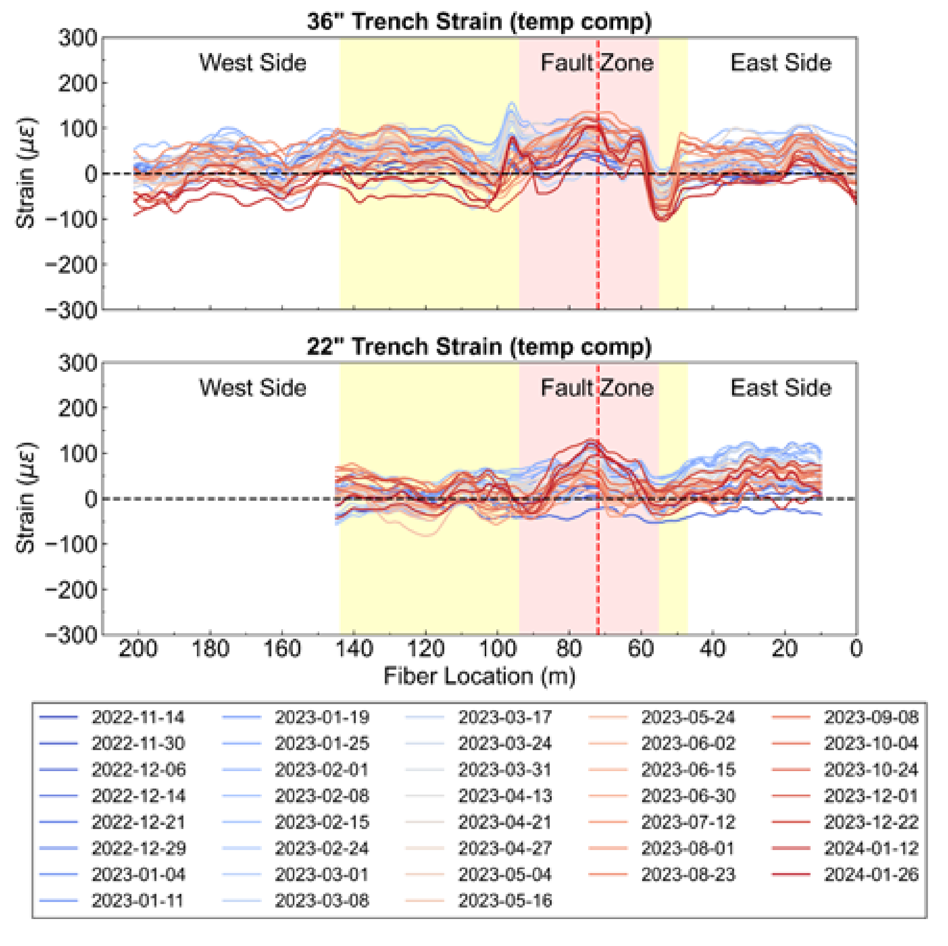
Pipeline Temperature



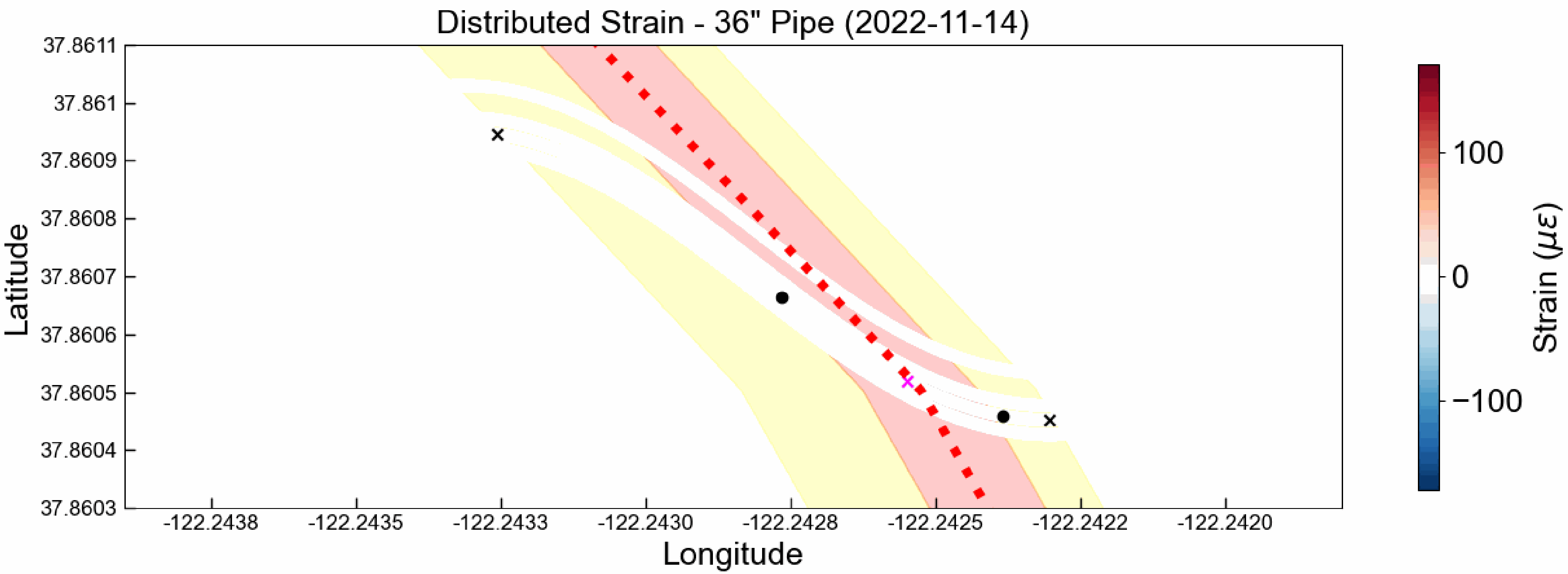
Manhole Temperature







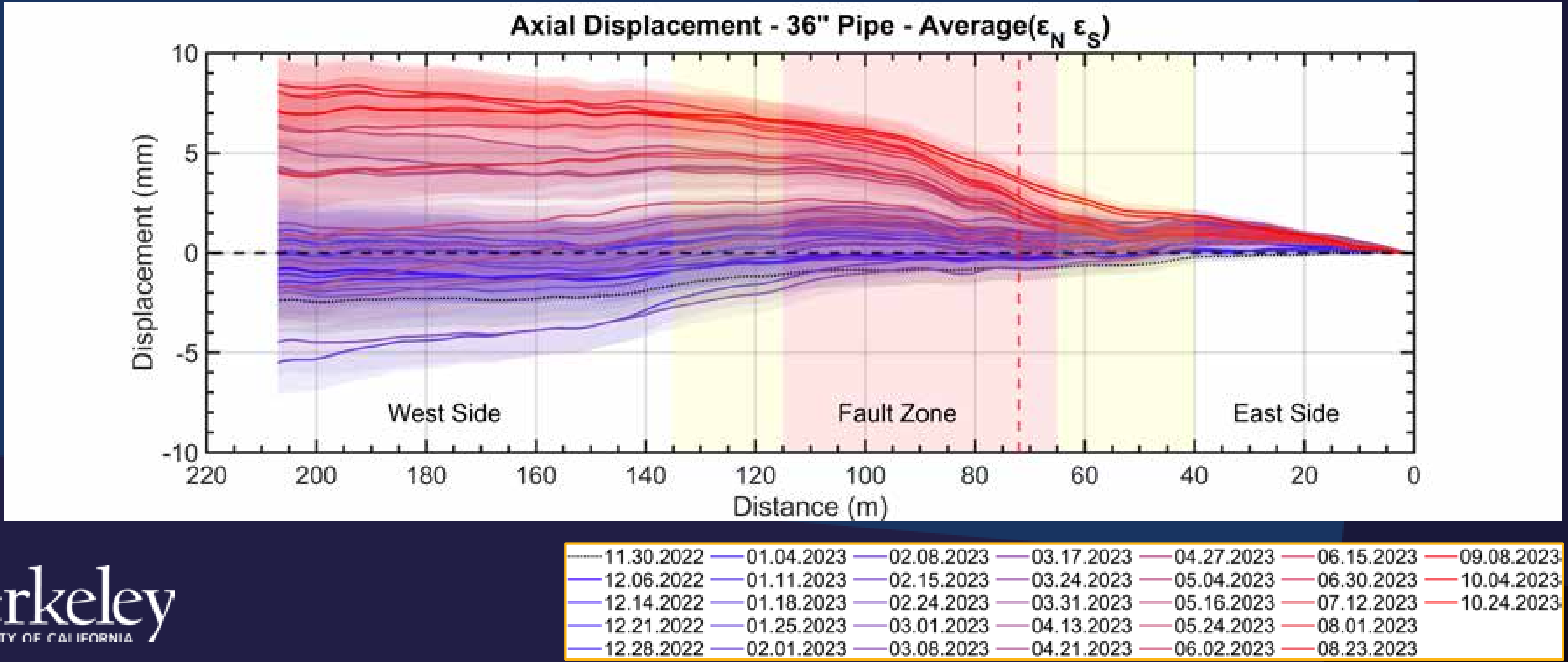
Berkeley
UNIVERSITY OF CALIFORNIA



Berkeley
UNIVERSITY OF CALIFORNIA

Pipeline Deformation (36” Pipe) (East Fixed)

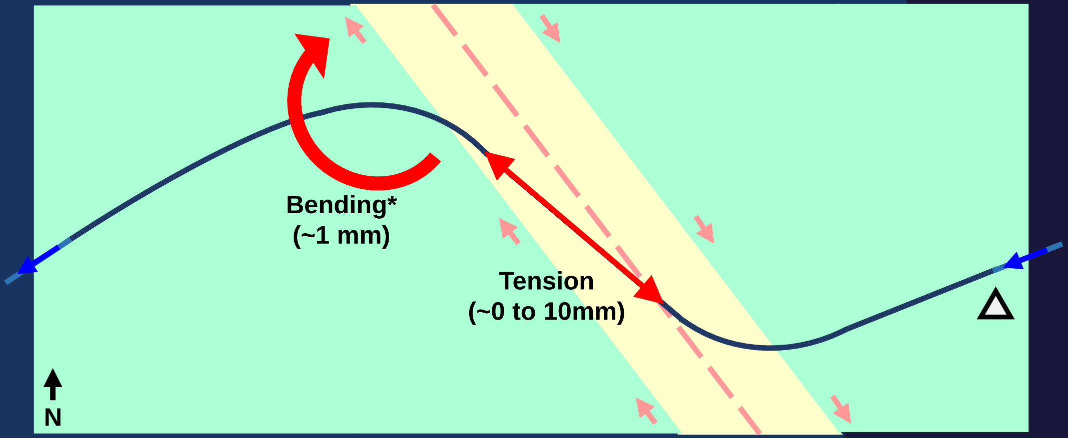
Axial Extension (mm)	Lateral Deflection (mm)
7 - 10	2 - 3

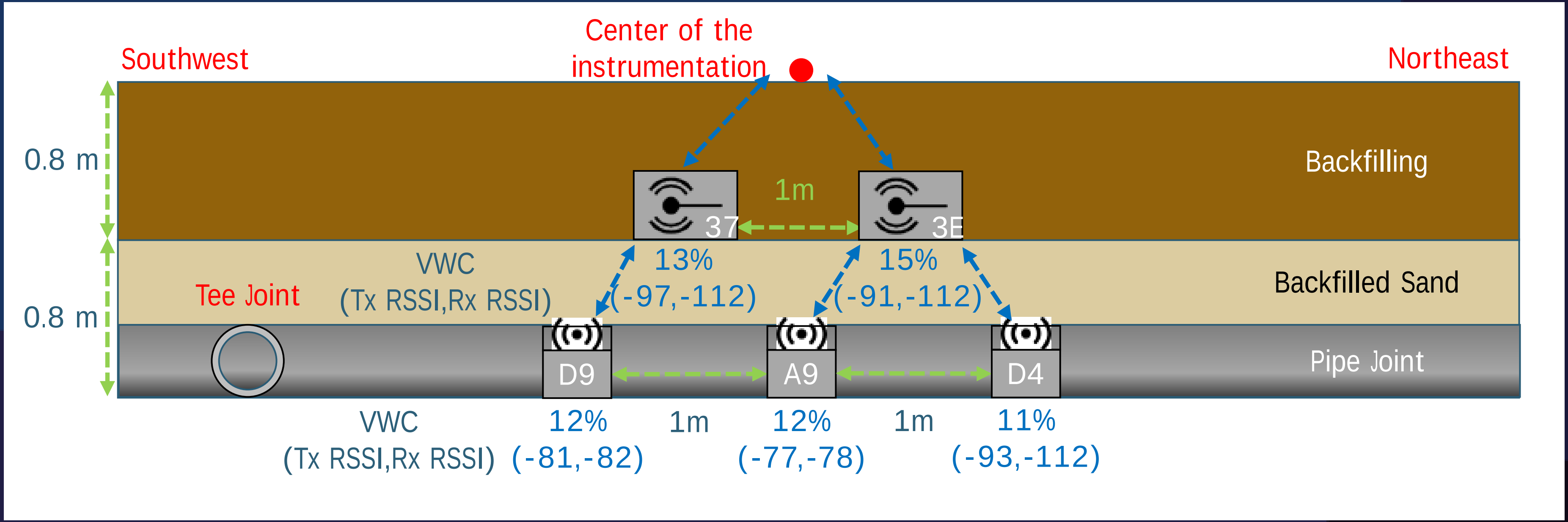


Est. Pipe Deformation - Conclusions

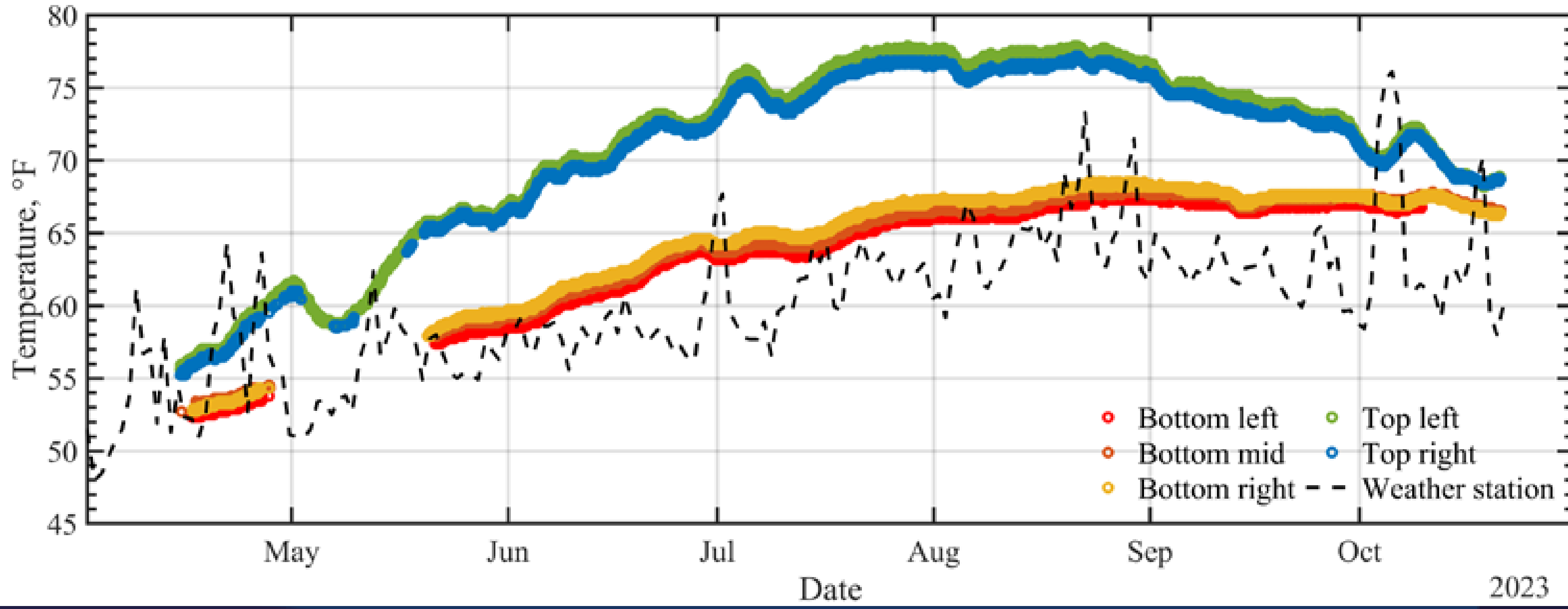
1. Combo deformation mechanism:
   - axial extension (along fault)
   - northward bending (across fault)
   - assuming east end fixed

2. Further monitoring needed to distinguish fault movement-related strain from other factors




Center of the instrumentation
Southwest
Northeast
0.8 m
0.8 m
Backfilling
1m
37
3E
VWC
(Tx RSSI,Rx RSSI)
13%
(-97,-112)
15%
(-91,-112)
Tee Joint
Backfilled Sand
D9
A9
D4
Pipe Joint
VWC
(Tx RSSI,Rx RSSI)
12%
(-81,-82)
1m
12%
(-77,-78)
1m
11%
(-93,-112)

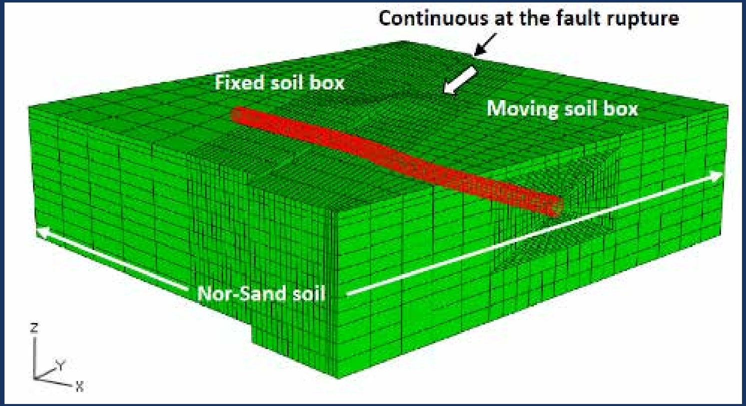
Measurement – Temperature

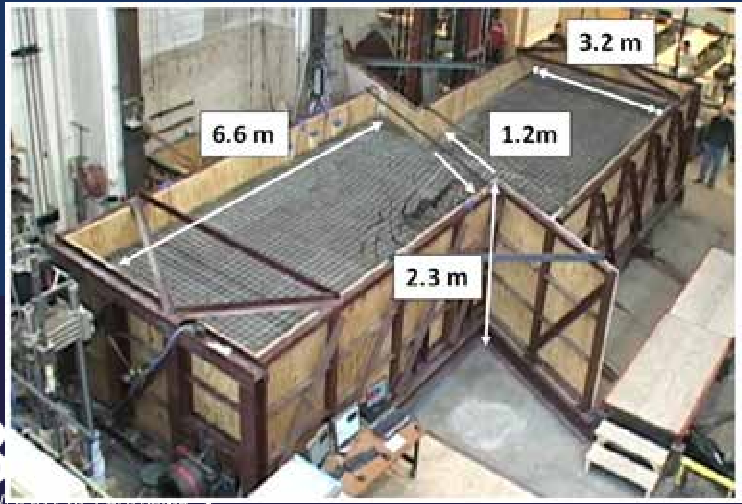


Monitoring of PG&E gas pipeline in Gilroy using distributed fiber optic sensing

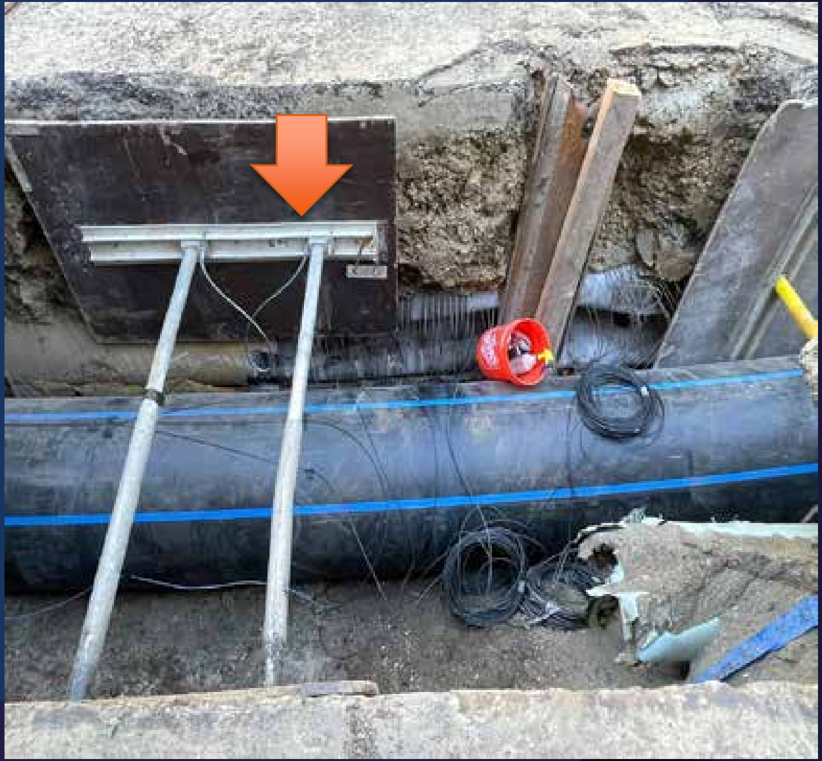
Berkeley
UNIVERSITY OF CALIFORNIA

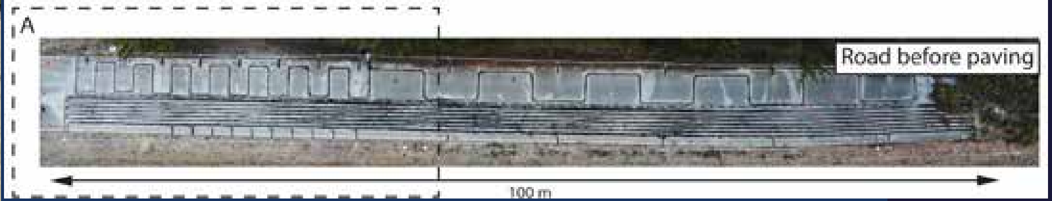
Design…

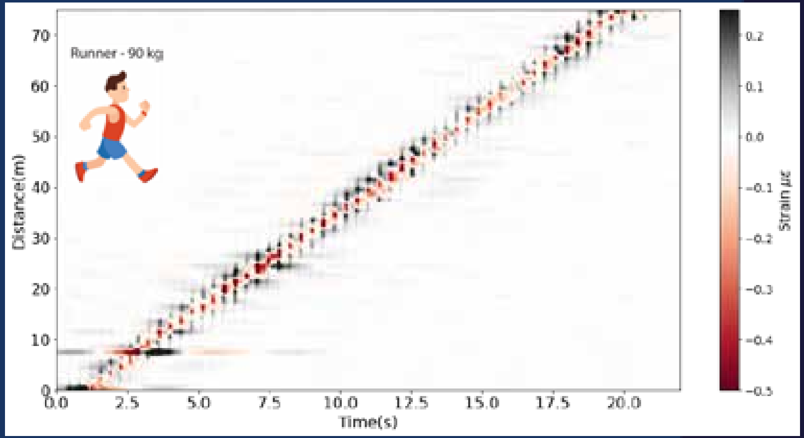


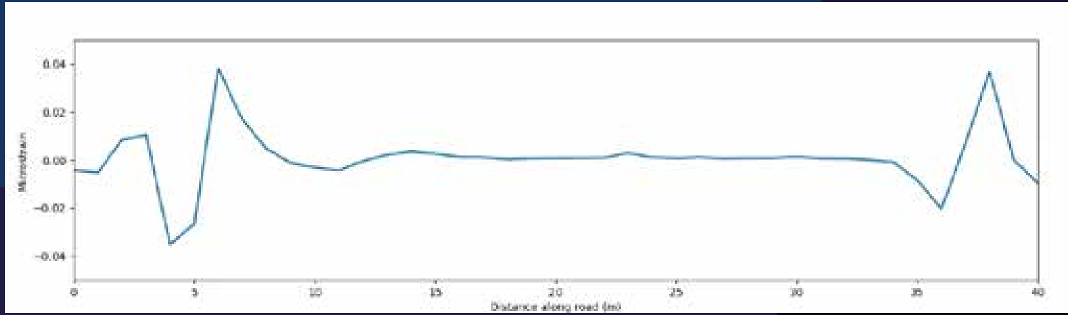


Reality…



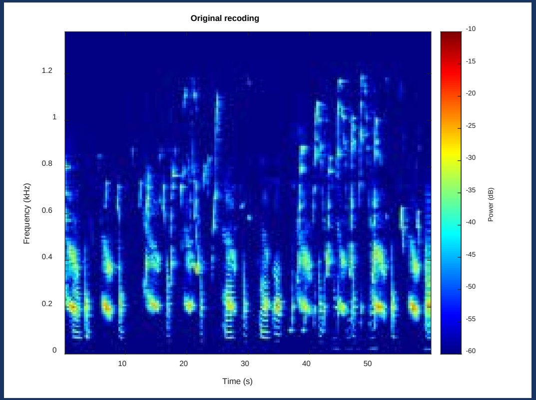


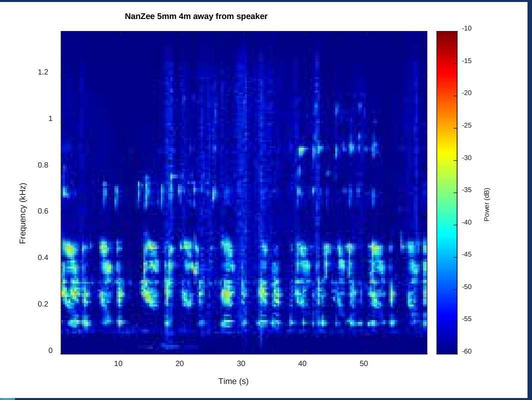


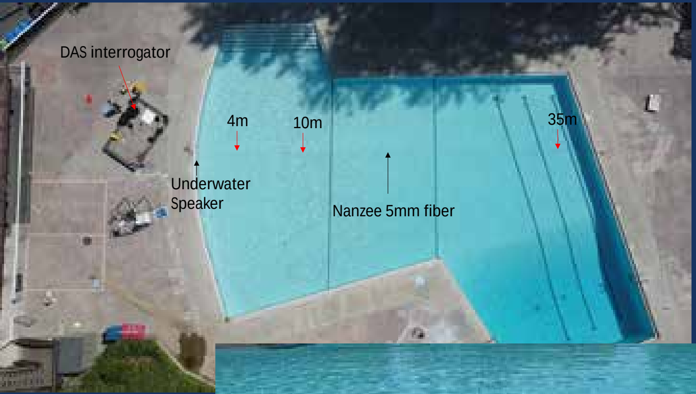


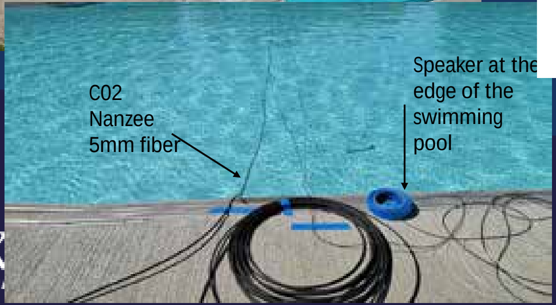
Berkeley
UNIVERSITY OF CALIFORNIA

QA/QC of spatial varying data sets









Robotics and Monitoring Technology

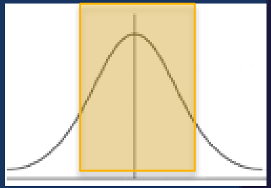
- Smart sensors and robotics
- Unmanned aerial vehicles
- Satellite imagery
- Ground penetrating radar

Berkeley
UNIVERSITY OF CALIFORNIA

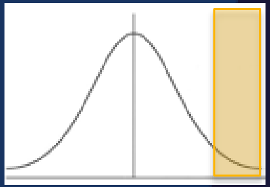
ET-4 Artificial intelligence and machine learning

Data analytics and human interpretation under normal conditions and extreme situations, leading to discovery of new materials and processes.

Value = <u>Data</u> + ML + Computation



Value = <u>Data</u> + ML + Computation
+ (Engineering judgement)



From prediction accuracy to prediction reliability

Berkeley
UNIVERSITY OF CALIFORNIA

ET-5: High performance computing in the cloud

Multi-scale simulations and data interpretation from sub-millimeter scale to tens of kilometer scale using Quantum computing

ET-6: Virtual reality, augmented reality and mixed reality

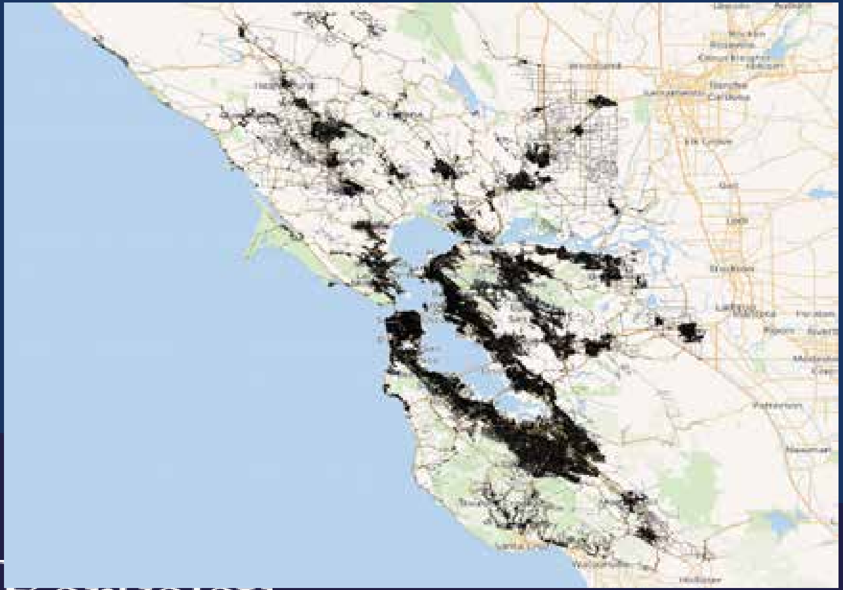
Creating an immersive environment linked to digital twin using wearable technologies for training and operation under normal extreme situations

ET-7: BIM to Socio-technical digital twin

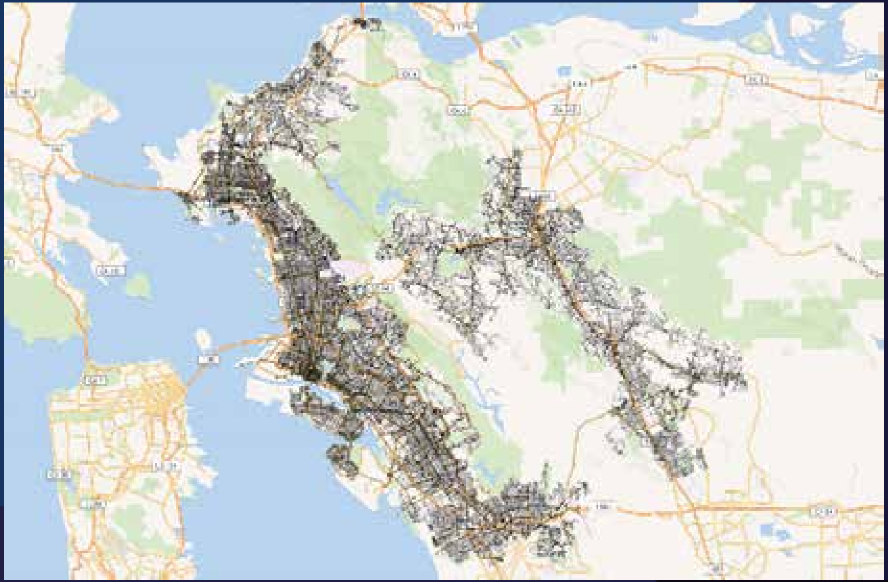
Infrastructure asset tracking to social behavior monitoring and modeling for digital reflection and extended reality

System of Systems

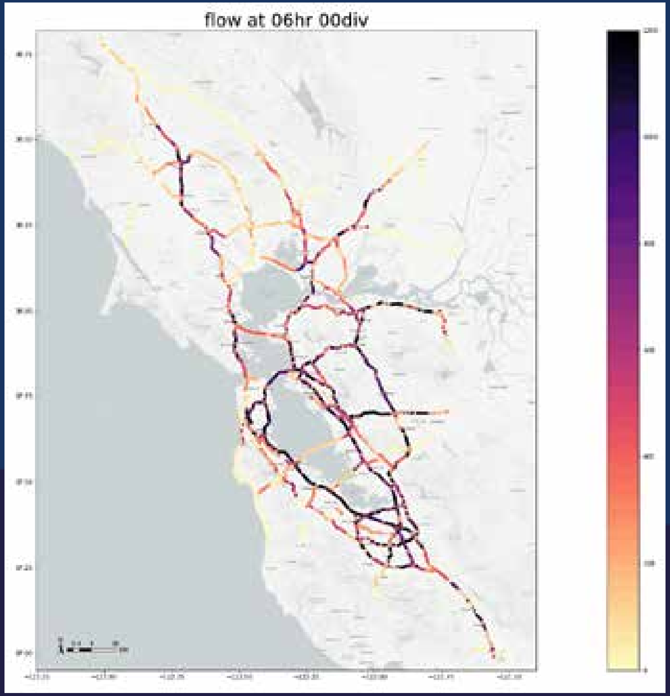
Road Network
250k nodes, 550k edges (OSM)
7 million people
13 people/road segment



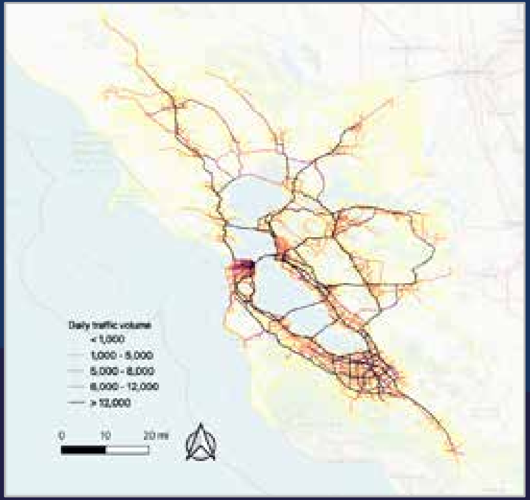
Water Network
100k joints, 100k pipes (EBMUD)
1.4 million customers
14 people/pipe segment



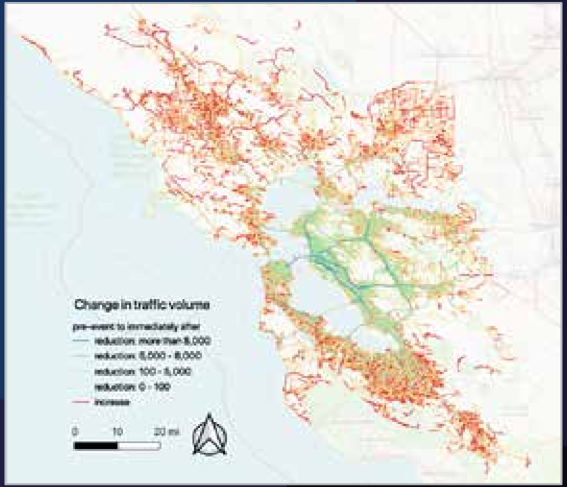
- 9 counties & 7 million people
- Road network: 549,008 links and 224,223 nodes.
- Travel demand: 15 million trips (close to the actual number of daily commute trips).
- Bay Bridge daily traffic: ~260,000



Pre-event traffic volume on Bay Area roads



Change in traffic volume Pre-event to immediately after



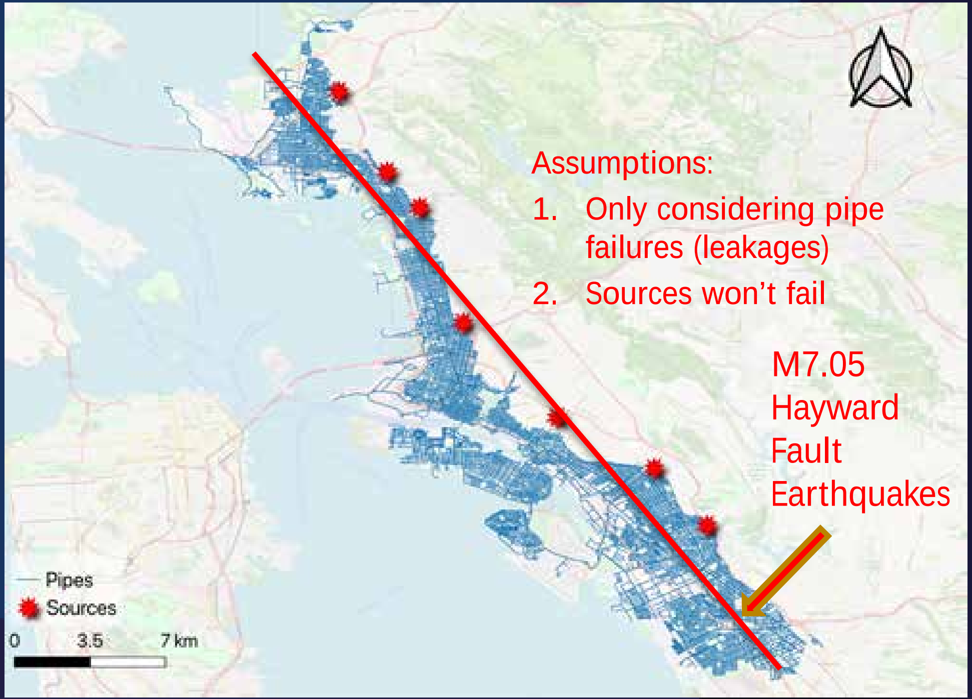
Post-earthquake WDN hydraulics analysis

Number of pipes: 65700

7223217 ft (2201km)

Total demand: 48610 GPM (around 40% of EBMUD demand)

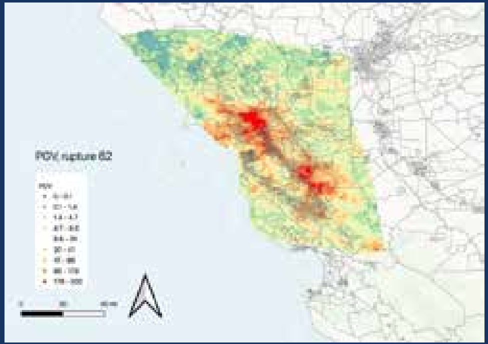
Sources: 7 control stations located at the boundary of the service zone with fixed head 150ft



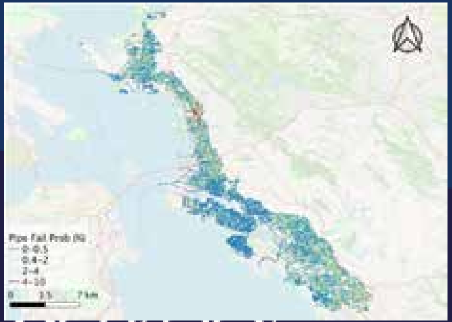
Berkeley
UNIVERSITY OF CALIFORNIA

Water pipeline damage after an earthquake
Hayward Fault Earthquake in the East Bay Area
4,200 miles of pipeline

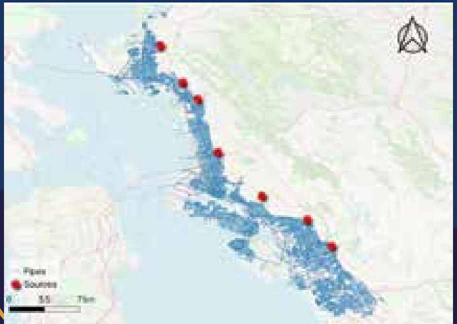
Step 1. EQ scenario + Site characterization



Step 2. Pipe damage



Step 3. Water network



Red tagged building

Traffic disruption

Interdependency

Average water shortage

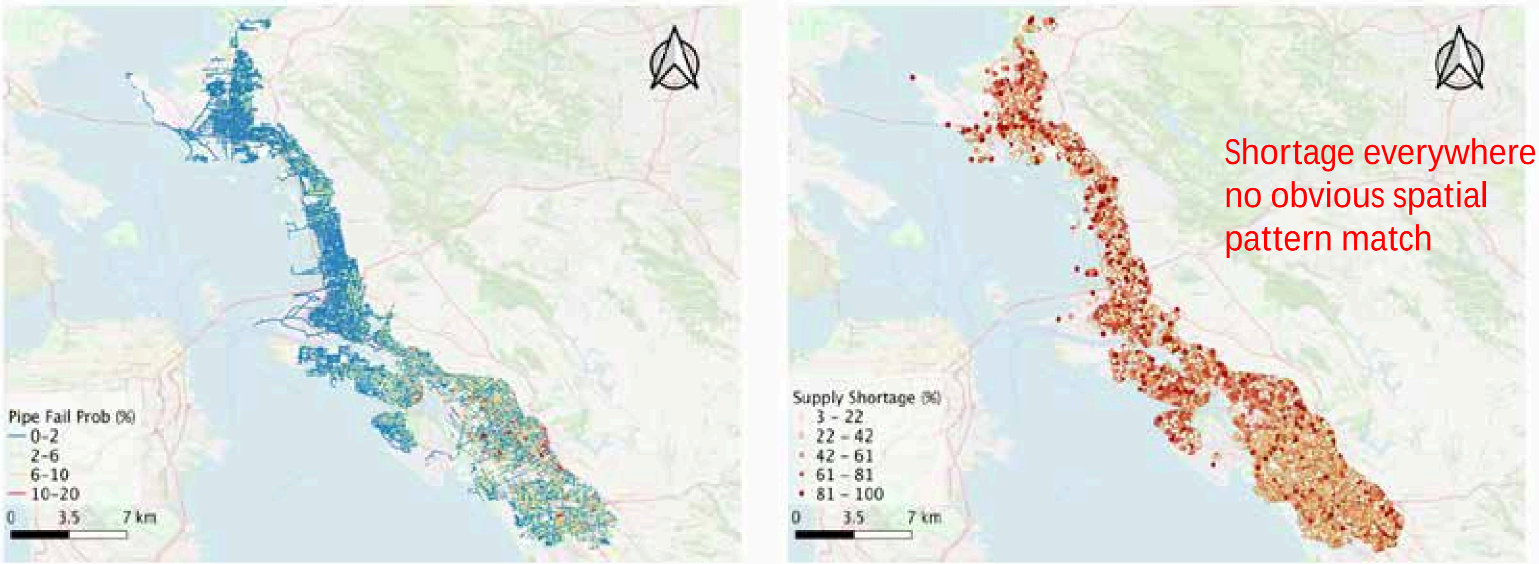
Standard deviation

Recovery, repair (values etc)

Simulation results

$$S_{tot} = \frac{(demand_{tot} - supply_{tot})}{demand_{tot}} * 100$$

Water Shortage (%)

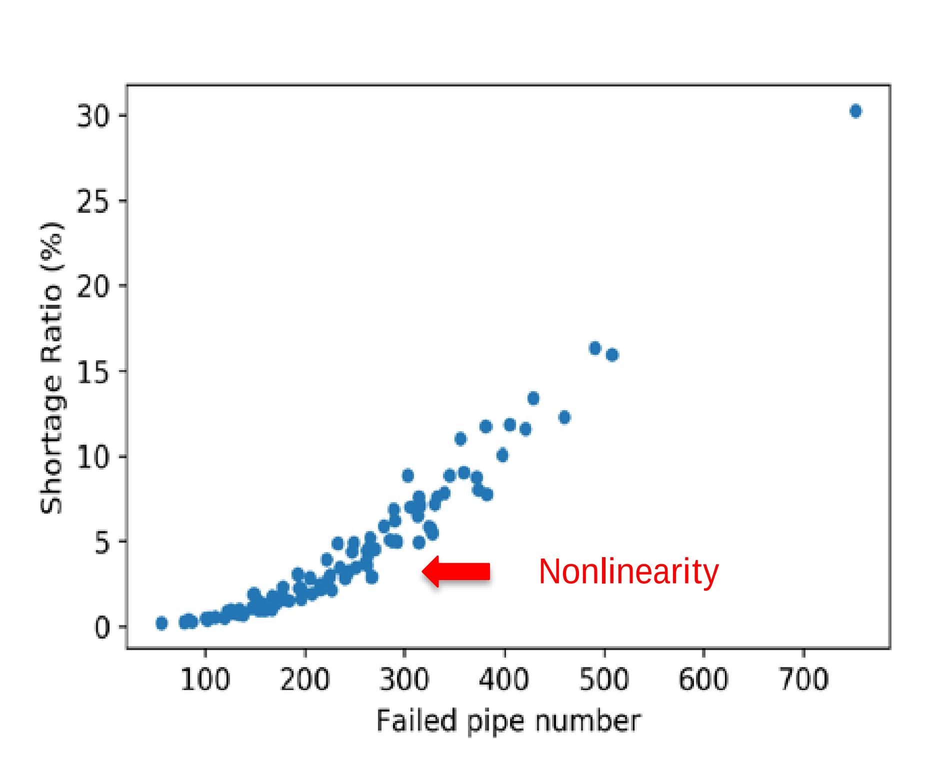


(a) Pipe fail probability (b) Demand Shortage

Large damage case: mean PGV value 16.87 cm/s and averaged simulated pipe break number 752

Berkeley
UNIVERSITY OF CALIFORNIA

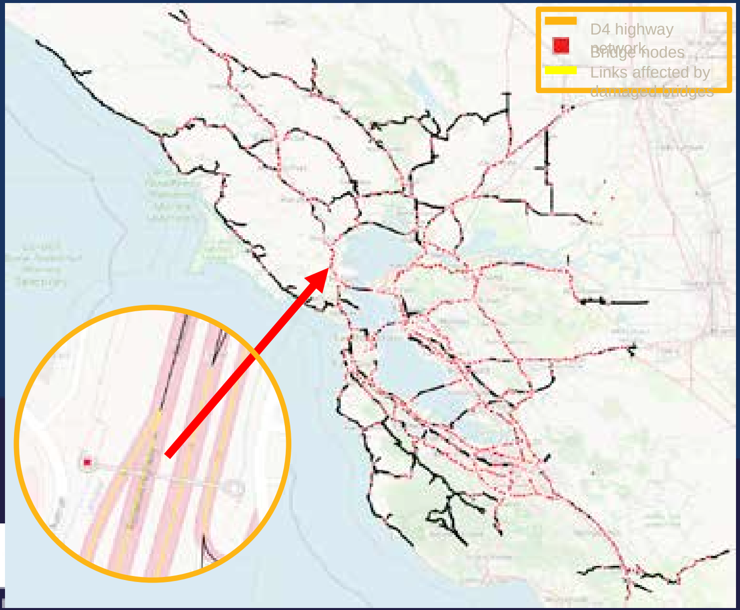
- Even under the same fault rupture event, the variance of earthquake impacts on a WDN is high (1-30 % water loss; 5-70% users impacted)
- The variance is due to the uncertainty of earthquake epicenter locations
- The relationship between number of damaged pipes and water loss is nonlinear. The rate of damage increase as number of failed pipes increase



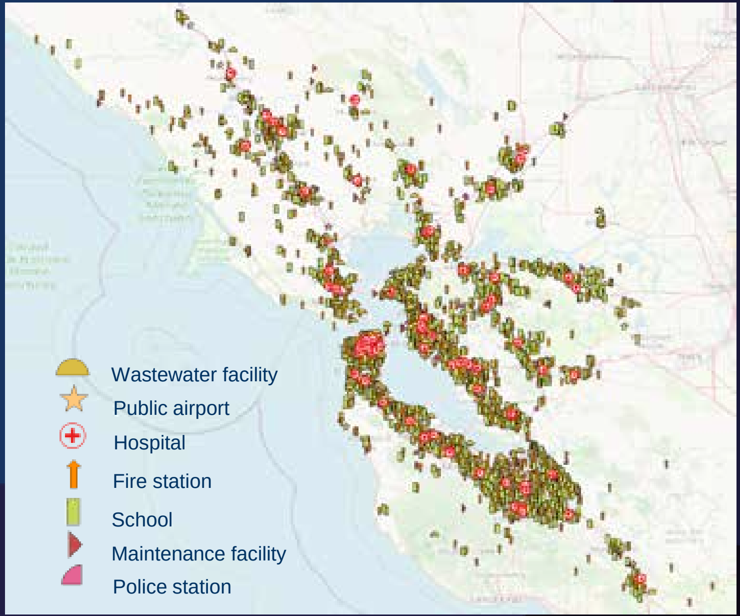
Berkeley
UNIVERSITY OF CALIFORNIA

"Important bridges" provide immediate access to emergency facilities after an earthquake.
"Recovery bridges" serve as vital links for rebuilding damaged areas shortly after earthquakes and should be available for public use a few days after a seismic event.

Caltrans Bridges



Critical facilities



Bridge Fragility X Transportation Access Fragility

Access to and out of critical facilities in the first 72 hours

Communities

On-Off ramps

Links to critical facilities

Berkeley
UNIVERSITY OF CALIFORNIA

ET-8 Edge computing

Local decision making rather than centralized decision making

ET-9 Ubiquitous and transparent security

Automating trust by block chain, digital ethics and service integration

ET10: New materials

Zero or negative carbon, self-healing, sensing and adaptive

ET11: Renewable technologies

Energy generation and storages from micro-scale to mega-scale

Berkeley
UNIVERSITY OF CALIFORNIA

Future Research Opportunities

- Dam Research
    - Dam and spillway performance
    - Post-earthquake dam inspection criteria
- Large transmission line monitoring
- Landslide modeling and impact on critical infrastructure
- Wildfire modeling to inform vegetation management and improve response efforts
- Climate and water supply modeling
- Watershed modeling to improve runoff estimates
- Advanced metering infrastructure

Berkeley
UNIVERSITY OF CALIFORNIA

Creating a Pipeline for the Future Workforce

High school students worked six week on four interdisciplinary projects discovering new technologies for use at the Center for Smart Infrastructure.

Projects involved coding, data management, writing, filming and editing, and research.

Berkeley
UNIVERSITY OF CALIFORNIA

CE 170A

Infrastructure Sensing and Modeling

- 3D modeling (point clouds from lidar and structure-from-motion),
- Remote Sensing (Satellite and optical and radar),
- Geophysics (seismic-wave analyses),
- Sensor systems (fiber optics, wireless sensor network, MEMS, conventional)
- Structural health monitoring and analysis
- Infrastructure network analysis (graph theory, GIS, simulations)
- Entrepreneurship in infrastructure and smart cities industry

Berkeley
UNIVERSITY OF CALIFORNIA

CE 112 - EBMUD Sponsored Class

Water and Wastewater Operations and Design

- Water Supply and Natural Resources
- Water and Wastewater Systems Design and Operations
- Infrastructure Maintenance, Renewal, and Replacement
- Sustainability and Resilience
- Emergency/Community

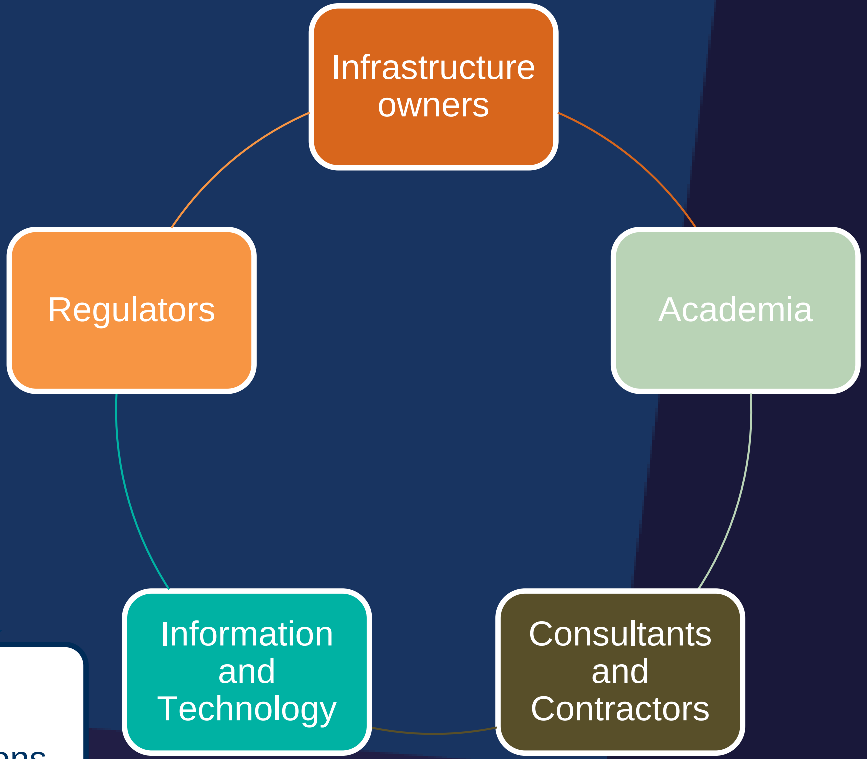
The Solution: Infrastructure Innovation Ecosystem

Finding Innovations

Yielding results

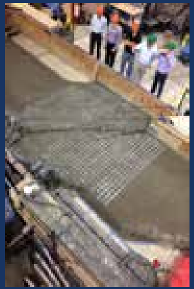
Market Creation
- Smart Infrastructure Market
- Community-based Resilience Market
- Financial investment

Savings for infrastructure owners
Increased reliability and safety
Proactive actions rather than reactive actions
Affordable energy, water, etc.



Berkeley
UNIVERSITY OF CALIFORNIA

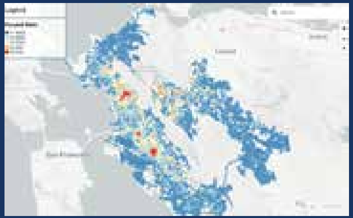
Center for Smart Infrastructure



Infrastructure
- Large scale testing facility
- Smart construction and maintenance

Monitoring and robotics technologies (UAV, fiber optics, GPR)

Resilient infrastructure network
- Aging physical infrastructure
- Energy management



Big Data and AI
Cyber threats

Sustainability
- Supply and natural resources
- Sea level rise, watershed
- Smart roads

Community Resilience
- Engagement & Public trust
- Interdependent infrastructure
- Risk of cascading failures
- Resiliency planning and design

Sponsored Undergraduate Course
- Technology and Engineering
- Innovation
- Community
- Skill training
- DICE

Berkeley
UNIVERSITY OF CALIFORNIA

Thank you

soga@berkeley.edu

Berkeley
UNIVERSITY OF CALIFORNIA