GPU-Accelerated AI Applications for Smart Civil Infrastructure

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Bentley® Advancing Infrastructure

Infrastructure Industry Going Digital

Planning → **Design** → **Construction** → **Operations**

Digital Context

Huadong Engineering Corporation Limited, PowerChina
Application of BIM Strategy for Shenzhen Qianhai Municipal Infrastructure
Shenzhen City, Guangdong, China

Pennsylvania State University,
Department of Architectural Engineering
Virtual Penn State Campus 1 University Park, Pennsylvania, United States

Digital Context

ARC Advisory Group

2017 Industry Reports

www.arcweb.com

Engineering Design Tools for Plant, Infrastructure, and Building Modeling 2017

- #2 (Overall)
- #1 in Electric T&D and Communication Systems
- #1 in Water and Wastewater Distribution

GIS 2017

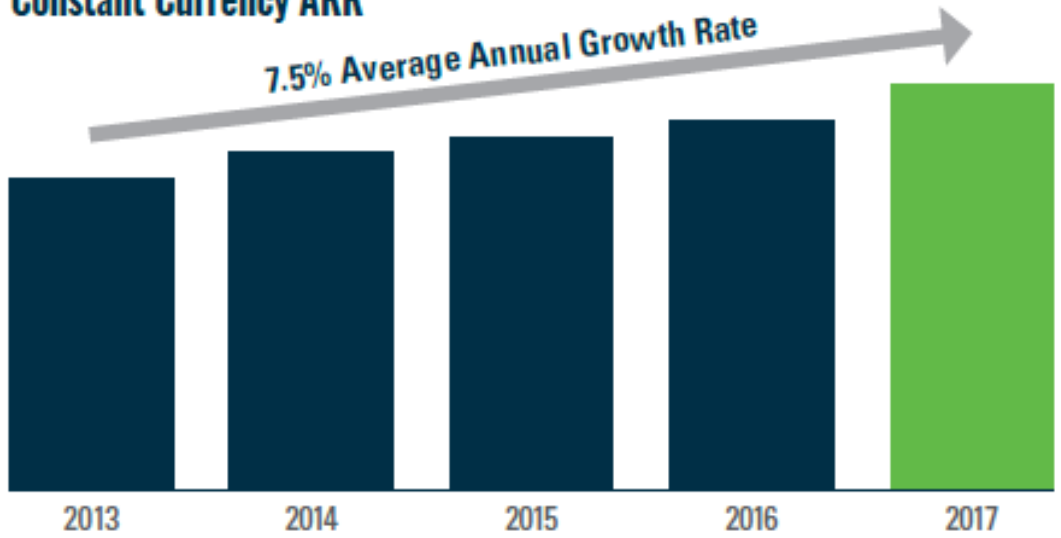
- #2 (Overall)

Sanborn Map Company, Inc.
Sanborn3D HD Maps for Autonomous Driving: Santa Clara
Santa Clara County, California, United States

Asset Reliability Software and Services 2017

- #1 (Overall) #1 ranking – new achievement in 2017
- #1 Electric Power T&D
- #1 in Oil & Gas
- #1 in Pharmaceutical & Biotech
- #1 in Transportation
- #1 in Water & Waste Water

Constant Currency ARR

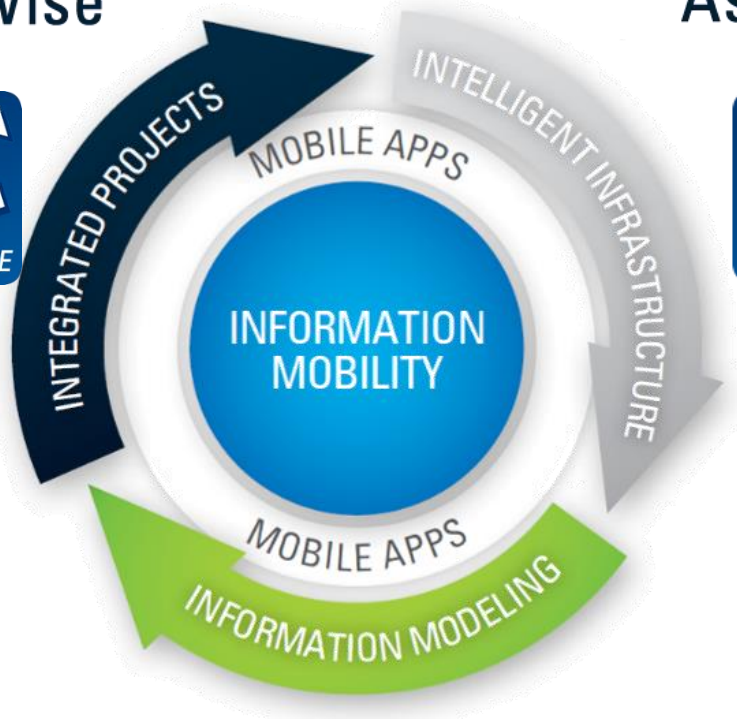


Bentley Software Platform Technology

ProjectWise

AssetWise

Project management

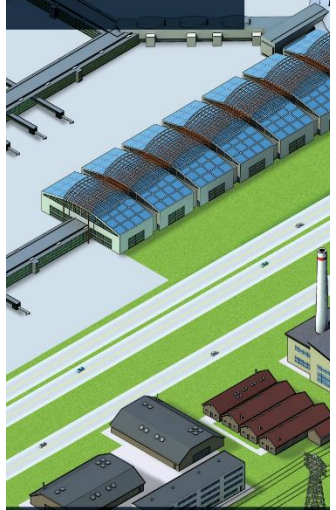


Asset management

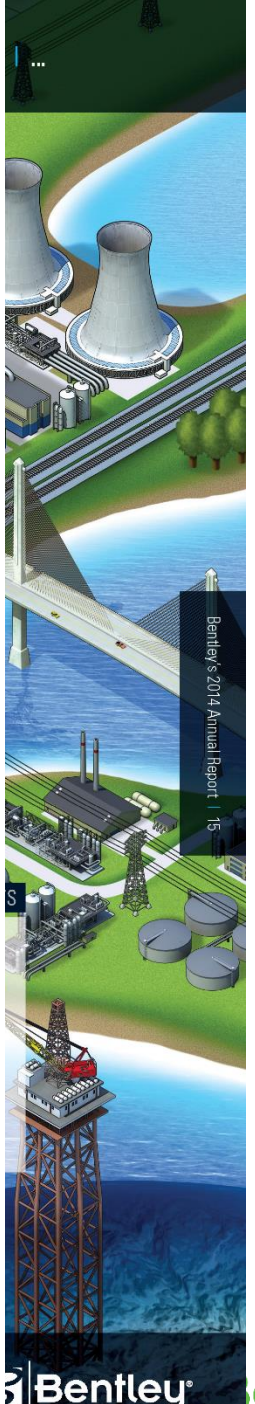
MicroStation

Modeling Platform

BENTLEY'S PROJECT PLAYBOOKS



New Products



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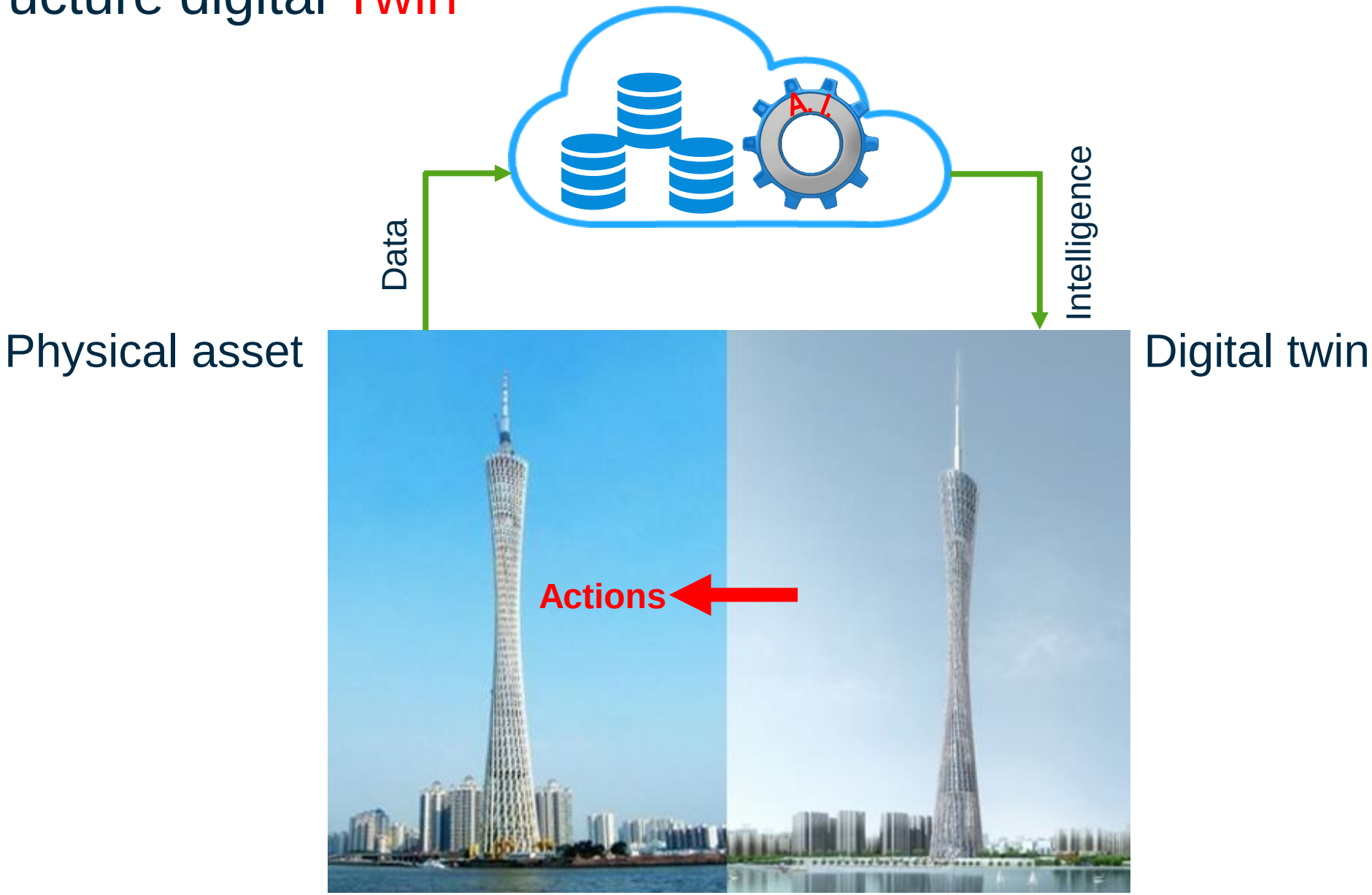
Advancing Infrastructure

Infrastructure digital Twin (iTwin)



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Semantic 3D City Model

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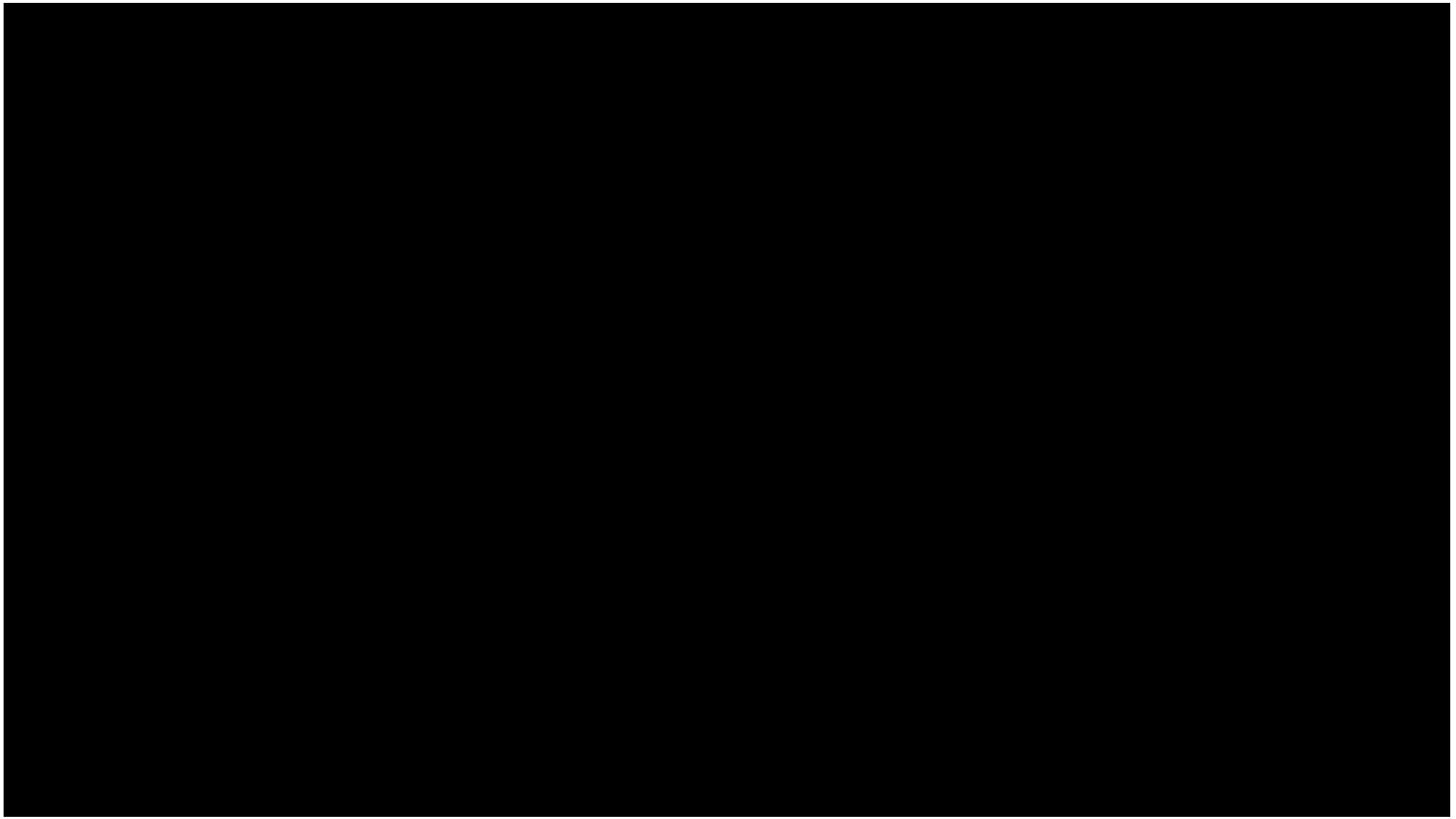
Philadelphia City Water and Energy Usage Visualization



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Applied Research for Infrastructure Digital Twin

Sensing Inspection → Data Acquisition → Data Analysis → System Modeling → Decision Support

Physical asset Digital twin

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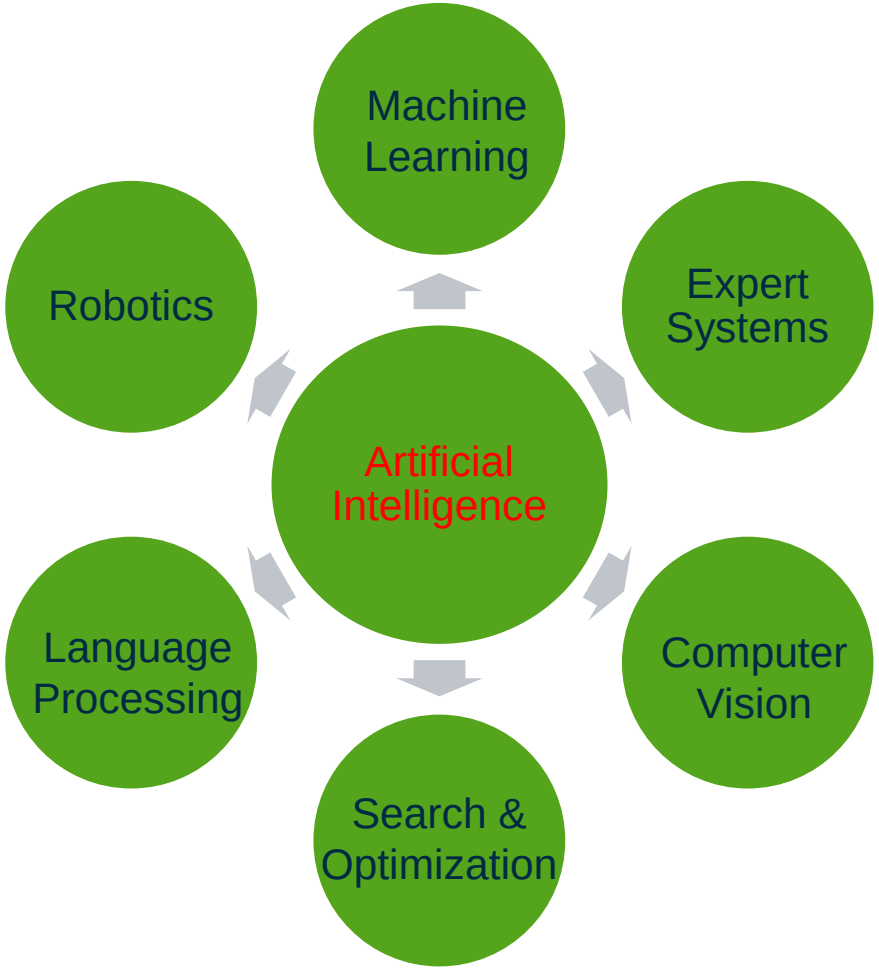
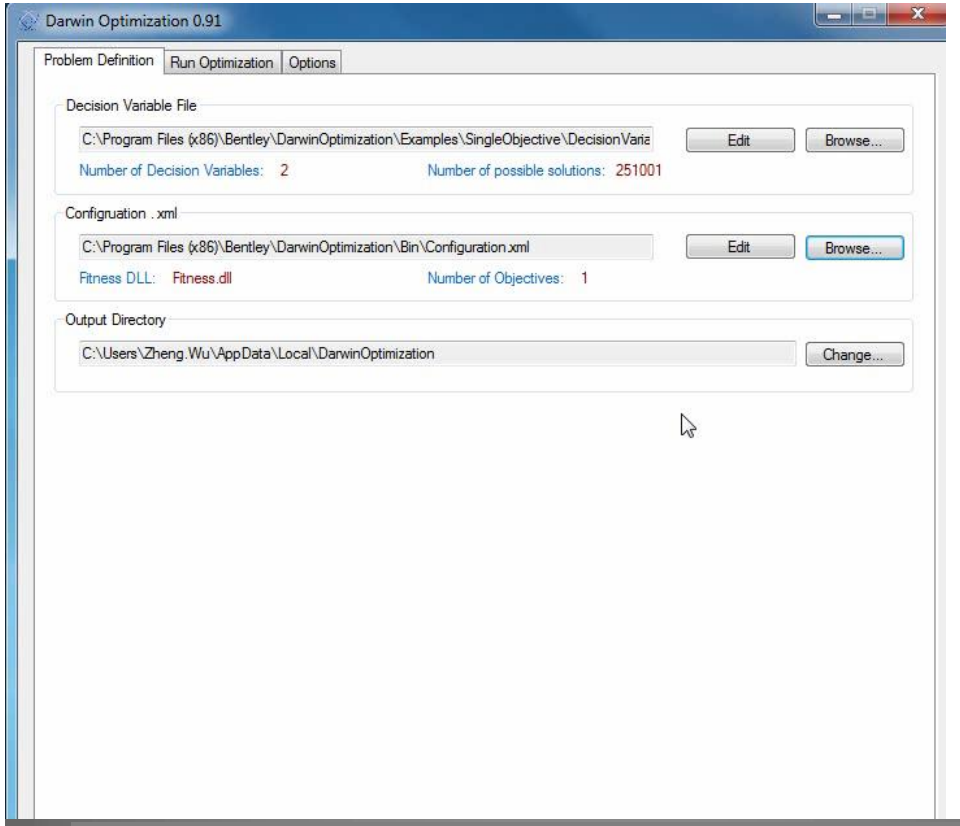
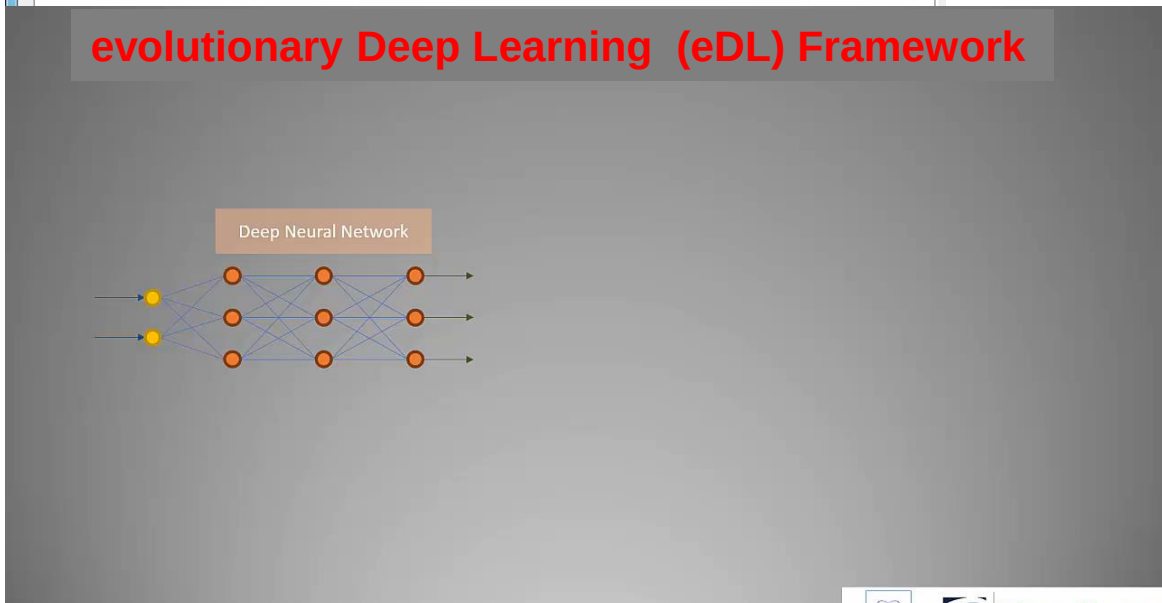
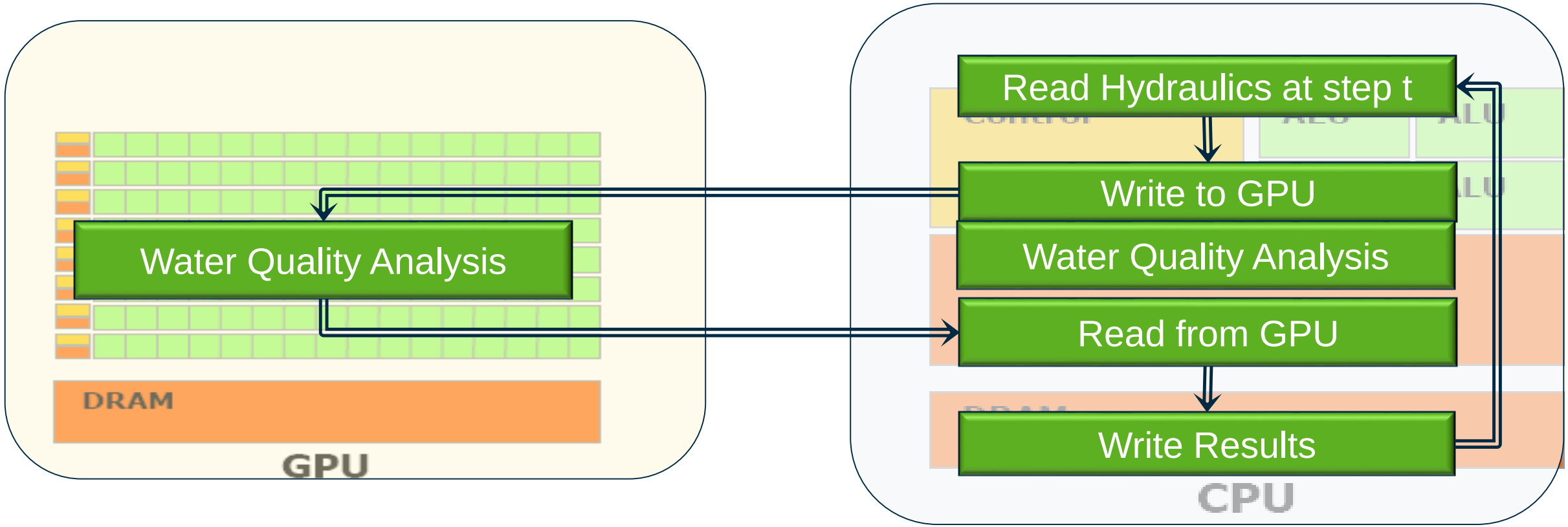
AI Application Research







GPU-Accelerated Analysis



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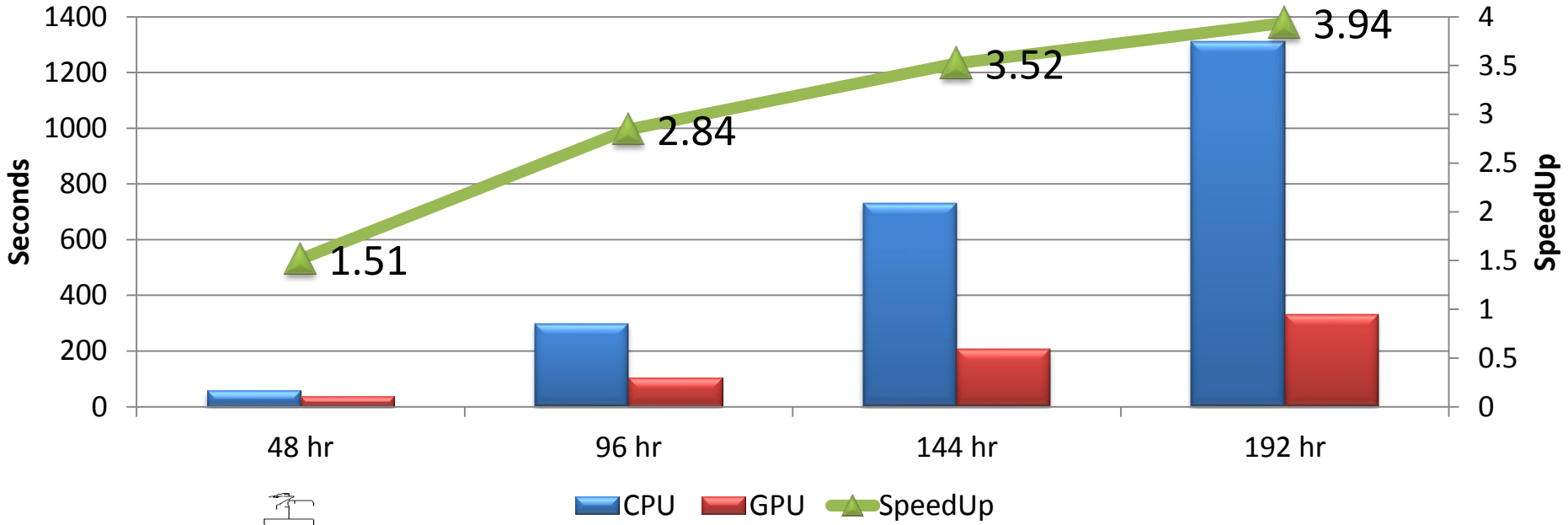
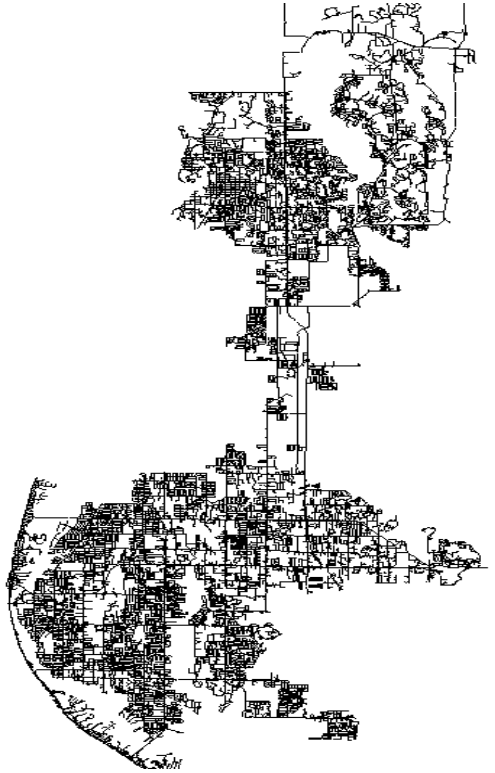
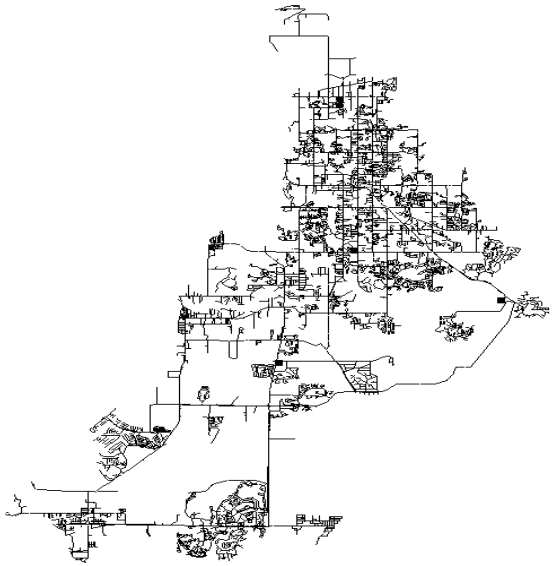
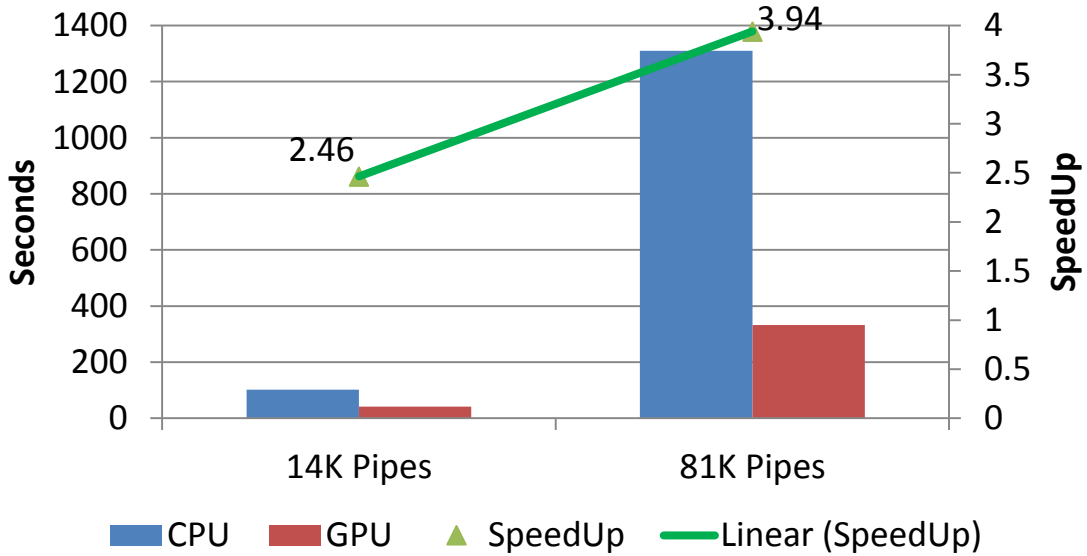
GPU-Accelerated Modeling









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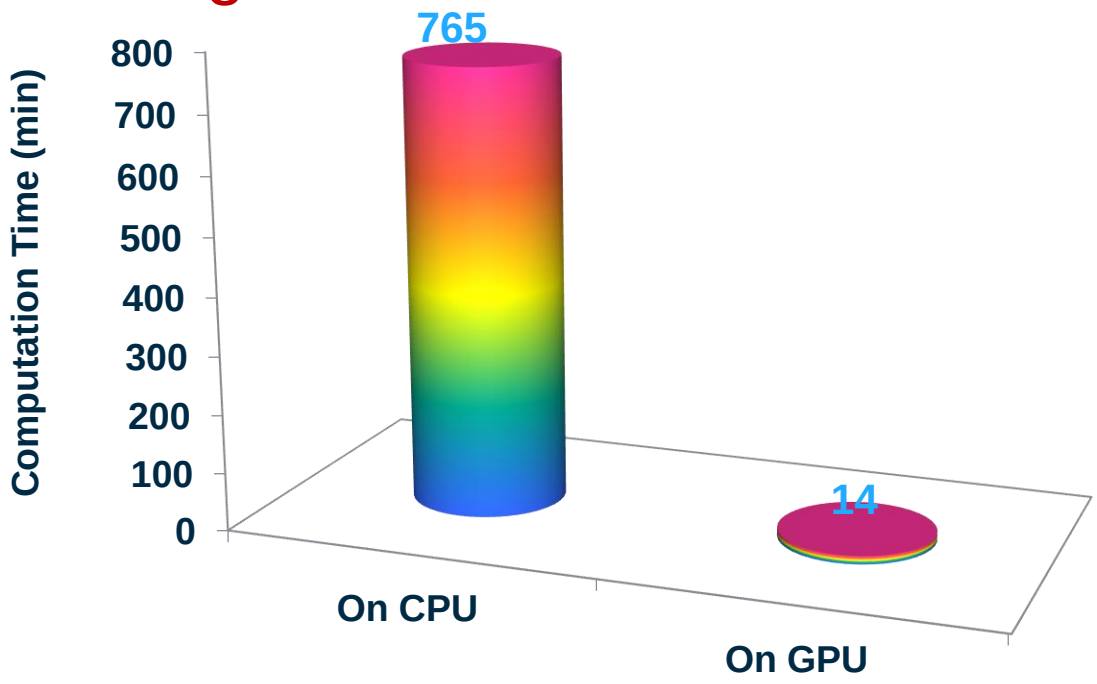
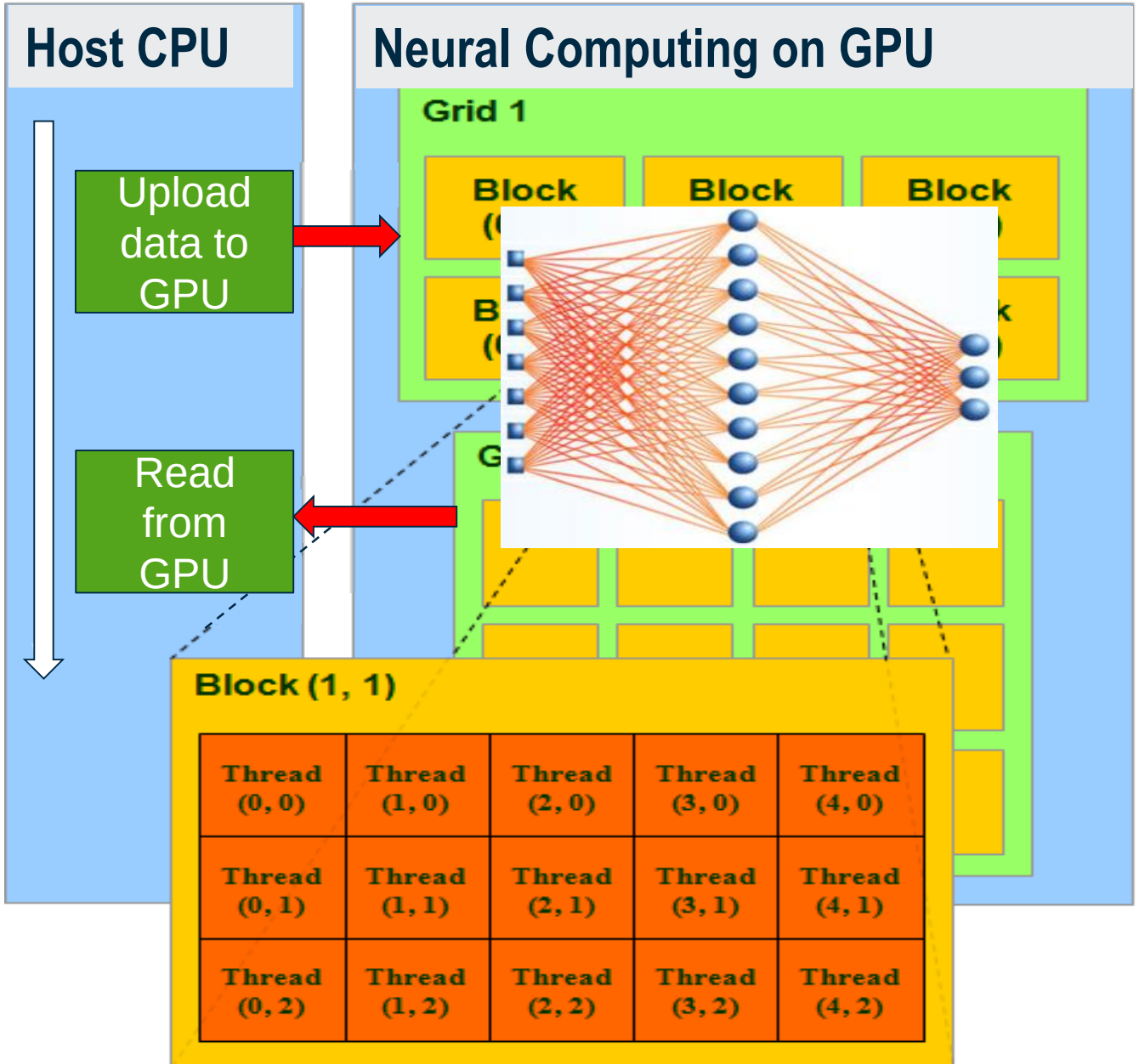
GPU-Data-Driven Model

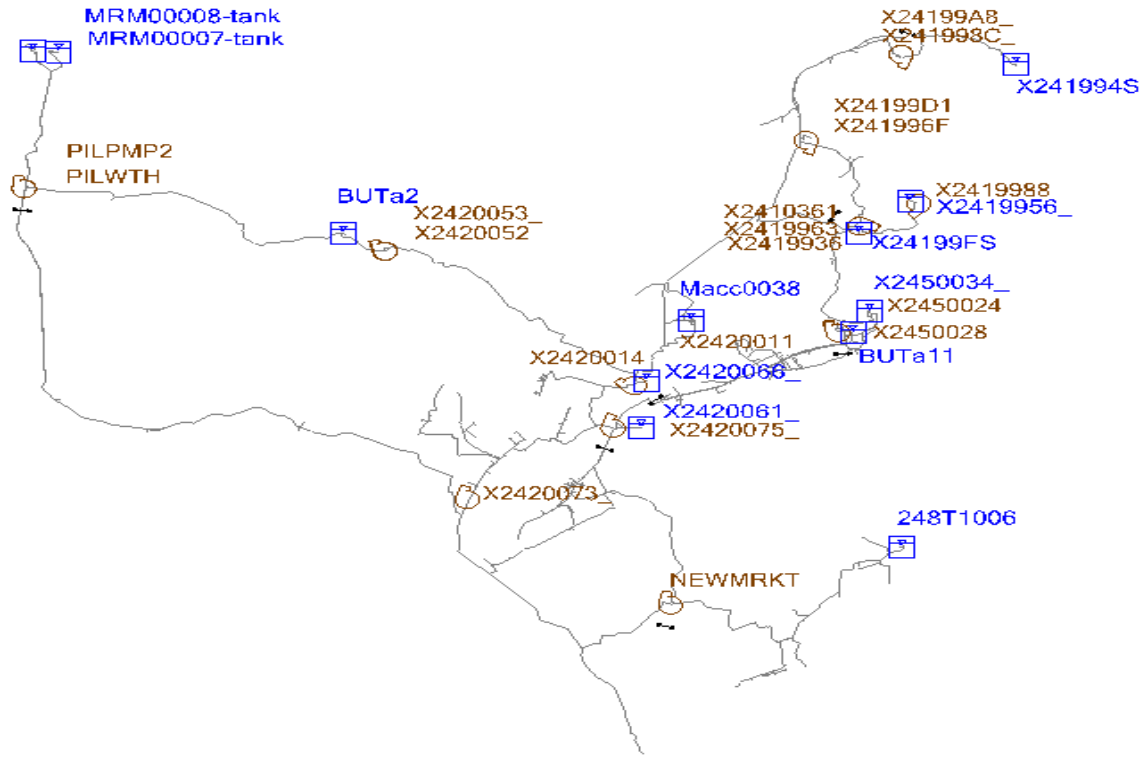
- Big data, big opportunity
- Data ≠ information
- Capture data relationships
- Fast ANN model training/calibration

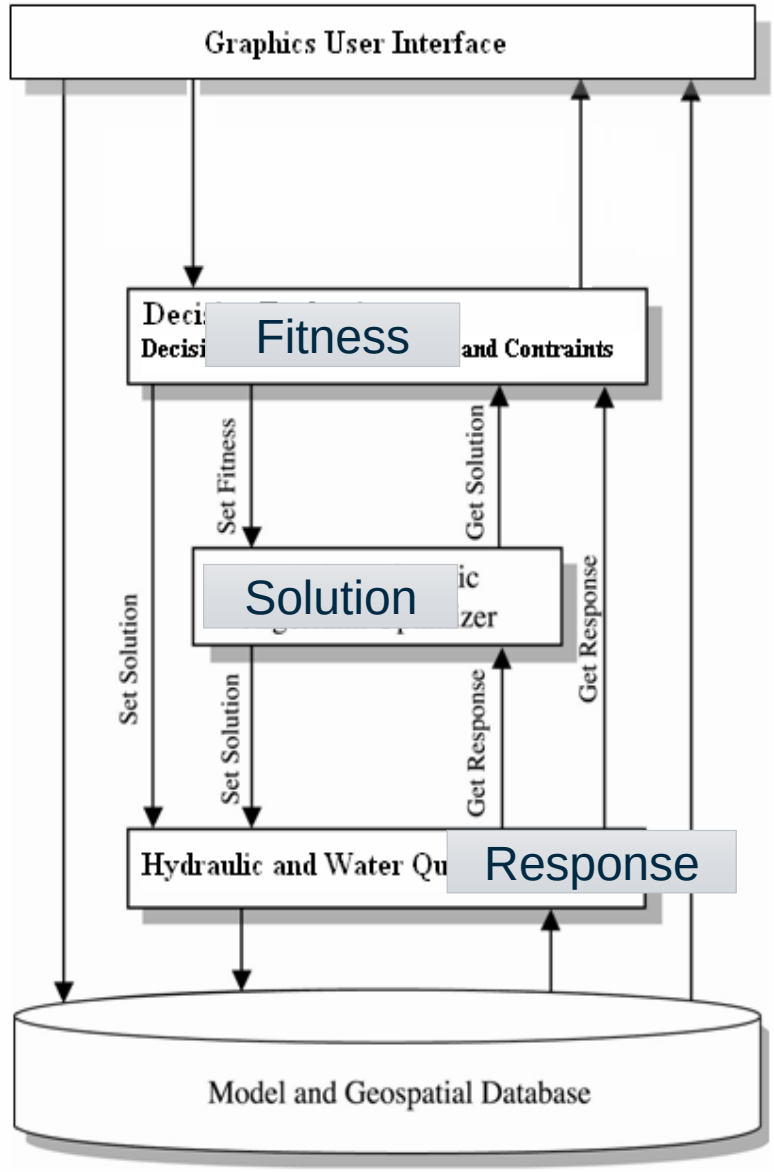




GPU-Pump Scheduling

- Optimize pump operation
- Minimize energy cost





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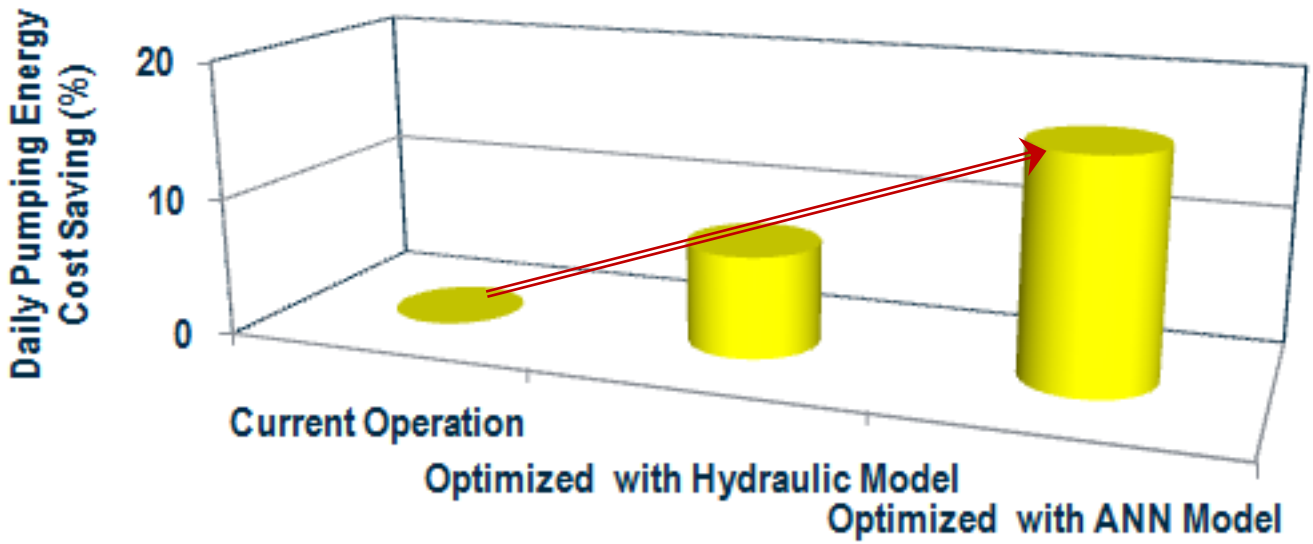
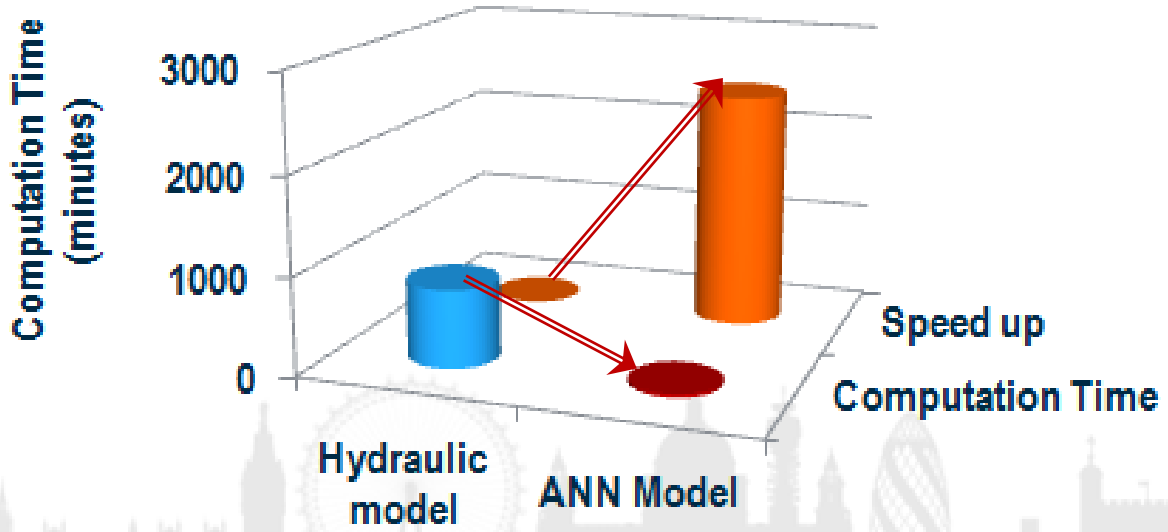
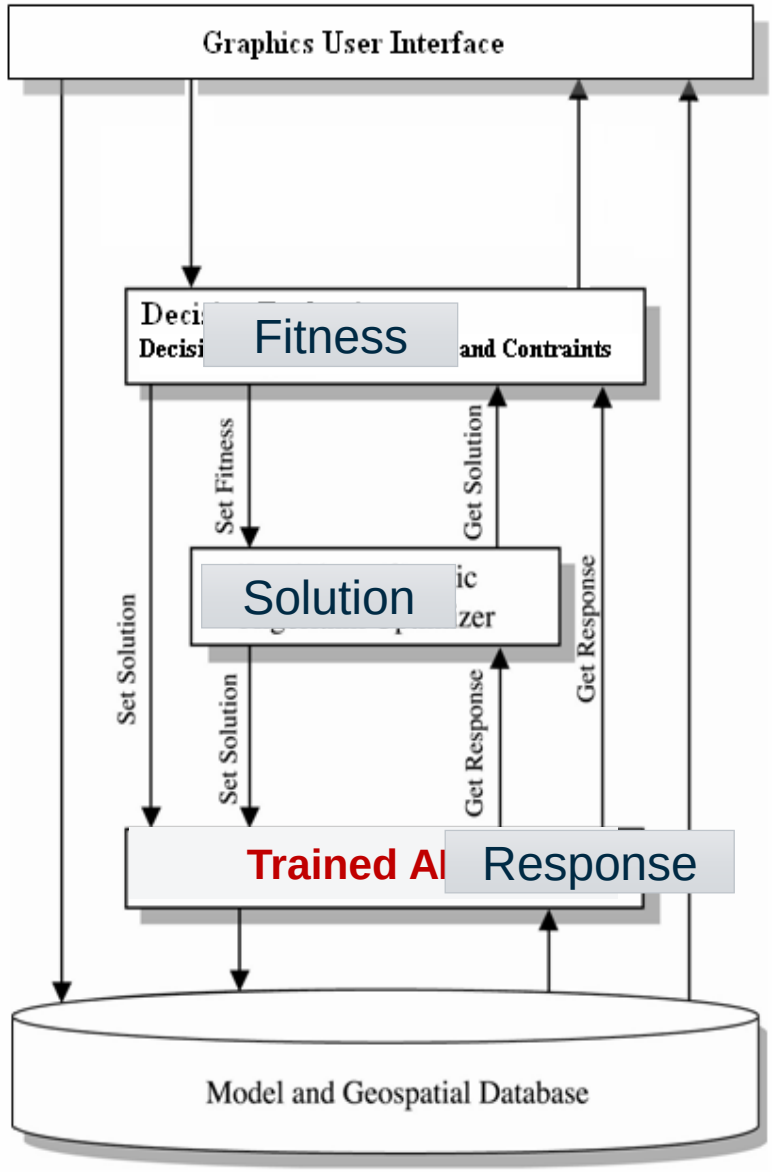
GPU-Accelerated Pump Scheduling







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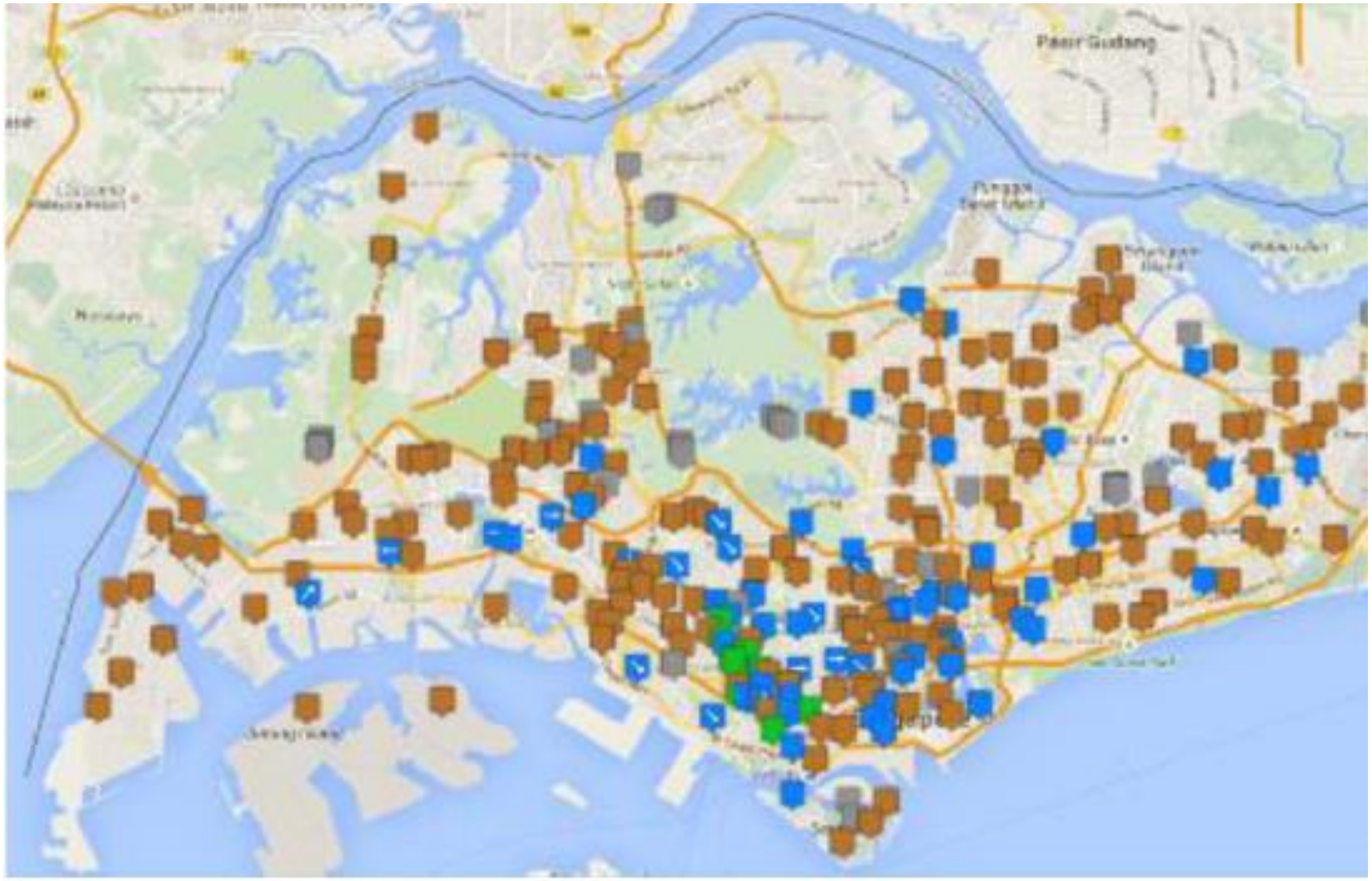
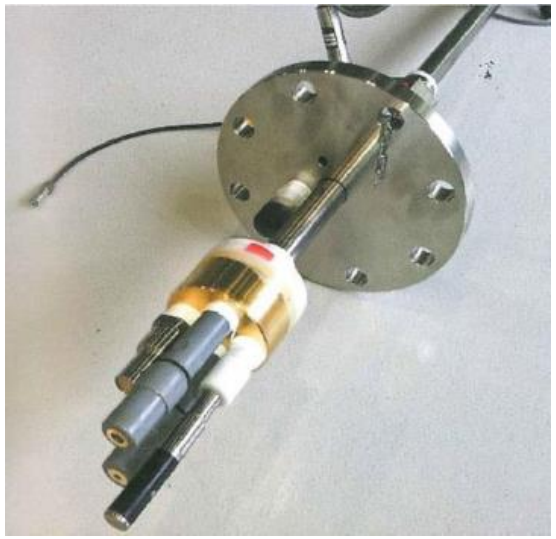
Singapore Smart Water Grid (SWG)





- 700 plus sensors
  - Pressure
  - Flow
  - pH, ORP, conductivity, temperature and turbidity

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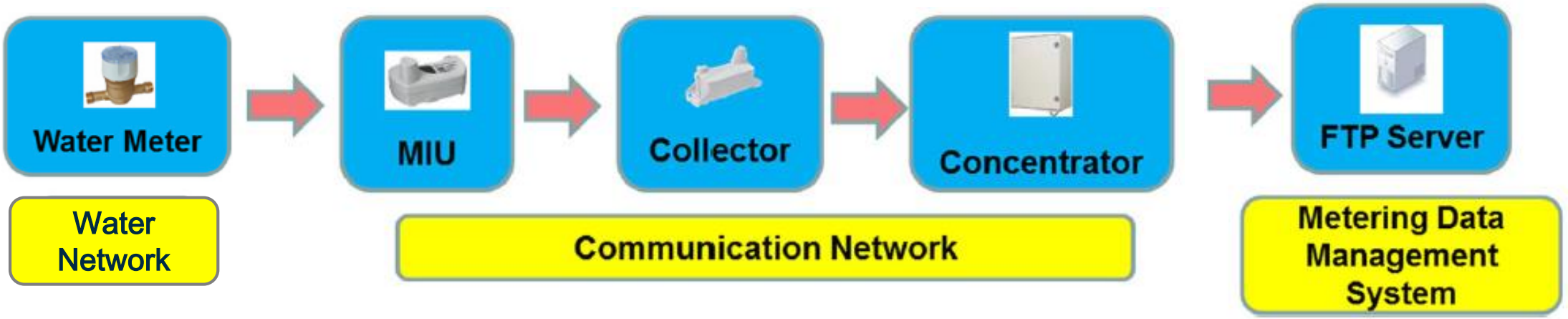
Real Time Monitoring for SWG: Digital Twin for Water Systems



- Challenges
  - Interoperability for sensors, communication and data management
  - Data analytics
  - Job redesign for PUB staff
  - Public communication
  - Further research and testing for SWG technology

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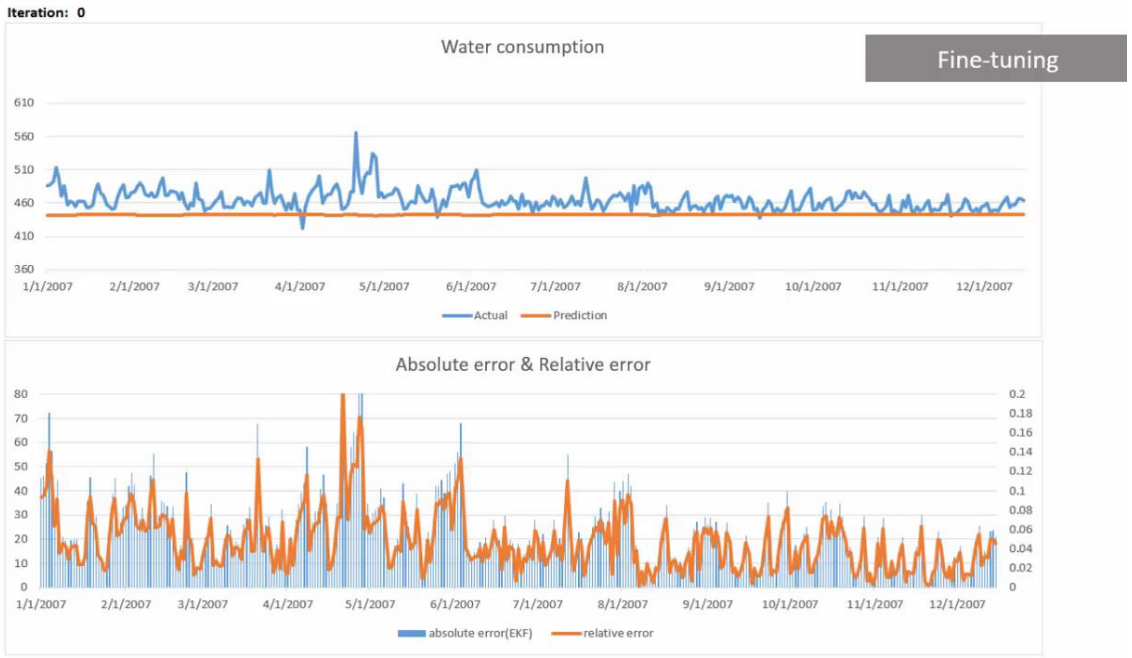
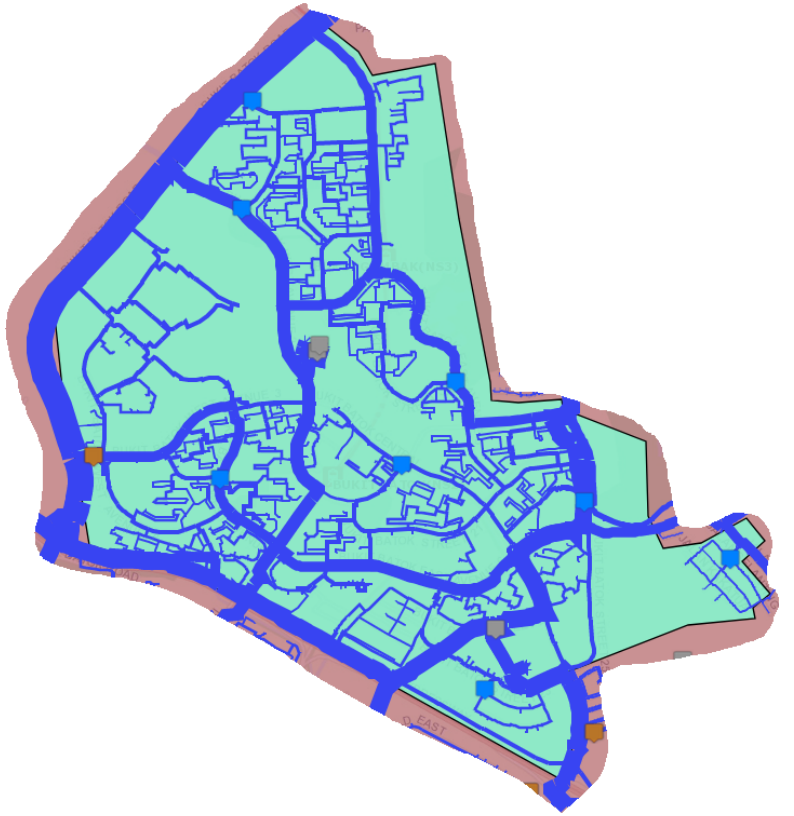
Operation Analytics

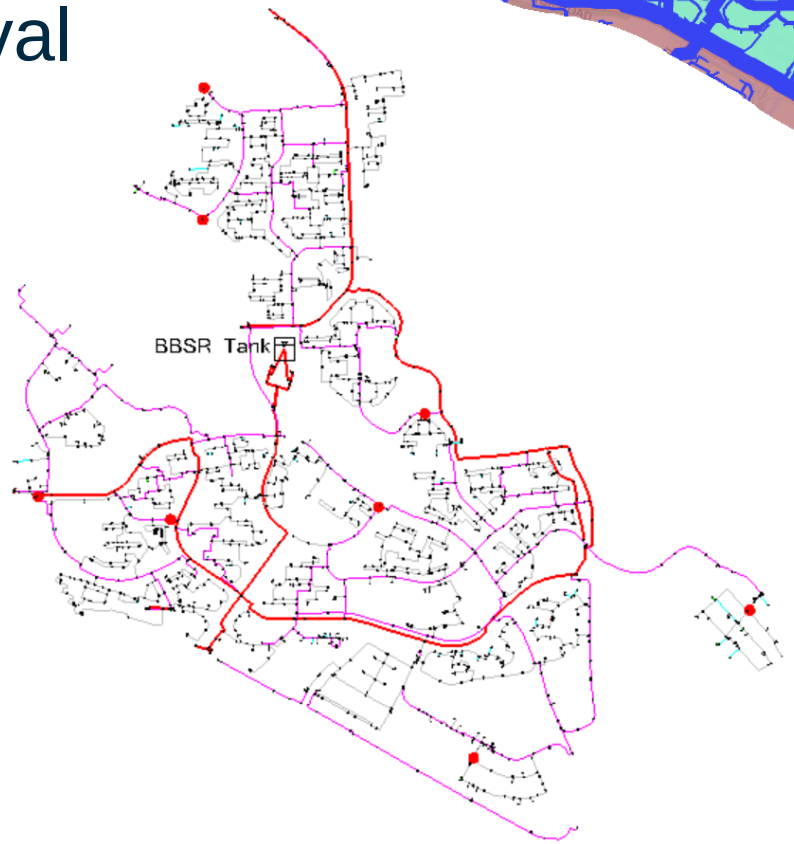
- Predictive analytics
- Anomaly detection



Case Study

- System layout with sensor locations
- One inflow time series in 5-min interval
- Pressures in 15-min interval at 8 locations
- Service tank levels in 15-min interval
- Hydraulic model





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Data Analysis and Event Detection

Flow Data Preprocess

Plot | Summary | Detail

Items	Value
Sensor name	flow
Start time	9/1/2017 12:00:00 AM
End time	10/31/2017 11:55:00 PM
Duplicated time step	0
Irregular time step	6
Missing time step	87
Sensor failure time step	1562
Total time steps	17481

Plot | Summary | Detail

Timestamp	Value	Error
9/1/2017 1:55 AM	2.42	Sensor failure
9/1/2017 2:00 AM	2.42	Sensor failure
9/1/2017 2:05 AM	2.42	Sensor failure
9/1/2017 3:40 AM	1.63	Sensor failure
9/1/2017 4:10 AM	1.36	Sensor failure
9/1/2017 4:25 AM	1.99	Sensor failure
9/1/2017 7:55 AM	6.69	Sensor failure
9/1/2017 8:00 AM	6.69	Sensor failure
9/1/2017 8:05 AM	6.69	Sensor failure
9/1/2017 3:55 PM	5.45	Sensor failure
9/1/2017 4:00 PM	5.45	Sensor failure
9/1/2017 4:05 PM	5.45	Sensor failure
9/1/2017 5:55 PM	6.91	Sensor failure
9/1/2017 6:00 PM	6.91	Sensor failure
9/1/2017 6:05 PM	6.91	Sensor failure
9/1/2017 8:25 PM	5.48	Sensor failure
9/1/2017 11:55 PM	3.55	Sensor failure

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Pressure Data Preprocess (Stn11)

Plot | Summary | Detail

Items	Value
Sensor name	stn11
Start time	9/1/2017 12:00:00 AM
End time	10/31/2017 11:45:00 PM
Duplicated time step	0
Irregular time step	0
Missing time step	0
Sensor failure time step	86
Total time steps	5856

Summary | Detail

Timestamp	Value	Error
9/1/2017 2:30 AM	39.01	Sensor failure
9/1/2017 12:15 PM	35.70	Sensor failure
9/1/2017 1:30 PM	35.94	Sensor failure
9/2/2017 2:30 AM	39.09	Sensor failure
9/4/2017 3:00 AM	39.69	Sensor failure
9/5/2017 2:45 AM	38.91	Sensor failure
9/6/2017 5:45 PM	38.04	Sensor failure
9/6/2017 11:45 PM	38.47	Sensor failure
9/7/2017 12:00 PM	37.94	Sensor failure
9/7/2017 1:15 PM	38.11	Sensor failure
9/7/2017 7:45 PM	35.89	Sensor failure
9/11/2017 12:15 AM	38.65	Sensor failure
9/11/2017 3:30 AM	39.76	Sensor failure
9/12/2017 2:15 AM	39.08	Sensor failure
9/12/2017 3:30 AM	39.37	Sensor failure
9/12/2017 11:15 PM	37.43	Sensor failure
9/13/2017 4:30 AM	39.71	Sensor failure
9/13/2017 1:45 PM	37.71	Sensor failure
9/14/2017 1:45 AM	38.86	Sensor failure
9/14/2017 4:15 AM	39.65	Sensor failure

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Anomaly Event Detection

Water event detector

Data pre-process | Decomposition | Outlier detection | Sensor event | System event | Real time data

Select event file

Flow event file: D:\Work\BBSZ data\event\30flow.csv

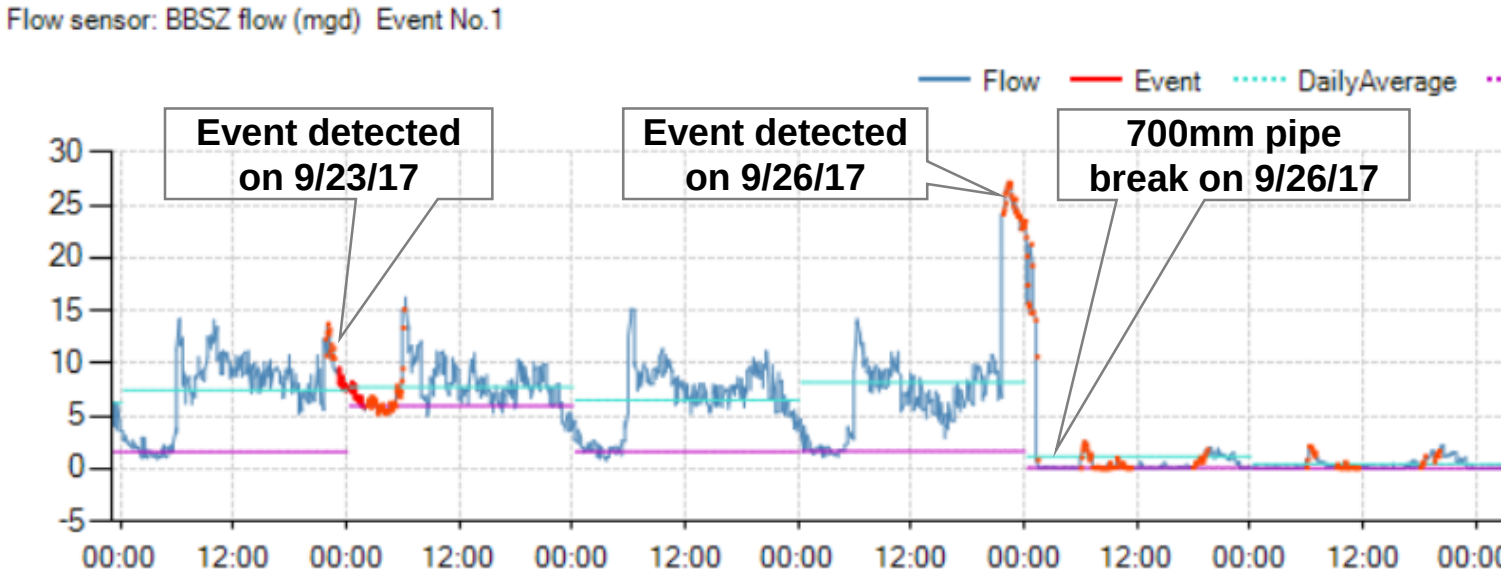
Pressure event file: D:\Work\BBSZ data\event\30stn11.csv
D:\Work\BBSZ data\event\30stn12.csv

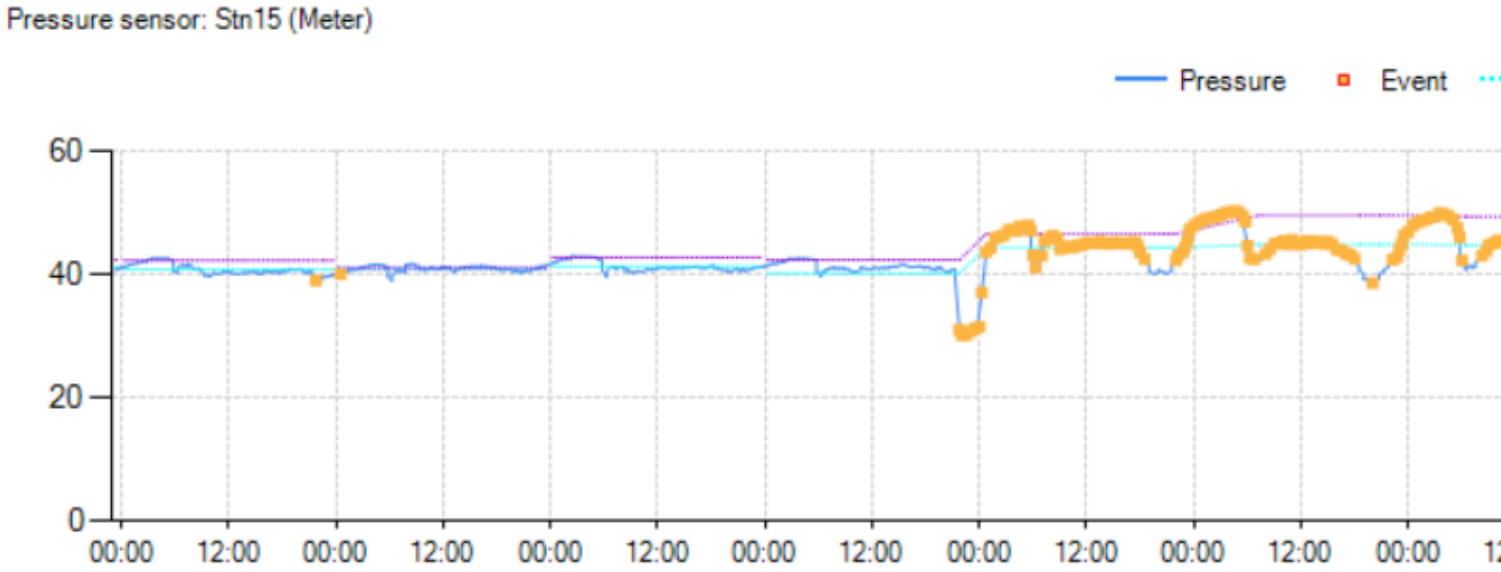
Set system criteria

Flow event: ☑ High ☐ Low Pressure event: ☐ High ☑ Low ☑ Flow and pressure correlation

Event reasult

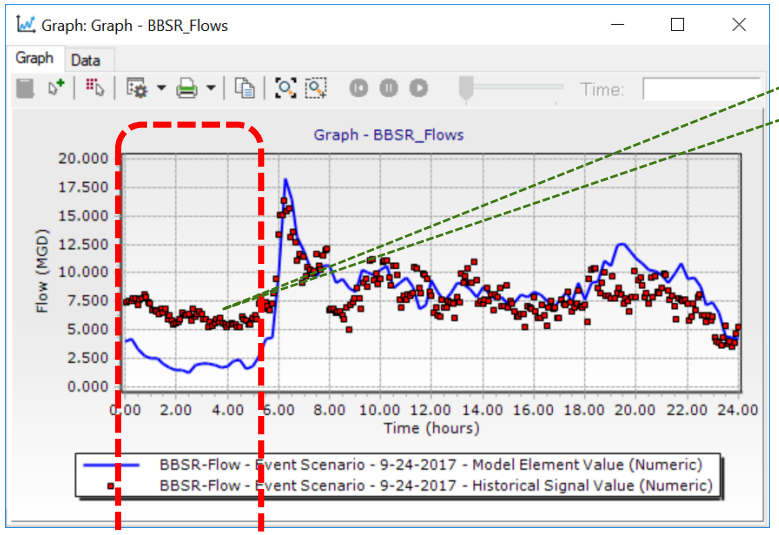
	Timestamp	Name	Value	Warning	duration	out difference
1	9/23/2017 11:15 PM	BBSZ flow	9.27	High	160	1.44
	9/24/2017 12:30 AM	Stn15	40.19	Low	30	-0.02
2	9/26/2017 9:50 PM	BBSZ flow	24.14	High	220	16.20
	9/27/2017 1:30 AM	Stn14	30.92	Low	300	3.74
	9/27/2017 1:30 AM	Stn16	37.54	Low	300	4.02

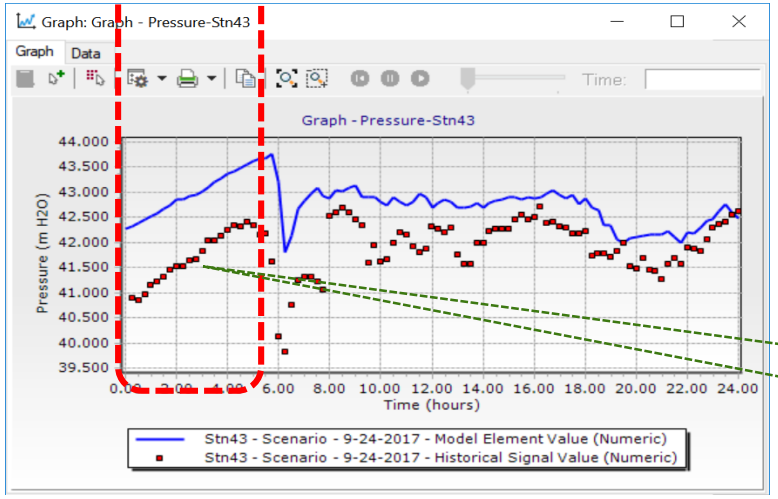




Simulation Results

Event on Sept. 23 2017

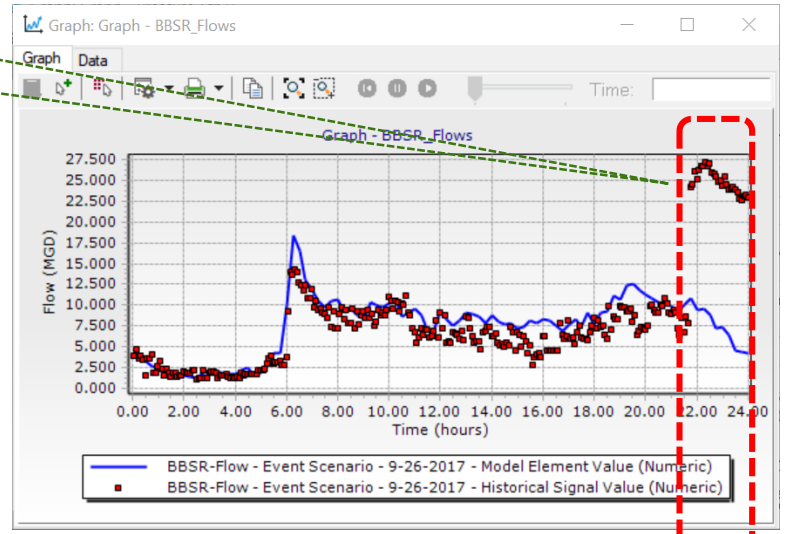


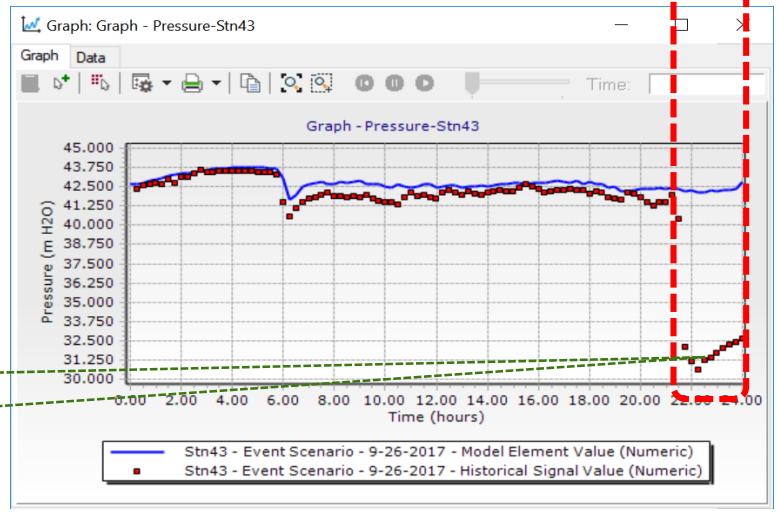


Increased flows

Pressure drops

Event on Sept. 26 2017





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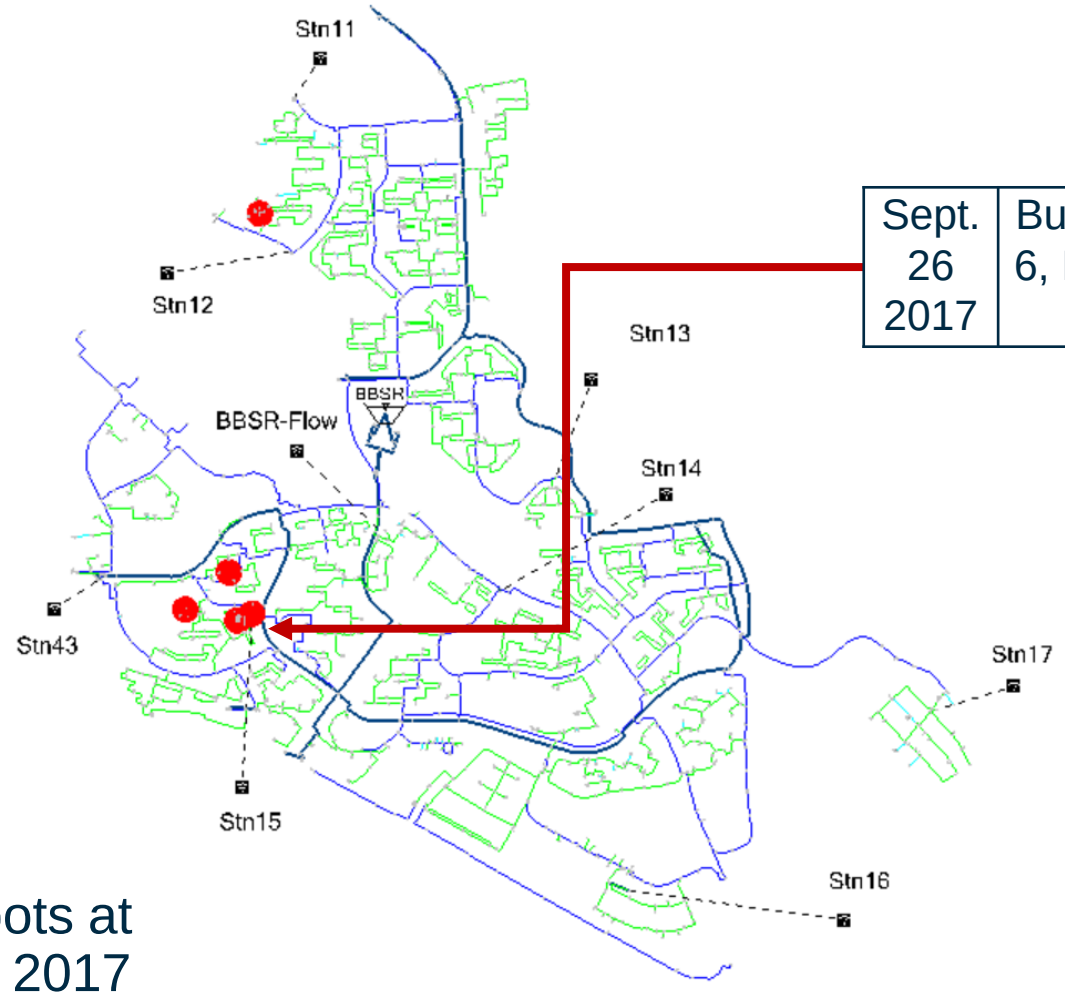
Anomaly/Leakage Event Localization



PUB Field Record

Sept. 26 2017	Bukit Batok W. Ave 6, Hdb-bukit Batok, 650185	700mm mains longitudinal crack

- Model-localized hotspots at 11:15 PM on Sept. 23 2017

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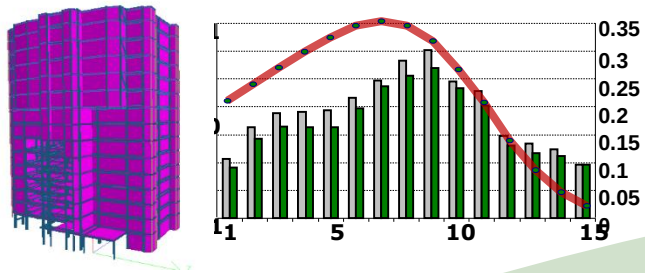
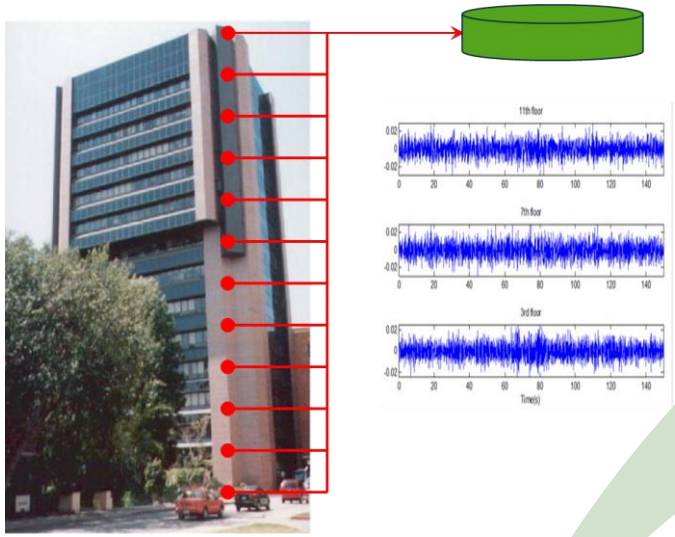
Digital Twin for Engineering Structures





Assessment, rating & maintenance

Data analysis & information extraction

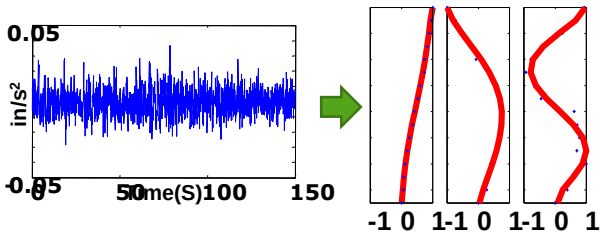
FE Model calibration
Damage detection
Load identification

Sensor placement
Vision sensor

SHM Extractor

SHM Calibrator

SHM Pretest



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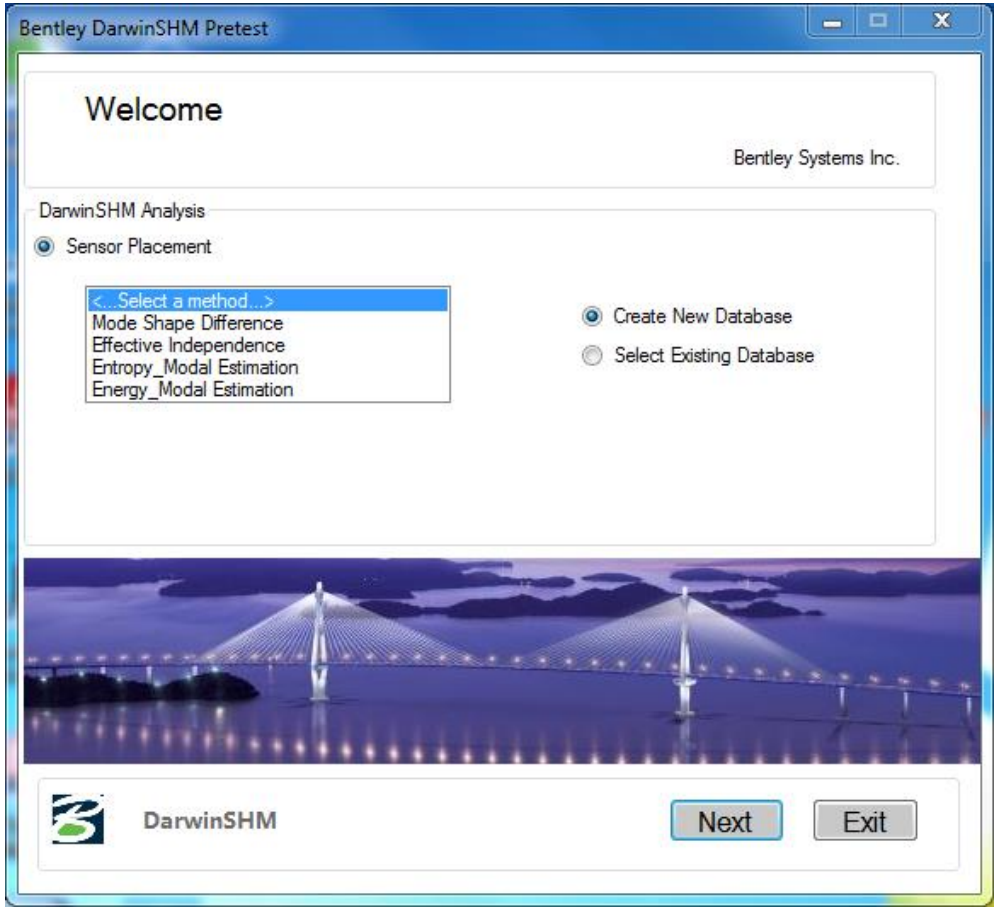
Applied AI Research for Infrastructure Digital Twin

Sensing Inspection → Data Acquisition

- DarwinSHM Pretest for SHM Sensor placement
  - Accelerometers
  - Strain Gauges

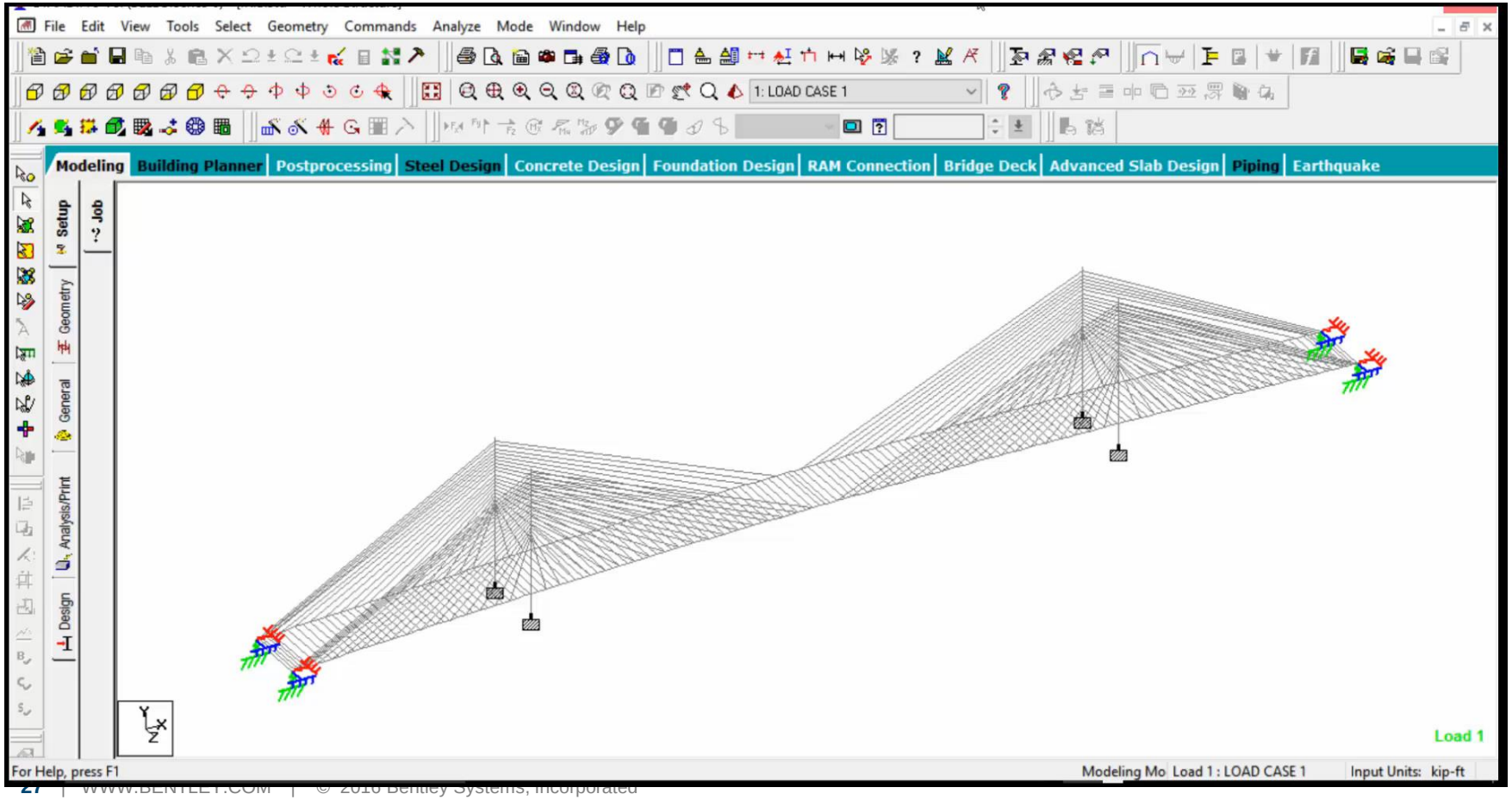


Zhou. K., Wu*, Z. Y. (2017). “Strain gauge Placement Optimization for Structural Performance Assessment” *Engineering Structure* 141 (2017) 184-197.

Zhou, Kai, Wu*, Z.Y., Yi, X. H., Zhu, D. P., Narayan, R. and Zhao, J. (2017). “Generic Framework of Sensor Placement Optimization for Structural Health Modeling”, ASCE. *J. Computing in Civil Engineering*, Vol. 31 No. 4, 1943-5487

Applied AI Research for Infrastructure Digital Twin

Sensing Inspection → Data Acquisition → Data Analysis → System Modeling



- Integrated with STAAD
- Responses
  - Displacements & Strains
  - Frequency & mode shapes
- Parameters
  - Section area
  - Young's modulus
- Features
  - FE model calibration
  - Damage detection
  - Load identification

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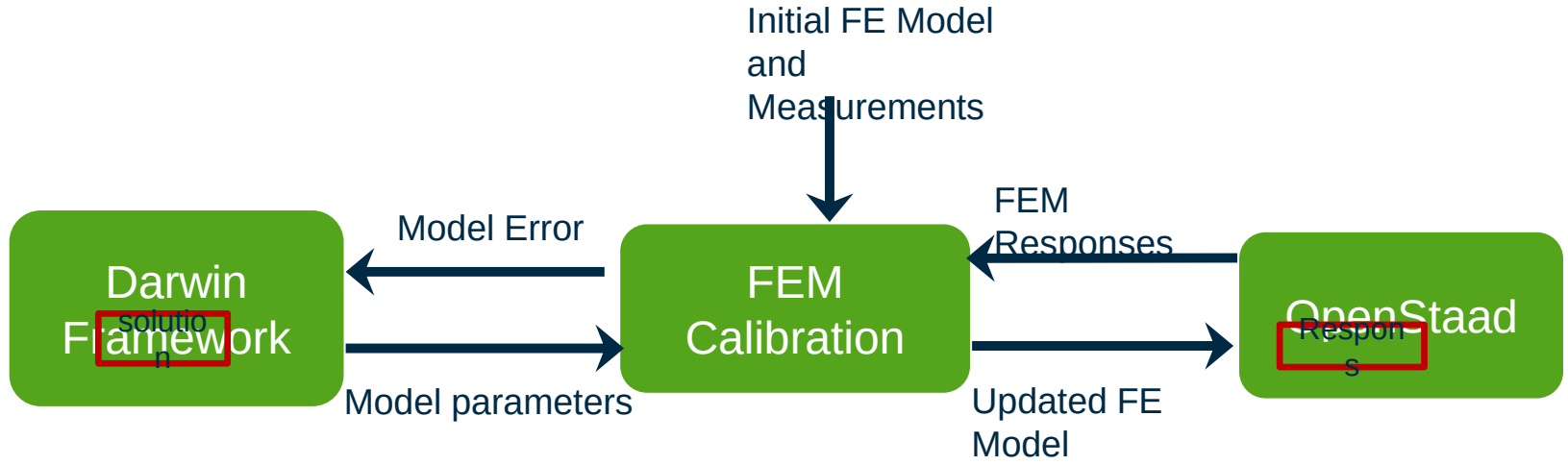
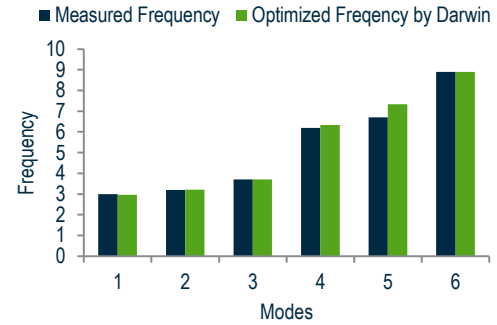
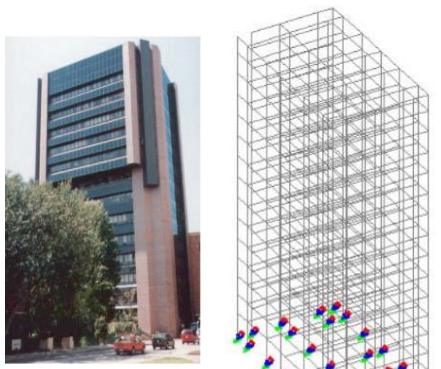
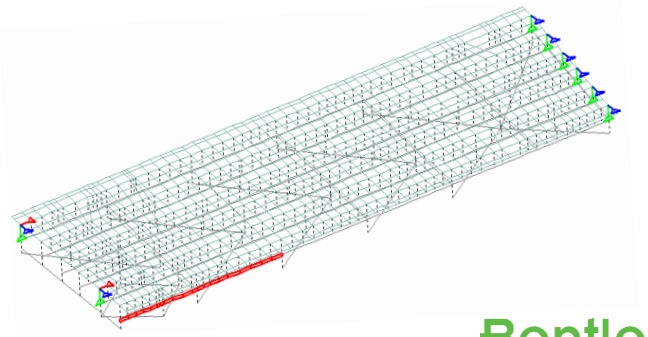
Finite Element Model Calibration

- Update finite element model for in-service structure
- Research projects
  - Applied to buildings and bridges









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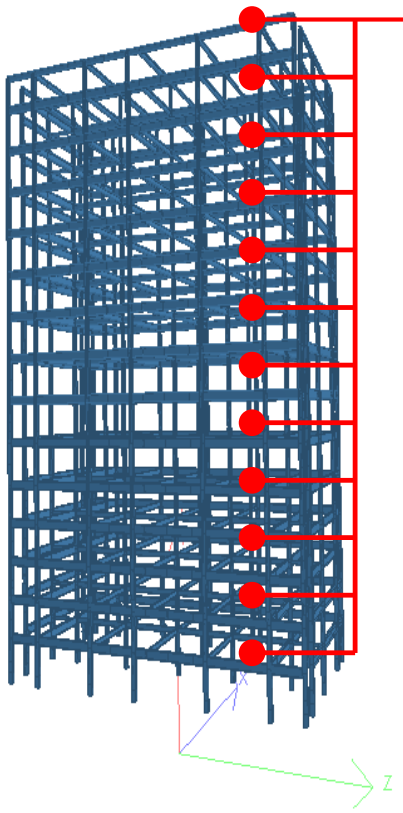
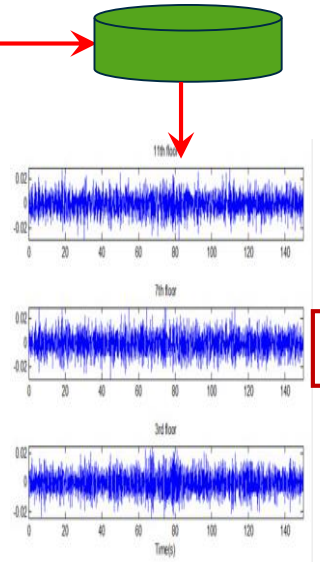
Building Finite Model Calibration

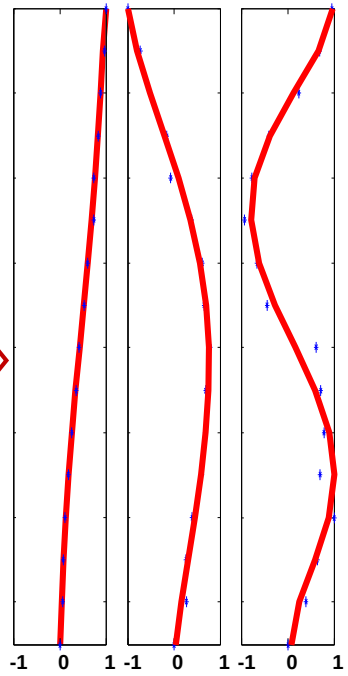
UCLA Factor Building



Sensor data

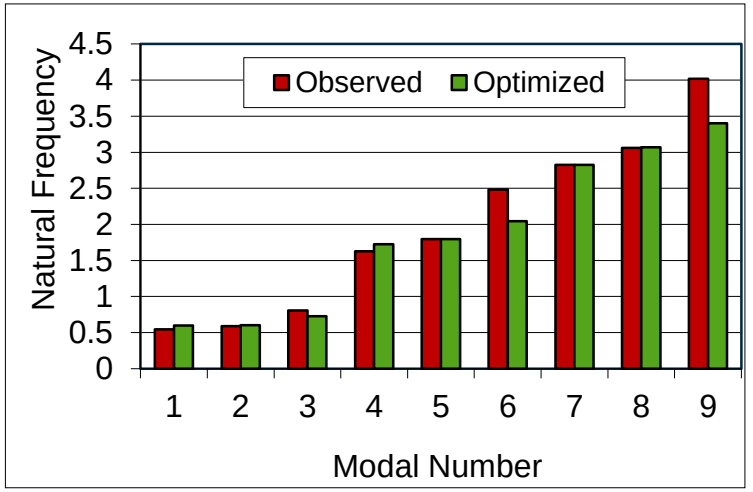


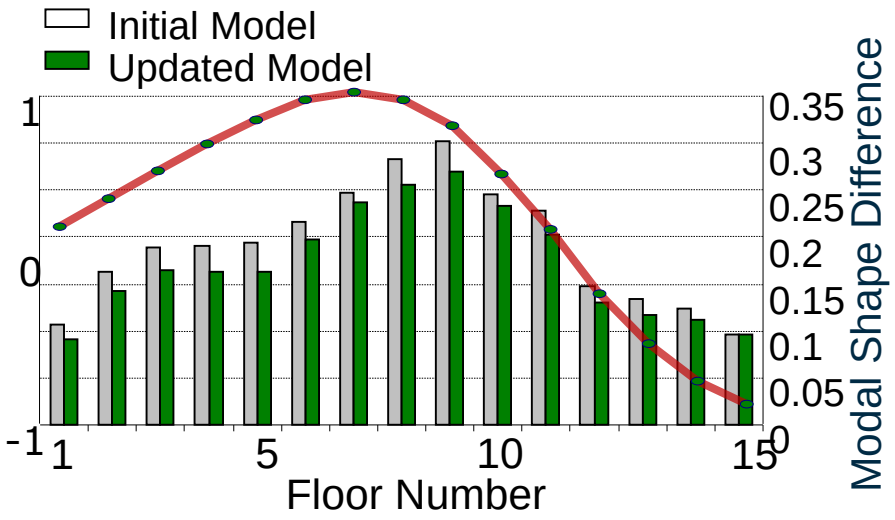
Modal Shapes



Frequency

Modes	Natural Frequency
1	0.545
2	1.626
3	2.791
4	0.576
5	1.790
6	3.071
7	0.795
8	2.774
9	4.151





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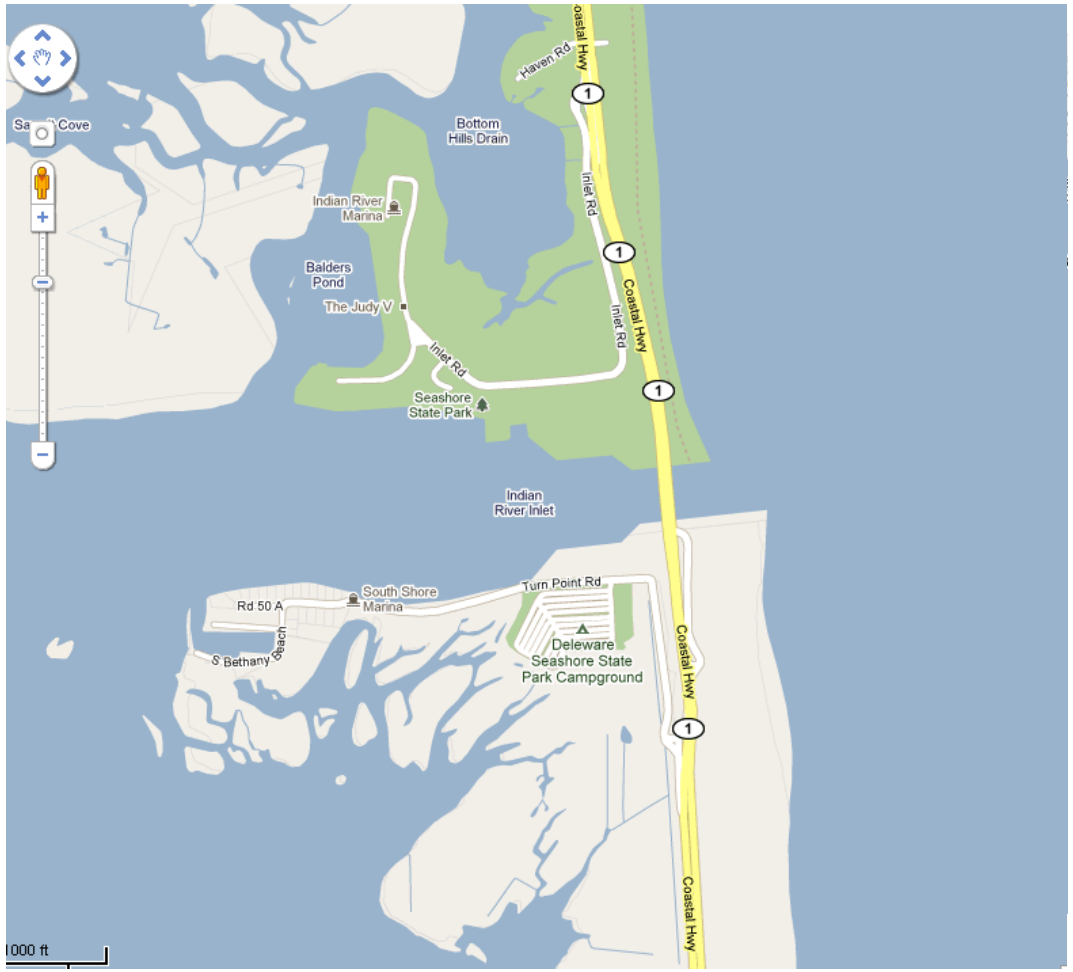
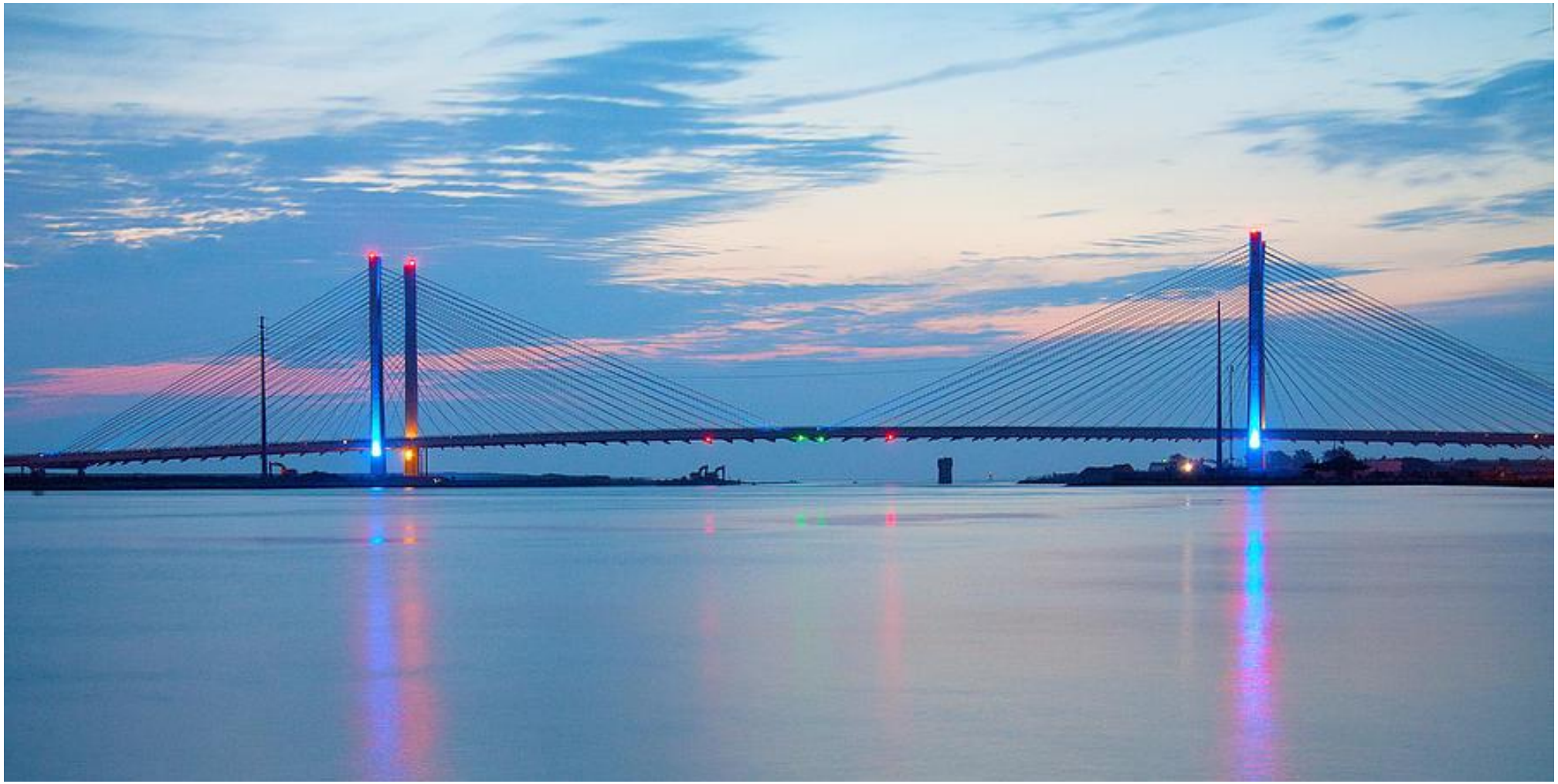
Indian River Inlet Bridge Location

- Bridge FE model calibration (with Dr. Shenton from Uni. Delaware)



Bentley

New Indian River Inlet Bridge



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Sensor Layout Layout

- 69 strain and temperature sensors
- 9 tiltmeters
- 16 chloride sensors
- 27 accelerometers
- 3 displacement gauges
- 2 anemometers

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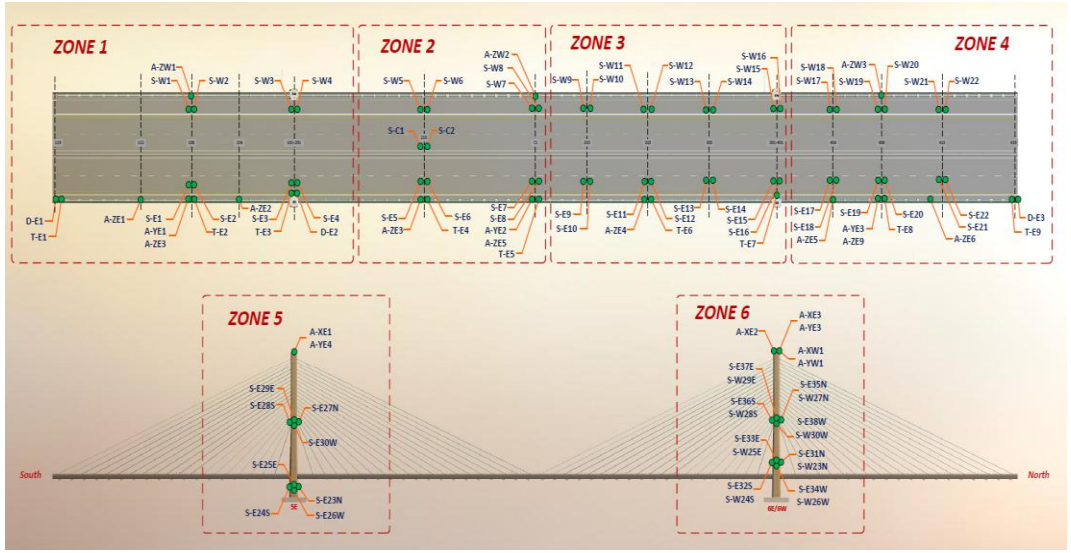
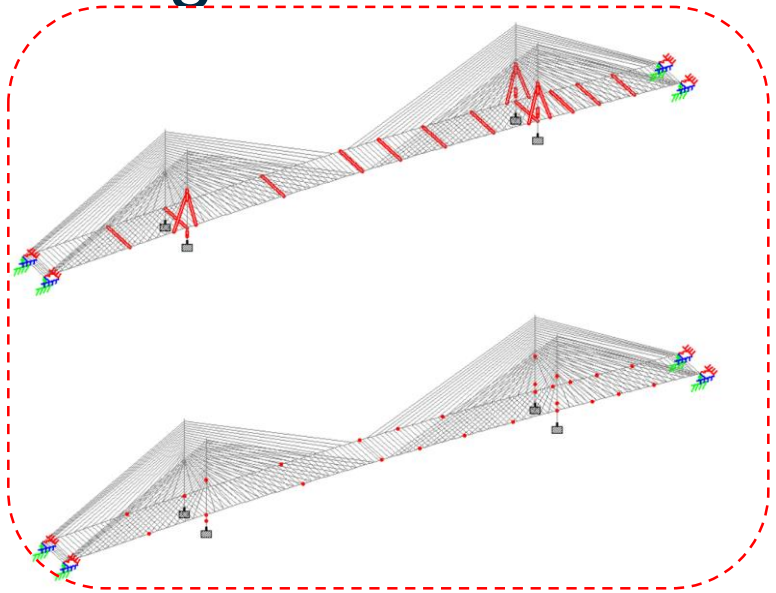
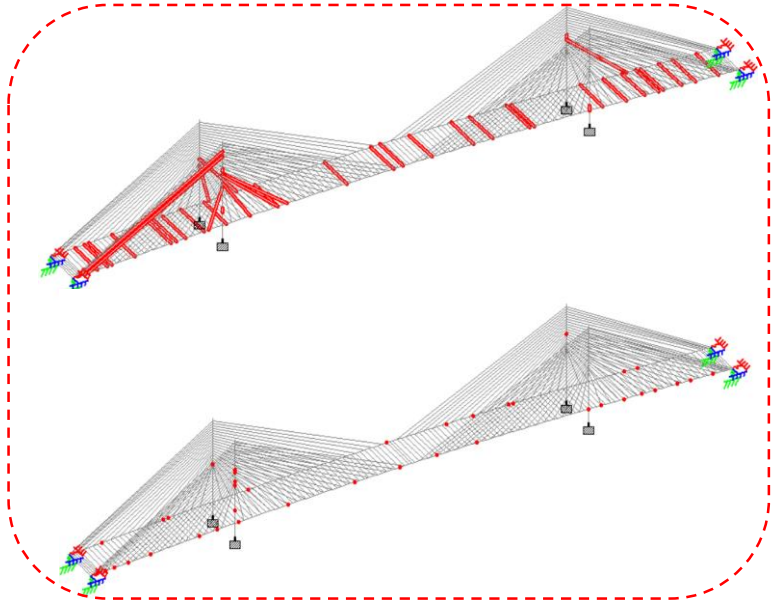
Sensor Plaement: Indian River Inlet Bridge in Delaware



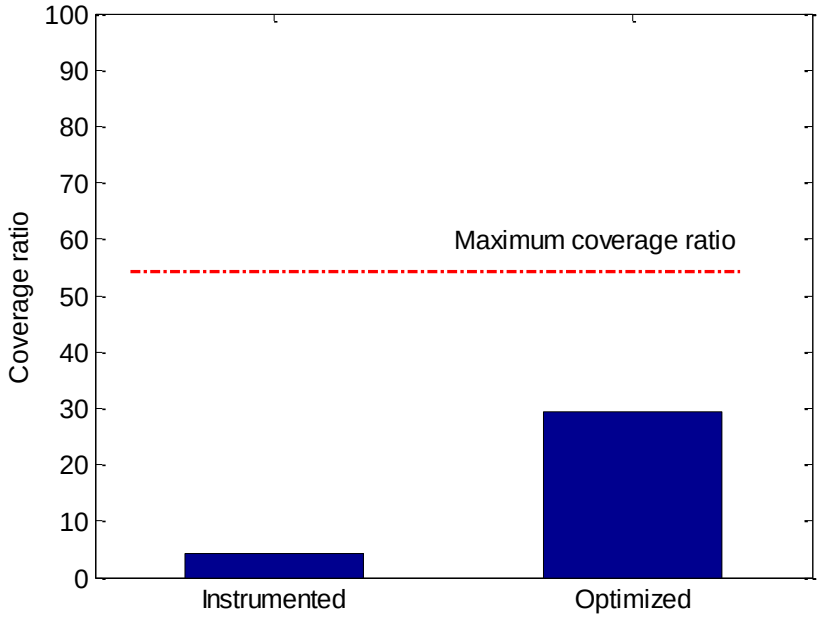
40-strain gauge



Instrumented



Optimized



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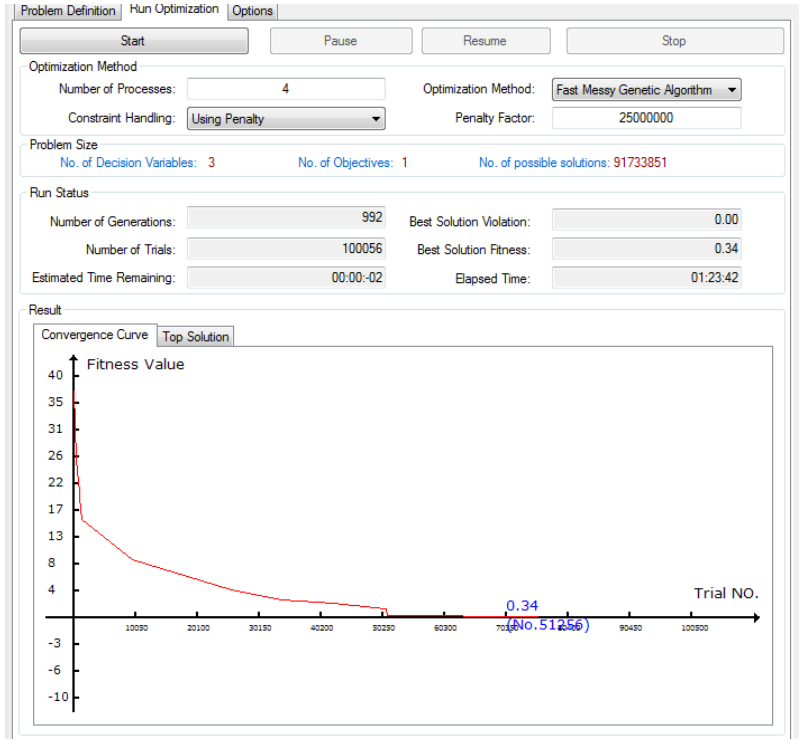
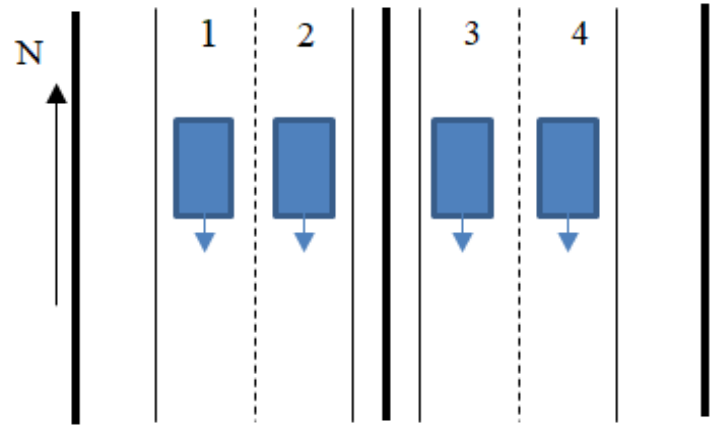
Bentley Darwin Optimization

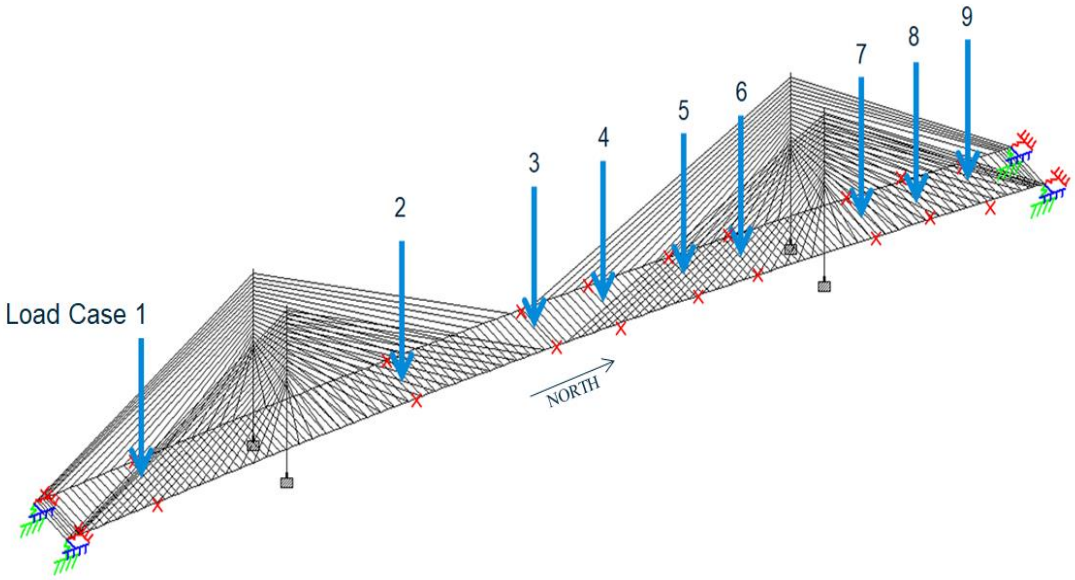
- Tool for calibrating a model of a structural system using measured structural response data
- UD expertise
  - Bridge engineering
  - Structural Health Monitoring
  - Indian River Inlet Bridge
- Test the tool by calibrating a signature bridge using strain response data



Strain Response Used for Calibration

- Load Test 2, November 2012
- 4 – truck pass
  - 110 strain response values
  - Magnitudes range from 2.5 to 90 microstrain





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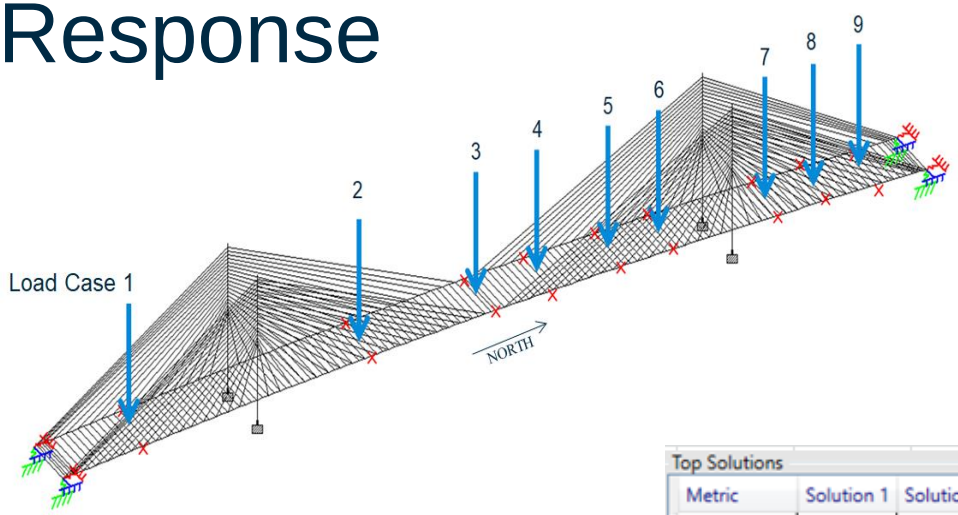
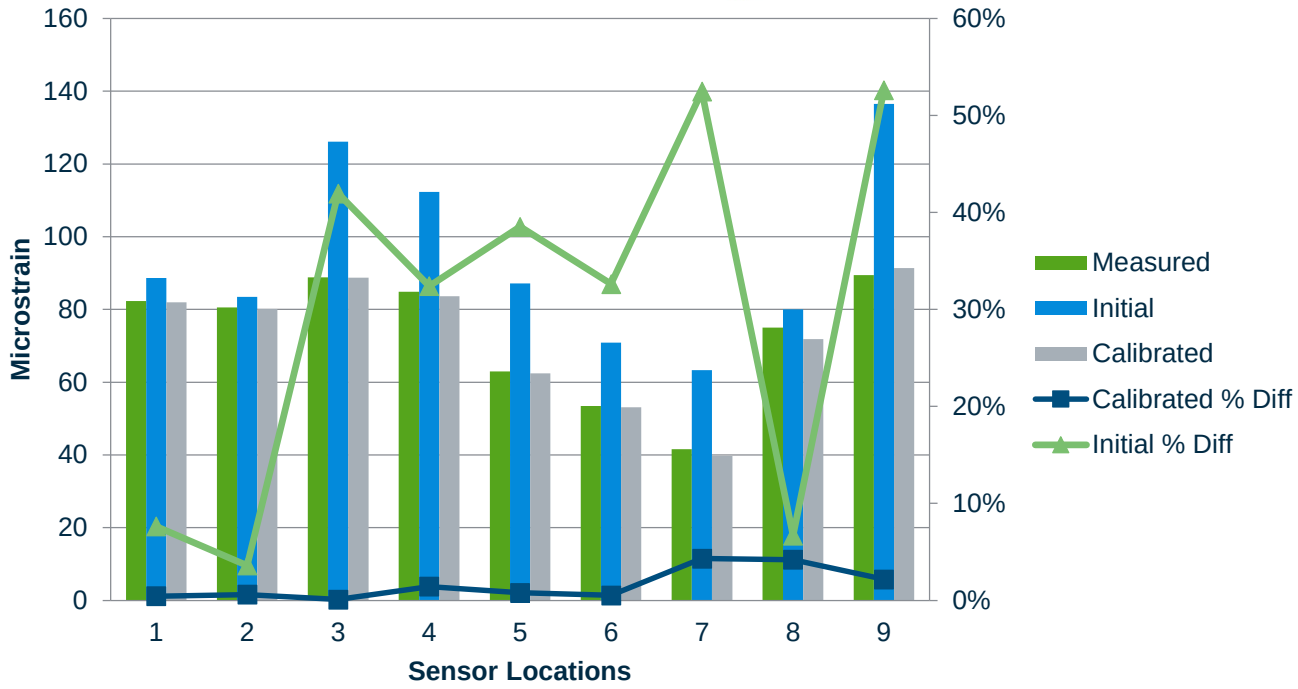
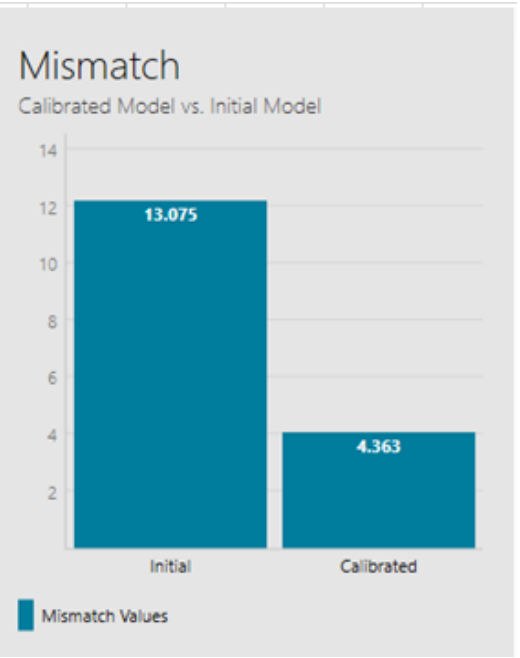
Calibrated Strain Response





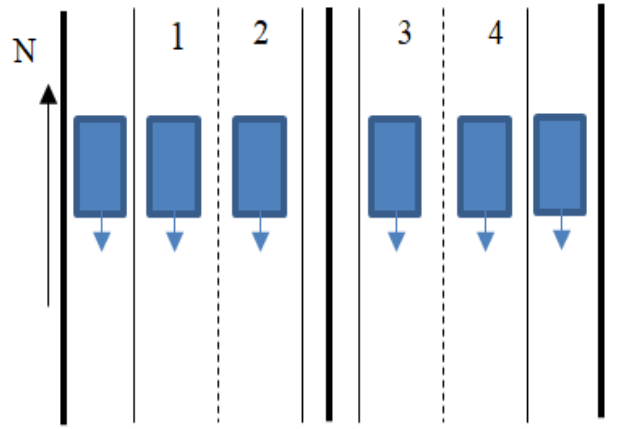
Top Solutions

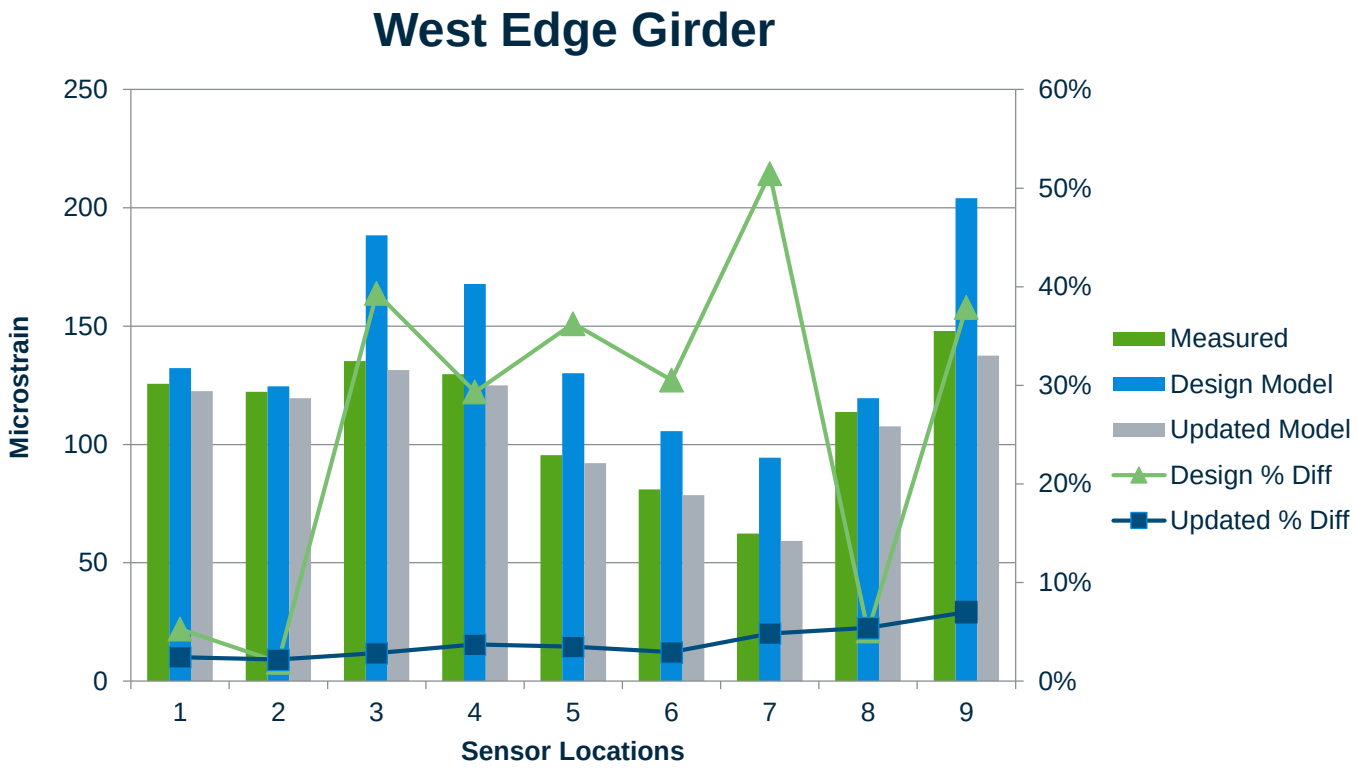
Metric	Solution 1	Solution 2	Solution 3
Objective	4.363	4.363	4.363
Violation	0	0	0
Parameter 1	1.5	1.5	1.5
Parameter 2	1.15	1.15	1.15
Parameter 3	1.45	1.5	1.5
Parameter 4	1.4	1.4	1.4
Parameter 5	1.6	1.6	1.6
Parameter 6	1.25	1.25	1.25
Parameter 7	1.35	1.35	1.35
Parameter 8	1.1	1.1	1.1
Parameter 9	1.55	1.55	1.55
Parameter 10	1.1	1.1	1.1
Parameter 11	1.05	1.05	1.05
Parameter 12	1.65	1.65	1.65
Parameter 13	1.55	1.55	1.55
Parameter 14	1.65	1.65	1.65
Parameter 15	1.55	1.5	1.55
Parameter 16	1.8	1.8	1.8
Parameter 17	1.2	1.2	1.2
Parameter 18	1.7	1.7	1.7

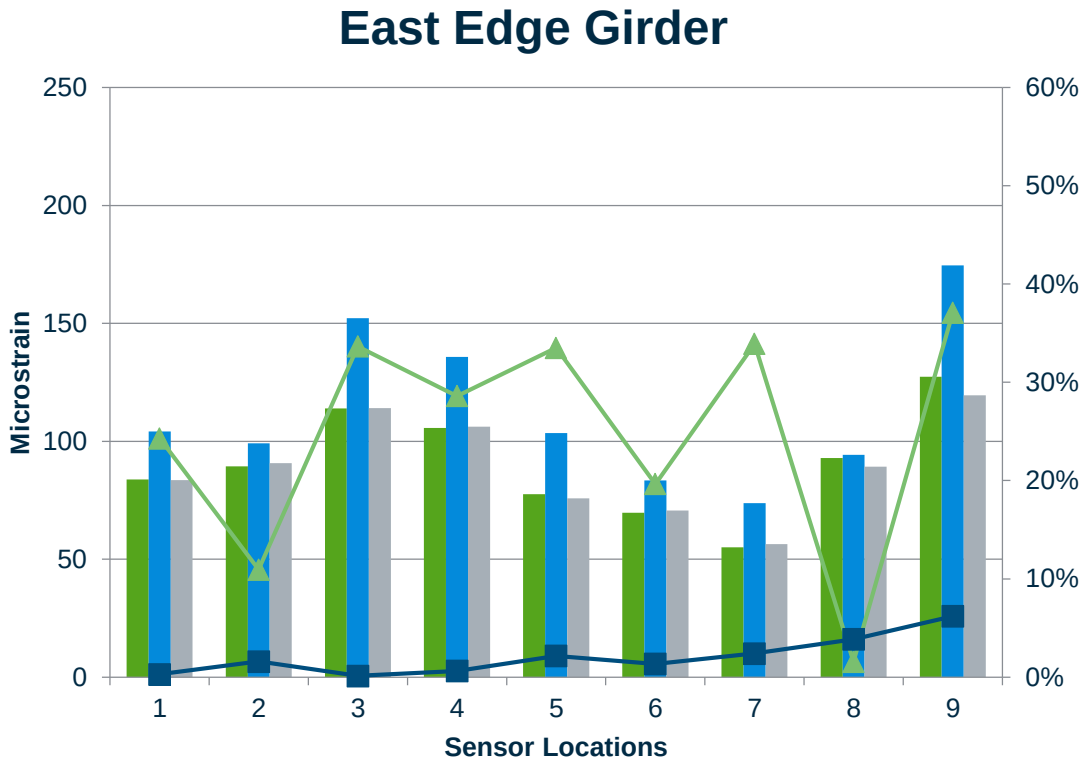


Validation of Calibrated Model

- 6-truck pass used for validation







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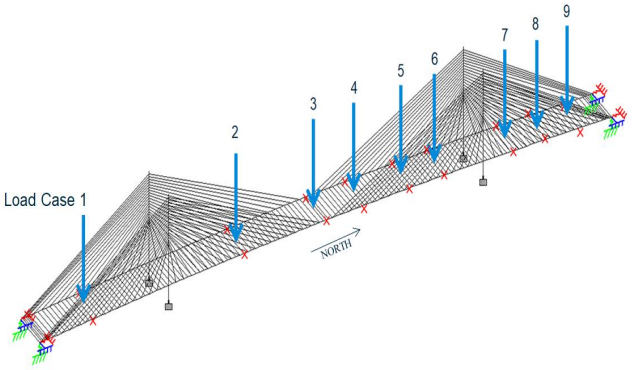
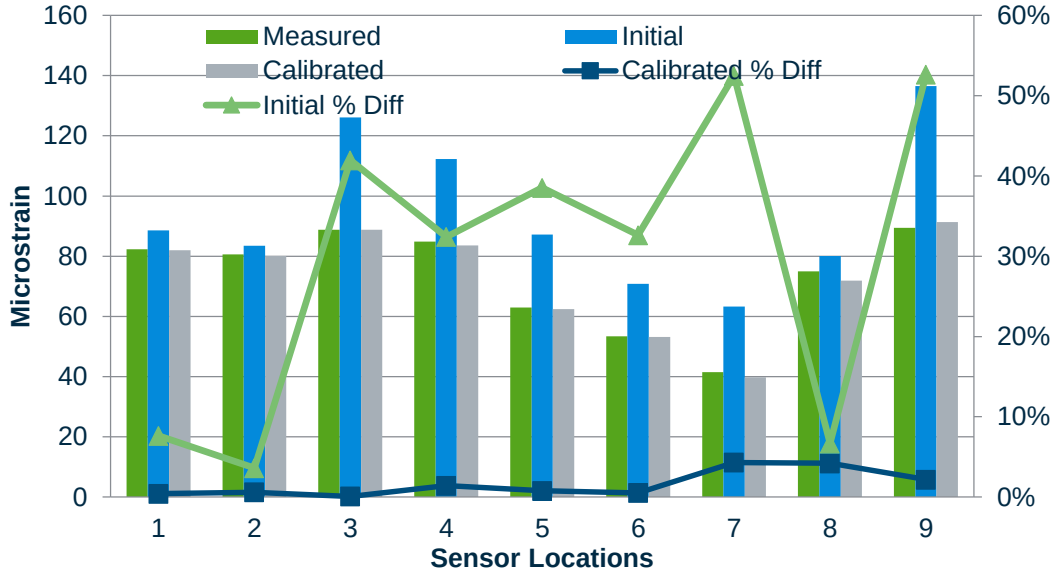
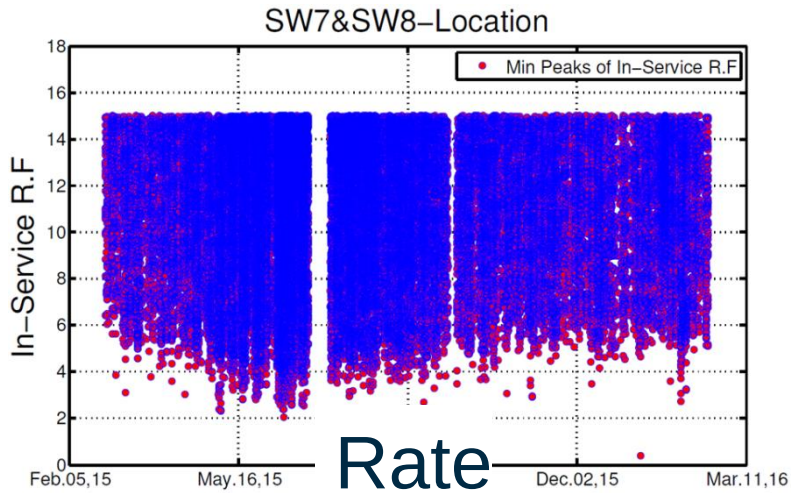
Structural Health Monitoring and Advanced Analysis of Bridges: A Pathway to Bridge Digital Twin



Calibrate





Rate

Video Camera as Sensor

- Conventional Sensors
  - Placed on structure
  - Limitations: high cost, safety concerns, service interruption
- Vision-based sensors
  - Remote sensing (non-contact)
  - Cost effective

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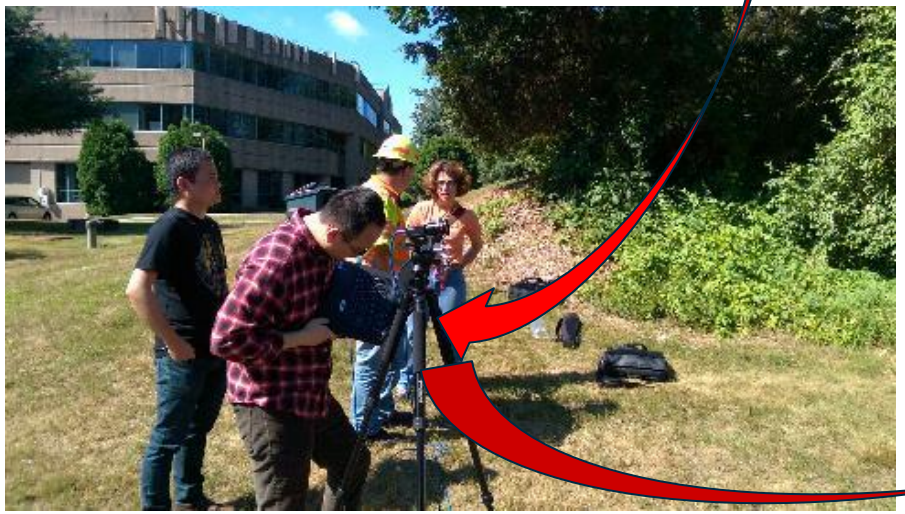
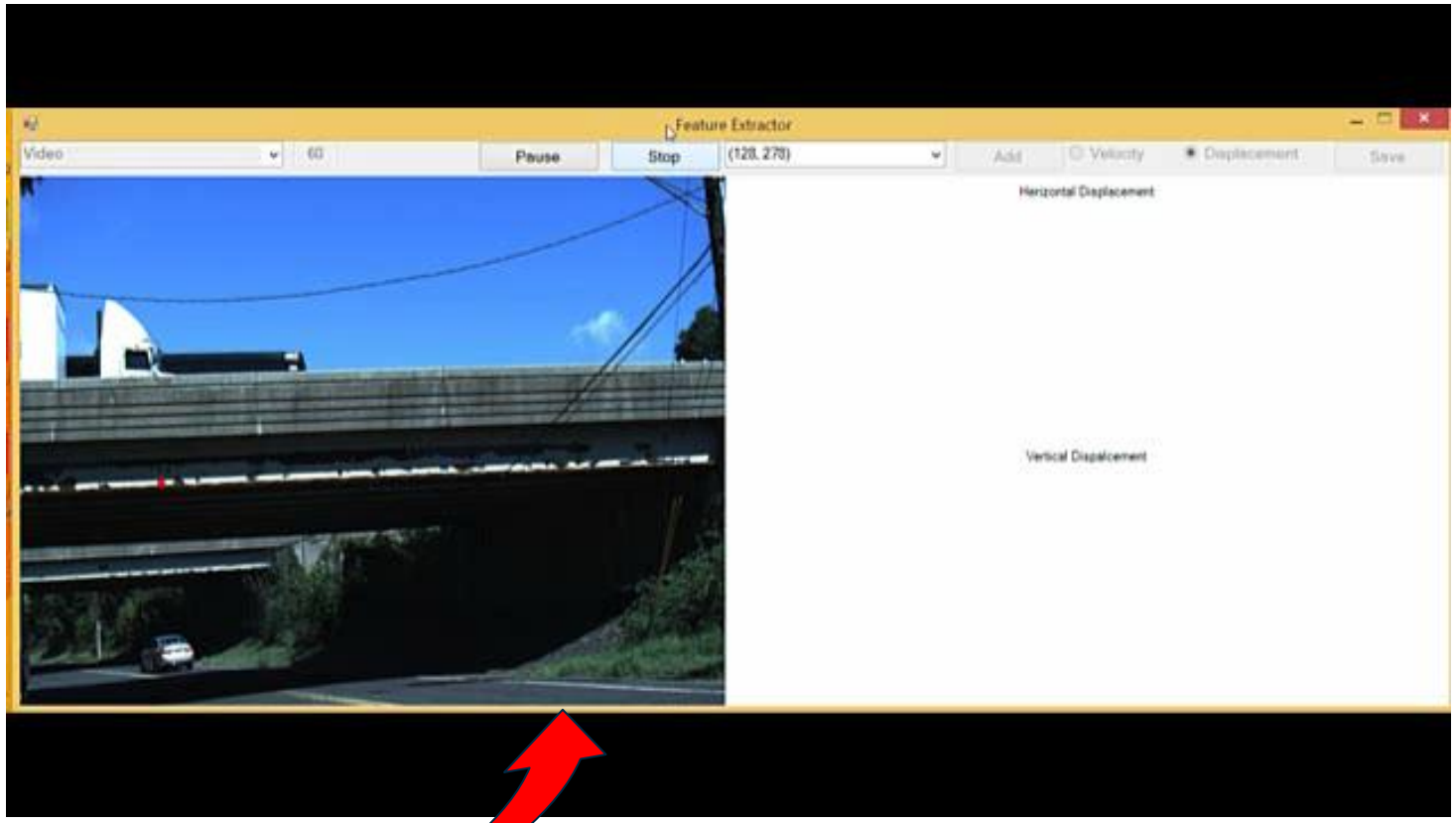
Vision Sensor (Video Camera) for SHM





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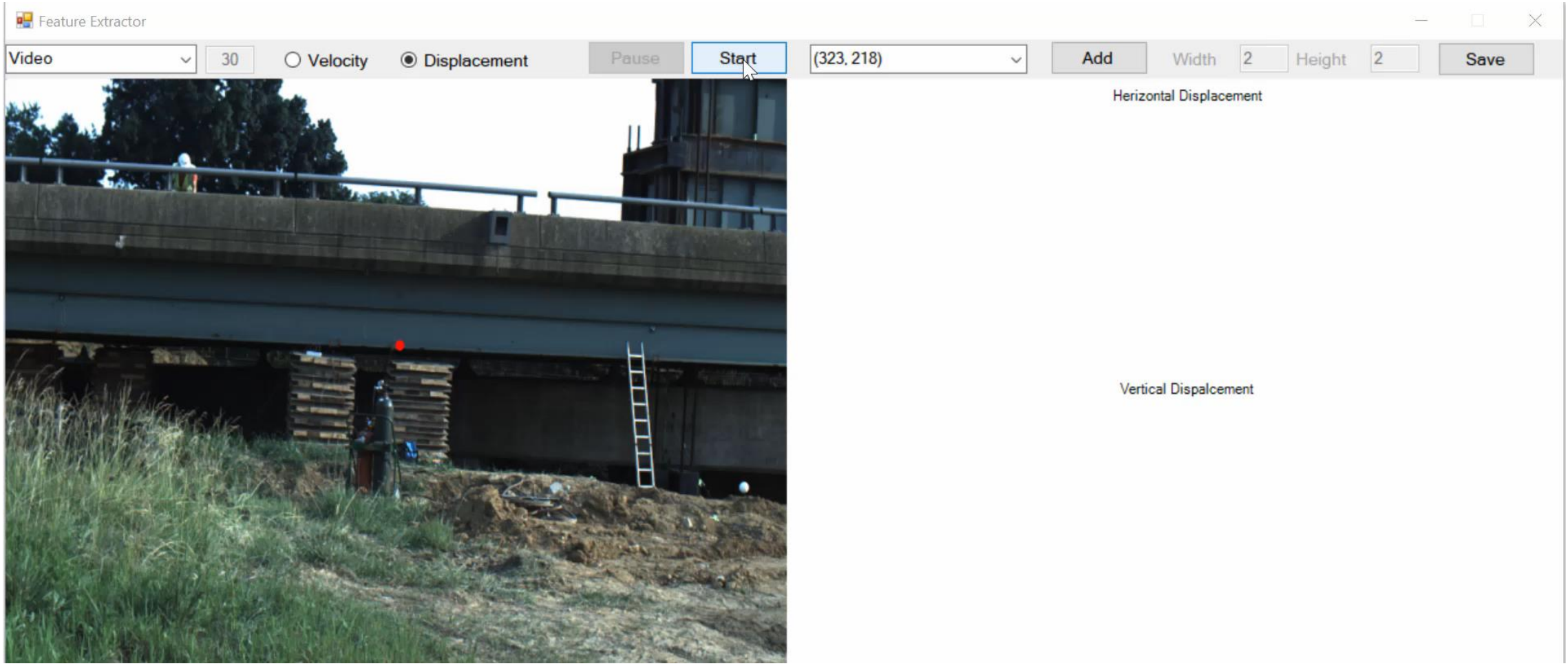
DRBA Bridges Test

- 28 strain gauges, 8 accelerometers, 6 displacement sensors and 2 tiltmeters (UD)
- Two video cameras (Bentley)
- Measuring responses for 5 cuts

Video Analysis for Extracting Structural Responses



Convention factor: 0.3137 inch/pixel

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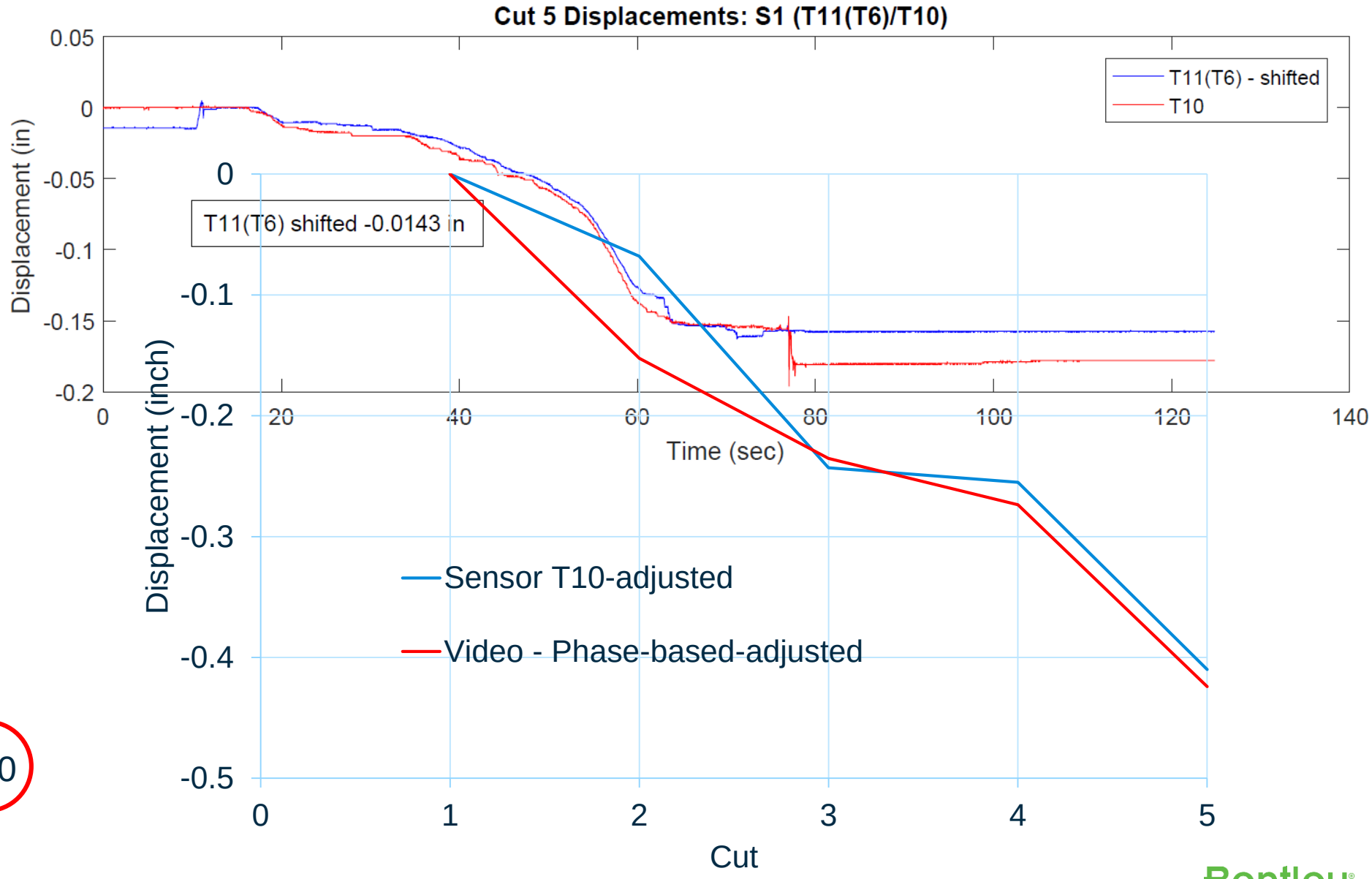
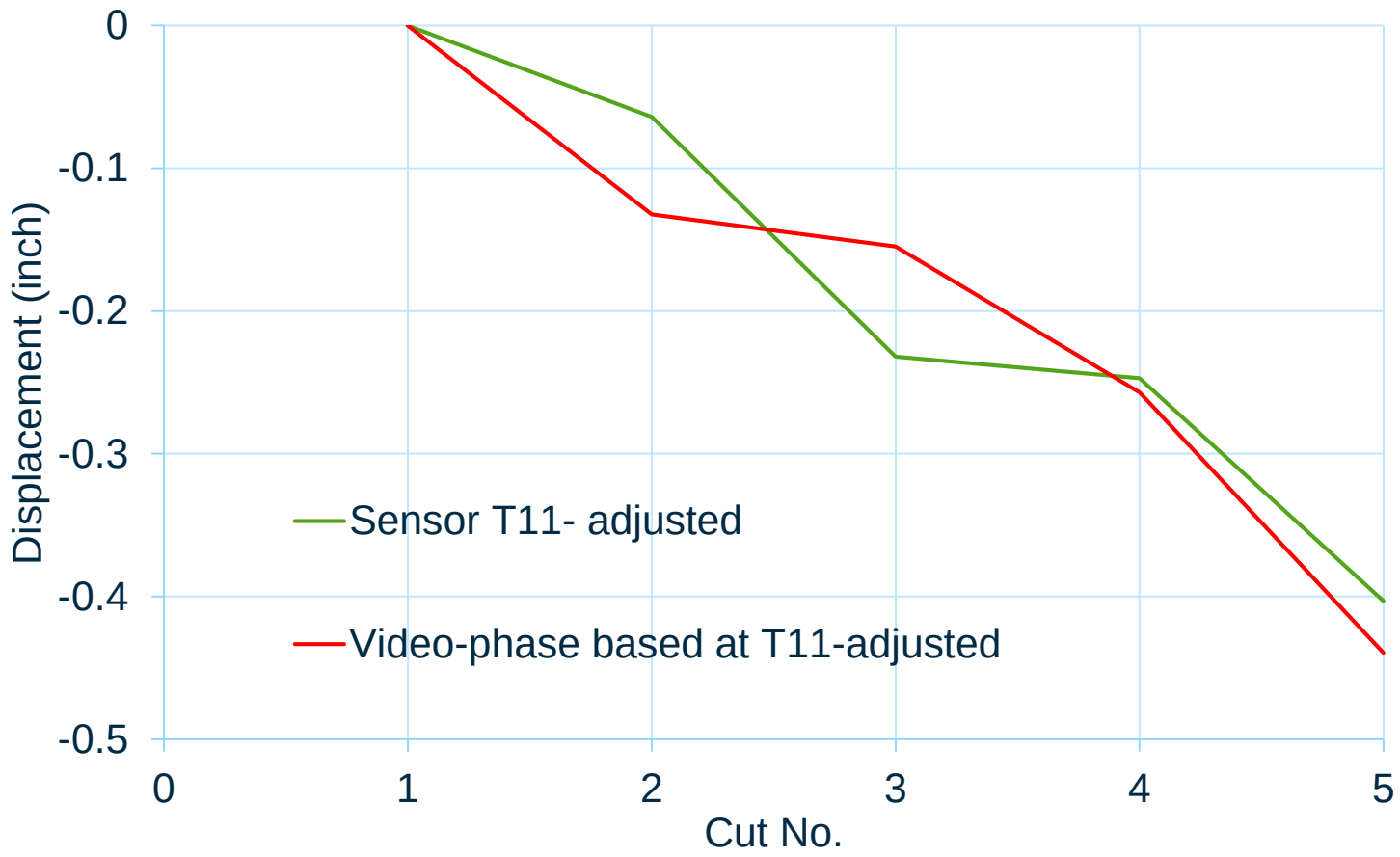
Comparison: Displacement at T10



Comparison: Displacement at T11



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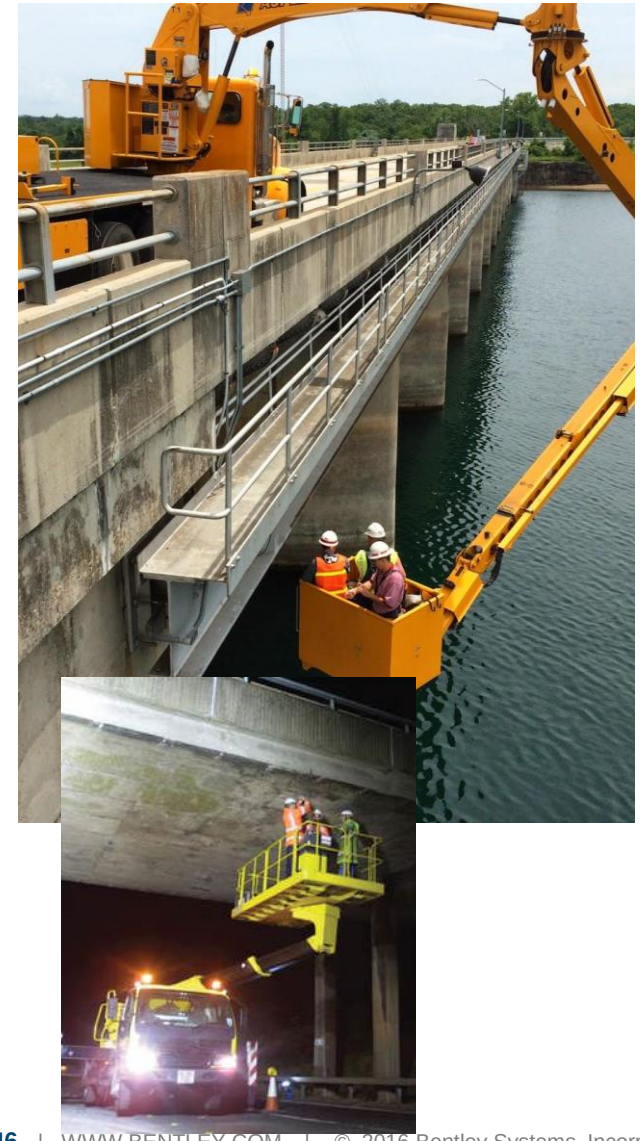
Infrastructure Inspection with Machine Learning



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Deep Learning Approach for Defect Detection

- Obtain inspection images and videos
- Work with Bentley users

- Label images with defects (e.g. cracks and corrosions)
- Train models e.g. Faster RCNN and/or Mask RCNN

- Model inference on images and/videos
- Applications of various cases (buildings, bridges, roads and tunnels)

- Build 3D model with inferenced images
- Perform defect statistics
  - Crack length, width and area
  - Level of corrosion and areas

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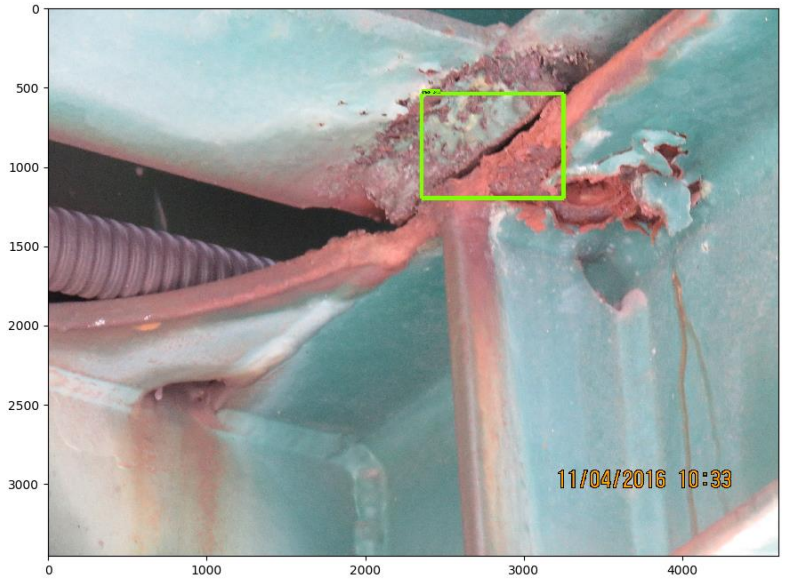
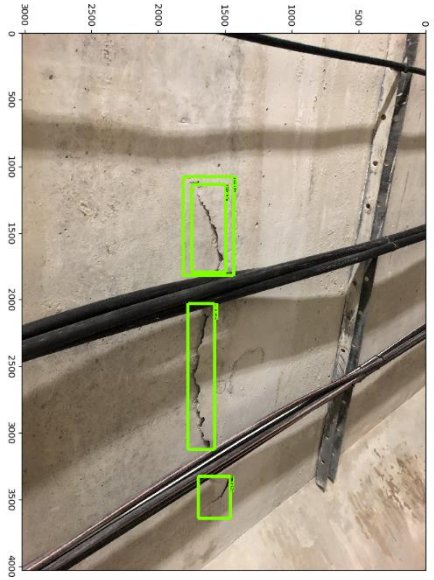
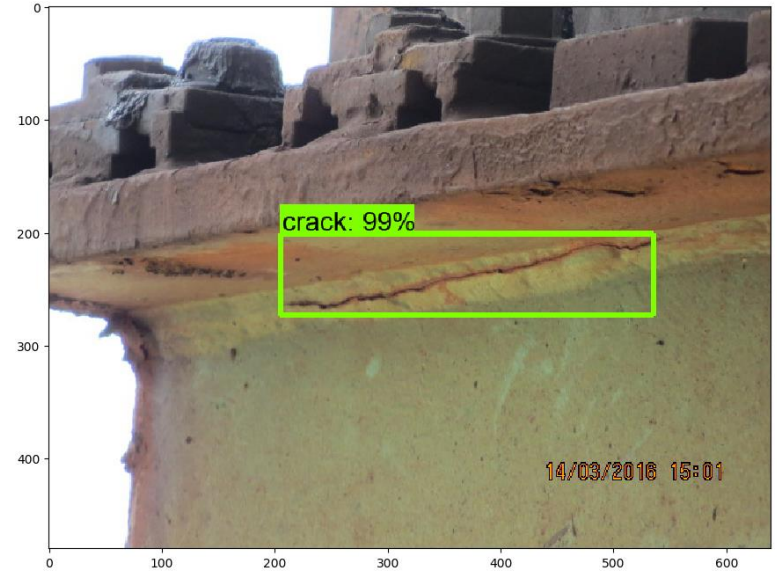
Deep Learning Model for Crack Detection







Deep Learning Applications – Crack Detection

Bridge with Deep Learning (Australia)

Road Inspection (Macao China)

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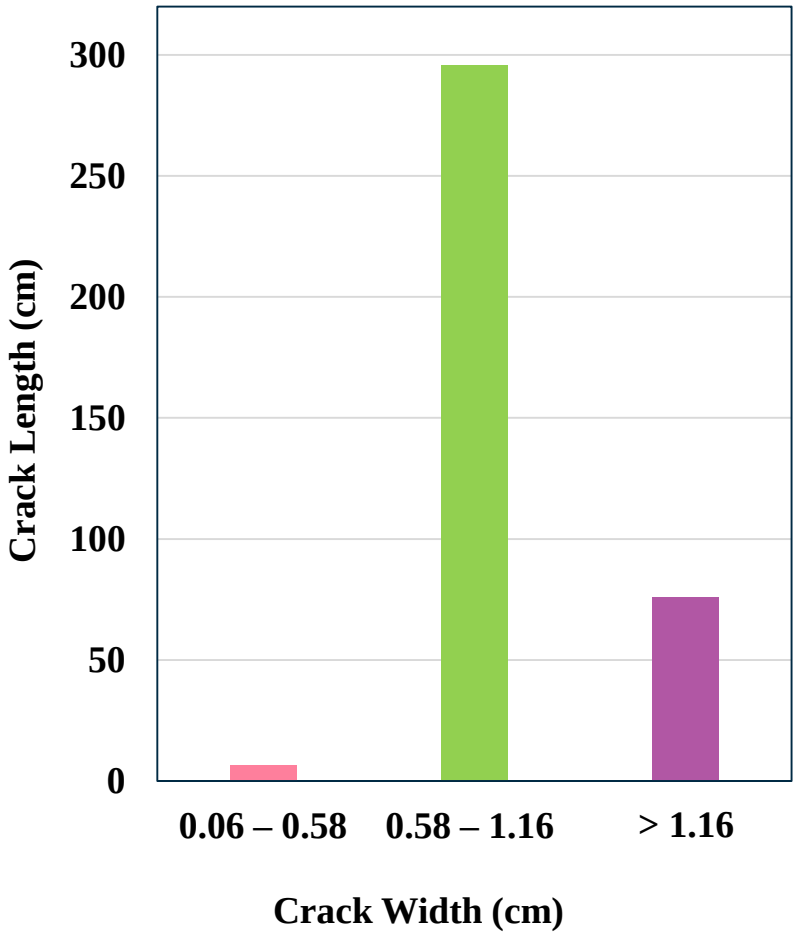
Crack Detection and Evaluation with 3D Model:



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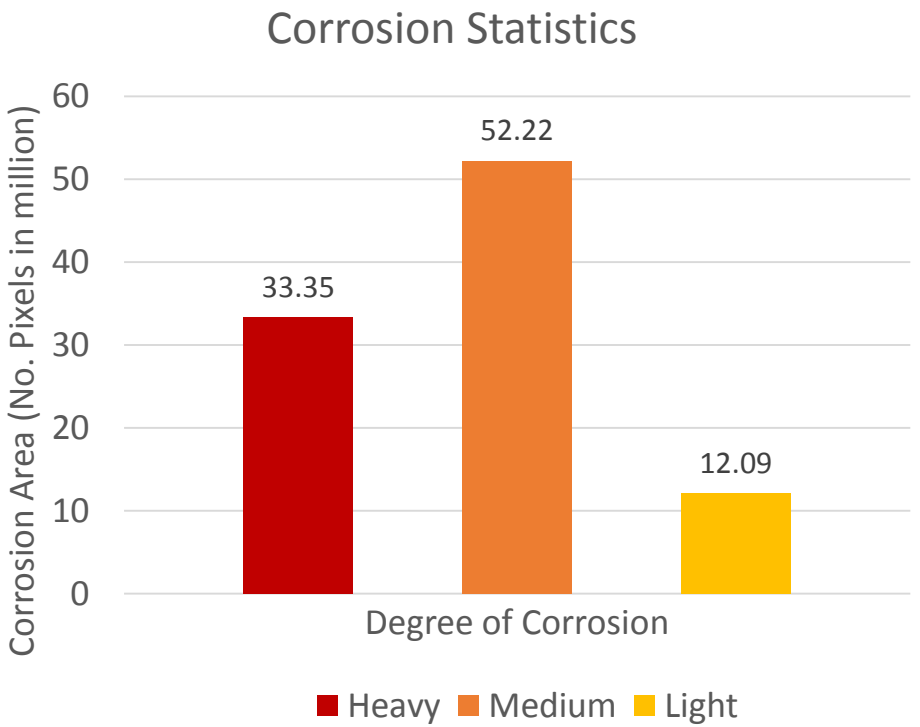
Corrosion Detection and Segmentation

- Applied semantic CNN (DeepLab) for corrosion detection and segmentation
- Classified by Corrosion Index (CI): Heavy: 0.75 < CI <=1; Medium: 0.6 < CI <=0.75; Light: 0<= CI <= 0.6



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Soft-Story Building Detection for Seismic Retrofit

- What is a soft story
  - level less than 70% as stiff as the floor immediately above it
- Characteristics of soft story buildings
  - multi-story building with Wide opening
  - Multi-use buildings with commercial retail on the ground floor
  - Retail buildings with mostly glass front

Examples of typical soft-story buildings

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Soft-Story Risk

- About 50% damaged homes at CA earthquake in 1989 were soft-story
- 1994 Northridge earthquake CA
  - about 200 buildings seriously damaged or destroyed
  - 16 people died at Northridge Meadows soft story apartment complex

- **Need for retrofitting soft story**

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Soft-story Buildings Classification

- Buildings classified by engineers
  - Accurate but time consuming
  - Good dataset for training deep learning models

- Apply deep learning
  - Images from Google Street View
  - Training data from Los Angeles
  - Testing data from Santa Monica

Soft-story buildings map. Classified by engineers at Santa Monica, CA

A typical soft-story building from google street view using Santa Monica DS

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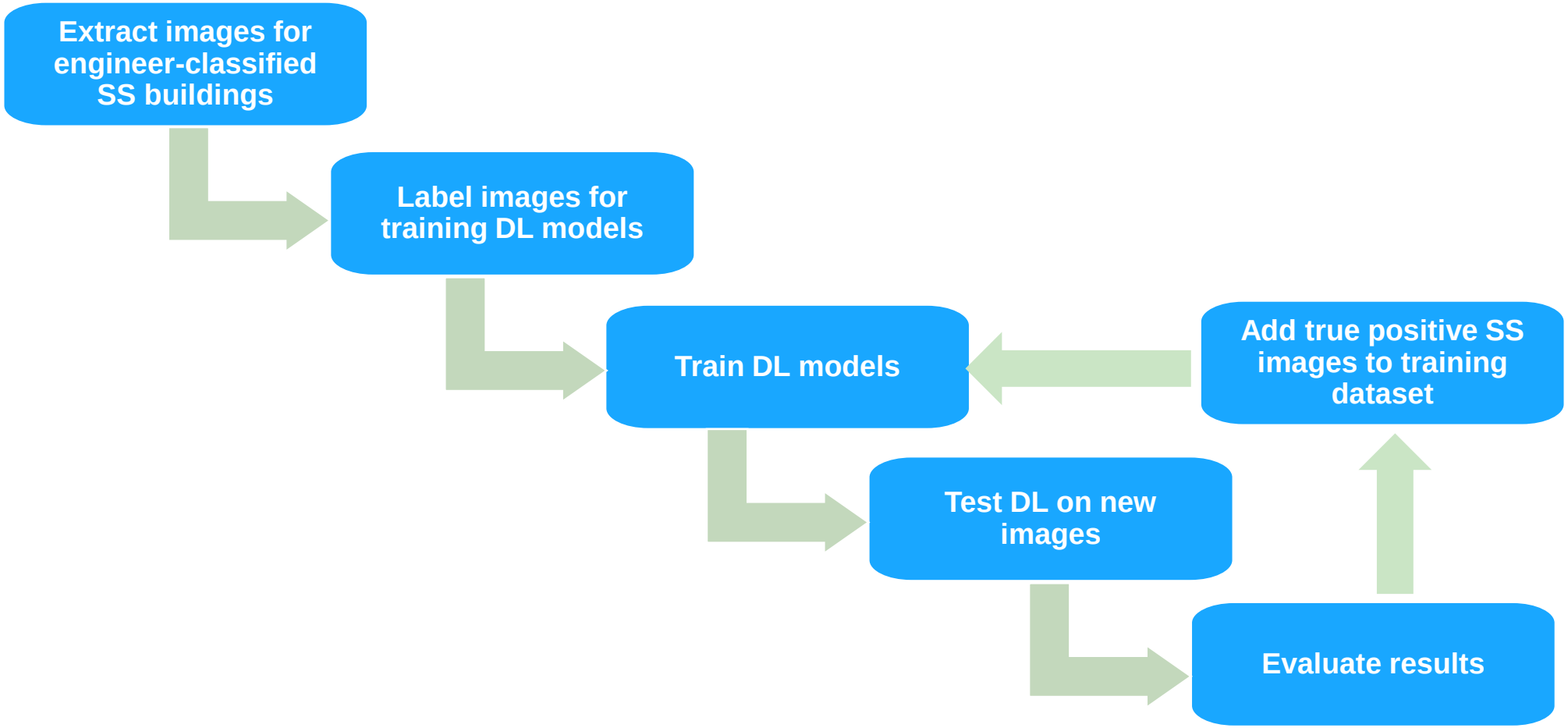
Proposed Approach



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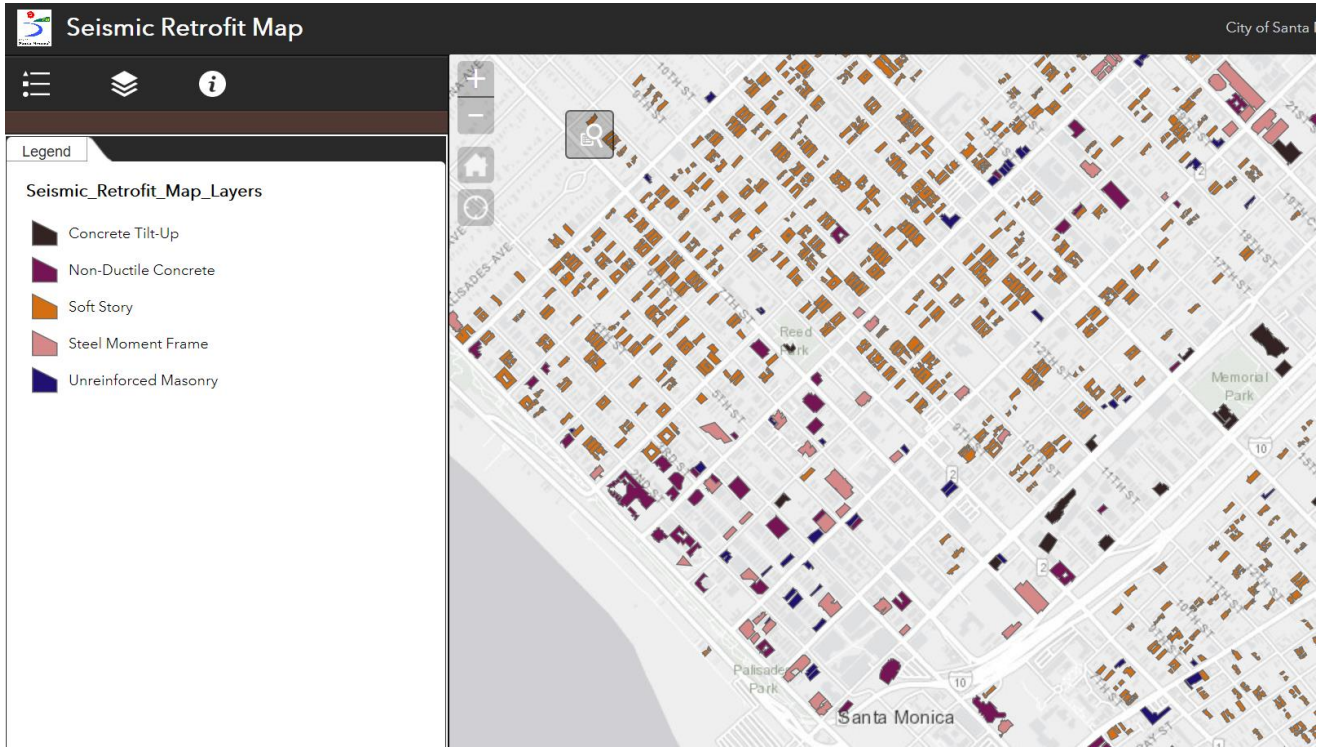
Dataset

- Training
  - 1267 Buildings classified by engineers
  - non-soft story buildings
- Testing
  - 1500 building from Santa Monica
  - non-soft story buildings



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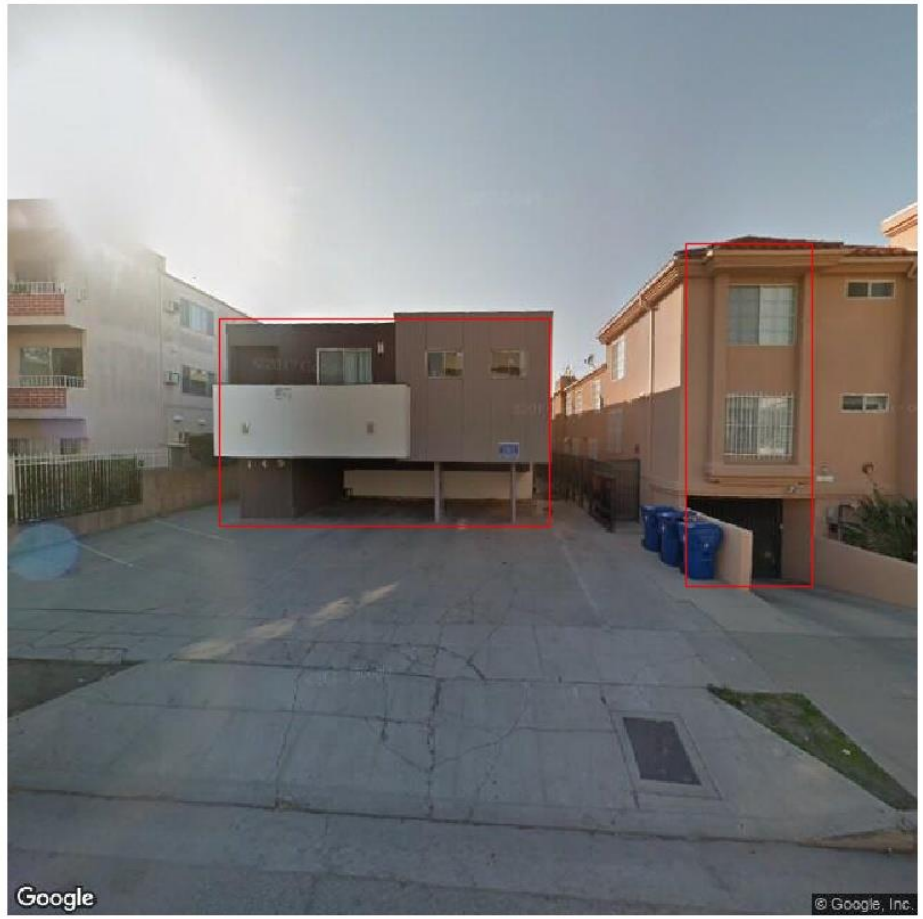
Soft-story Detection

- Data sets preparation
  - Only using images of buildings with clear opening of the first floor (900 images)
  - Annotate only part of the building that may cause collapse.
- Training
  - Use 800 images for training and 100 images for testing
  - Using feature extractor network with the best accuracy, ResNet101 & Inception-ResNet



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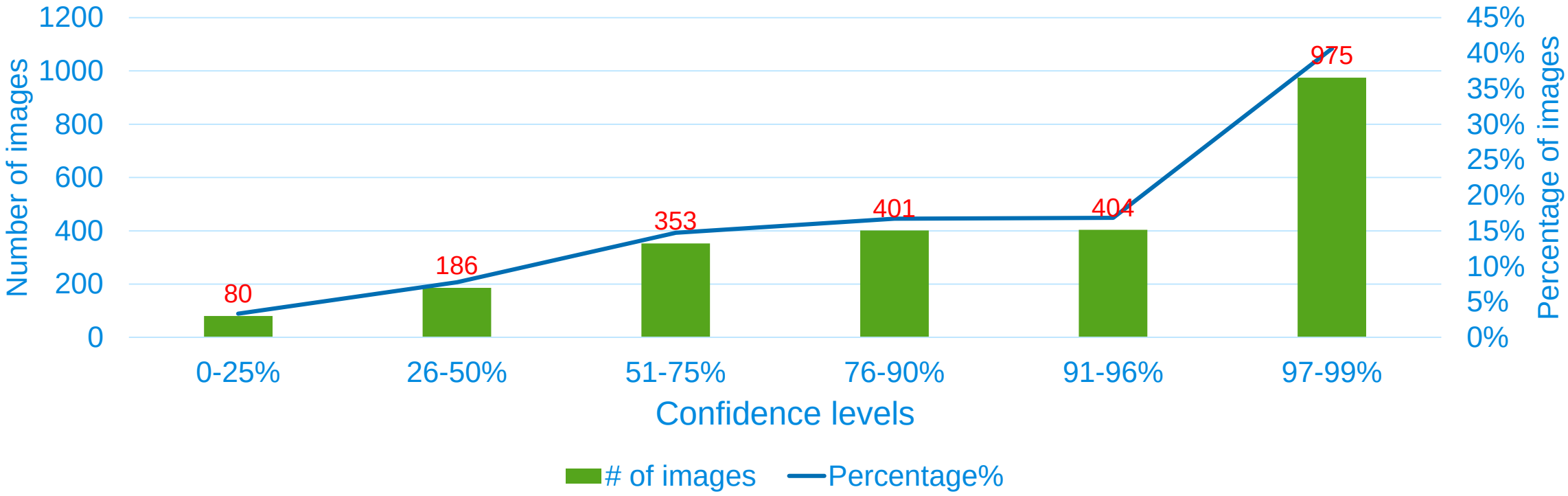
SS Detection Model Performance

- Tested 2399 images
- 75% detected with confidence >75%



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Integrated Work Flow for Soft Story Detection

Obtain List of Address → Download Images from Google Street View → Run Inception-ResNet for Soft-Story Detection → Annotate SS in Google Map

Address	City	State	Zip
5802 4TH AVE NW	SEATTLE	WA	98107-2117
5806 4TH AVE NW	SEATTLE	WA	98107-2117
5808 4TH AVE NW	SEATTLE	WA	98107-2117
5814 4TH AVE NW	SEATTLE	WA	98107-2117
5820 4TH AVE NW	SEATTLE	WA	98107-2117
5822 4TH AVE NW	SEATTLE	WA	98107-2117
5824 4TH AVE NW	SEATTLE	WA	98107-2117
5828 4TH AVE NW	SEATTLE	WA	98107-2117
5834 4TH AVE NW	SEATTLE	WA	98107-2117
5834 1/2 4TH AVE NW	SEATTLE	WA	98107-2117
5838 4TH AVE NW	SEATTLE	WA	98107-2117
5842 4TH AVE NW	SEATTLE	WA	98107-2117
5844 4TH AVE NW	SEATTLE	WA	98107-2117
310 NW 60TH ST	SEATTLE	WA	98107-2138

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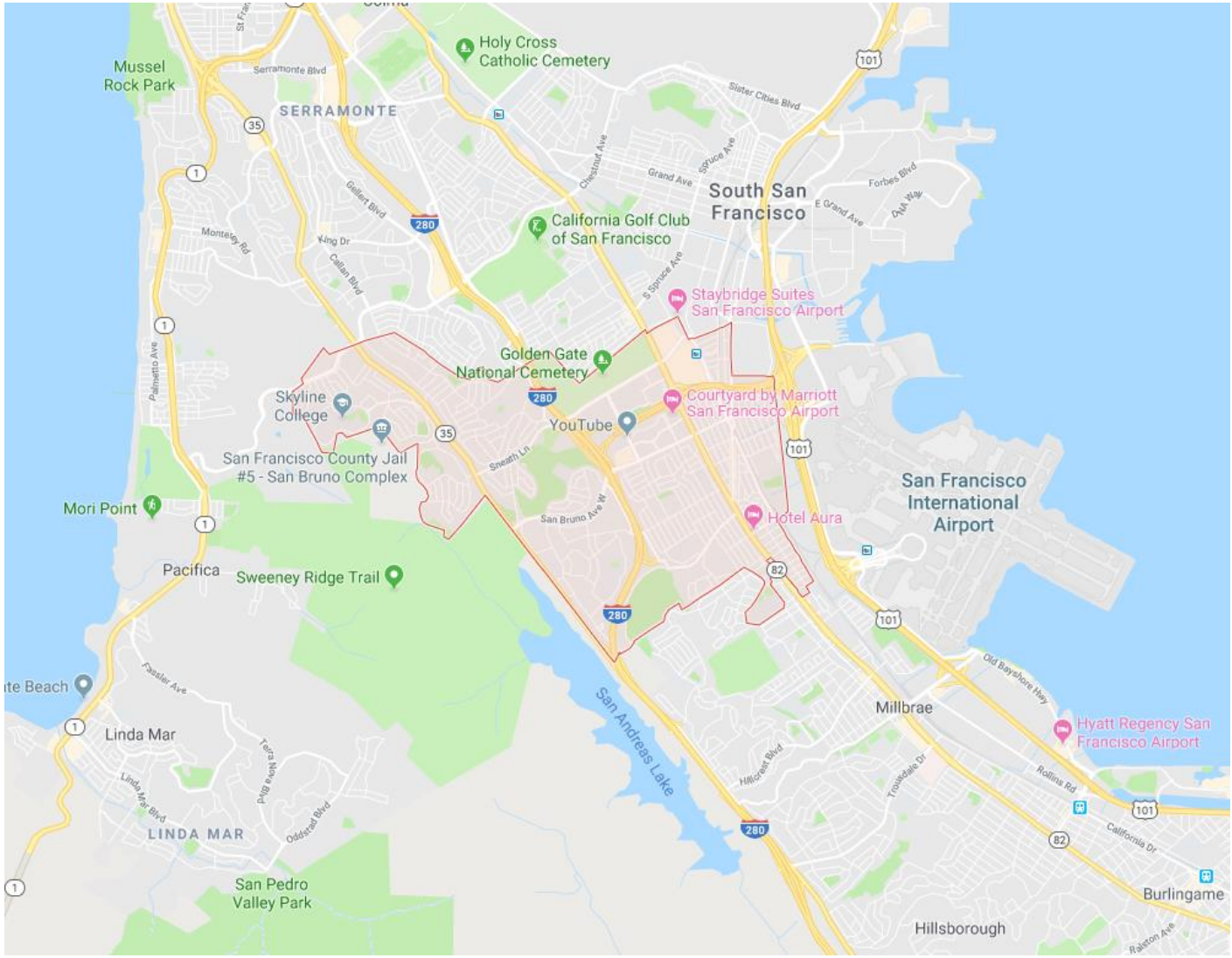
Test Area: San Bruno, CA

- Acquired and tested ~7600 addresses.
- ~3400 addresses were detected as soft-story.



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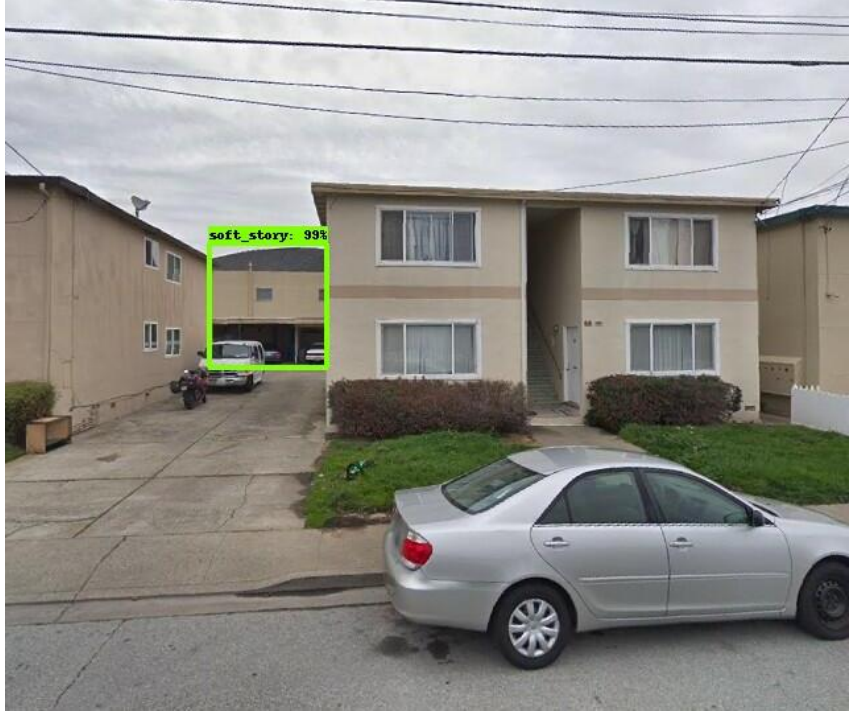
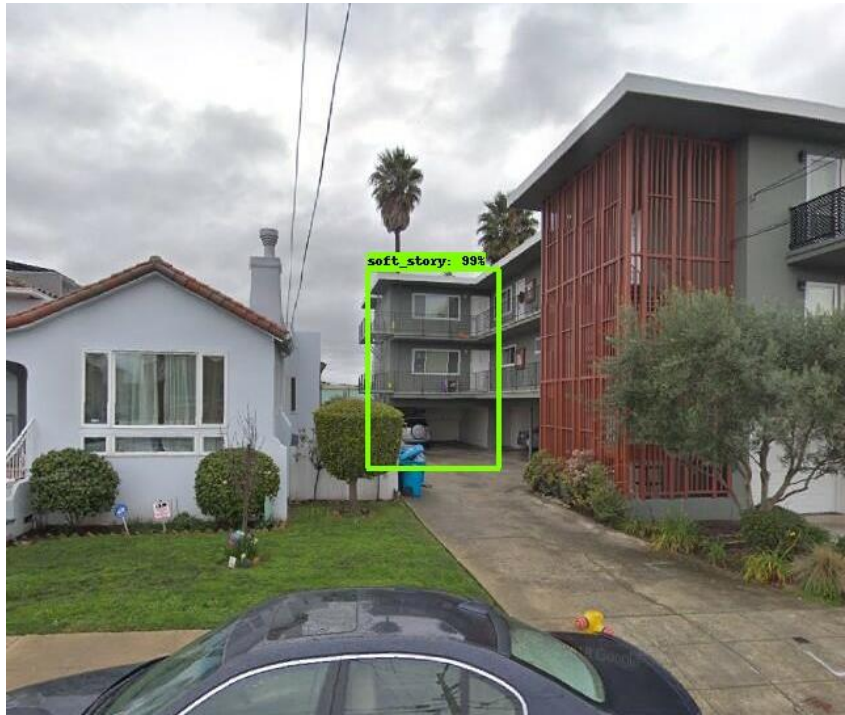
soft_story: 99%


soft_story: 99%

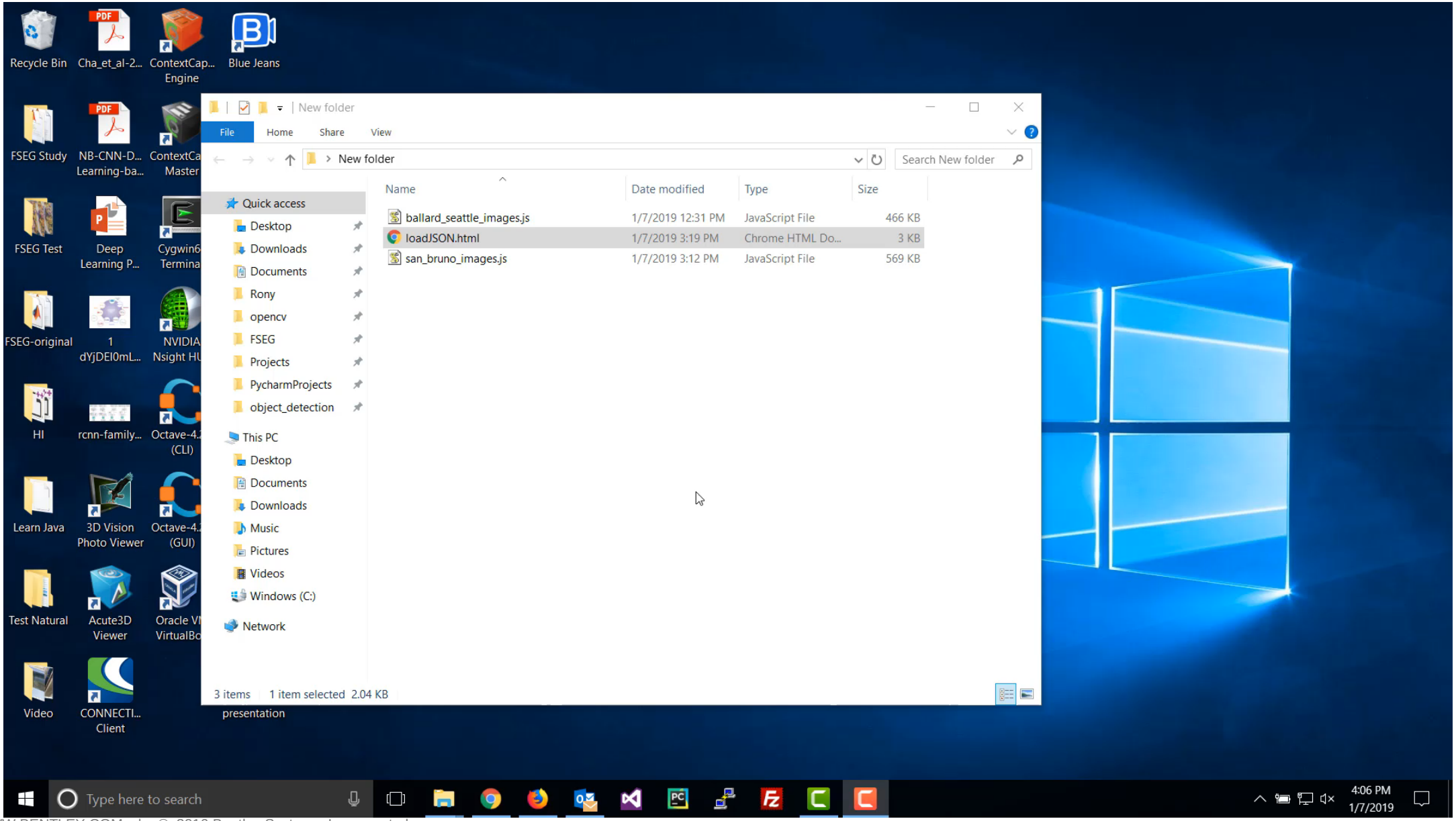

soft_story: 60%


soft_story: 99%


soft_story: 99%


soft_story: 99%

SS Buildings Annotated in Google Map (San Bruno, CA)



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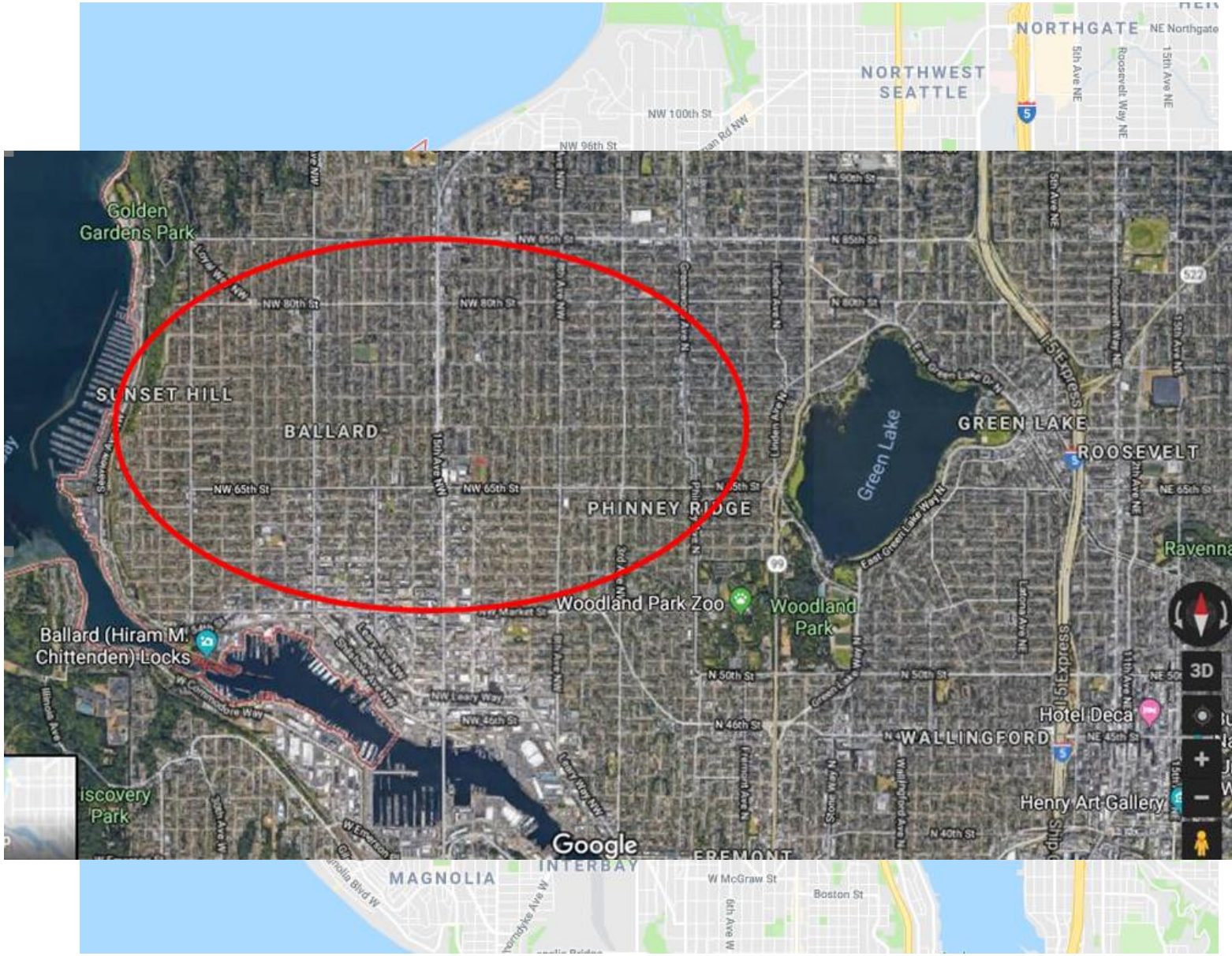
Test Area: Seattle, WA

- Acquired and tested ~8200 addresses.
- ~2700 addresses were detected as soft-story.

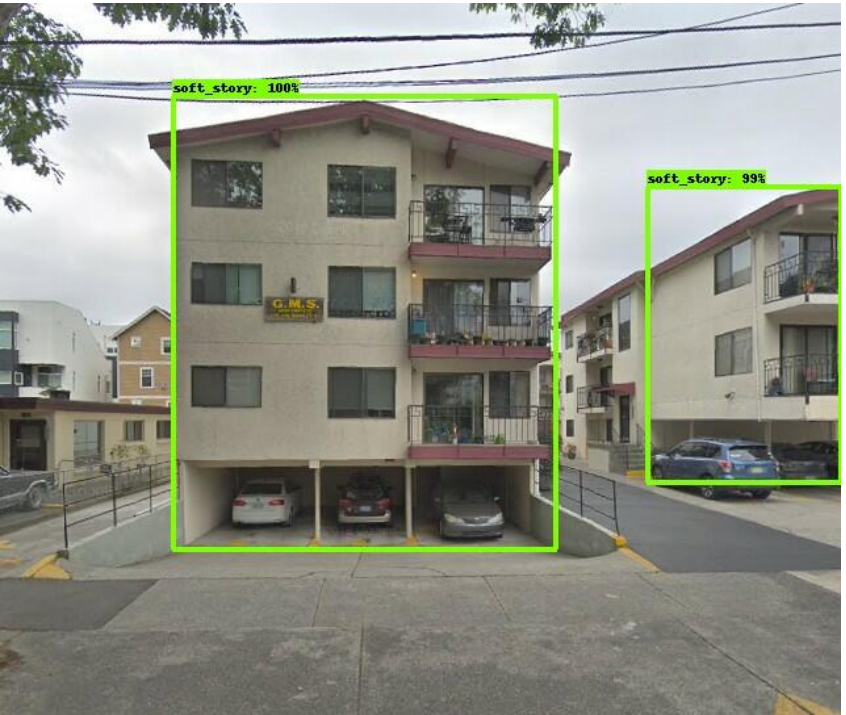


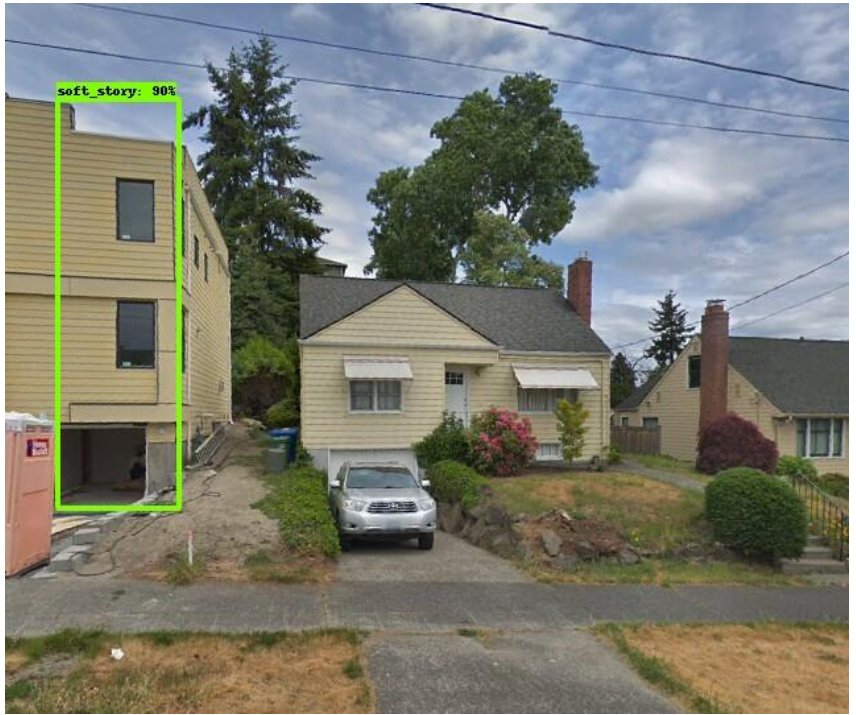
Bentley

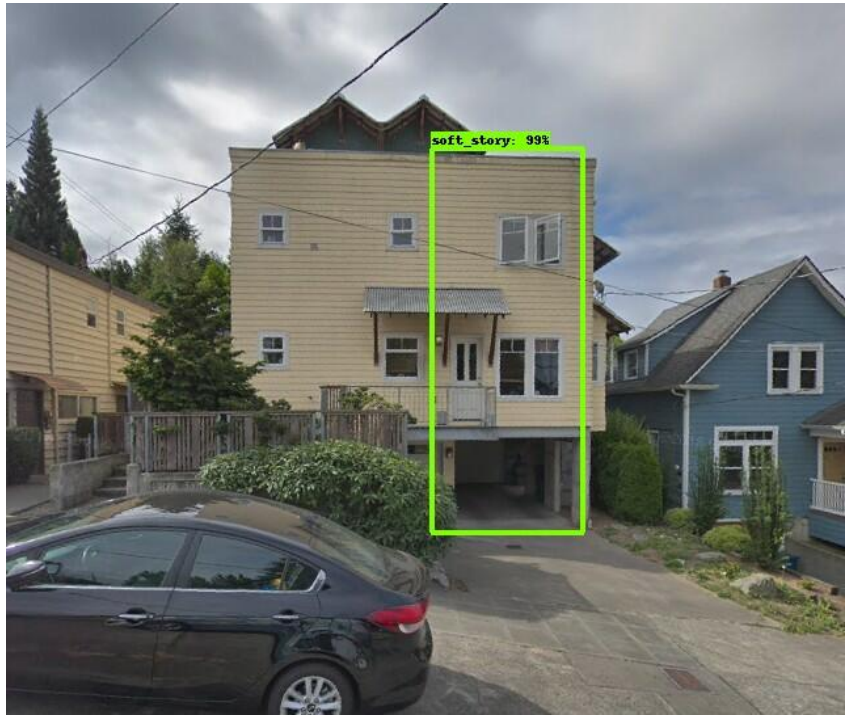

soft_story: 100%
soft_story: 99%


soft_story: 99%
soft_story: 99%

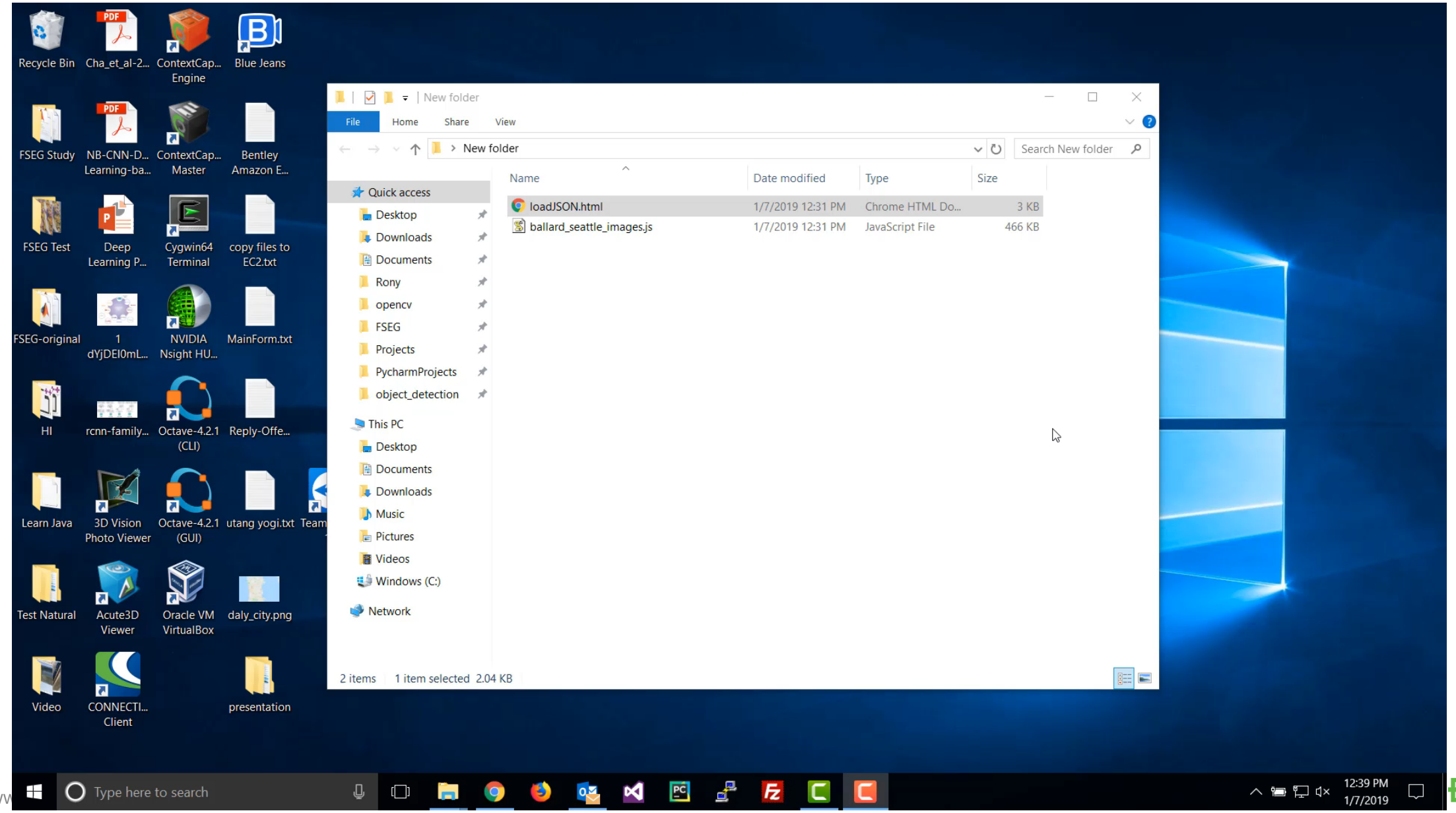

soft_story: 99%


soft_story: 100%
soft_story: 99%


soft_story: 90%


soft_story: 99%

SS Buildings Annotated in Google Map (Seattle, WA)



Research Collaborations

- Multidiscipline：Civil/Environmental/structural，Electrical Eng., Computer science etc.
- Multi Sectors: Water，power, transportation and buildings etc.

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Summary

- Research for AI-based systematic approaches
- Connect data environment with Bentley software
- Construct various digital models
  - Semantic models: 3D mesh/texture models, point cloud etc.
  - Data-driven: machine learning, statistics etc.
  - Physics-based: finite element analysis, hydraulics and water quality etc.
  - Decision-support: optimization models
- Enable digital twin for smart infrastructure
- Accelerate computations

Thank You !

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