Japan-U.S. Collaboration on the Seismic Performance of Reinforced Concrete Structures

NSF Award Number: CMMI 2000478

UNIVERSITY of WASHINGTON

INTRODUCTION

BRIEF PROJECT OVERVIEW

CONTEXT AND PROJECT FOCUS

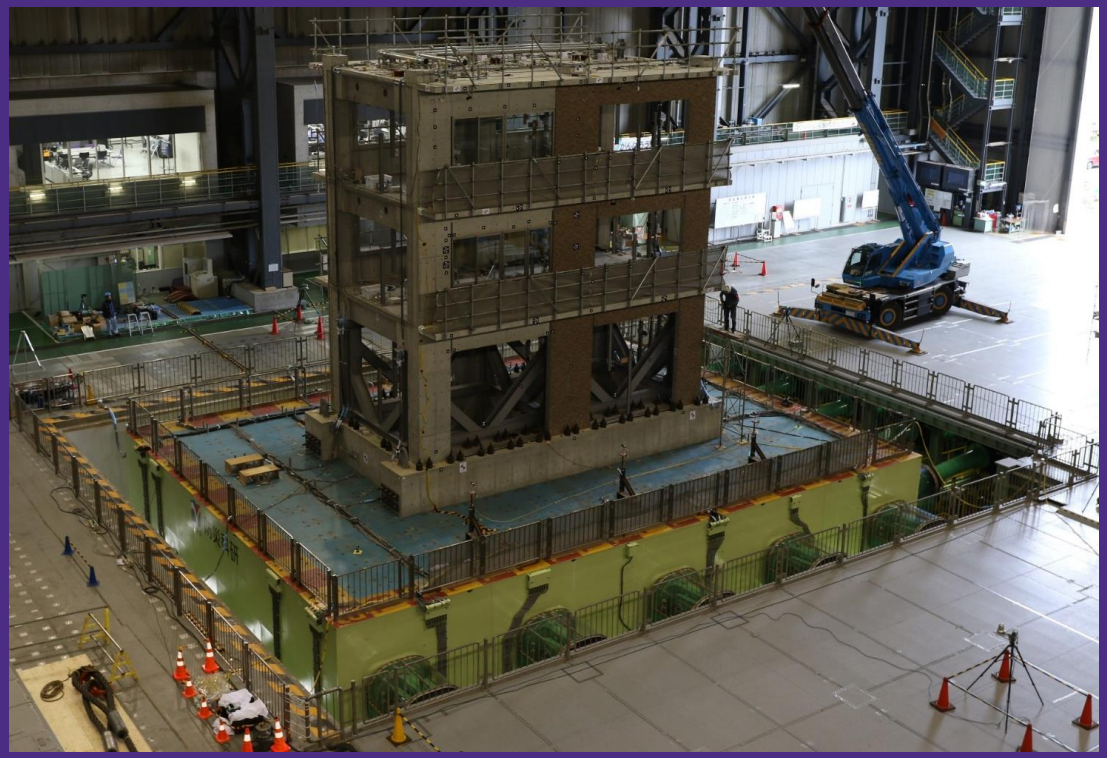
Context: Damage-based post-earthquake assessment of reinforced concrete buildings

Main focus: Collection of “controlled” data and data processing

E-DEFENSE FULL-SCALE SHAKE TABLE TEST

Tokyo Metropolitan Resilience Project:

Full scale shake table test of 3-story reinforced concrete building



PROJECT ACTIVITIES/OBJECTIVES

- Deploy state of the art equipment available through the NEHRI RAPID Facility (lidar)
- Collect experimental data (i.e. point clouds) while gaining reconnaissance experience in a controlled environment
- Process data collected and evaluate data quality in the context of extracting relevant performance features (e.g. global displacements, inter-story drifts, crack locations, crack orientation and crack opening)

US RESEARCH TEAM

University of Washington (lead institution) – LiDar

Paolo M. Calvi (PI), Laura Lowes (Co-PI), Tatsuiko Sweet (Graduate student), Tyson Touma (Undergraduate student)

"RAPID" Facility

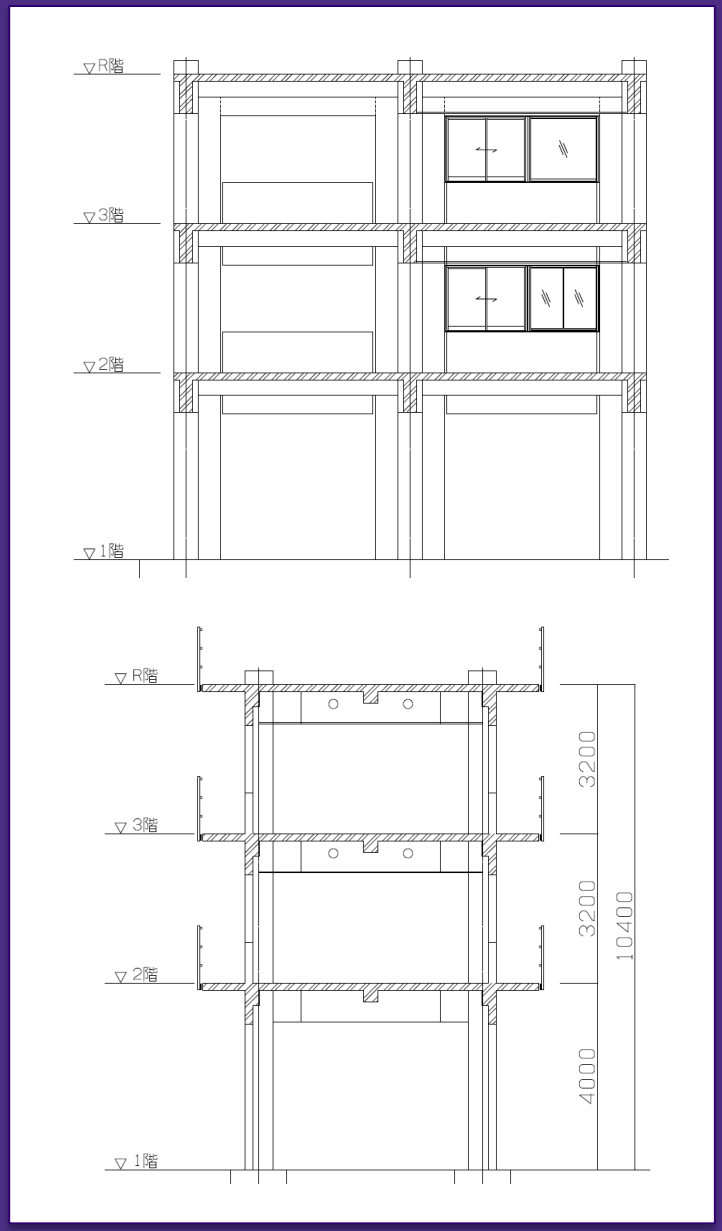
Jeff Berman (RAPID Facility Operations Director), Jacqueline Peltier (RAPID Facility Operations Specialist) and Andrew Layda (RAPID Facility Operations Engineer)

University of Nevada, Reno – Digital Image Correlation (DIC)

Mohamed Moustafa (PI) , Luna Ngeljaratan (Postdoc)

TEST SPECIMEN

- 3-Story Concrete Moment Frame
- 10.4m (34ft) tall
- Investigate the impact and behavior of structural and non-structural elements
- Note: Ground motion was applied in E-W direction only



TEST SPECIMEN

- Non-structural concrete details:
  - Standing wall
  - Hanging wall
  - Seismic slits
  - Wing wall

- Other non-structural elements:
  - Suspended Ceiling
  - Traditional Mortar vs Epoxy for tile
  - Pipes on roof, attached vs non-attached
  - Window

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TESTING AND SCANNING TIMELINE

Baseline (BL) Scans

12/3 Day 1:
- Design wave 20%
- Design wave 100%

Test 1 (T1) Scans

12/4 Day 2:
- Design wave 150% (1)

Test 2 (T2) Scans

12/6 Day 3:
- Design wave 150% (2)
- Design wave 160%

Test 3 (T3) Scans

EQUIPTMENT USED

SCANNERS AND TOTAL STATION

EQUIPMENT USED

Leica RTC360 3D Laser Scanner

- High Portability
- Fast 3D scanning (3mm at 10m setting used)
- Panoramic images
- Semi-automatic point cloud registration

Image from: https://leica-geosystems.com/products/laser-scanners/scanners/leica-rtc360

EQUIPMENT USED

Leica RTC360 3D Laser Scanner

- Scans entire surrounding in 5 mins, including unwanted points
- Lower resolution than P50
- Resulting dataset can be excessively large

Image from: https://leica-geosystems.com/products/laser-scanners/scanners/leica-rtc360

EQUIPMENT USED

Leica ScanStation P50

- Long-range (> 1km)
- High-resolution scans (0.8mm at 10m setting used)
- Can select scan region
- Line Scan mode

Image from: https://leica-geosystems.com/en-us/products/laser-scanners/scanners/leica-scanstation-p50

EQUIPMENT USED

Leica ScanStation P50

- Can do a quick, low-res scan (equivalent to RTC360) in approximately 5 mins
- Typical setup took 40-60 mins (max resolution scans can take 2 hours+)
- Heavy compared to RTC360

Image from: https://leica-geosystems.com/en-us/products/laser-scanners/scanners/leica-scanstation-p50

EQUIPMENT USED

Leica Nova TS16i

- Robotic Total Station
- Scan range of 3.5km with prism and 1km on any surface
- High accuracy and precision (readings used as control for P50 and RTC360 point clouds)

Image from: https://abtech.cc/en/produits/leica-viva-ts16a-ts16p-et-ts16i/

DATA COLLECTION

LIDAR DATA AND CONTROL COORDINATES

DATA COLLECTION

LiDAR Data and Control Coordinates

- **RTC360**: Scans from ground level, balcony, table, and interior to get full picture of environment. MANY LOWER RESOLUTION SCANS
- **P50**: Scans focused on specimen, especially damaged areas. FEWER SCANS but HIGH RESOLUTION
- **TS16i**: Coordinates for control targets on facility and specimen collected from 3 locations (2 from South Balcony, 1 from East Ground level)

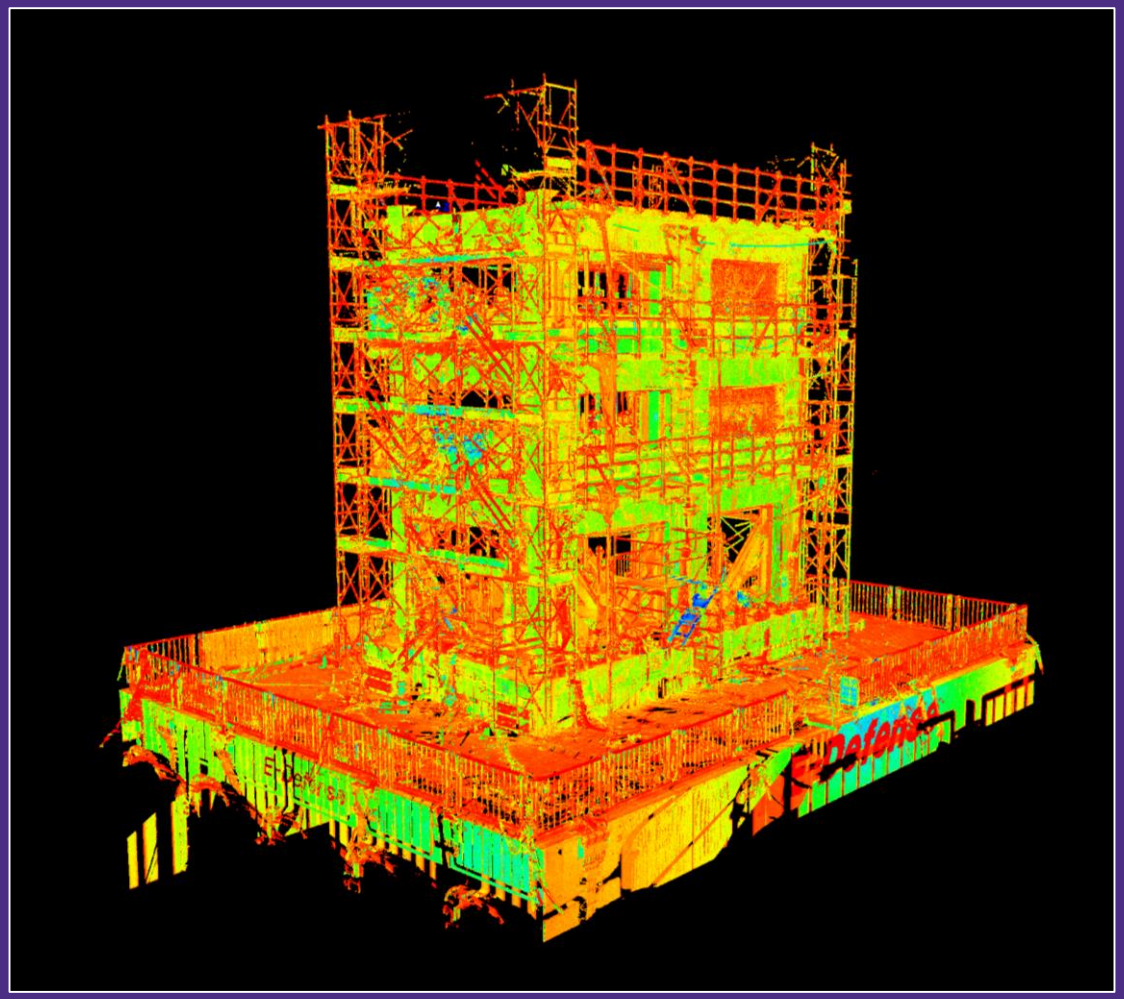
Point Cloud (Specimen Isolated)

Each point contains:

> x, y, z coordinates

> Intensity

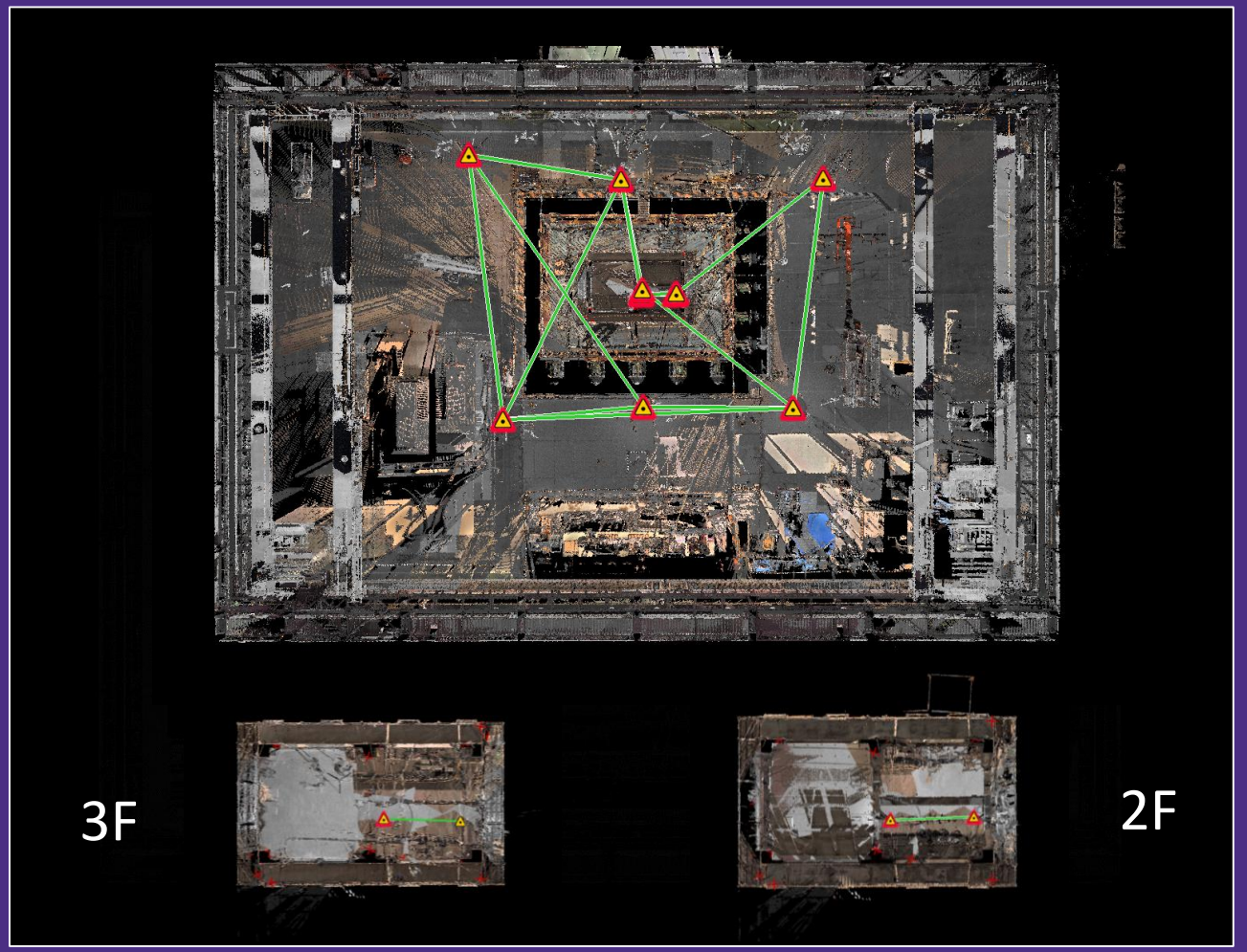
> RGB color values



P50 scans from T3 shown, intensity view

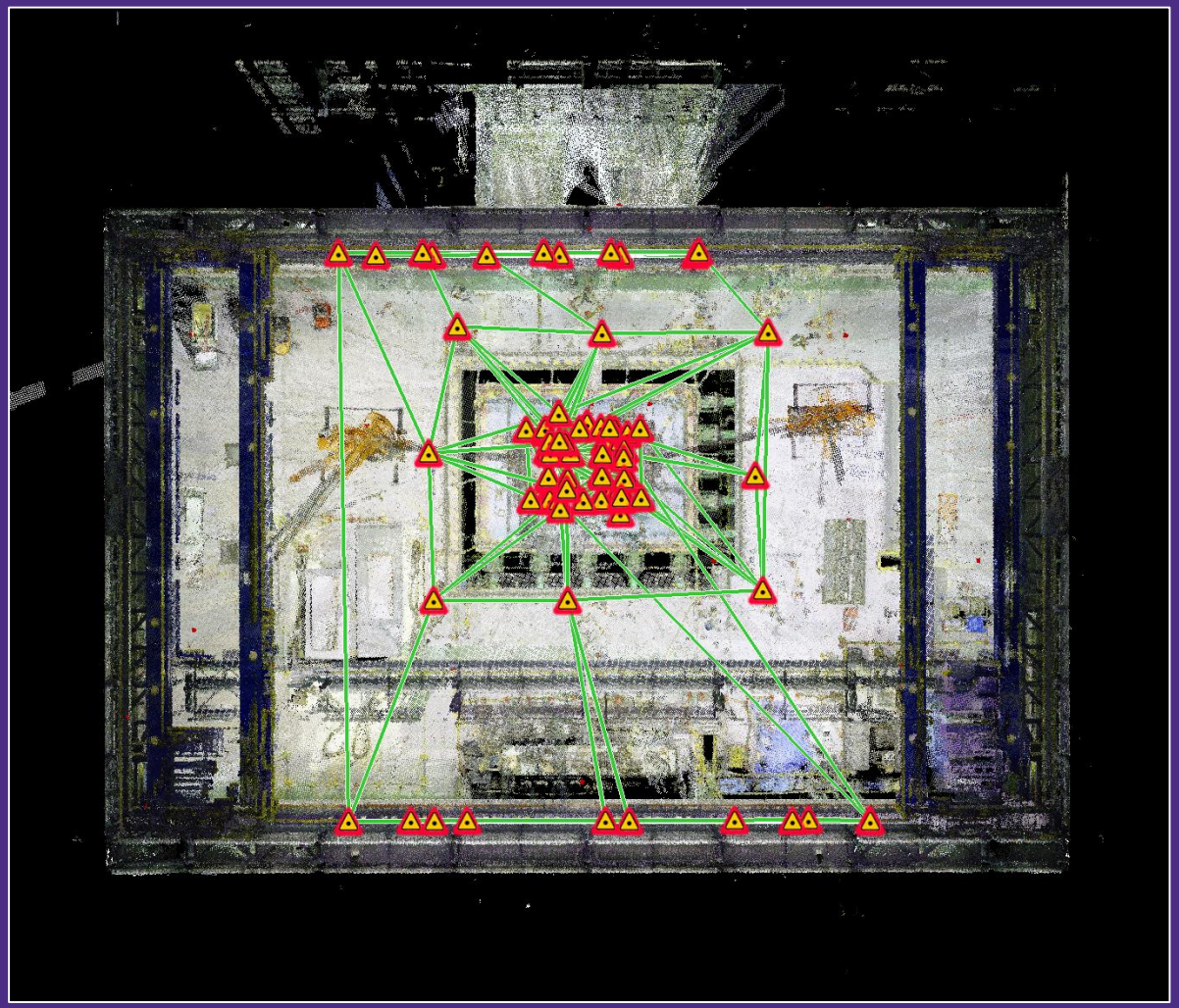
P50 Test 3 Scans (11 setups)

- 2,016,903,250 points (unedited)
- 961,442,936 points (specimen and table only)

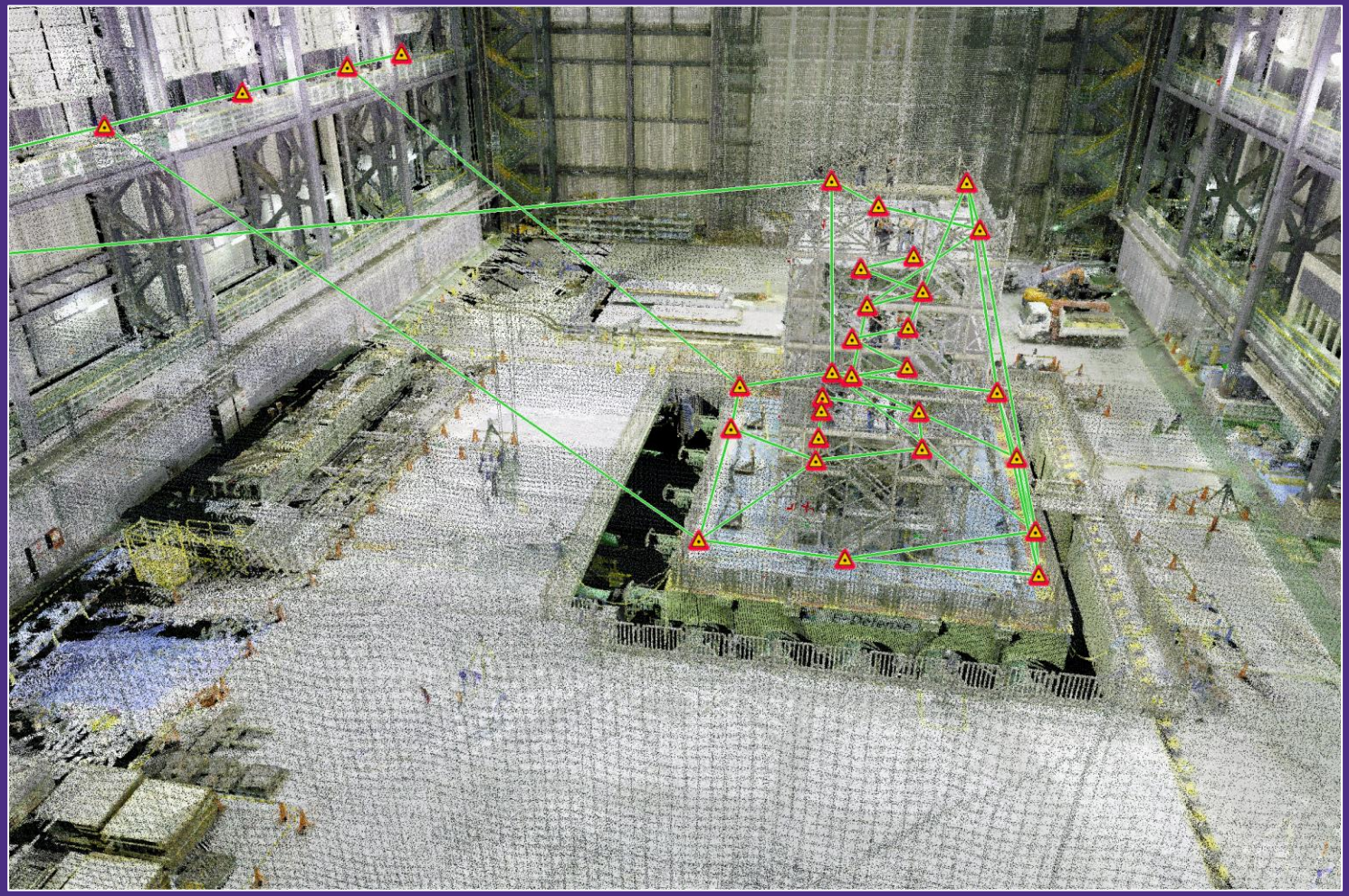


RTC360 Test 3 Scans (81 setups)

- 8,904,398,771 points (unedited)
- 2,624,982,508 points (specimen and table only)



Point Clouds



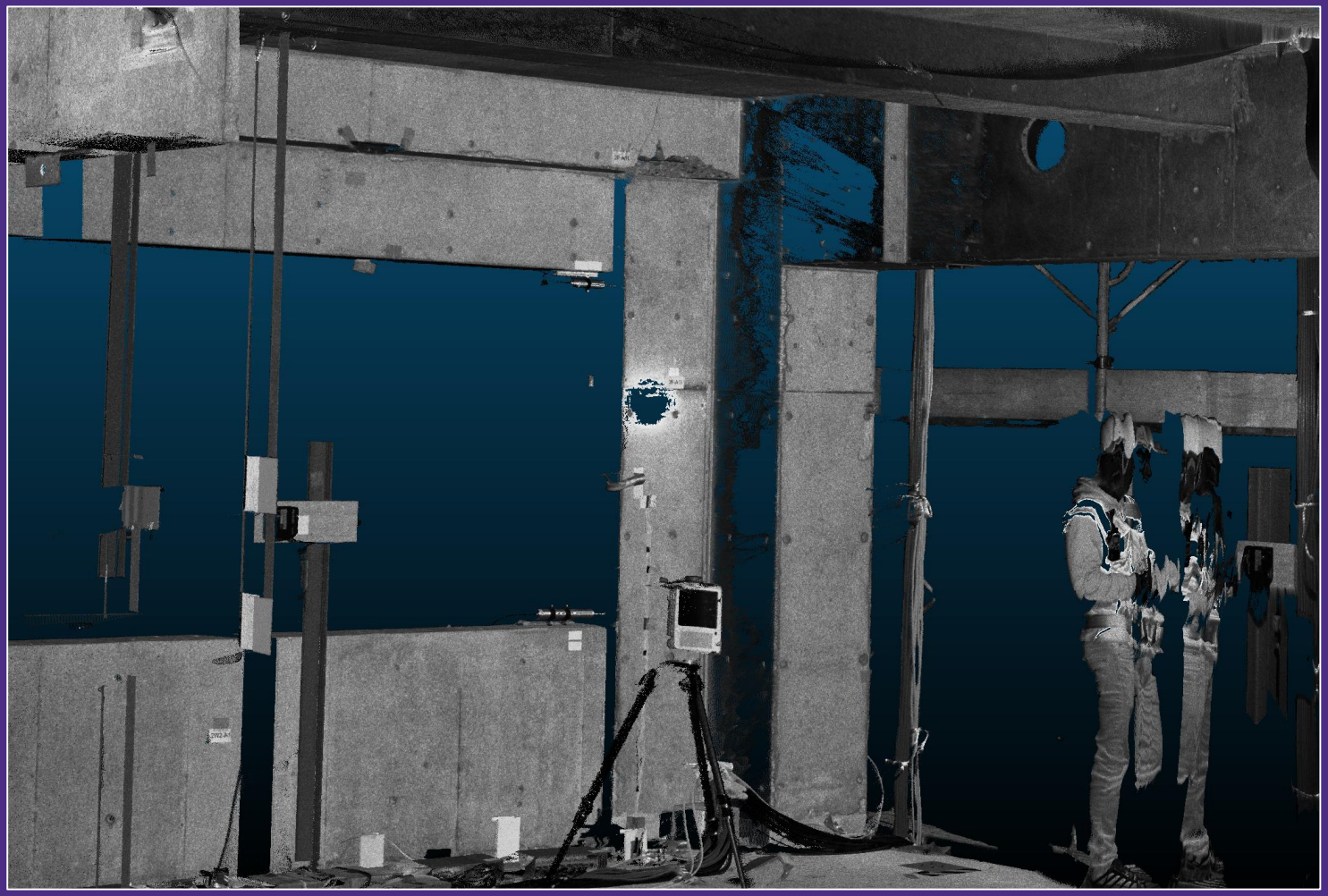
Note: RTC360BL point cloud viewed in Leica Register 360

Point Cloud

Exterior Scan Example (P50)

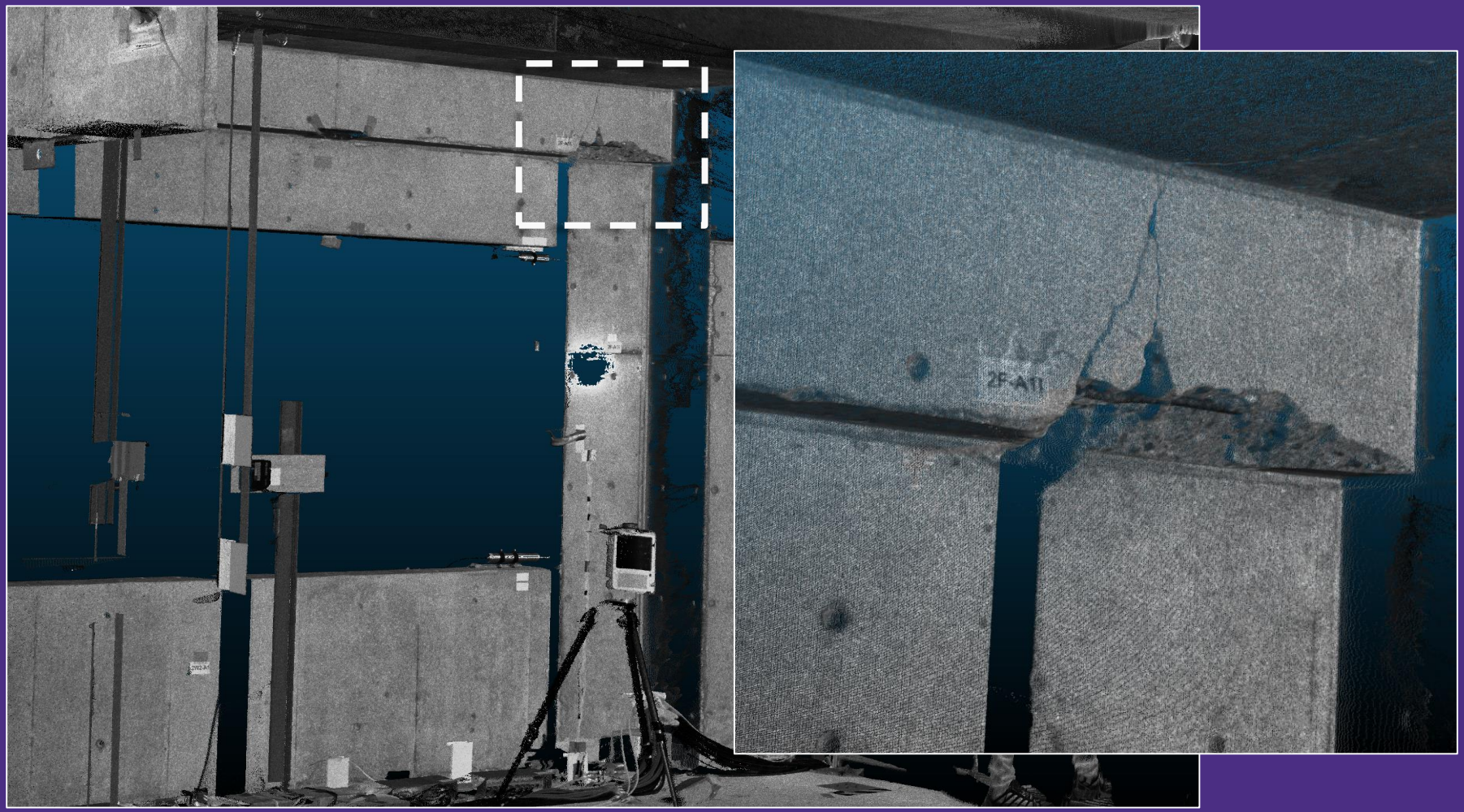
Point Cloud

Interior Scan Example (P50)



Point Cloud

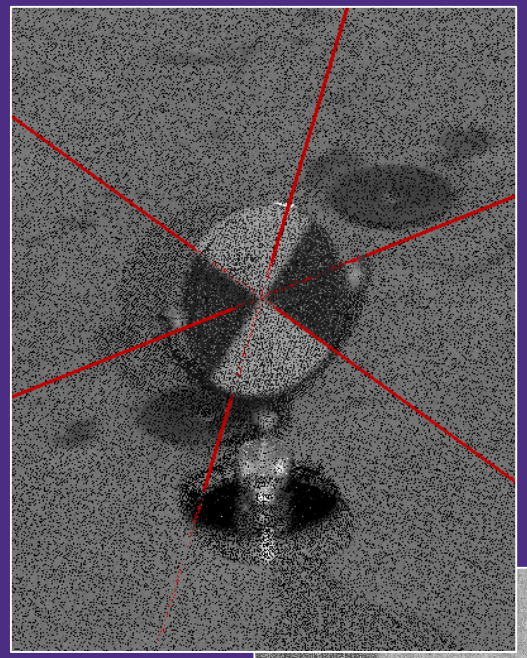
Interior Scan Example (P50)

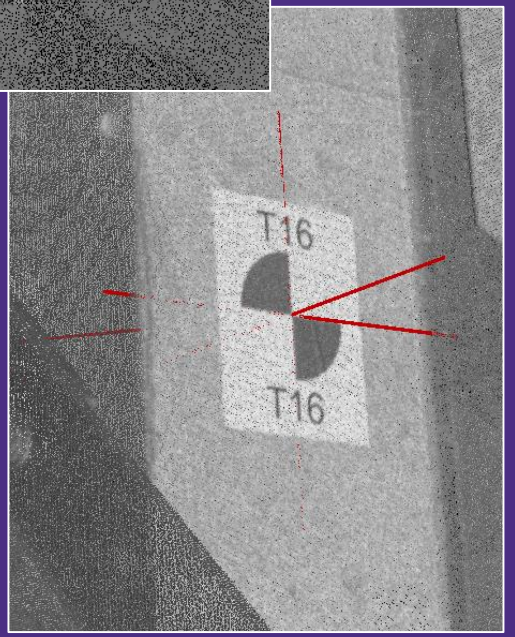


TARGETS

LiDAR Point Cloud and TotalStation

- B/W targets placed on specimen and facility
- Used to apply control to point clouds
- Mostly peel-and-stick paper targets; some magnetic targets on specimen





TARGETS

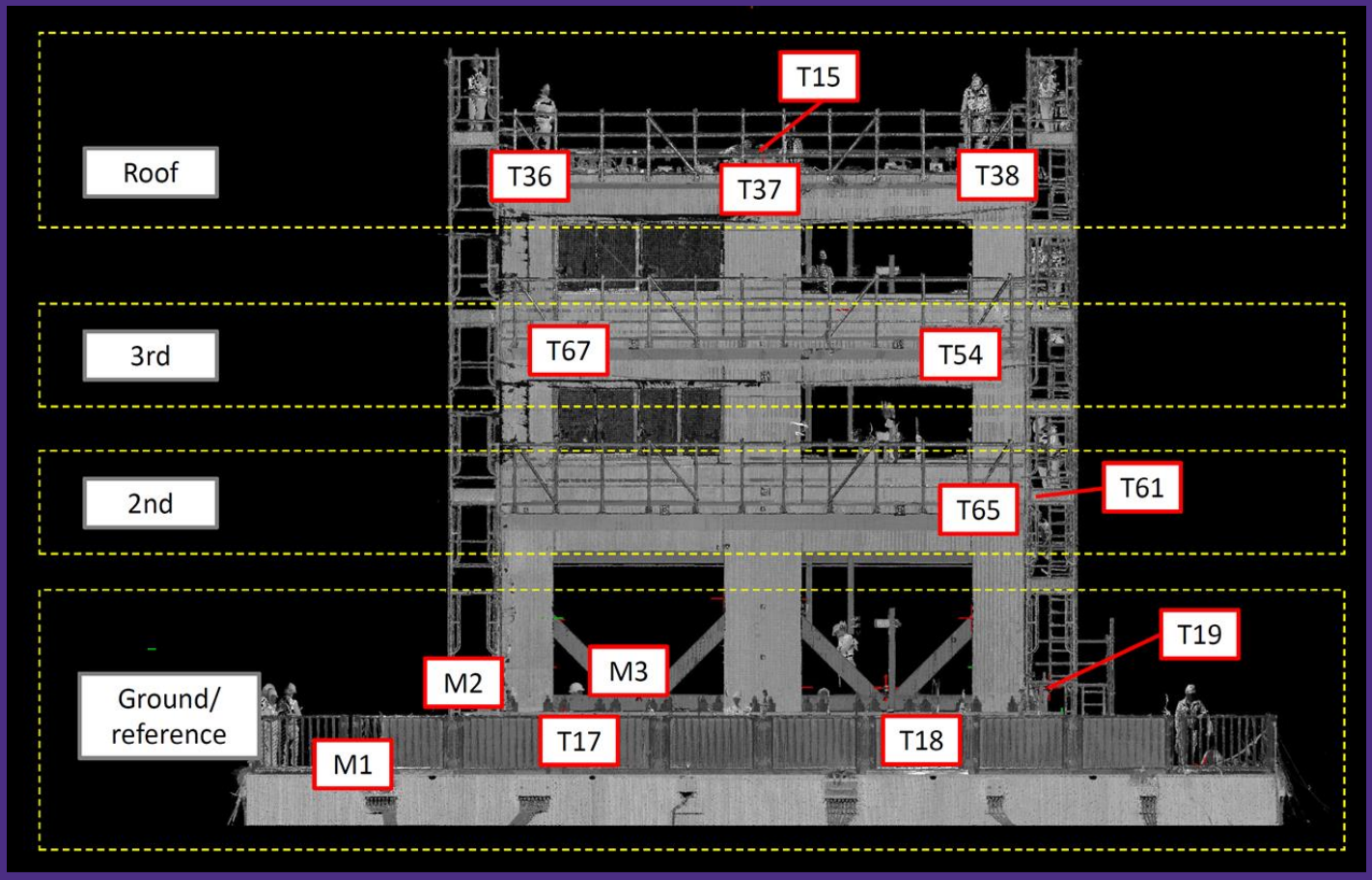
Targets on Specimen

Paper Targets

Magnetic Targets

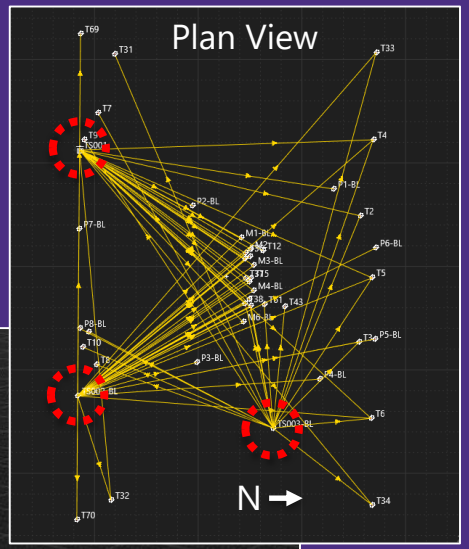
TARGETS

Targets on Specimen



TARGETS

Total Station Measurements



Targets

Specimen

Balcony Total Station Setups

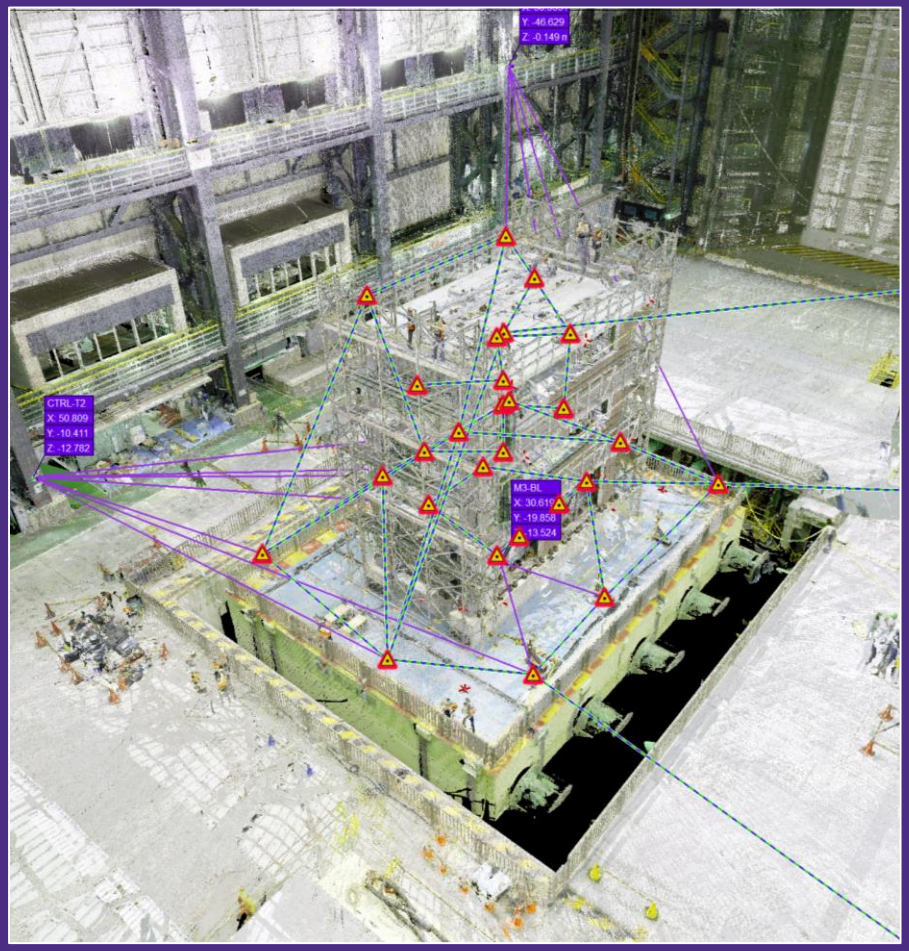
Ground level Total Station Setup

N

10 m

Apply Control File to Point Cloud

- Fit registered P50 and RTC360 point cloud to control file created using Total Station
- Improve accuracy of point cloud
- Enforce same coordinate system between all point clouds using facility targets

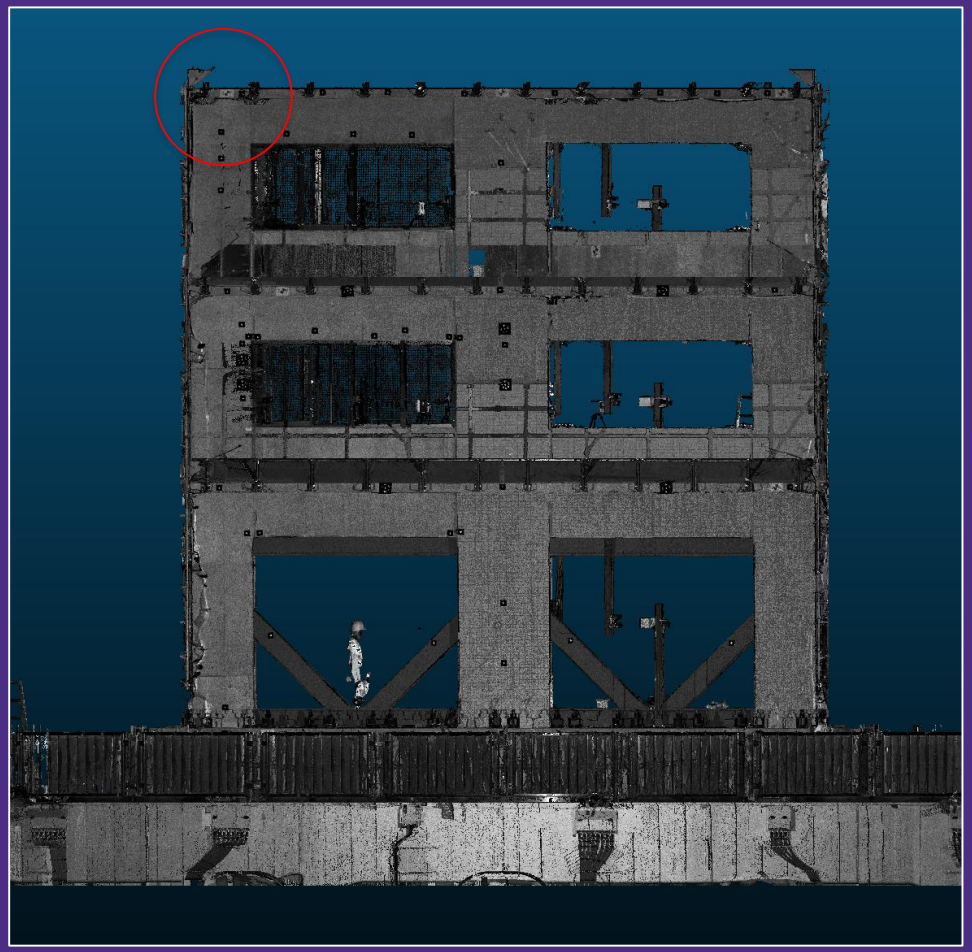


GLOBAL DEFORMATION

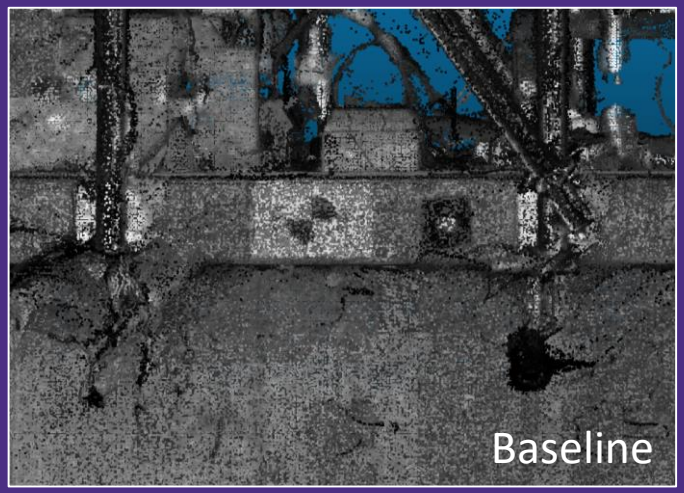
RESIDUAL DEFORMATION AFTER EACH TEST

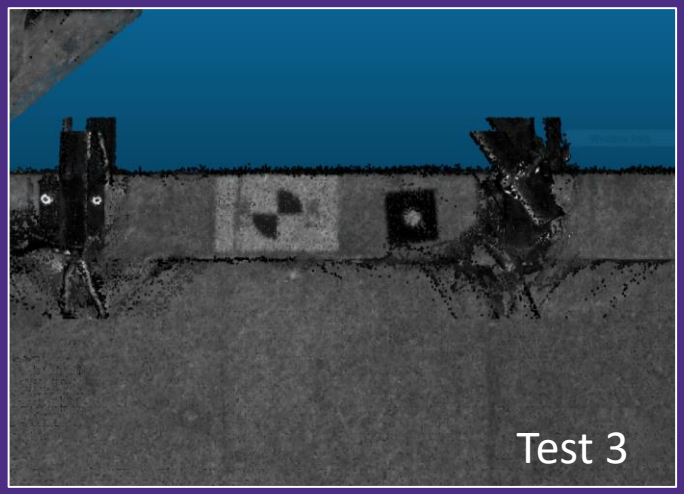
GLOBAL DEFORMATIONS

- Directly comparing coordinates between different point clouds
- All point clouds are shifted to the same coordinate system (based on facility)
- Keep track of table location

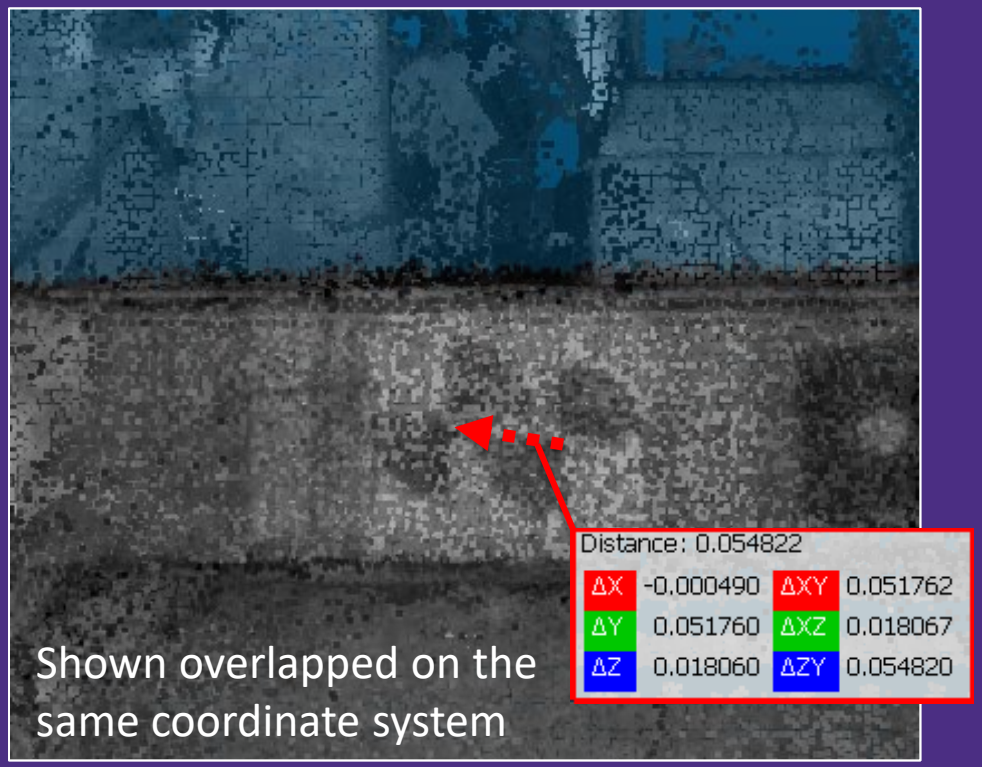


GLOBAL DEFORMATIONS



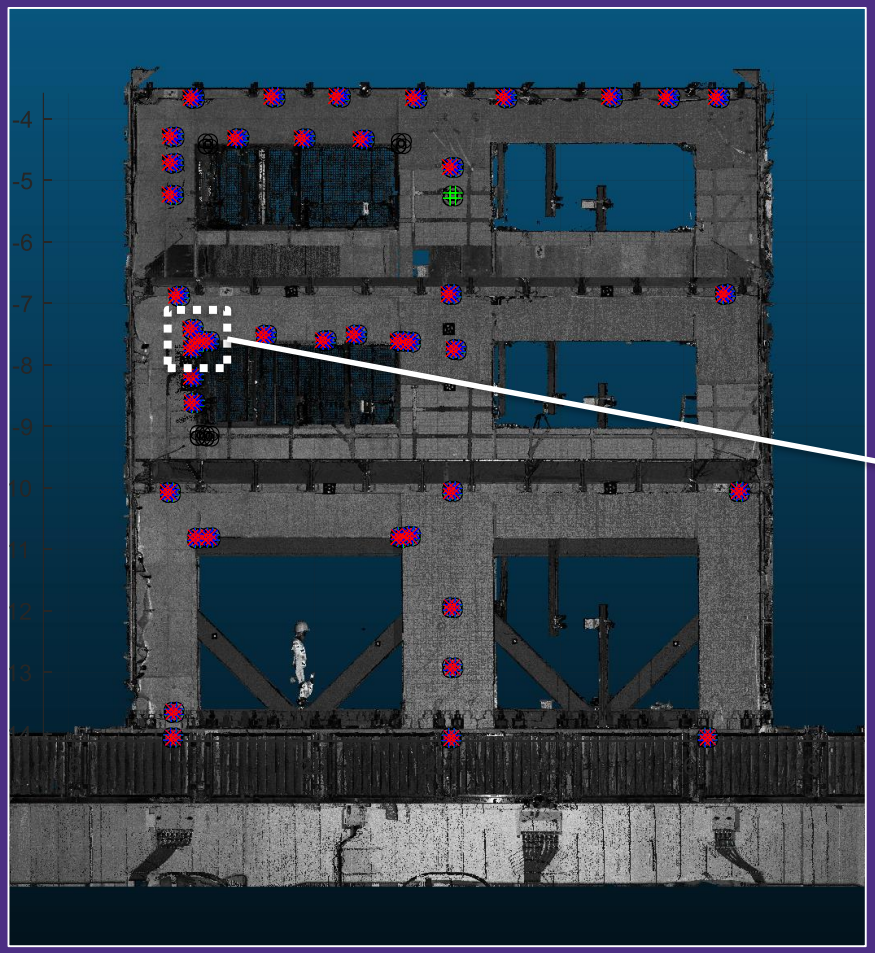


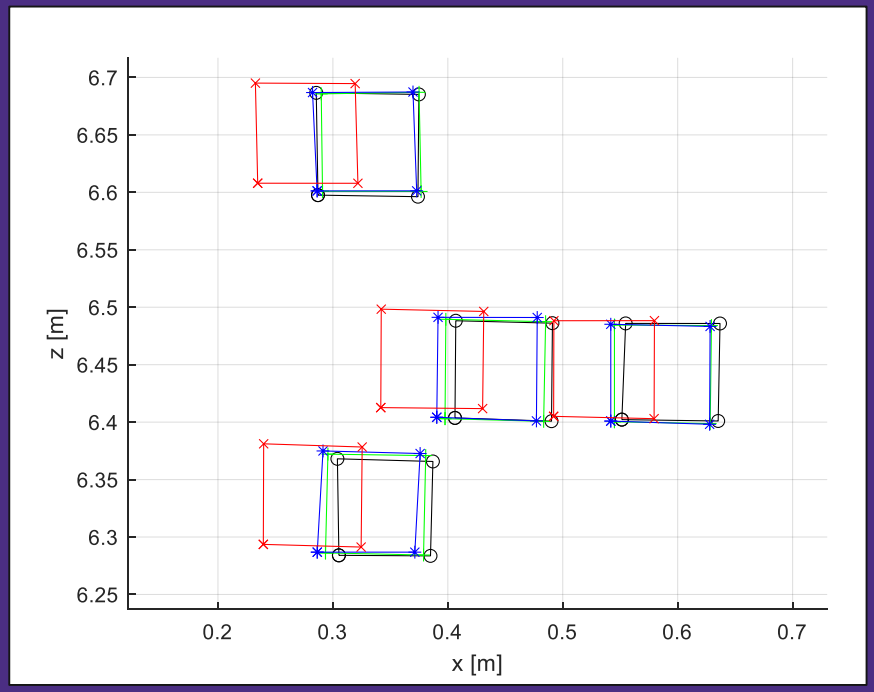
Directly measure deformations



GLOBAL DEFORMATIONS

Black = Baseline
Green = Test 1
Blue = Test 2
Red = Test 3



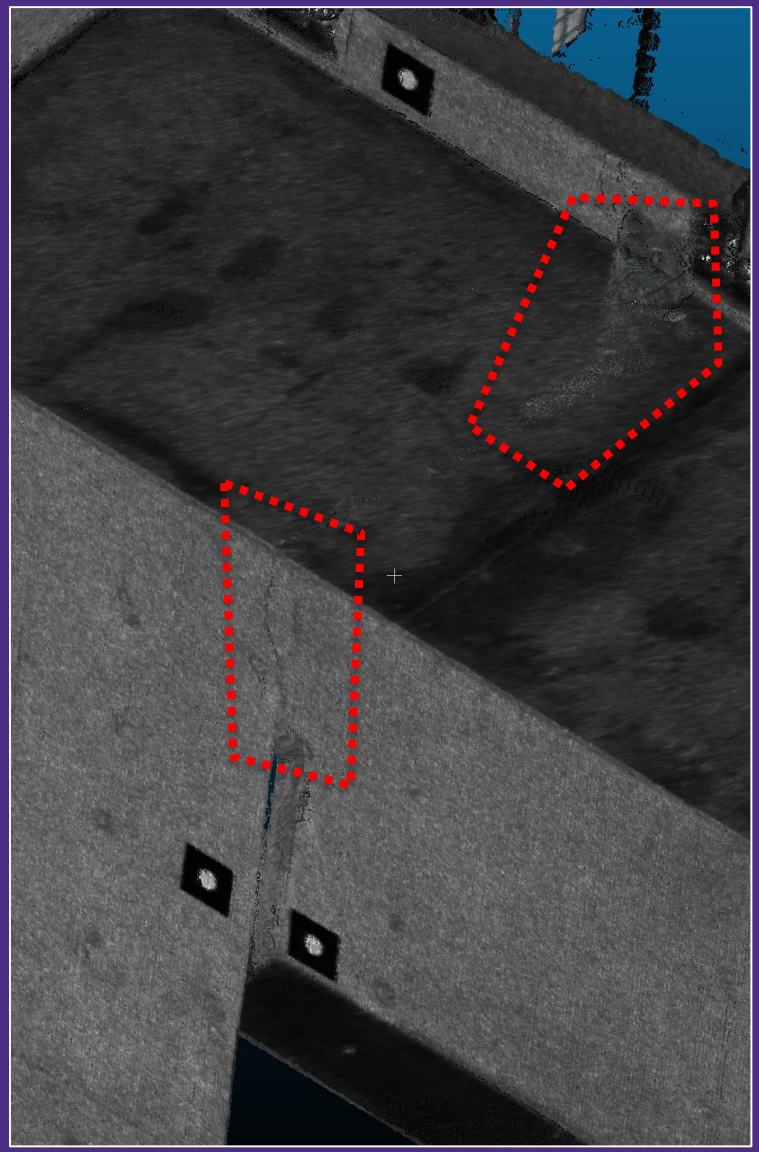


DAMAGE DETECTION

CRACK IDENTIFICATION IN POINT CLOUDS

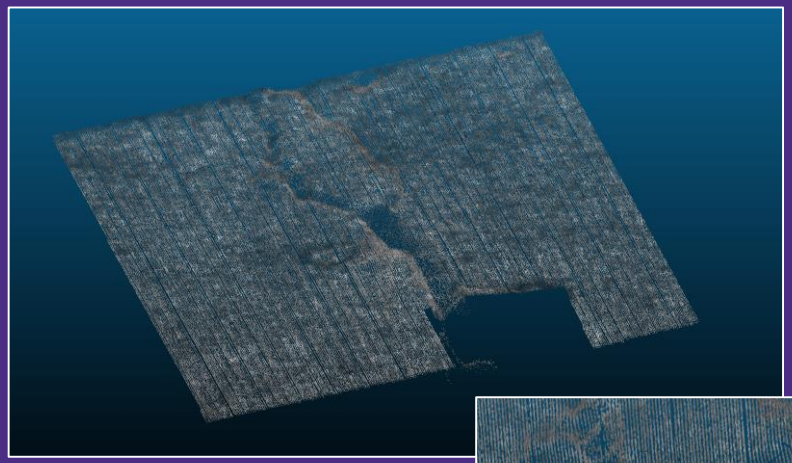
DAMAGE DETECTION

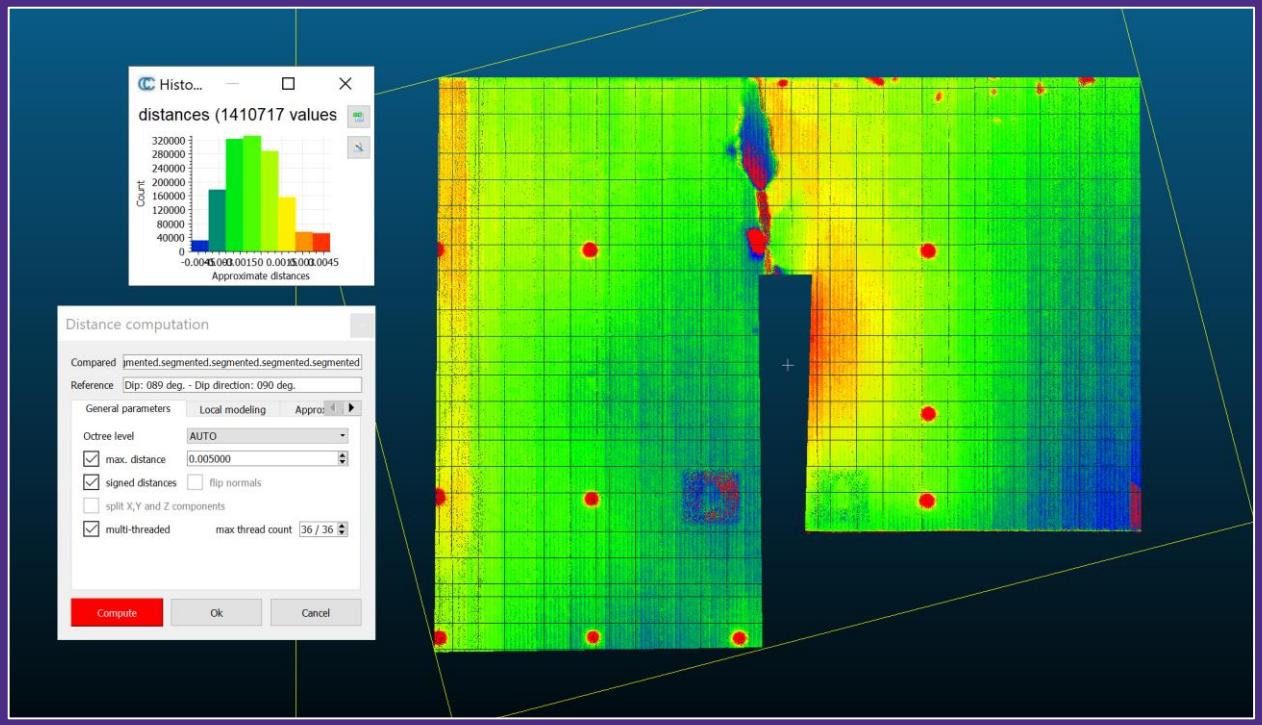
- Identifying cracks, spalling, exposed rebar from Point Clouds
- Data includes x, y, z coordinates, intensity, and RGB values
- Start by picking LARGE cracks and applying filtering techniques from crack detection for images



DAMAGE DETECTION

Fitting a surface and computing orthogonal distances

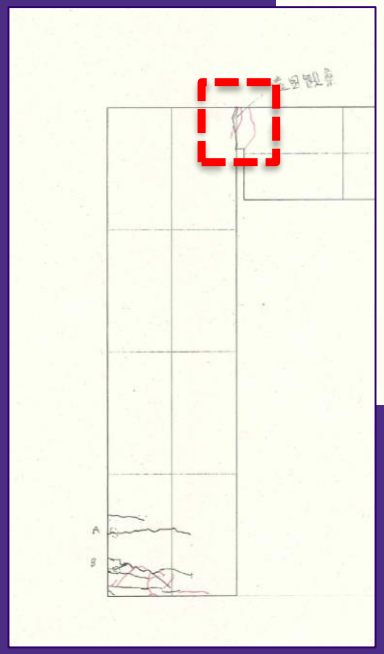


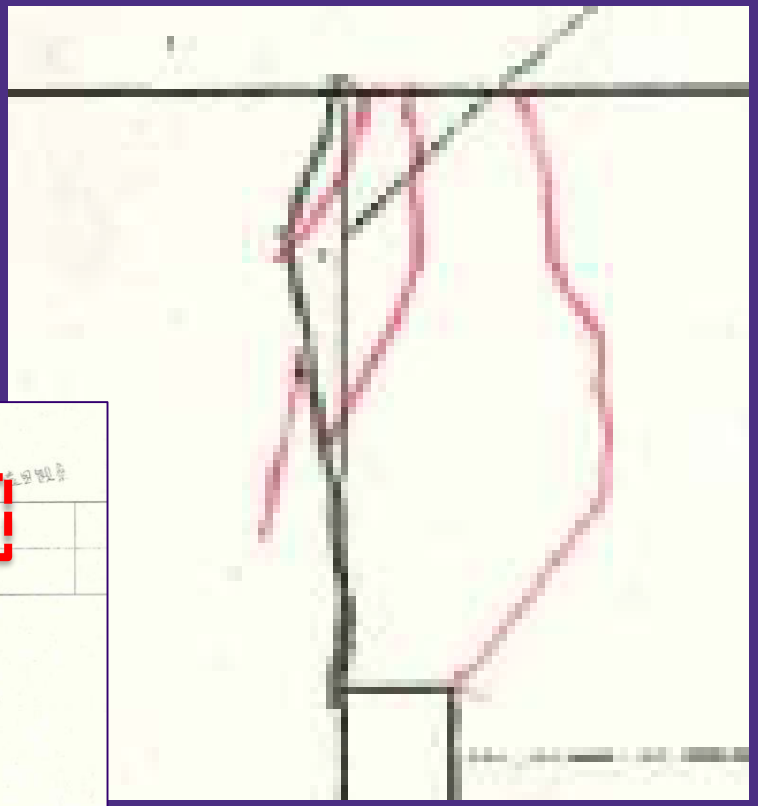


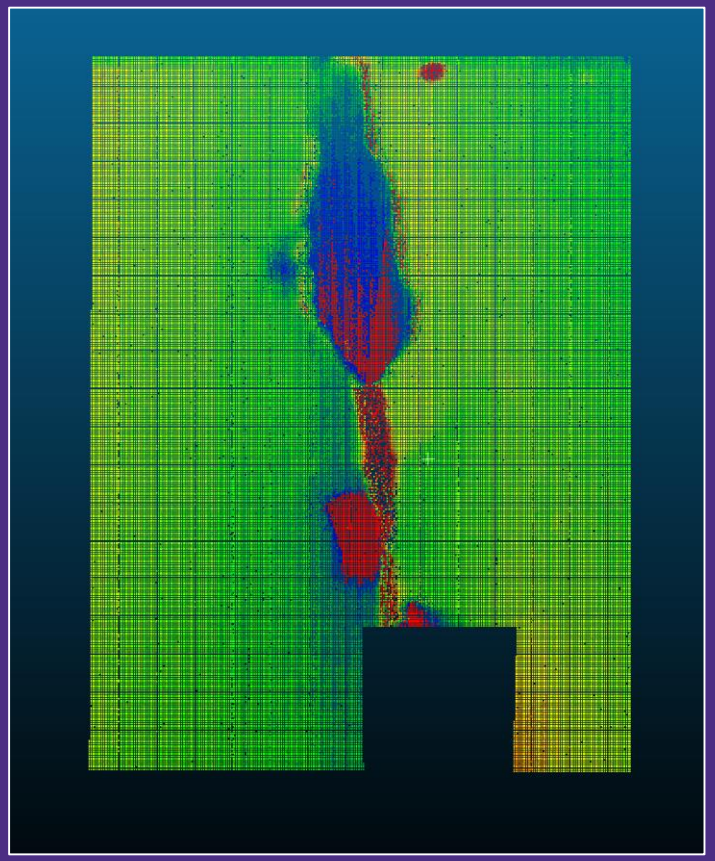
If visually identifiable, crack widths can be measured directly

DAMAGE DETECTION

Comparing Point Cloud to manual crack records provided by the Japan team

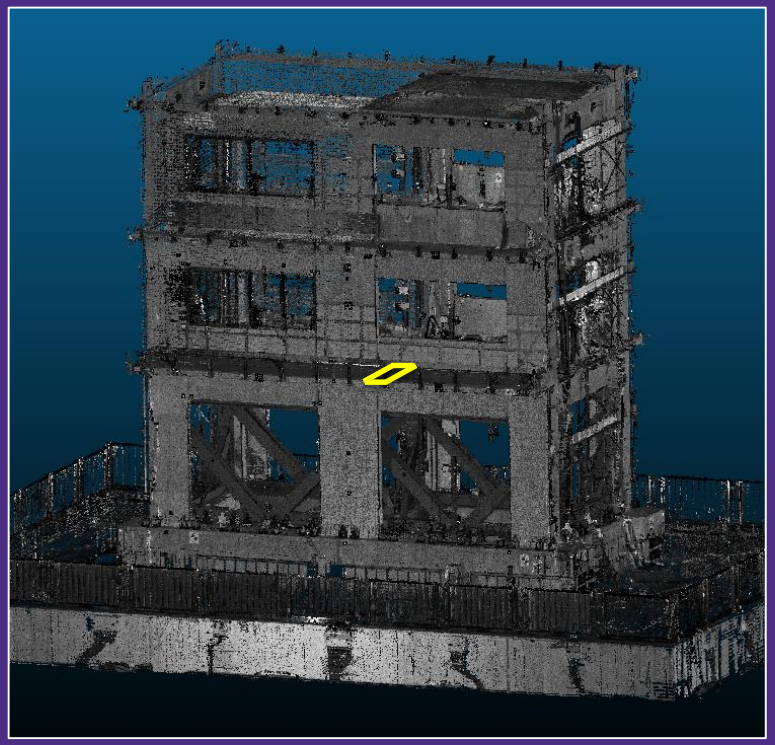


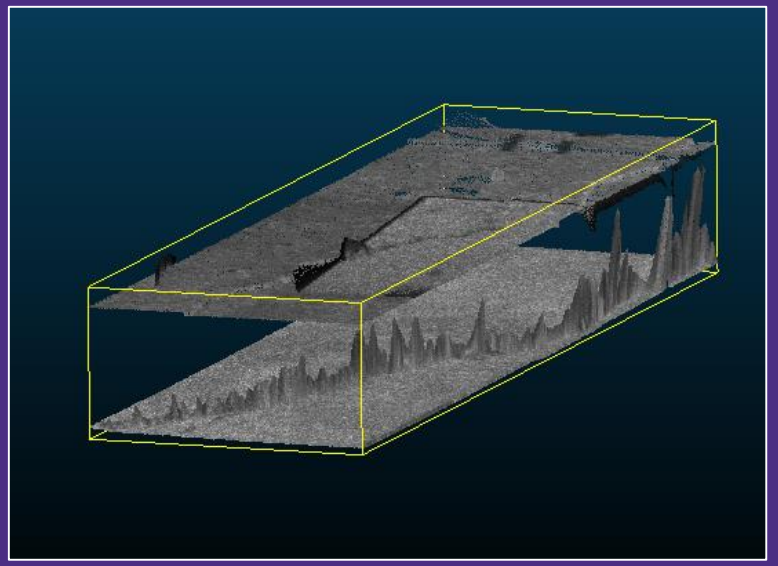


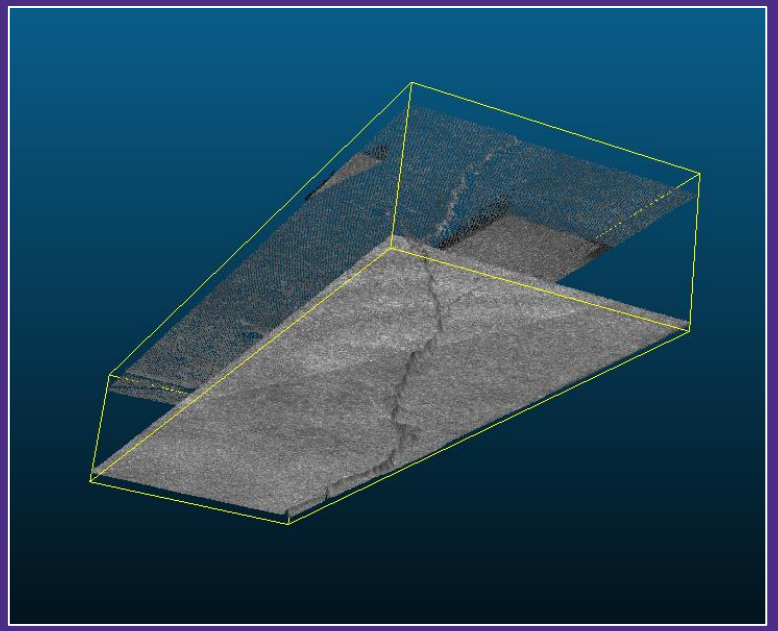


DAMAGE DETECTION

> Example of a slab crack where high-resolution scans were taken above and below

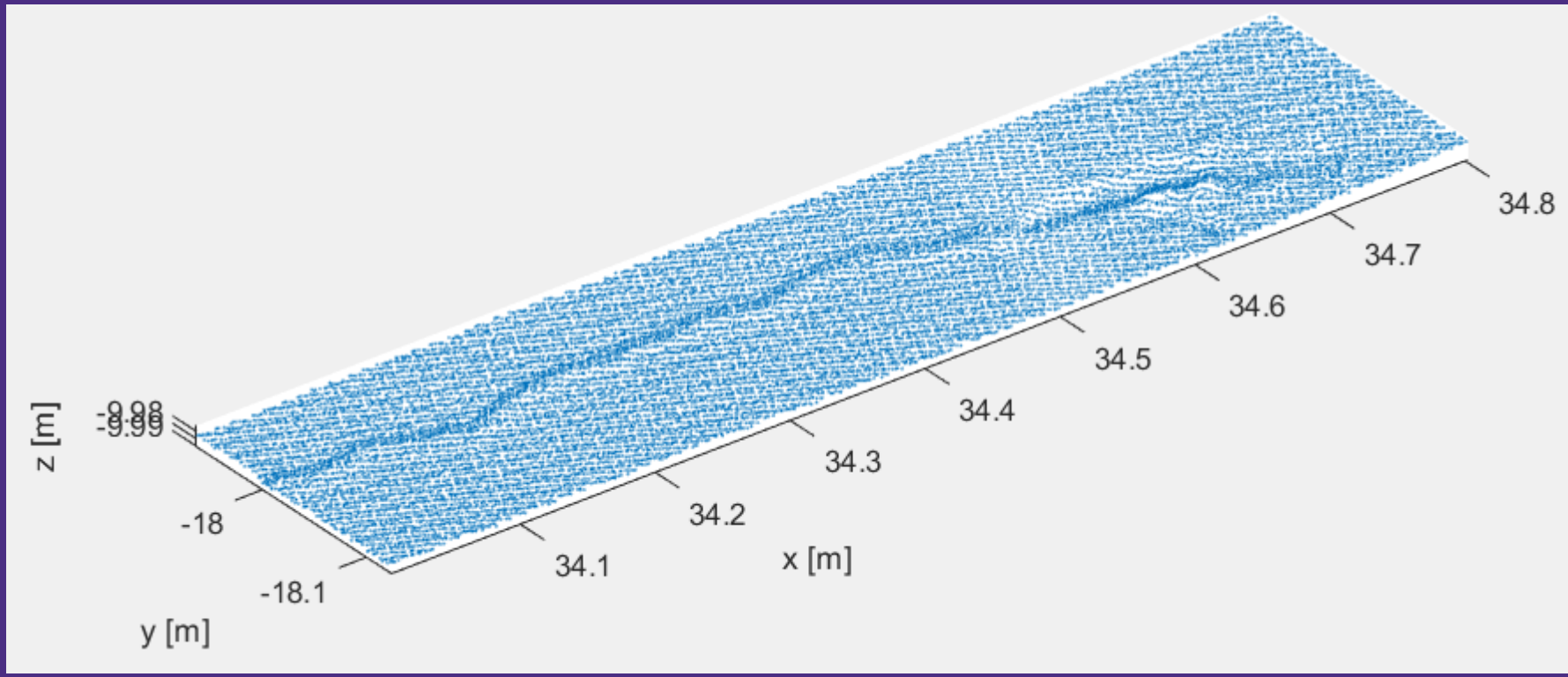






DAMAGE DETECTION

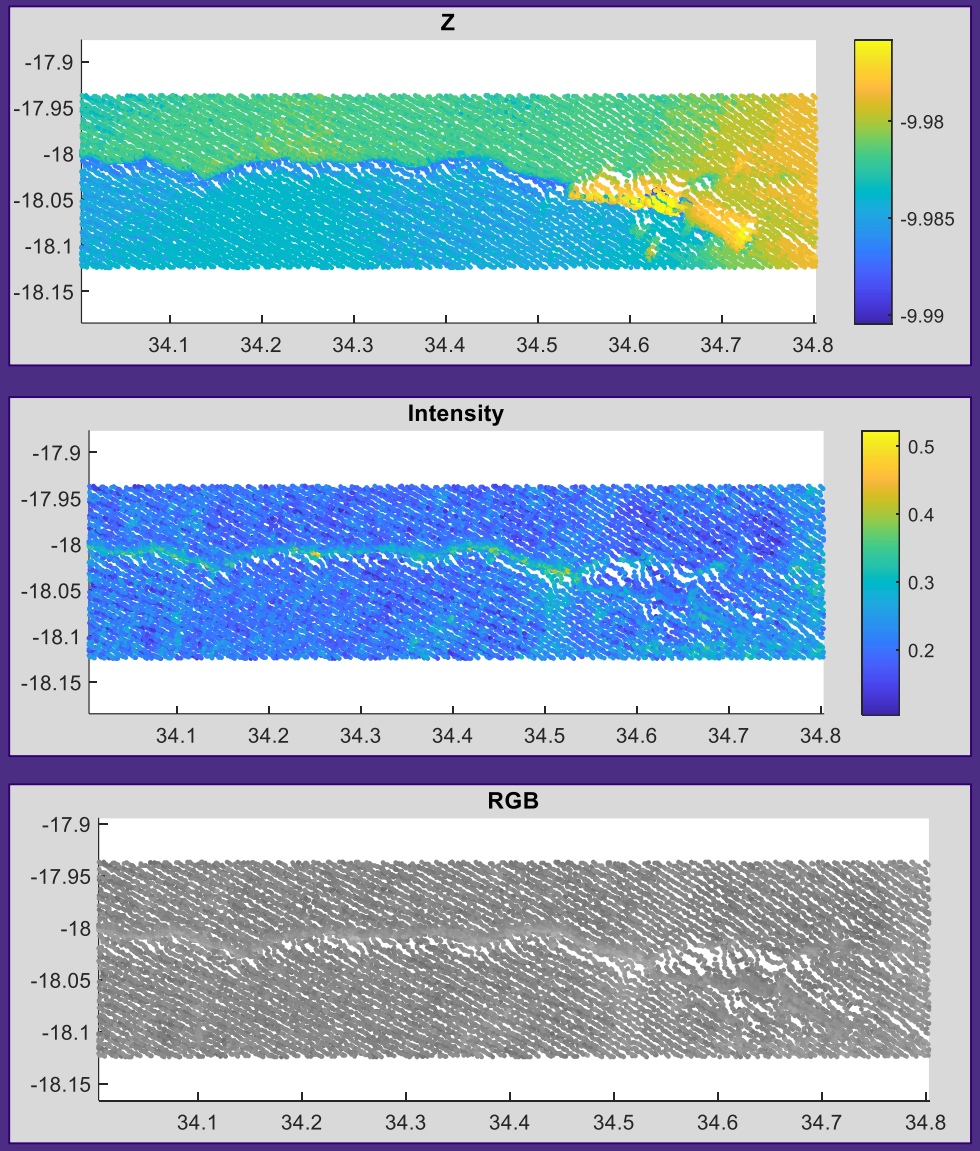
> Isolated crack



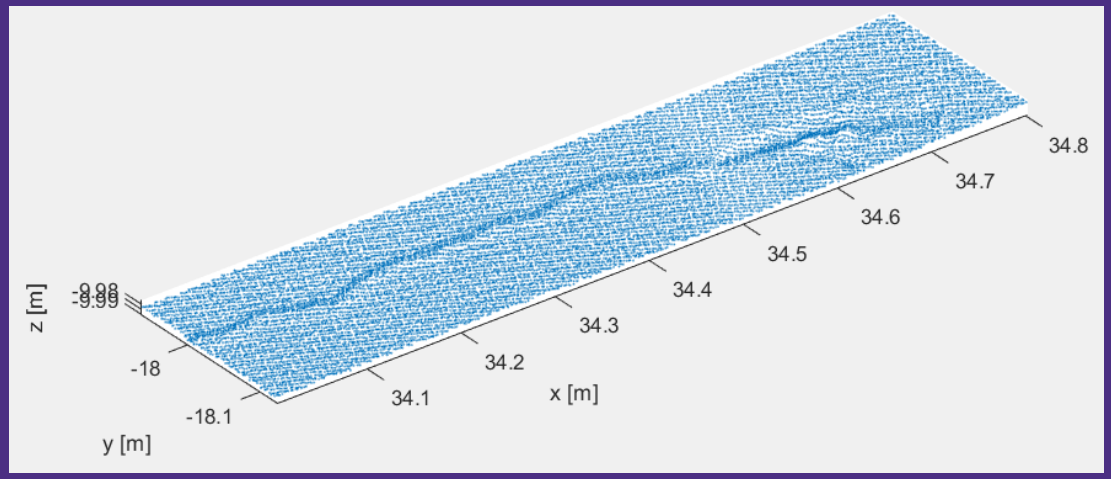
DAMAGE DETECTION

Adapting 2D Image Filtering Techniques to 3D Point Clouds

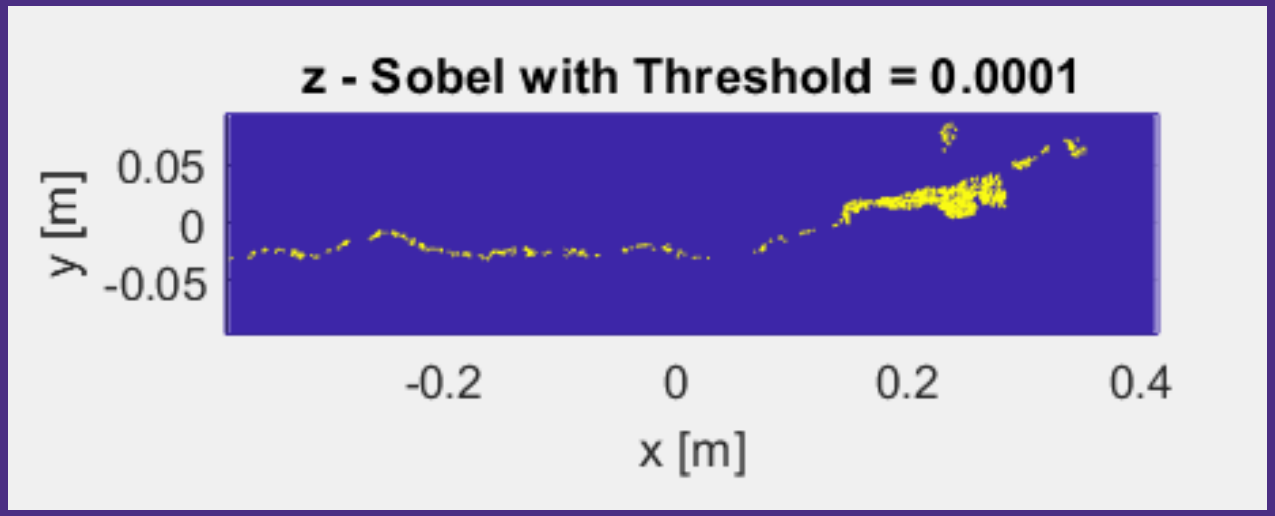
- Can apply filter to any of the parameters (including a combination)
  - Orthogonal distance z (physical displacements)
  - Intensity (material and textural differences)
  - RGB



DAMAGE DETECTION



Example: Sobel filter applied to orthogonal distance z [m] to construct a "crack map"



> Applying image filtering techniques to isolated crack

DAMAGE DETECTION

FUTURE GOALS

- Detecting finer cracks/damage
- More automation
  - Avoiding features not damage-related
  - Automatically extract surfaces from a 3D dataset
- Using the damage information collected
  - Damage assessment
  - Model building

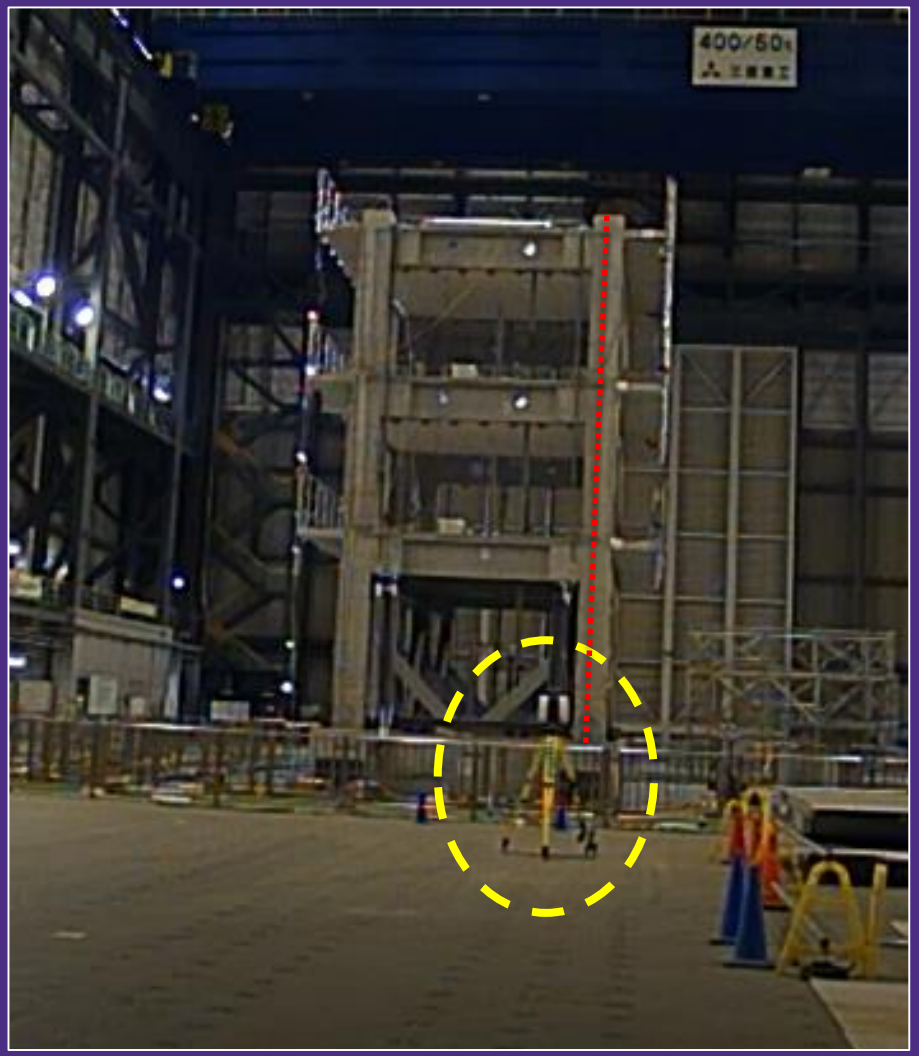
P50 LINE SCAN

DYNAMIC PROFILE DATA

P50 LINE SCAN

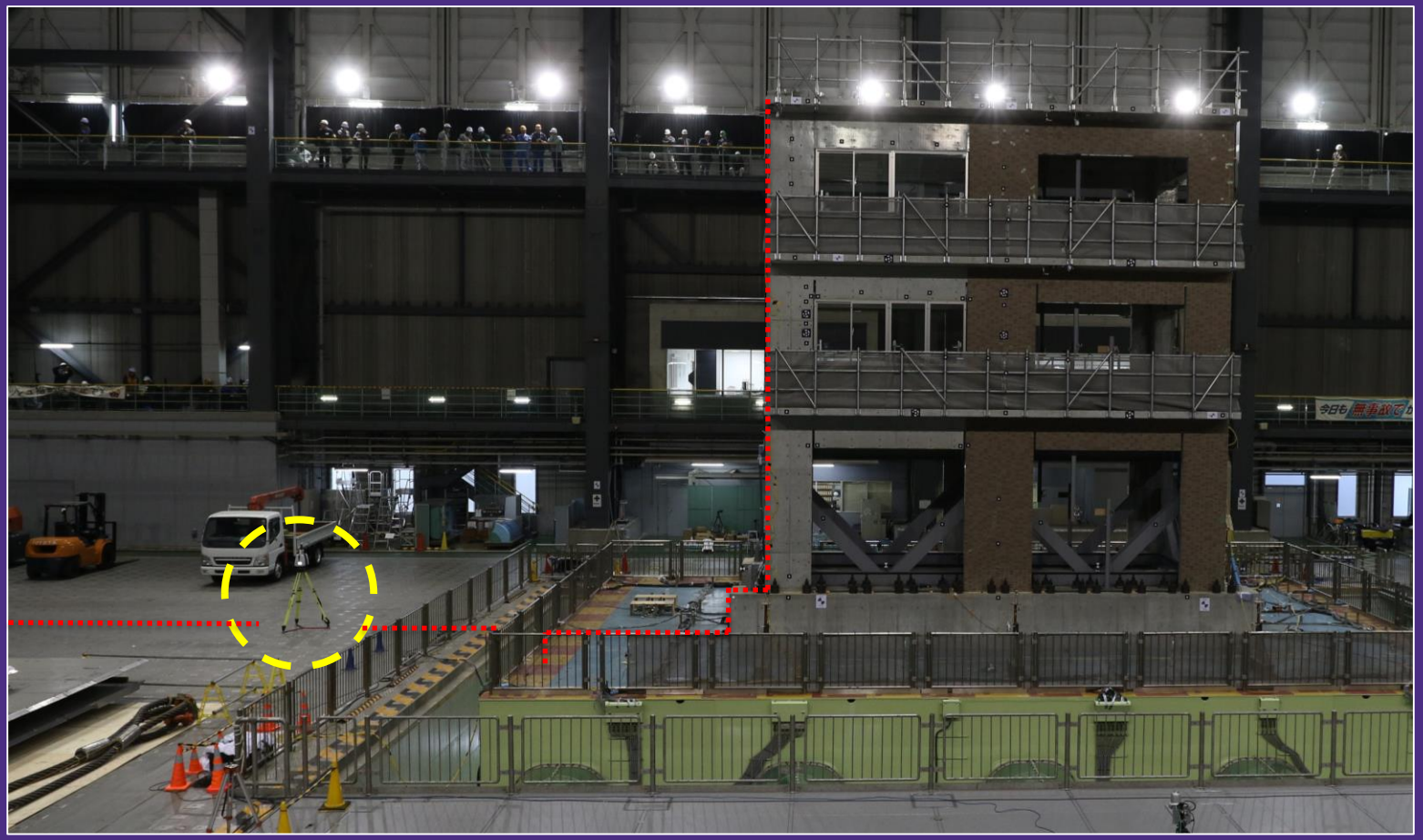
Dynamic Profile Scan

- Record column profile during shake test
- Single line scan at 50 hertz
- Line-of-sight technology



P50 LINE SCAN

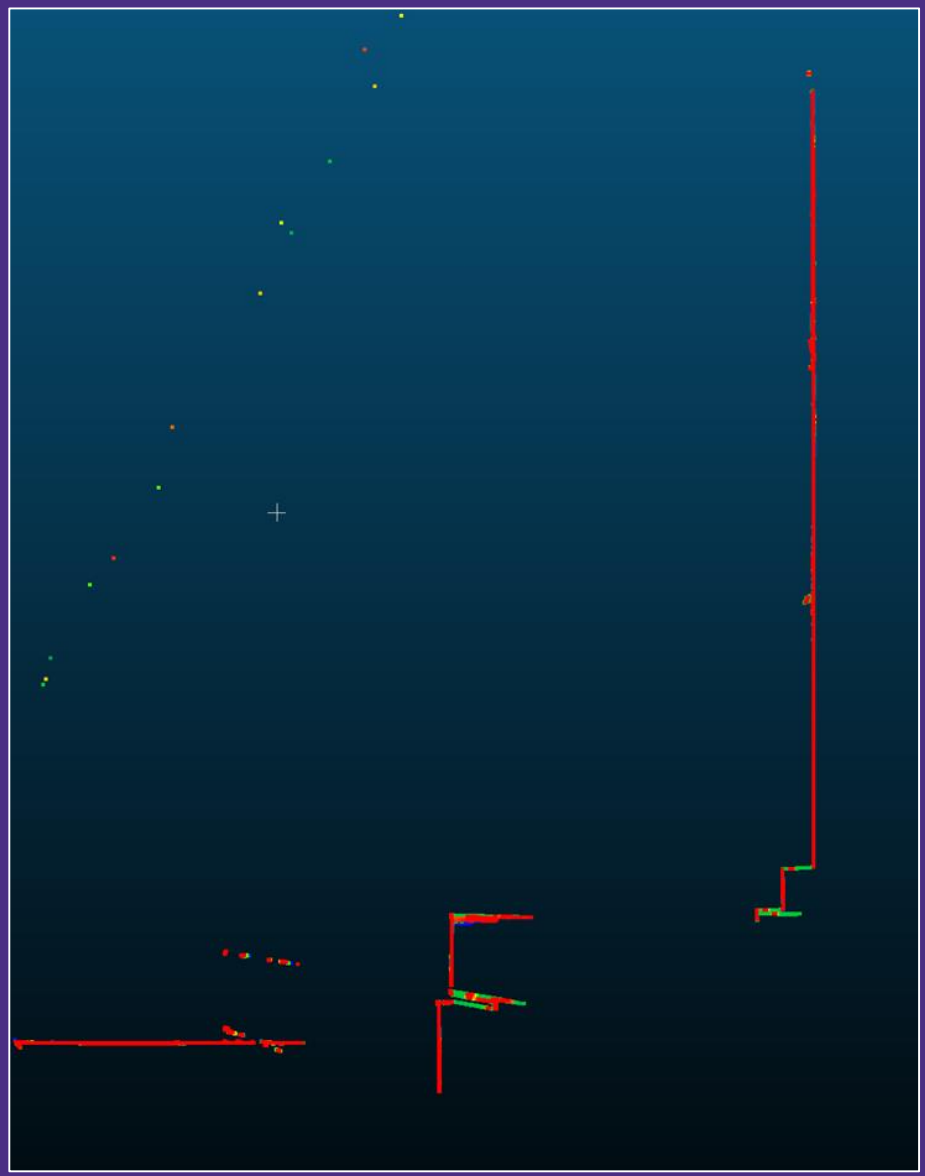
Dynamic Profile Scan



P50 LINE SCAN

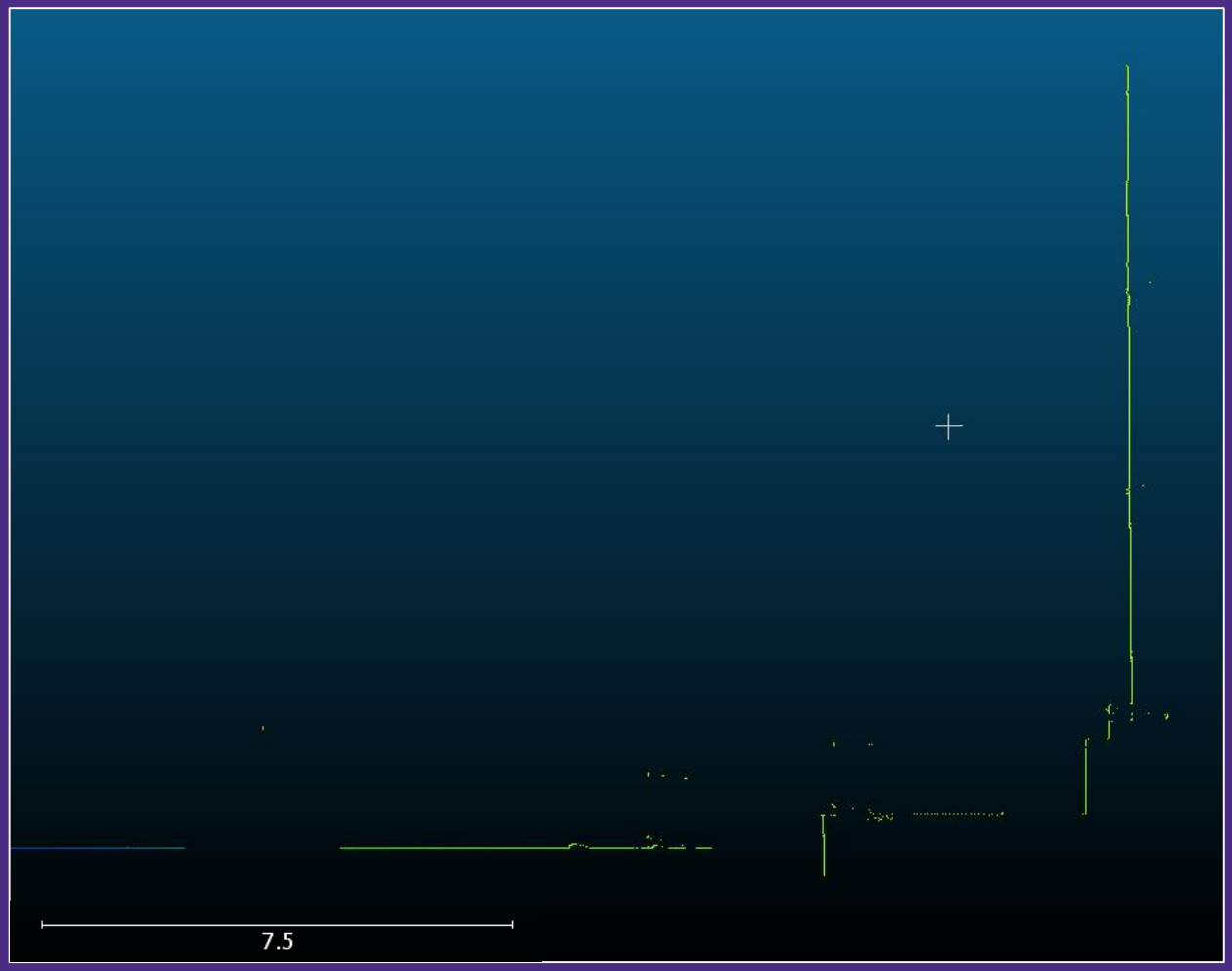
Dynamic Profile Scan

- Record column profile during shake test
- Single line scan at 50 hertz
- Line-of-sight technology



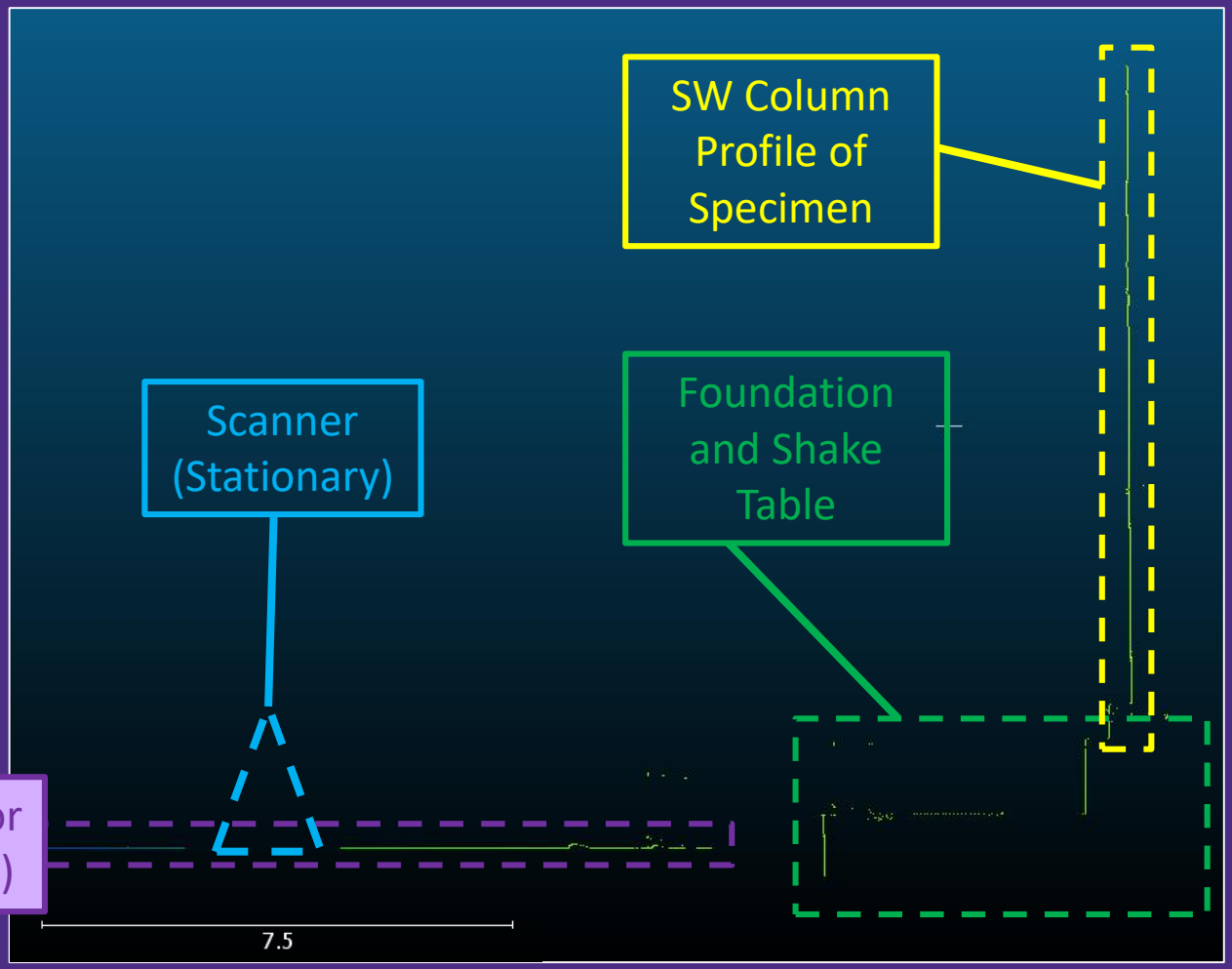
P50 LINE SCAN

These profiles were collected throughout the test at 50 hertz



P50 LINE SCAN

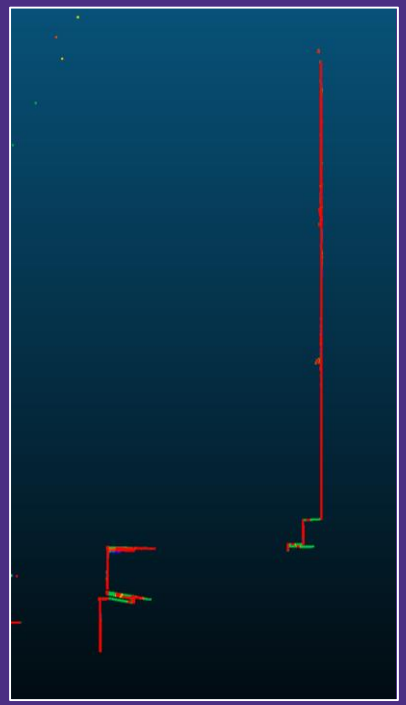
These profiles were collected throughout the test at 50 hertz



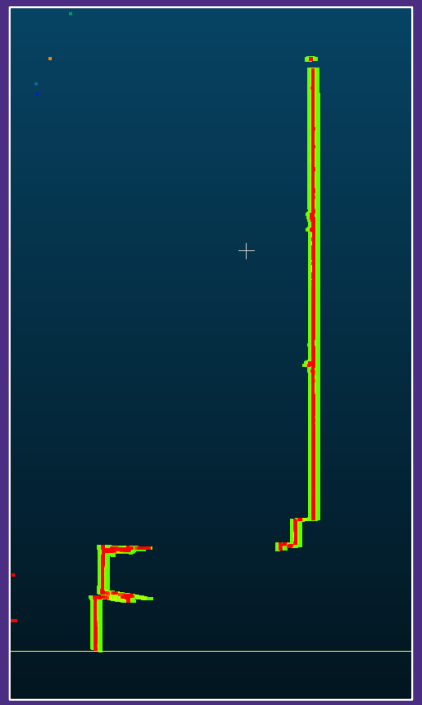
P50 LINE SCAN

Comparison of different Line Scan series from different tests

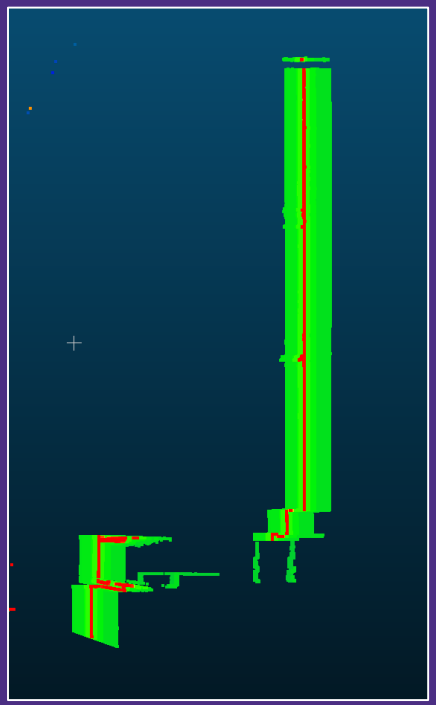
No Motion



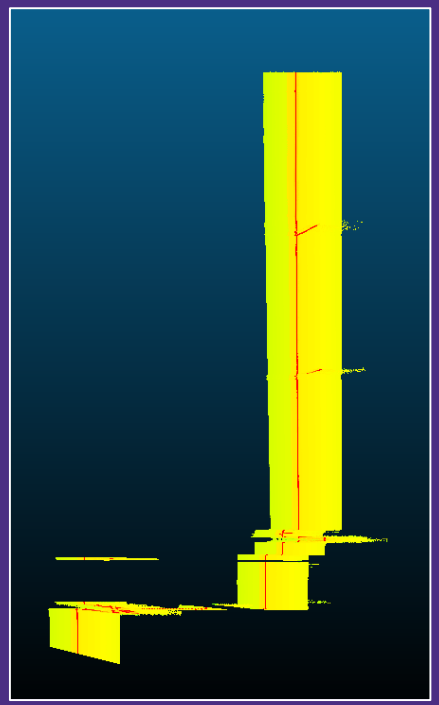
20% Design



100% Design



160% Design

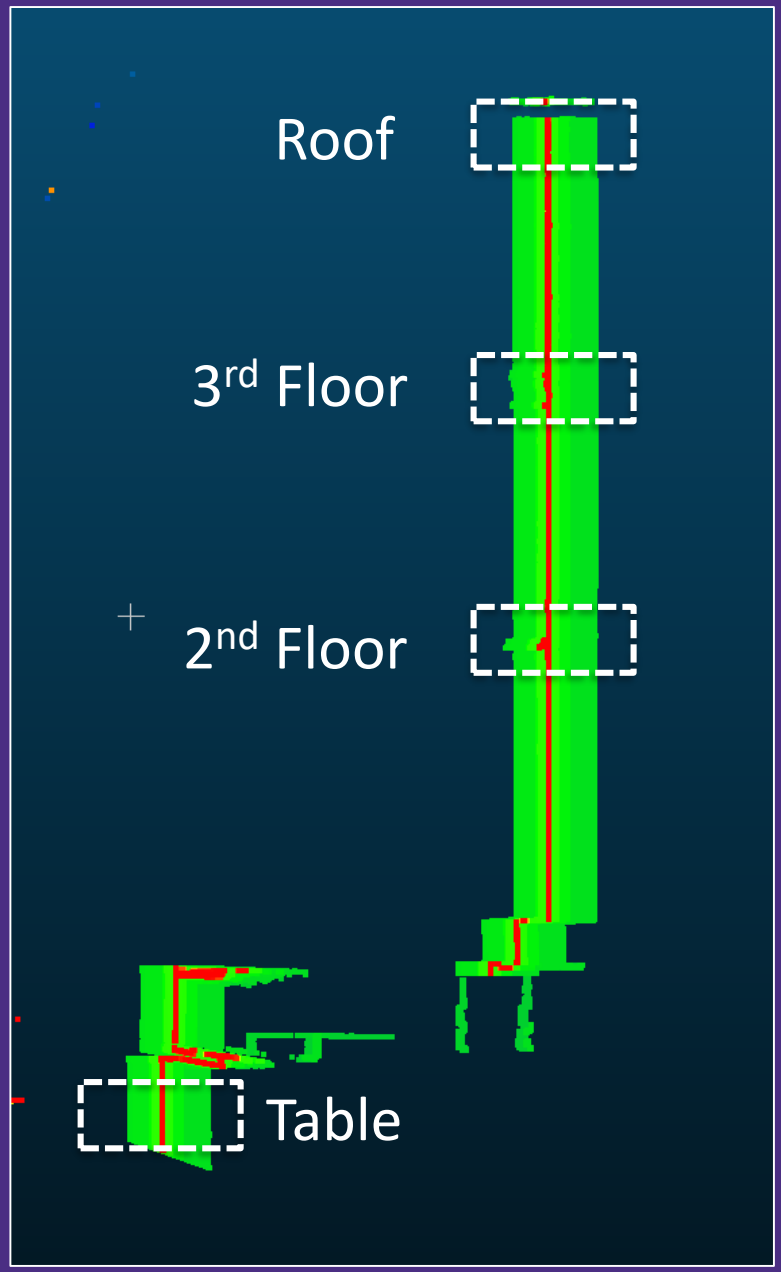


Note: Most of the motion is due to shake table, displacements relative to table need to be computed

P50 LINE SCAN

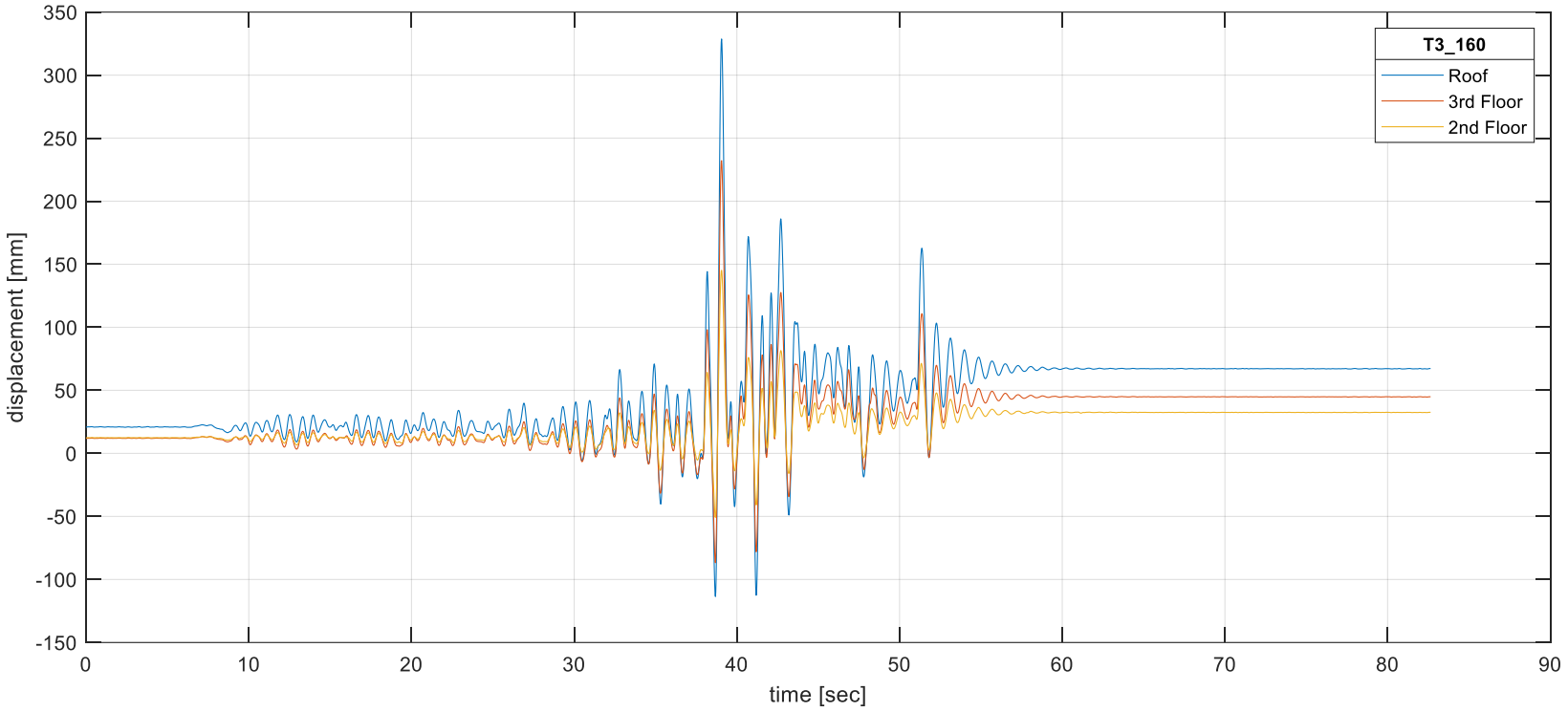
Compute Relative Displacements

- Keep track of horizontal table displacements over time
- Keep track of horizontal displacements at various floor levels
- Find difference



P50 LINE SCAN

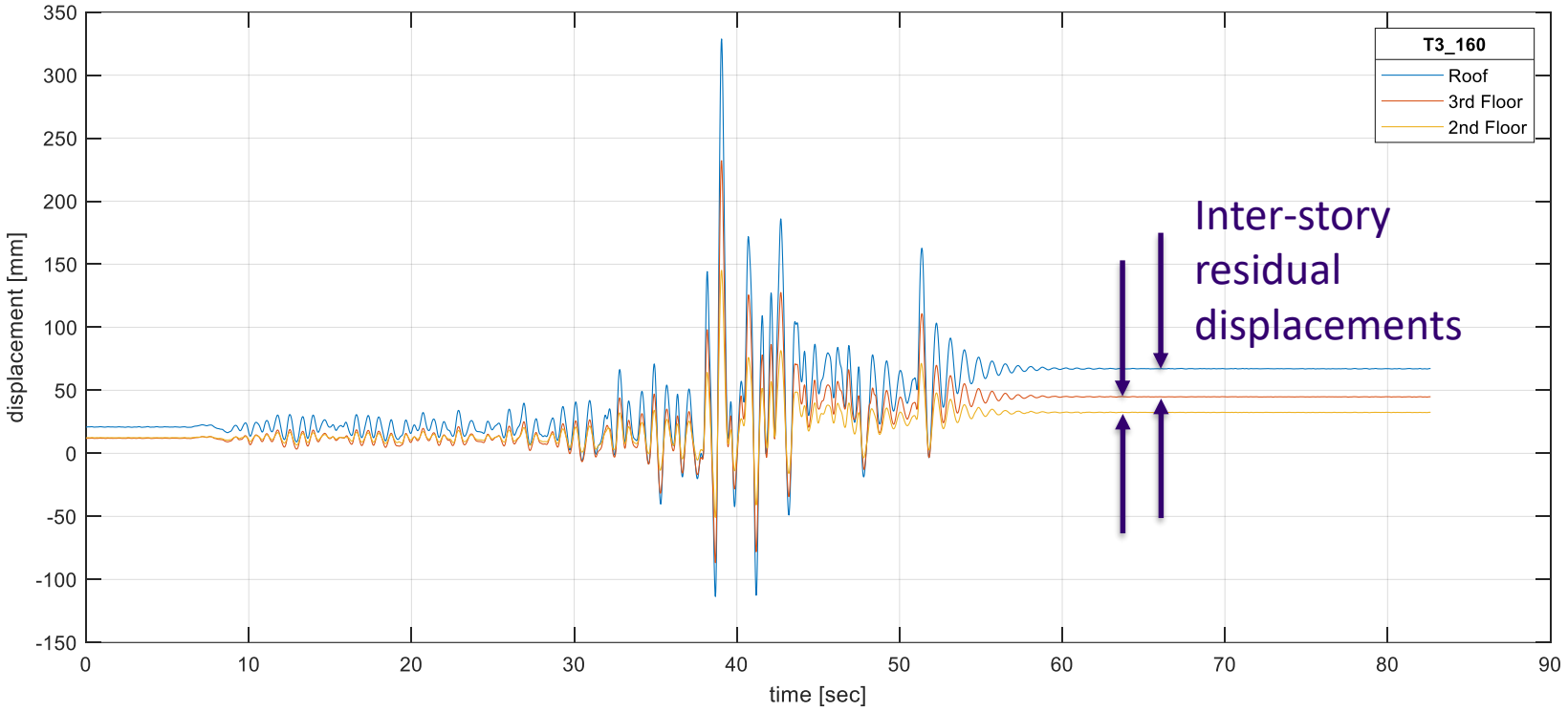
Compute Floor Displacements Relative to Table



Results from Design Wave 160% test shown

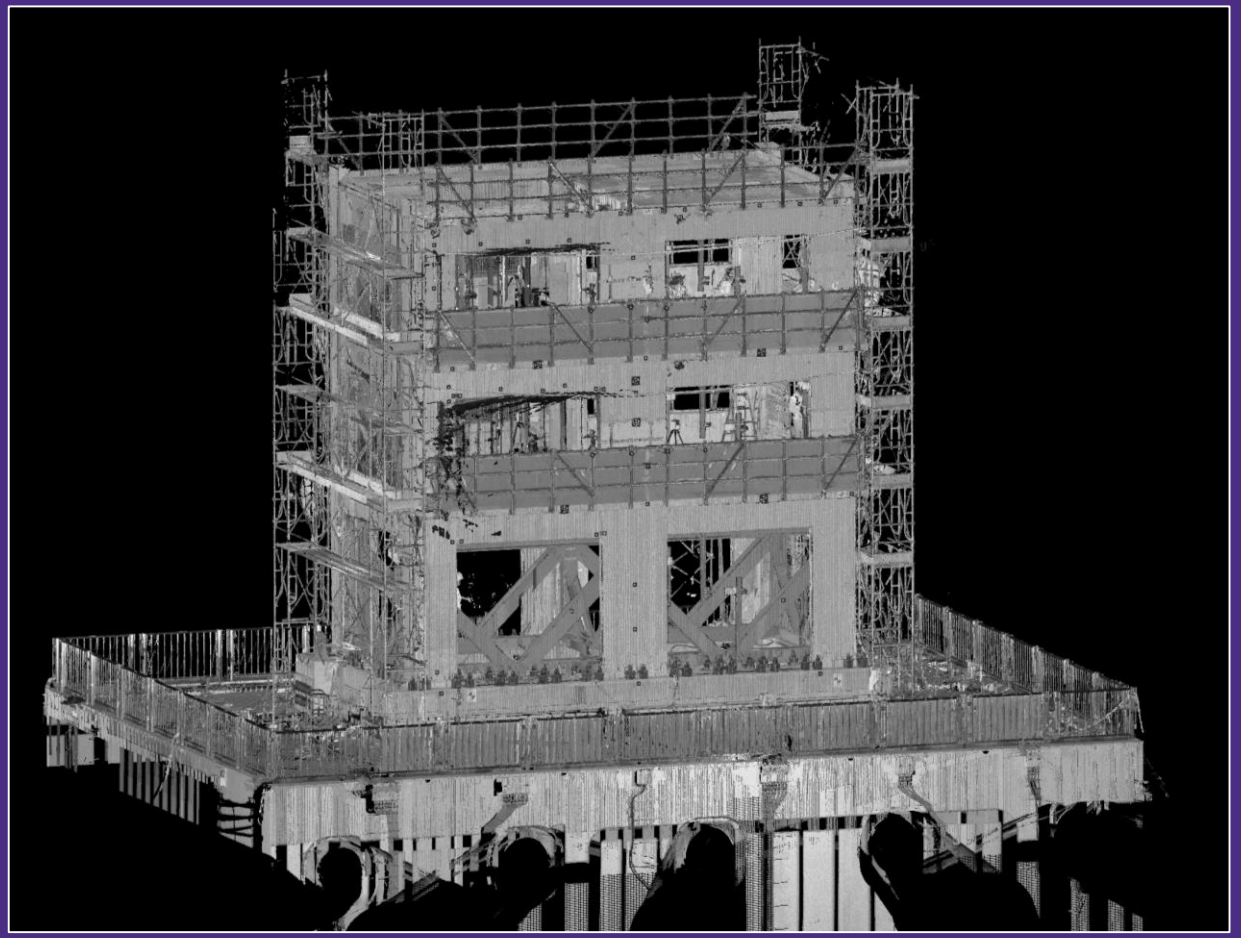
P50 LINE SCAN

Compute Floor Displacements Relative to Table

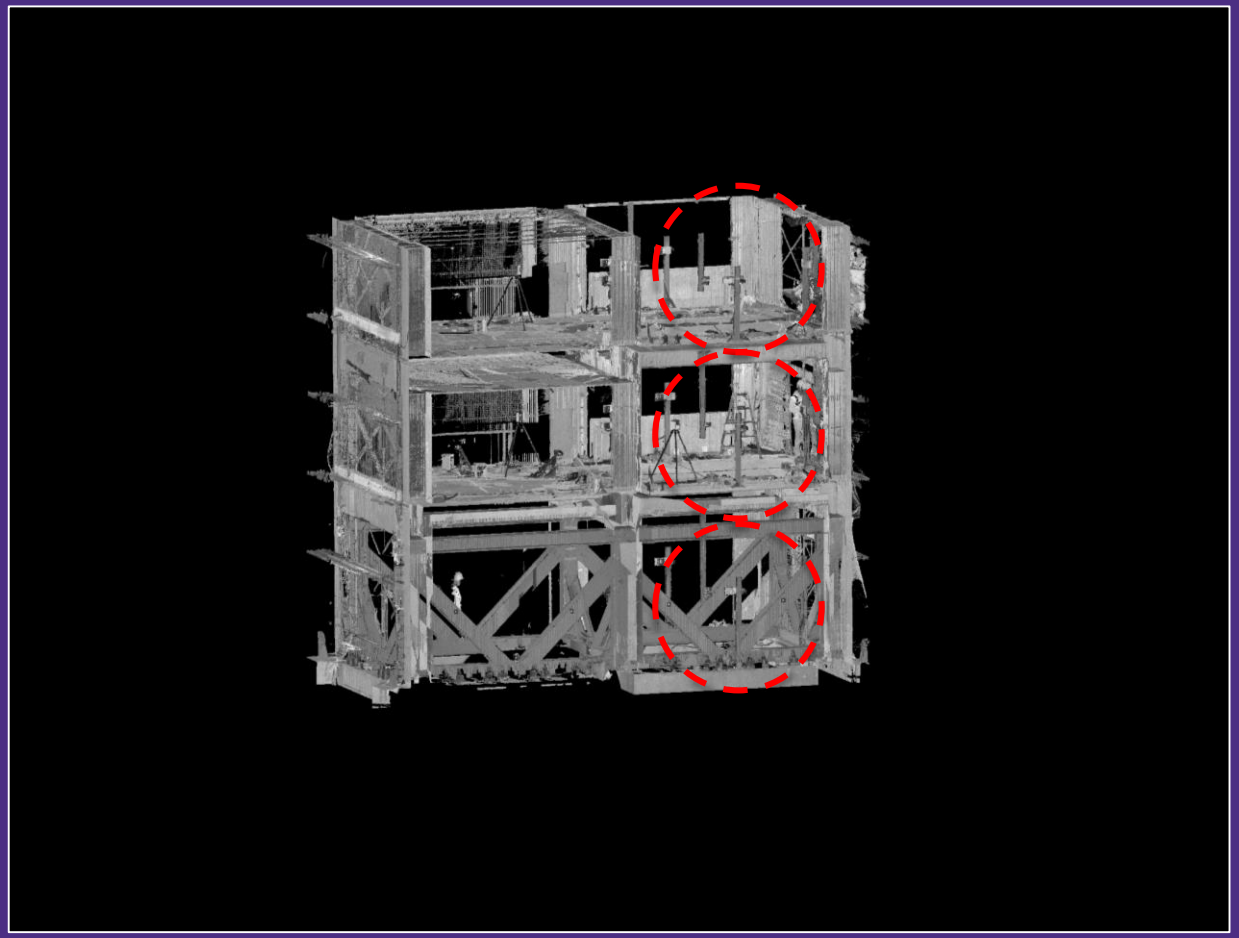


Results from Design Wave 160% test shown

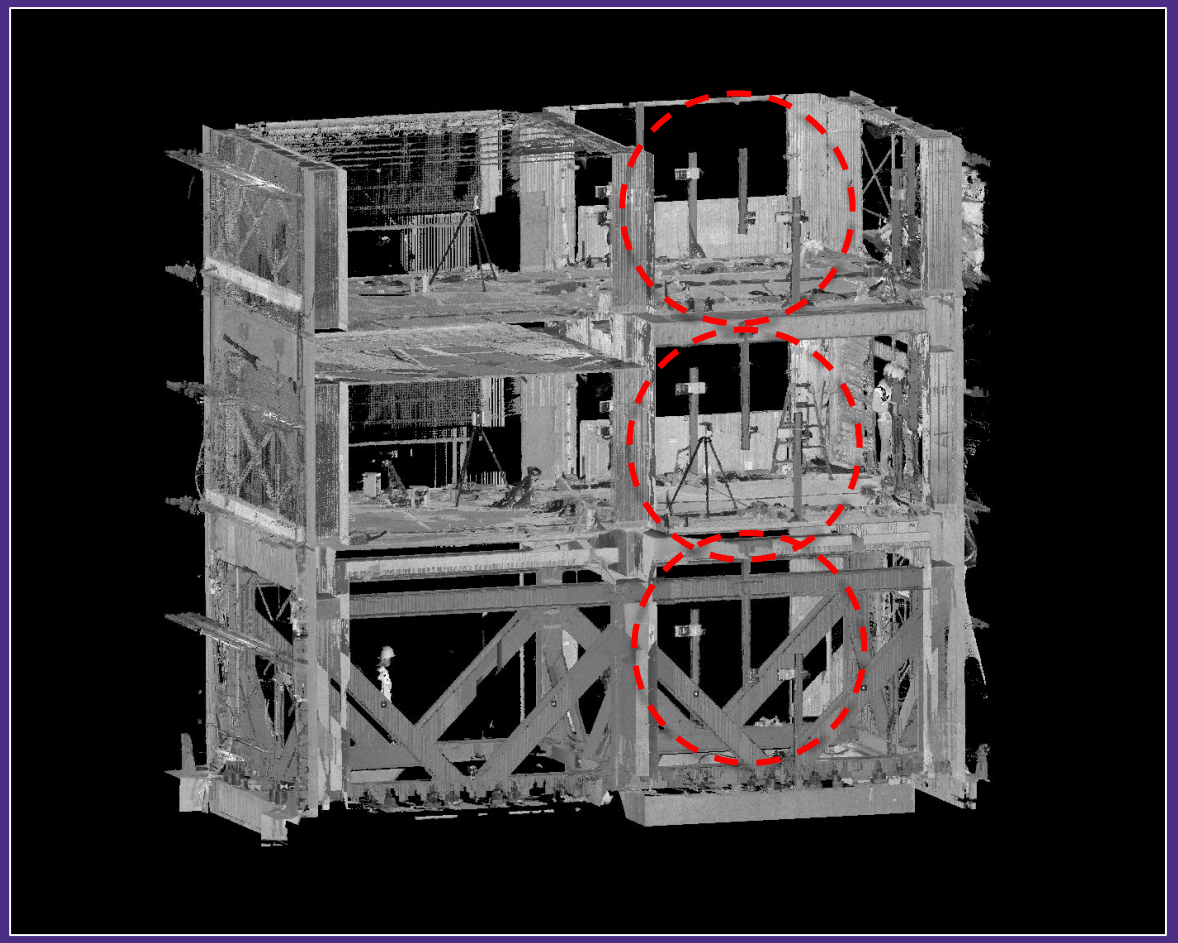
Comparison to Inter-story Laser Measurements



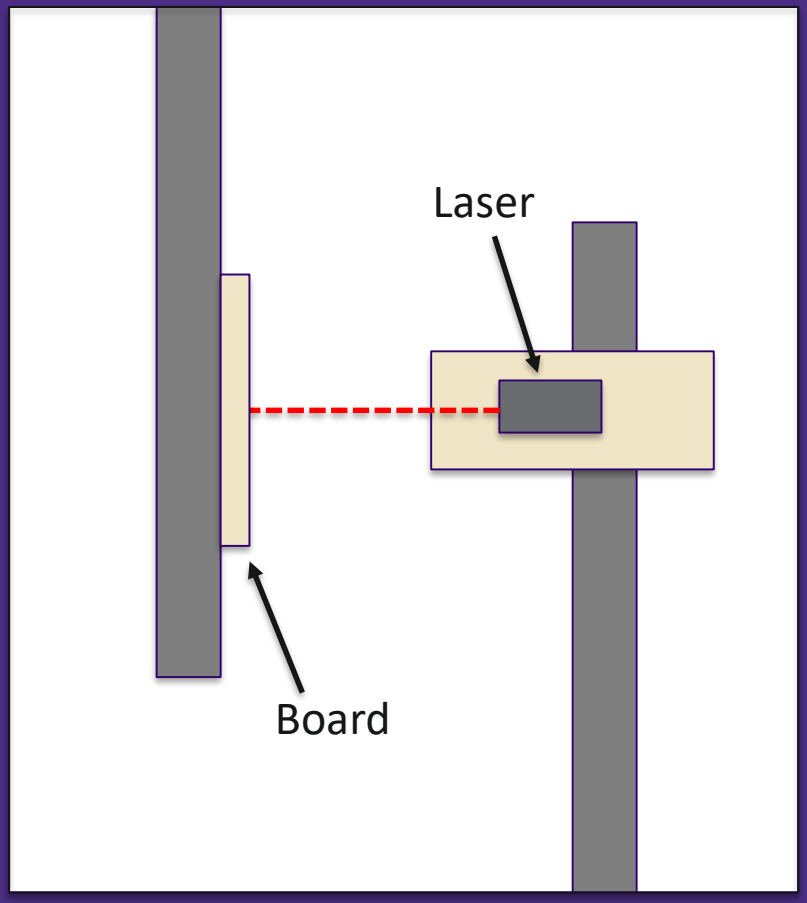
Comparison to Inter-story Laser Measurements

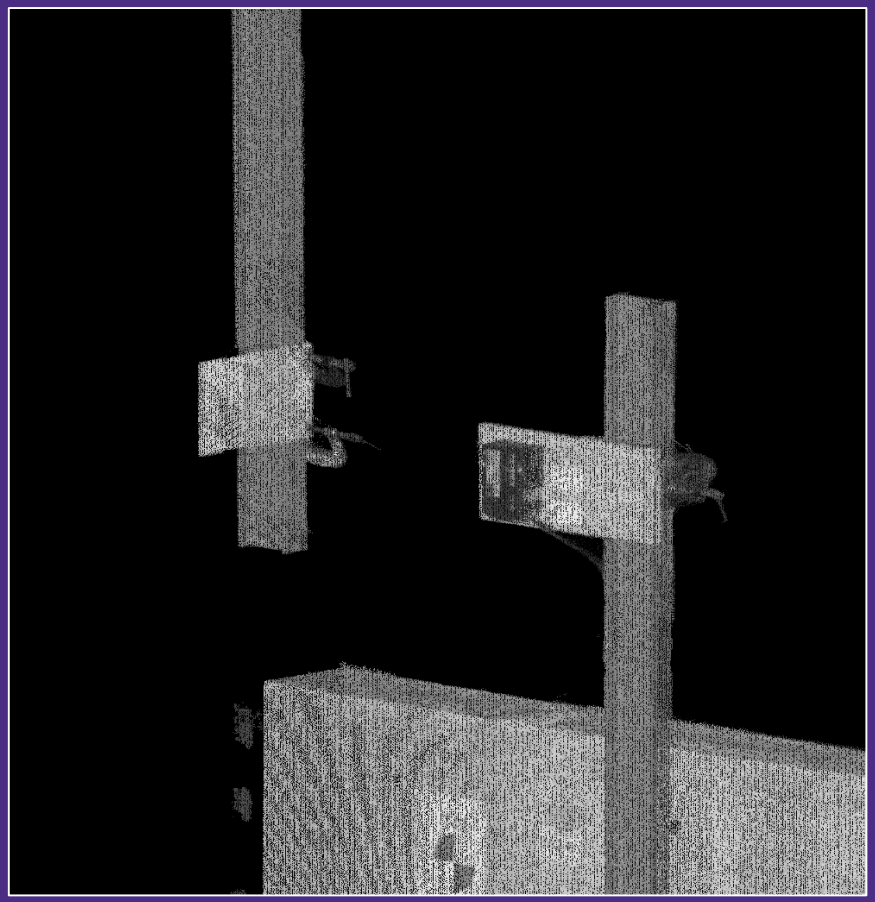


Comparison to Inter-story Laser Measurements



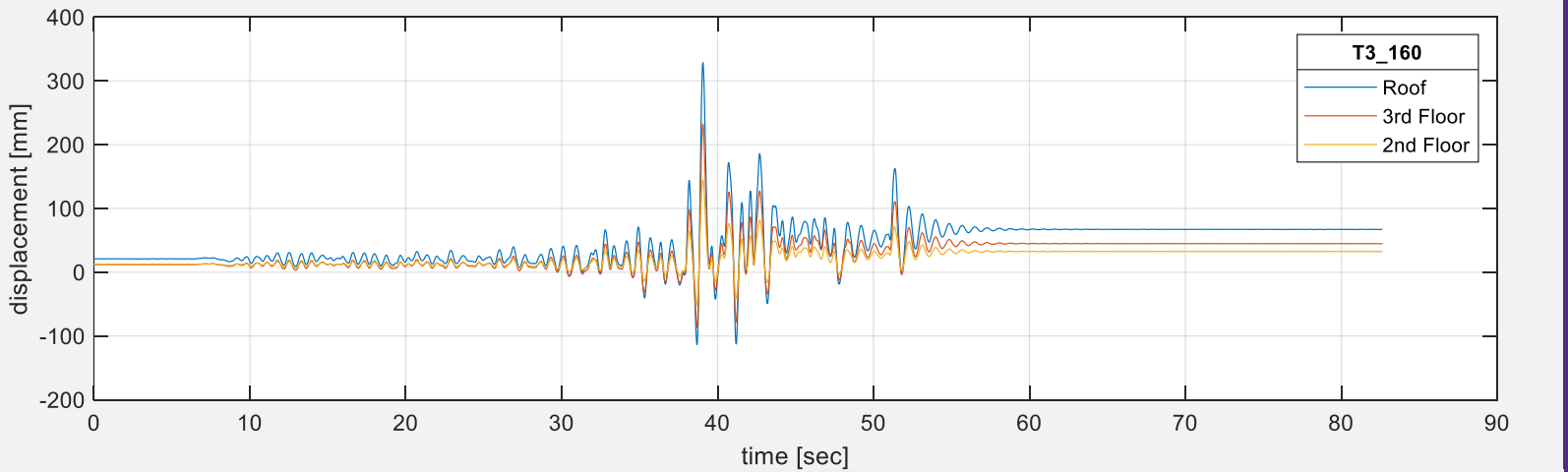
Comparison to Inter-story Laser Measurements



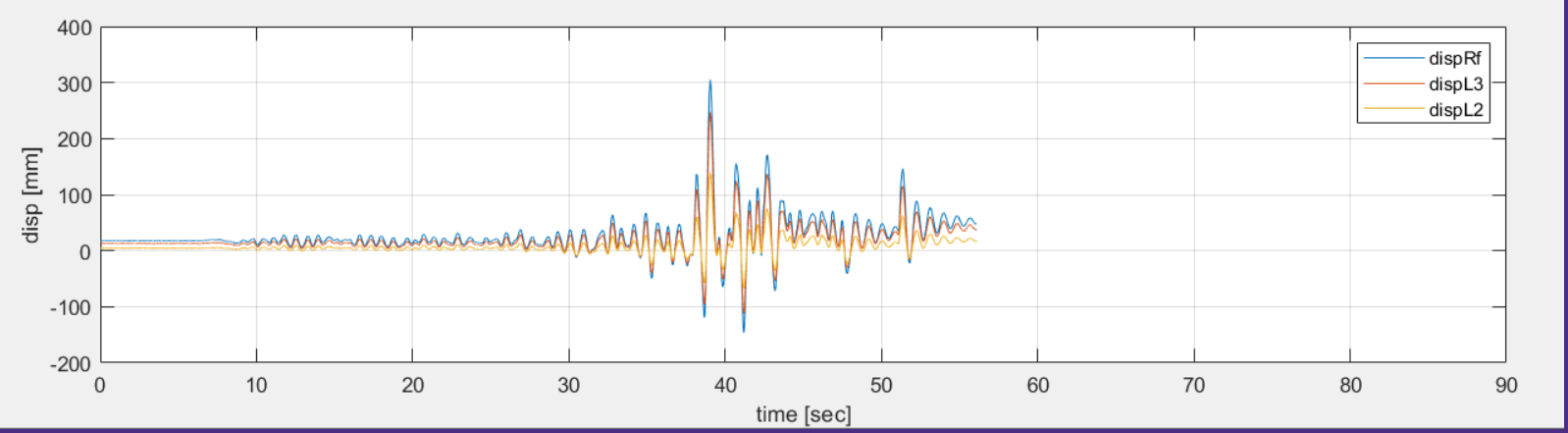


P50 LINE SCAN

Comparison of Line Scan results and inter-story laser measurements from Japan team



Line Scan



Inter-story Laser

Results from Design Wave 160% test shown

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Questions?