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

NSF Award Number: CMMI 2000478
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 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
TESTING AND SCANNING TIMELINE

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

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

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

Baseline (BL) Scans
Test 1 (T1) Scans
Test 2 (T2) Scans
Test 3 (T3) Scans
EQUIPMENT 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

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

EQUIPMENT USED

Leica ScanStation P50

> Long-range (> 1km)

> High-resolution scans (0.8mm at 10m setting used)

> Can select scan region

> Line Scan mode

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

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)

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

Magnetic Targets

Paper Targets

M1

M2

M3

T17

W
TARGETS

Total Station Measurements

Specimen

Balcony Total Station Setups

Ground level Total Station Setup

UNIVERSITY of WASHINGTON
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 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

Baseline

Test 3

Directly measure deformations

Shown overlapped on the same coordinate system

Distance: 0.054822

ΔX: -0.000490
ΔXY: 0.051762
ΔY: 0.051760
ΔXZ: 0.018067
ΔZ: 0.018060
ΔZY: 0.054820
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
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
These profiles were collected throughout the test at 50 hertz.
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
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Comparison to Inter-story Laser Measurements
P50 LINE SCAN

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

Results from Design Wave 160% test shown
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Questions?