Deformation/Displacement Measurement Using 3D Laser Scanning

Research Team Leaders

Dr. Fatih Oncul, Ph.D., Dr. Wasim Barham, Ph.D.

Data Collection Teams

Point Cloud Scanner - Dr. Pavan Meadati, Ph.D.

Total Station - John M. Lee, RLS, Daniel Branham, RLS

Displacement Gauge – William Lotz, Chance Dennis

January 26, 2012

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Deformation/Displacement Measurement Using 3D Laser Scanning

AGENDA

- **Introduction** (Mr. Lee) 5 min
  - Participants & Companies

- **Project Overview**
  - Research topic (Dr. Oncul, Dr. Barham) 20 min
    - **Q&A** 5min
  - Surveyors involvement (Mr. Lee, Mr. Branham) 20 min
    - Pre-project Discussions & Engagement Agreements
    - **Q&A** 5min

- **Outcomes and Metrics**
  - Data collection outcome (All) 20 min
  - ROI calculations
  - **Q&A** 5min

- **Conclusions / Recommendations** (All) 10-15 min

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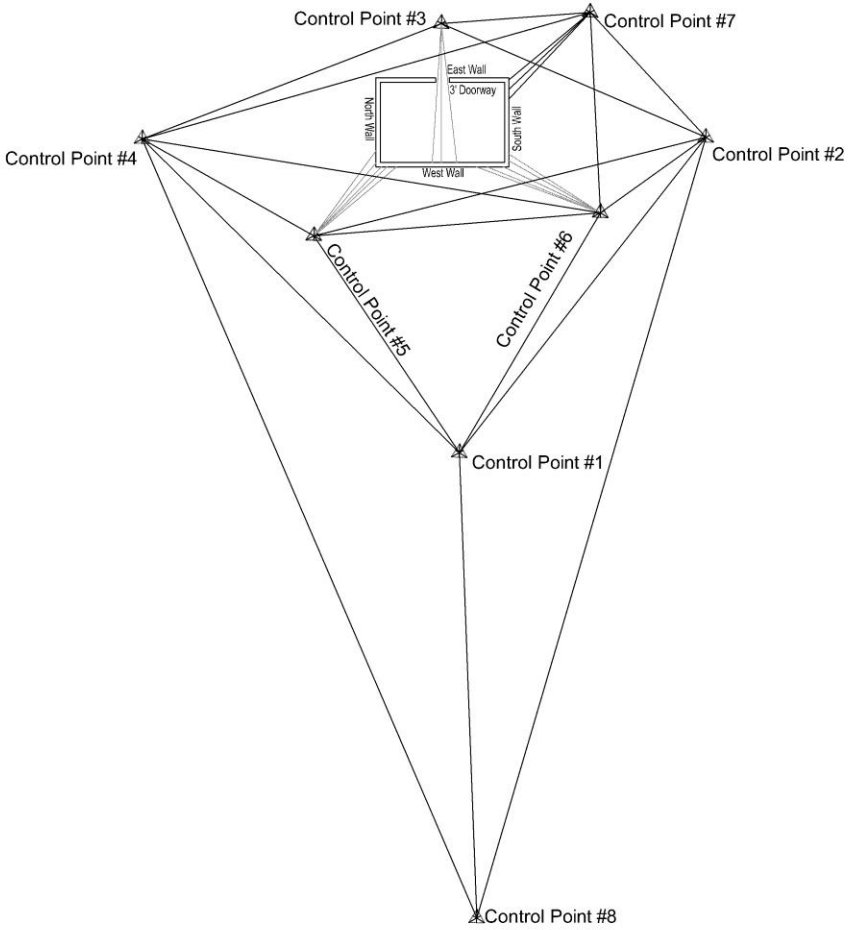

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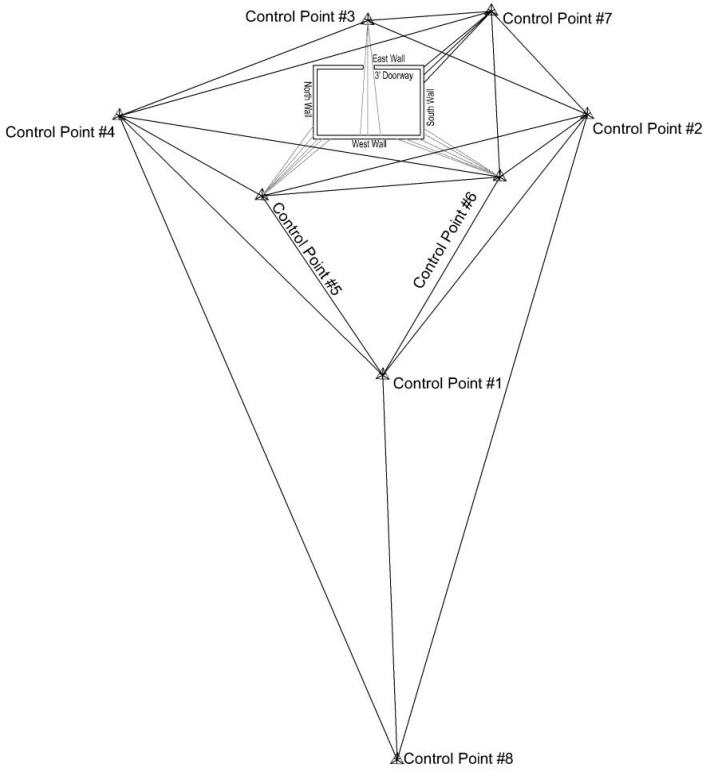

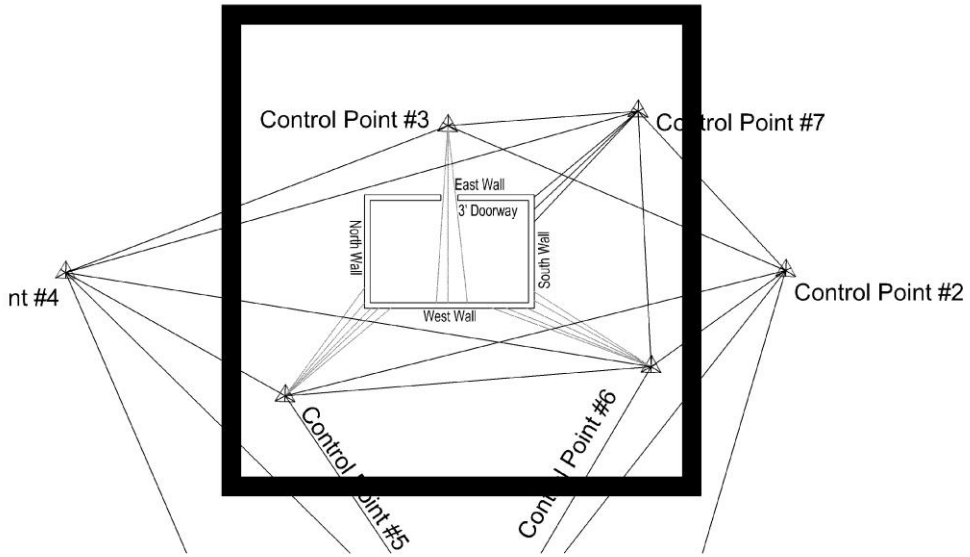

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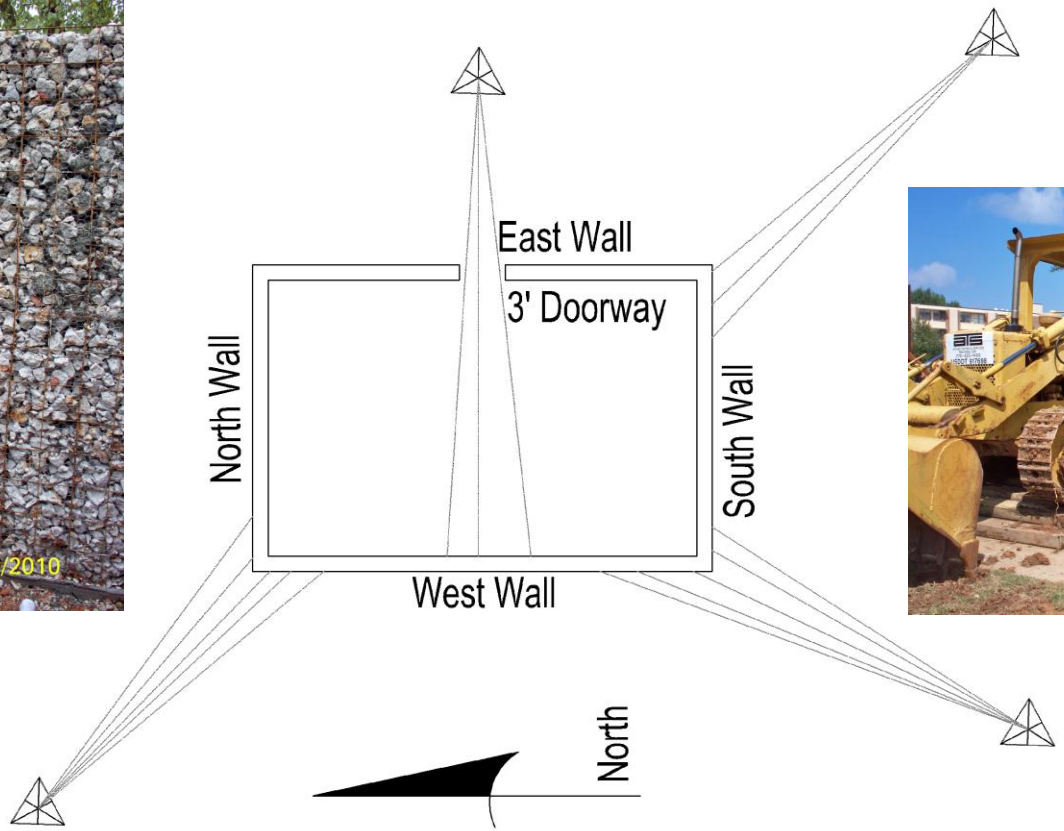

PLAN VIEW OF RUBBLE HOUSE
SHOWING DATA COLLECTION LINE LOCATIONS
SCALE N.T.S.

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PROJECT OVERVIEW

- **Client Request**
  - Researchers Project Topic
    - The Structural Properties of the Conscience International Rubble House Building Technique
  - Data Collection Team Proposals

- **Repeatable Techniques / Data Integrity**
  - Performance Requirements
  - Data Collection and Validation Requirements

- **Actions Taken / To-be Taken**
  - Taken: Engagement of three data collection teams
  - Taken: Project schedule set
  - Taken: Data Collection completed
  - To-be Taken: Final Analysis Report presentation to ASCE

- **Safety Items / Concerns**

Deformation/Displacement Measurement Using 3D Laser Scanning
PRE-ENGAGEMENT DISCUSSIONS

- Expected Number of Data Points to be collected for Analysis
- Safety / Site Requirements
- Cost (Time and Materials / ‘Not To Exceed’ Pricing)
  - Labor
  - Equipment
- Project Time Frames
- Quality / Attention to Detail
  - Research Level Data Collection Work
  - Data Collection Opportunities will only occur once, cannot go back and get it later

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Deformation/Displacement Measurement Using 3D Laser Scanning

POSSIBLE OR ASSUMED RISK

- Human Error
- Equipment Failure
- Weather
- Lack of Light / Time of Day

- Airborne Projectiles
  - Fragments of Mortar
  - Unexpected fracturing or Breaking of Walls

- Unstable Surfaces
- Unstable Equipment
  - Ladders
  - Scaffolding
- Premature Wall Failures or a failure in the hydraulics of the pressure rig

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Deformation/Displacement Measurement Using 3D Laser Scanning
SAFETY

- Technicians Job Performance Responsibilities
  - Safety Practices to follow
  - Site Safety Practices

- Required Equipment
  - Safety Vest
  - Work Gloves
  - Hardhat
  - Steel Toed Boots
  - Safety Glasses / Goggles
  - Boundary Tape

- Laser Eye Protection

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Deformation/Displacement Measurement Using 3D Laser Scanning

METHODS OF COLLECTIONS

- **Displacement Gauges**
- **Total Stations** (Prism-less (optional), Non-robotic)
- **Point Cloud Scanner** (Color optional)

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Deformation/Displacement Measurement Using 3D Laser Scanning

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Deformation/Displacement Measurement Using 3D Laser Scanning
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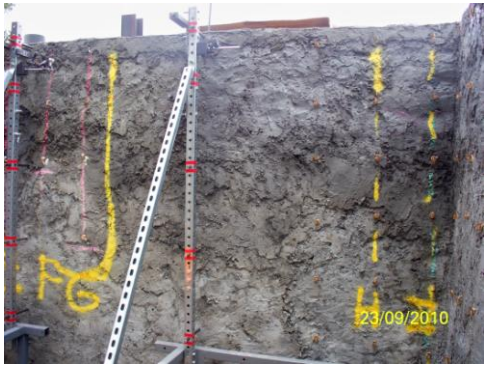

Question and Answer Session

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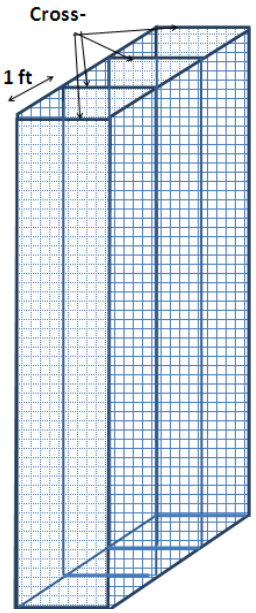
A Rubble House is…



- a structure with walls made out of wire baskets filled with loose rubble

- environmentally friendly (recycles concrete rubble)

A Rubble House is…

- a permanent house for the needy
- an alternate temporary emergency shelter for disaster areas

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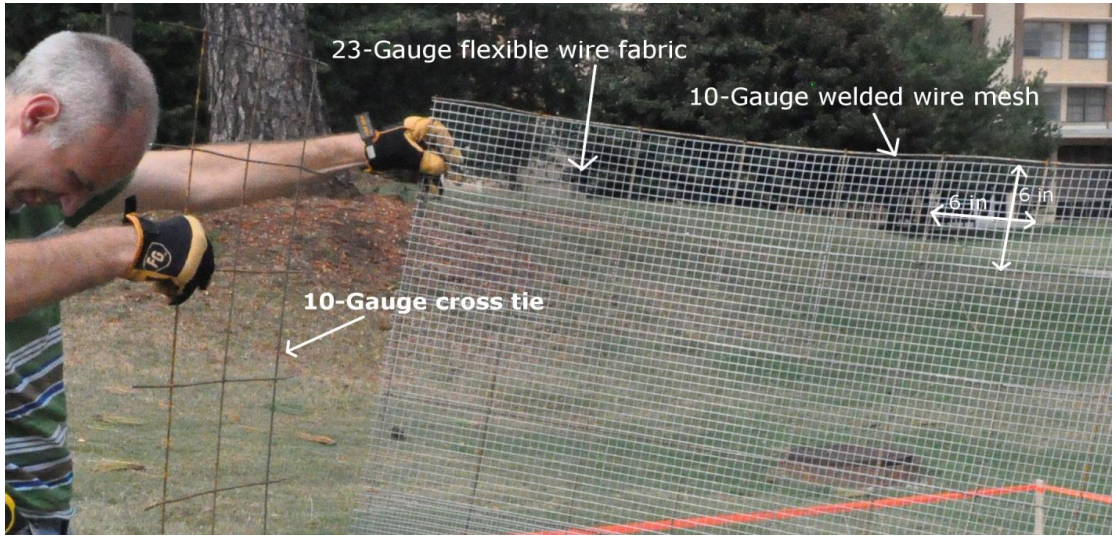
A Rubble House is…

- built with simple tools, easily available materials, and local labor.



- earthquake resistant ???

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Demonstrations with Concrete Battering Ram.

Brick Wall

Rubble Wall

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Conscience International

CONSCIENCE INTERNATIONAL

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Haiti Replacement Homes Project

Since the earthquake last year, we have been providing humanitarian aid to the people of Haiti. Our current focus is on building permanent homes made from the rubble of destroyed buildings. Using an innovative building system that we developed in Haiti, we are able to take the rubble from destroyed buildings and use it to build permanent, seismically resistant houses for Haitians who lost their homes during the earthquake.

Learn More

Ongoing Projects

- Haiti
- Pakistan
- Sudan
- Ethiopia
- Gaza

Conscience in the Media

See where Conscience International is making news.

Building Rubble Homes in Haiti

Help Us Rebuild Haiti

Donate More than a year later, Conscience International is still on the ground in Haiti, continuing to build homes for those left homeless as a result of last years earthquake. Your financial support is needed to allow us to continue providing urgently needed permanent housing.

Home

Rubble House Development

To further test and develop our Rubble House design, Conscience International is partnering with Southern Polytechnic State University to build a rubble house on the school campus for further research and development. The CI/SPSU Rubble House Project website includes daily updates as well as a live feed for monitoring progress.

Research Phases

- Phase 1: Preliminary, static loading, sponsored locally, @ SPSU

- Phase 2: Comprehensive, full-scale shake table test(s), sponsored by NSF? @ University of Buffalo?

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Objectives of Phase 1

- Evaluate current construction techniques and propose cost-effective improvements
- Perform static load testing on a full-scale RUBBLE-HOUSE
- Create computer models for static and dynamic analyses
- Make recommendations for future seismic shake table experiments
- Draft construction and design guidelines based on experimental and numerical findings

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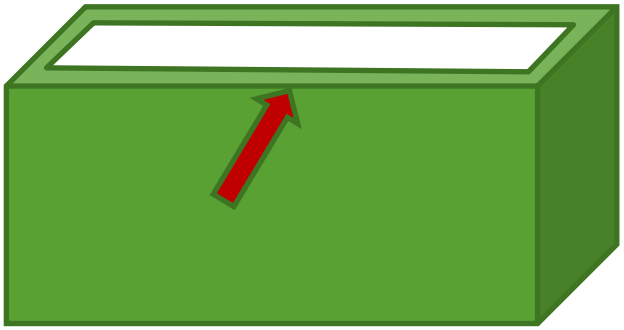
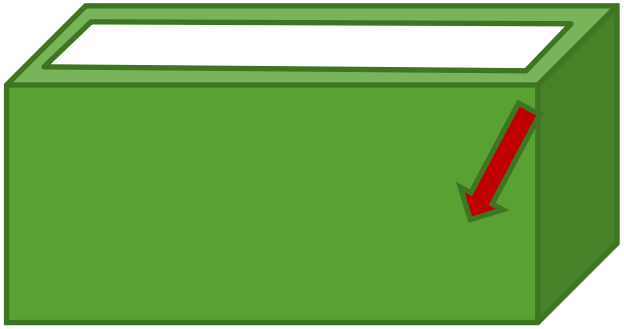
Static Field Load Testing Schedule - Phase 1

Test 1

Test 2



Test 3



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Objectives of Phase 2

- Perform full-scale shake table tests
- Study compaction behavior of the rubble under a main seismic event and series of aftershocks
- Determine failure modes
- Study the performance of proposed improvements from Phase 1
- Develop rubble house construction guidelines

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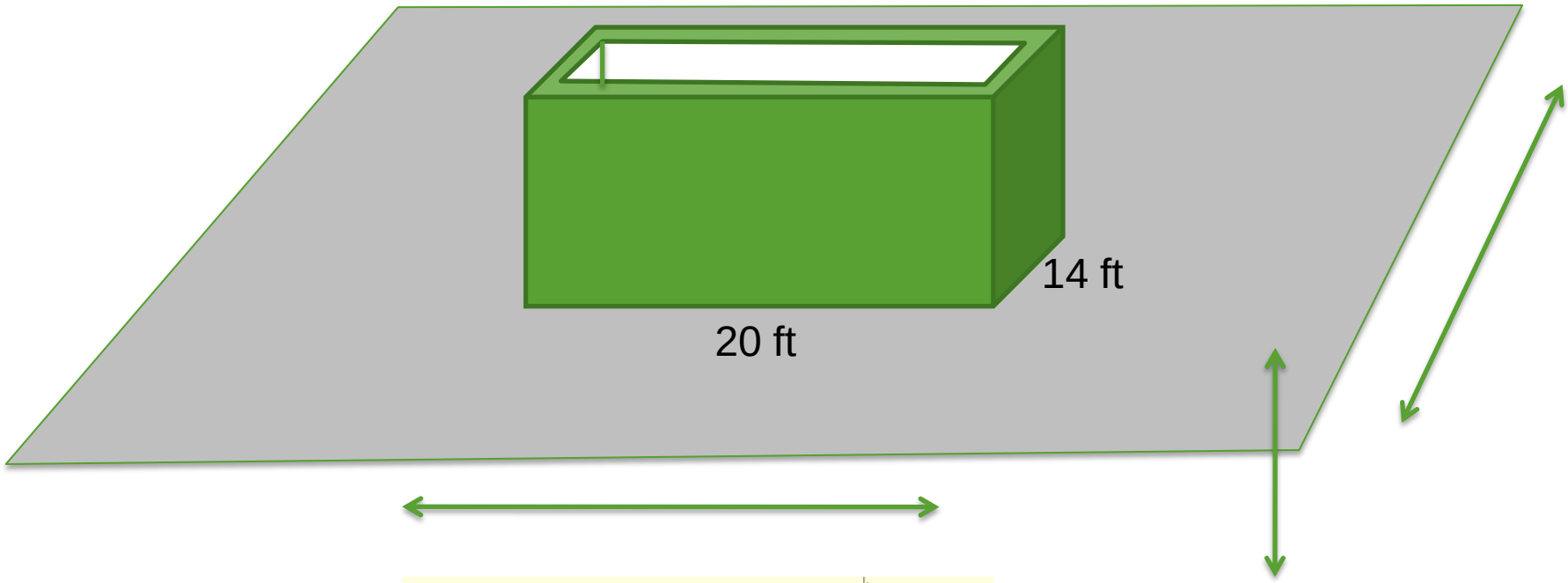
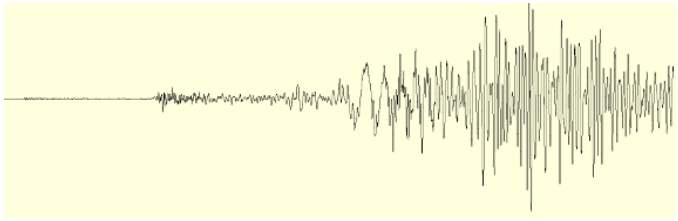
Seismic Shake Table Test - Phase 2





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Measurements

- Three Methods
  - Disp. gauges
  - Total Stations
  - 3D Laser
- Expectations
  - Be able to measure small displacements
  - Required precision: 0.01 in
  - Capture displacements during unloading
  - Cost

(a) Displacement gauges.

(b) 3D Laser scanner.

(c) Total stations.

Displacement/Deformation Gages

Displacement gage

Deformation gage

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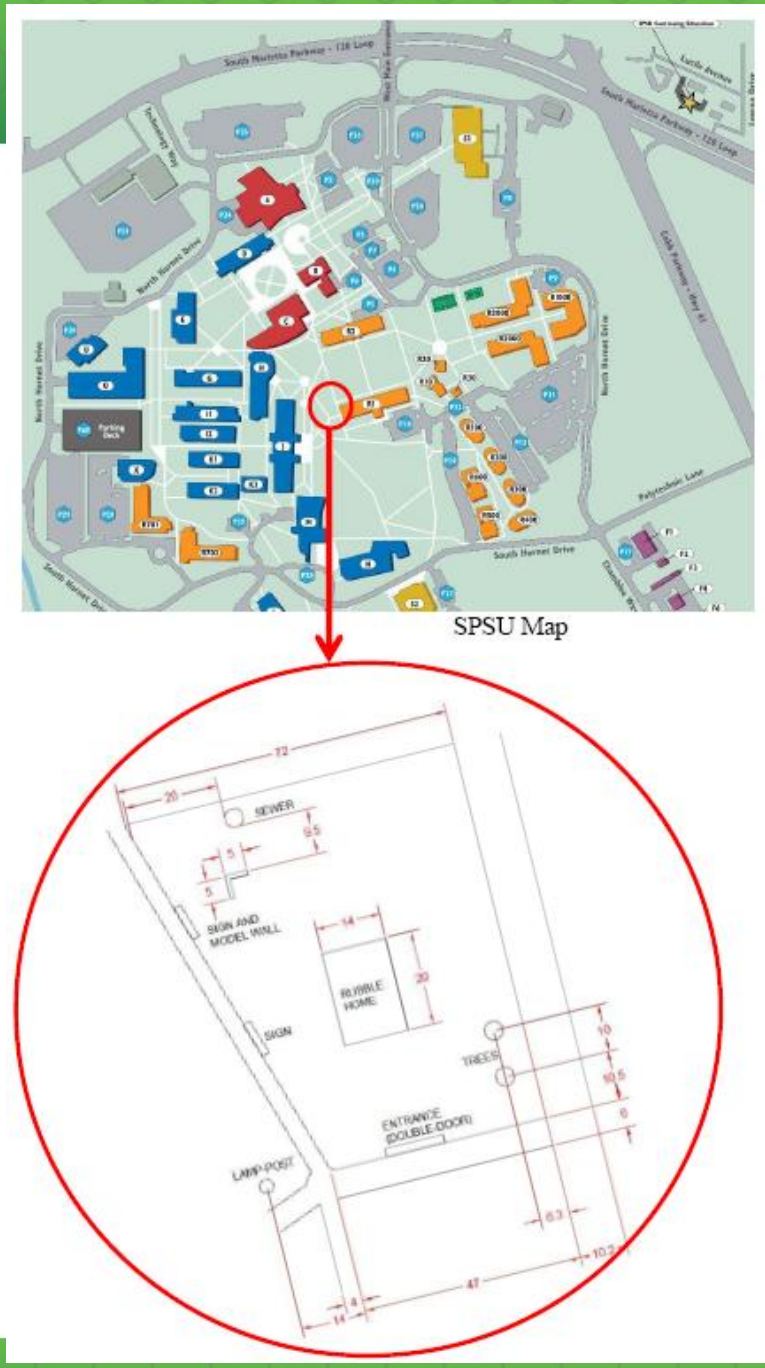
Location


East Wall
South Wall
West Wall
North Wall
NATIONAL


SPSU Map
72
20
SEWER
5.5
5
5
SIGN AND MODEL WALL
14
30
RV/MH HOME
SIGN
TREES
10
10.5
6
ENTRANCE (DOUBLE DOOR)
LAMP POST
6.3
10.2
47
8
14

In Haiti

(a) Foundation installation

(b) Wire basket preparation

(c) Baskets filled with loose rubble

(d) Adjusting window and door openings

(e) Applying cement finish

(f) Roof installation

(g) Final look of a typical Rubble-House in Haiti

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At SPSU

(a) Foundation installation

(b) Wire basket installation

(c) Wire baskets being filled with loose rubble.

(d) Applying cement finish

(e) Final look of the rubble-house on SPSU campus.

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Student Involvement





- More than 100 students participated..
- 600 hours of student labor time..

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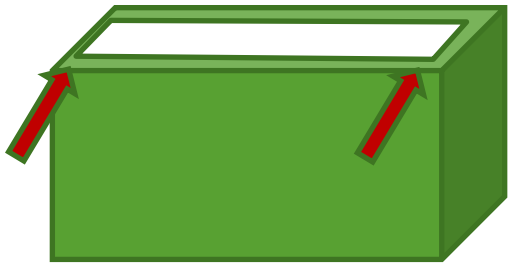
TEST 1

- In-plane push



(a)

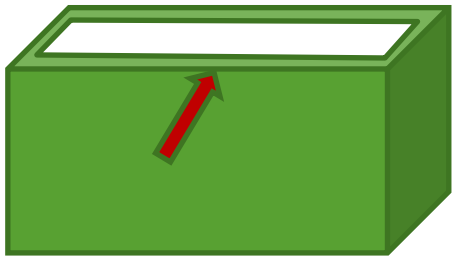
(b)

(c)

(d)

TEST 2

- Center push



(a)

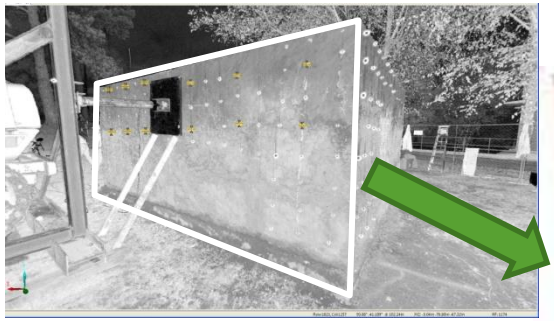
(b)

(c)

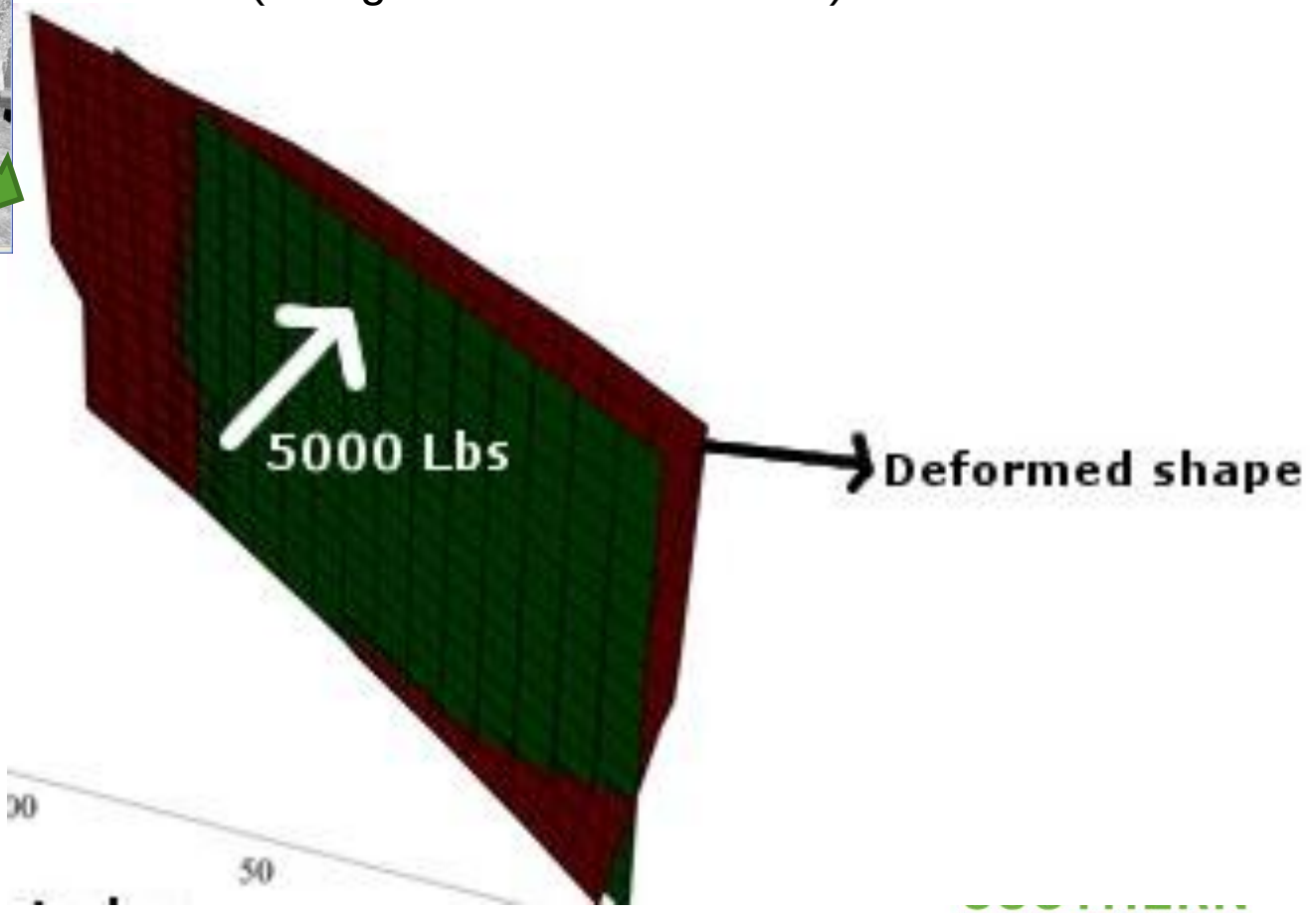
(d)

3D Laser Scan Picture – Test 2: Center Push

Deformed Shape – West Wall

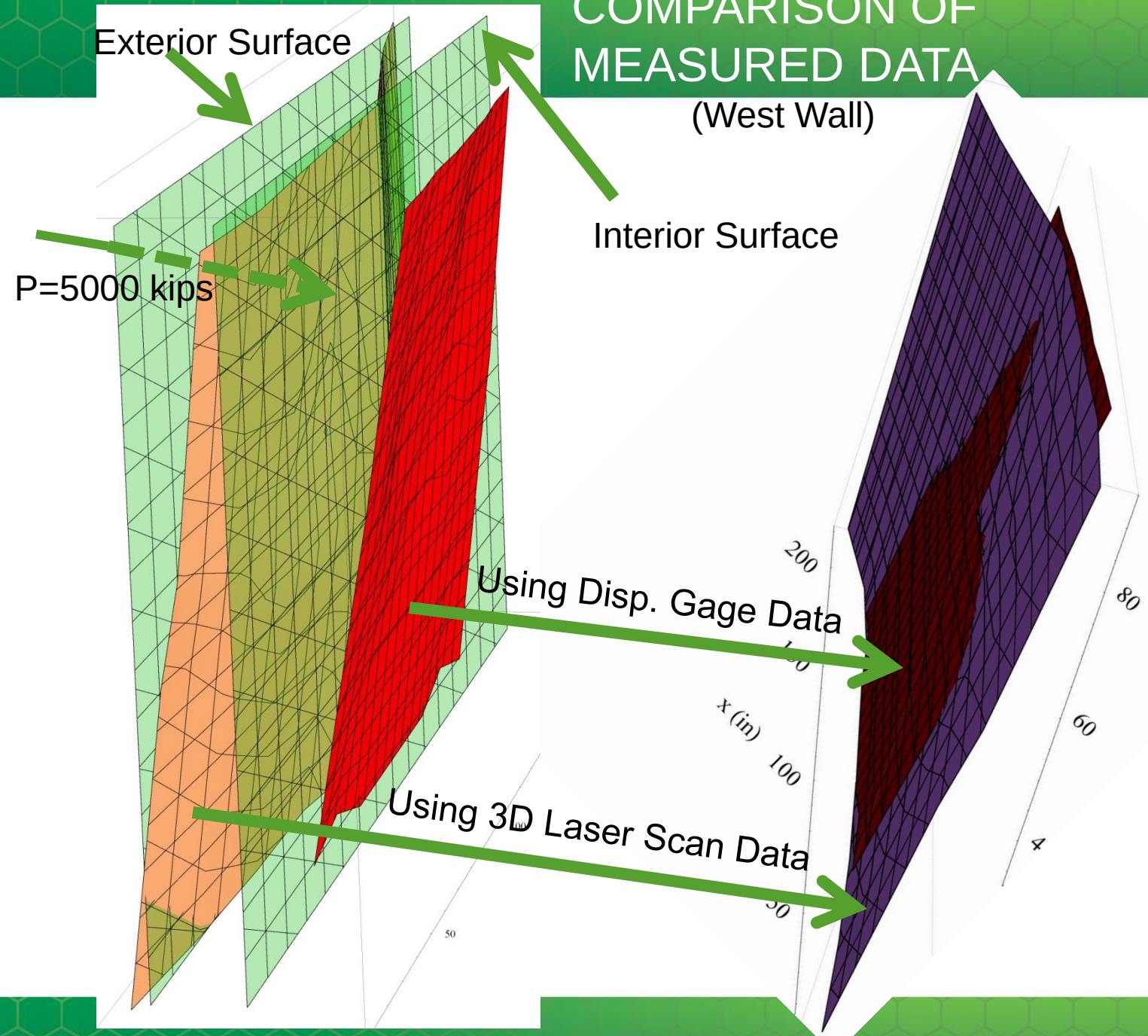


(Using 3D Laser Scan Data)



COMPARISON OF MEASURED DATA

(West Wall)



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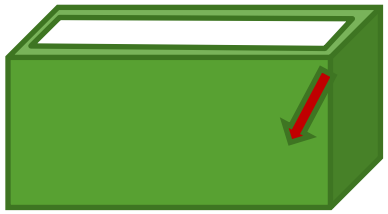
TEST 3

- Destructive



(a) Truck with a front winch.

(b) Wrap around chain link.

(c) Load gauge.

(d) Wooden block at SE corner.

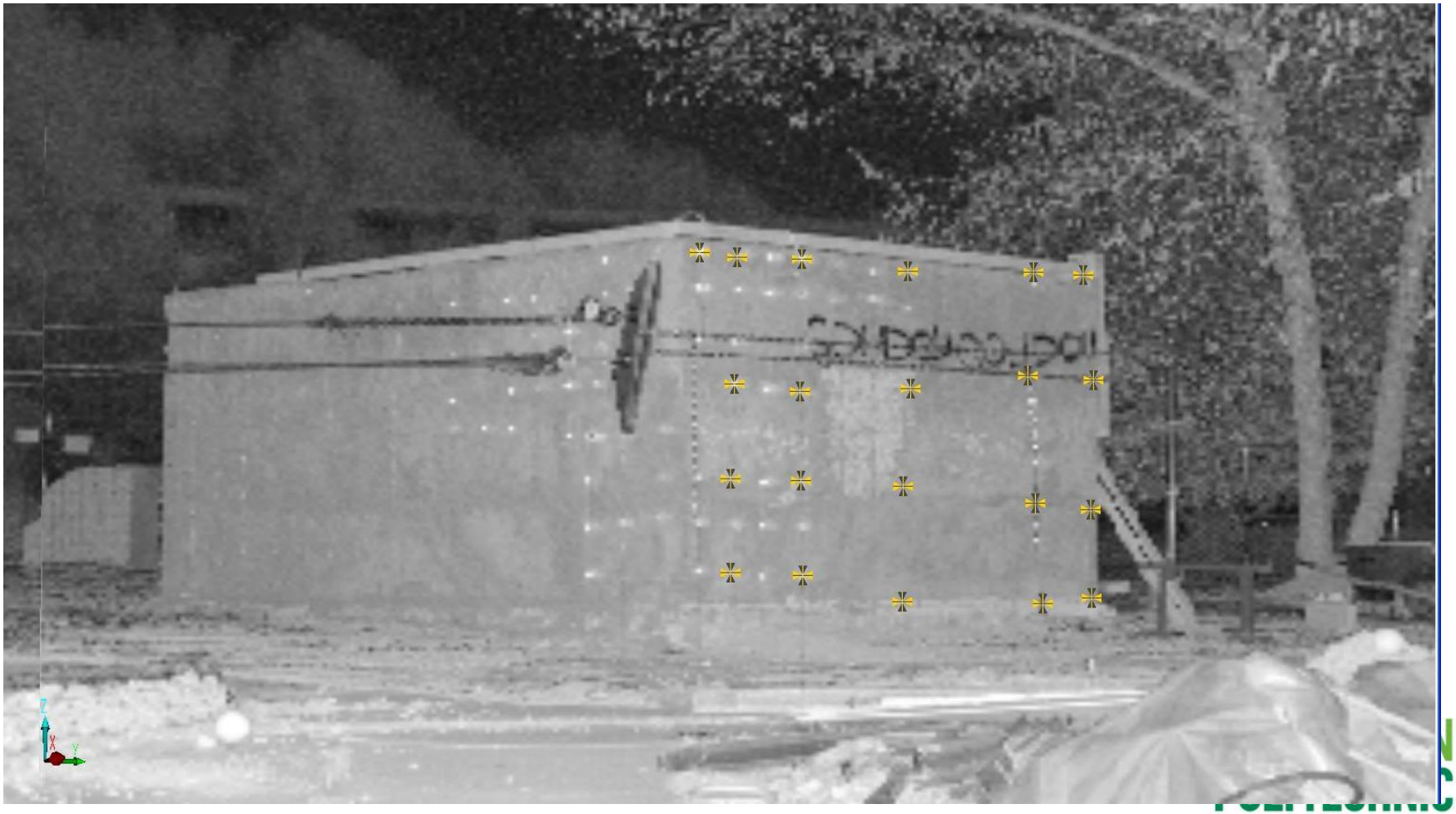
Post-failure

(a) Rubble-House after failure

(b) South-east corner.

(c) South-east corner bottom.

3D Laser Scan Picture – Test 3: Destructive



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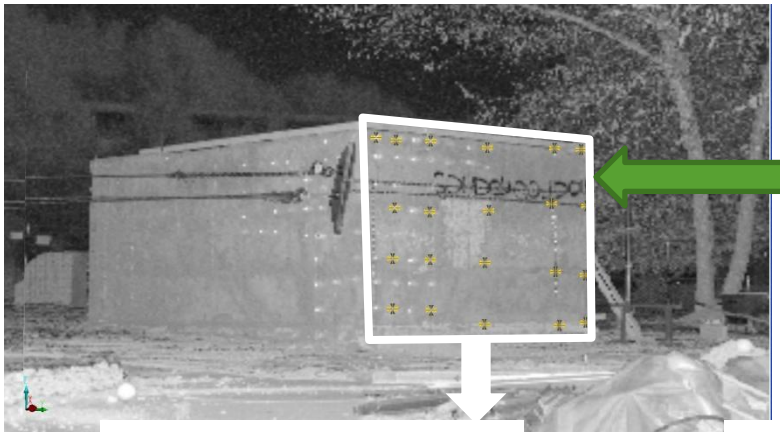
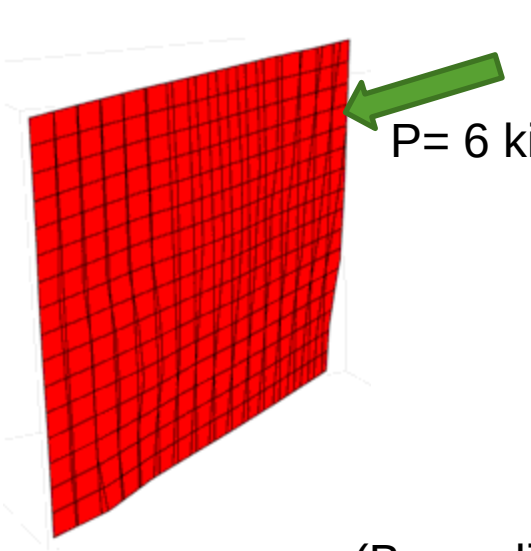
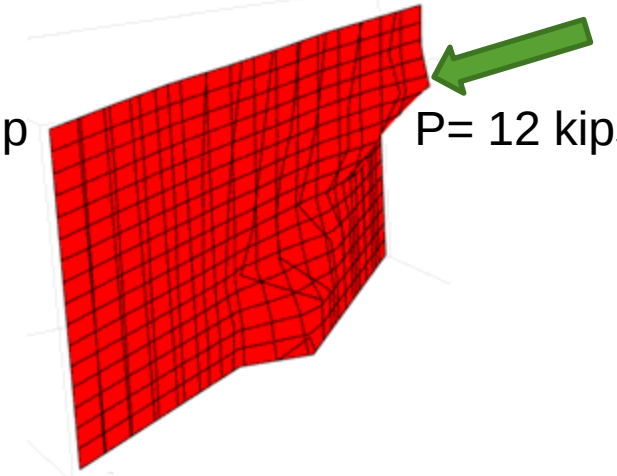
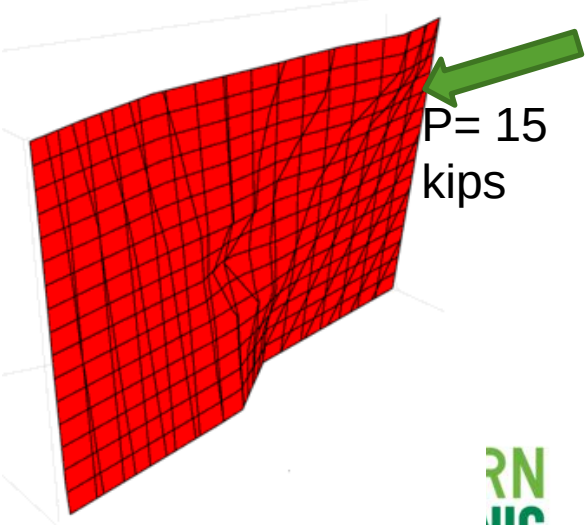
Deformed Shape – South Wall

(Using 3D Laser Scan Data)









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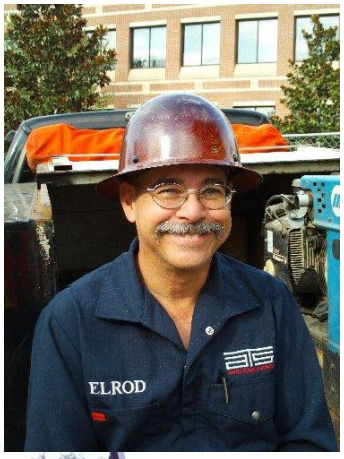
ATS – Applied Technical Services
Marietta, GA



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PAUL LEE
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ATLANTA DEMOLITION
Preparing for Progress

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Conclusions (Dr. Oncul)

- Displacement gauge
  - Quick and easy
  - Reasonable precision

- Total Stations
  - Reasonable precision
  - Multiple “well defined” data points

- 3D Laser Scanner
  - Reasonable precision
  - Multiple “point cloud” data points

- More than one data collection method is always preferred

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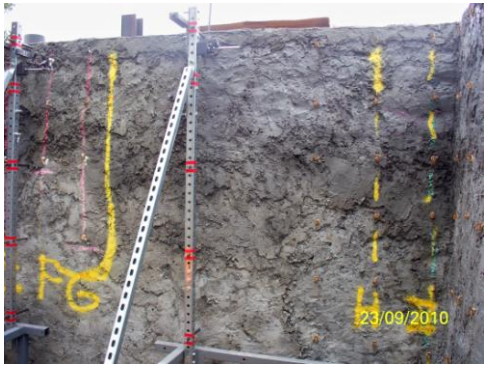
Deformation/Displacement Measurement Using 3D Laser Scanning



Question and Answer Session

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Deformation/Displacement Measurement Using 3D Laser Scanning

DATA COLLECTION HIGH LEVEL PLAN

- Provisioning
  - Design / Assembly / Training
- Site Preparation
  - Equipment Setup
  - Establish Control
- Measurement Techniques
  - Pre-project trial evaluations
  - Pre-project data processing
- Cost
  - ROI – per collected point / per used data point

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Displacement Gauge Data Collection

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Deformation/Displacement Measurement Using 3D Laser Scanning
DISPLACEMENT GAUGES – PROVISIONING

- **Design**
  - Custom manufactured for each job
- **Construction**
  - Multiple day lead time
- **Placement**
  - Equipment has limited mobility and must be normal to displaced surface
  - Frames must be positioned to avoid interfering with pressure applicators
  - Measurement Technician must enter dangerous work area to take readings
- **Training**
  - Requires limited skills to operate
  - Supervisory attention required during each measurement

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Deformation/Displacement Measurement Using 3D Laser Scanning

DISPLACEMENT GAUGES – SITE PREPARATION

- **Establish Control**

- **Equipment Placement**
  - Determine the Area of Operation
  - Range of Valid Data / Tolerance of Calipers
  - Placement of Ladders, Scaffolding, and target measurement areas
  - Labeling of Surfaces, Targets

- **Setup of Hardware**
  - Pre-trial testing
    - Simulated Data Collection
    - Data processing
    - Ladders, Lights, technician placement

- **Tie to Control Procedures**
  - Frames should be located and tied to structure, total station and point cloud control points

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DISPLACEMENT GAUGES – MEASUREMENT TECHNIQUES

- **Pre-trial data collection evaluation**
  - Set displacement gauges to starting position
  - Set measurement calipers to zero position
  - Displace gauge using a fixed size object
  - Read, record and validate the starting / benchmark values
  - Ensure that no movement has occurred in frame of displacement gauge

- **Pre-trial data processing evaluation**
  - Using recorded values, compute the displacement
  - Determine if fixed object displacement value is within tolerance to the measured displacement

Deformation/Displacement Measurement Using 3D Laser Scanning
DISPLACEMENT GAUGES – OUTCOME / RESULTS

- **Data Obtained**
  - Students performed construction, data collection and (Dr. Oncul) reduction
  - Frames with 5 Gauges were read
    - 5 tests each day for 2 days
    - 5 points per test session
    - Measurement calipers were verified to 0.01 (inches)
  - Displacement Gauge Team Work Process
    - 1 team of 2 persons (one measurement technician / one documentation technician)
    - Data validated by taking multiple measurements, then averaging results
  - Total data collected (3 frames*5 gauges*5 tests*2 days = 150 data points)
    - Data collected during two of three days of testing
    - Displacement gauge frames removed from work area during destructive test sequence
    - All data point **WERE** utilized by researchers in analysis

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DISPLACEMENT GAUGES – COSTS

- **Costs**
  - **Total Costs = $2,000.00**
    - Materials & Construction Cost ($500.00)
    - Data Collection teams ($15/hr *80 hrs = $1,200.00)
    - Data reduction (team & researchers) $15/hr * 20 hrs = $300.00)
  - **Research team ROI ($2,000 / 150 points = $13.33 / pt)**
    - Per collected data point
      - All 150 points reviewed for validity
    - Per analyzed data point
      - All 150 points used for final analysis
  - **Displacement Gauge Team ROI**
    - Per collected data point ($2,000 / 300 readings = $6.67 / pt)
    - Per collection period ($1,500 / 80 hours = $18.75 / hr)
    - 2 technicians ($18.75 / 2 persons = $9.38 / hr)

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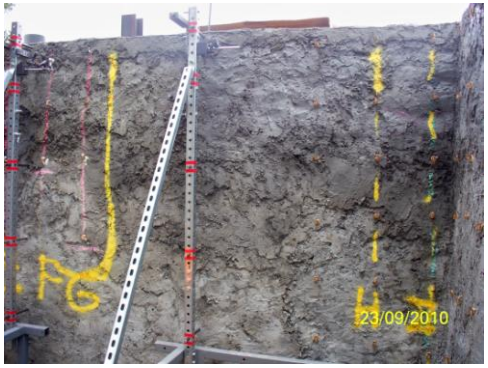

Question and Answer Session

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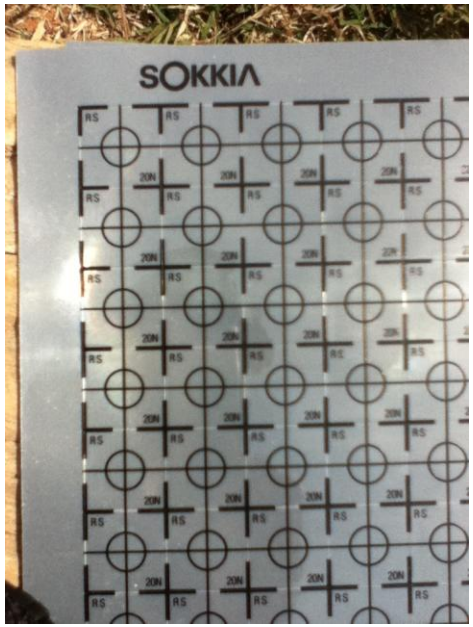
Total Station Data Collection

Total Station Data Collection



Deformation/Displacement Measurement Using 3D Laser Scanning

TOTAL STATION - PROVISIONING

- **Design**
  - Use standard Non-robotic 6 second Construction total stations (Topcon Sokkia CTS-6) equipment packages which include instrument, tripod, prism, prism pole, tribrach, tripod, sheet of 400 (10mm) Sokkia stick-on targets.
- **Construction**
  - Equipment and operators obtained from local companies
    - J.A. Evans & Associates Land Surveyors
    - Paul Lee Consulting Engineering Associates, Inc.
    - Optical Engineering
    - SPSU
- **Placement**
  - Limited mobility, Equipment must be placed to see control and avoid interfering with pressure applicators but pressure equipment could move during loading
  - Equipment capabilities allowed for data collection from about 35 feet from work zone
- **Training**
  - Requires skilled operators to collect data
  - RLS attention required during each measurement session

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Deformation/Displacement Measurement Using 3D Laser Scanning

TOTAL STATION – SITE PREPARATION

- **Establish Control ahead of test session**
  - Control Traverse Setup, Run and Validated Before Test
  - Reflector Targets obtained and attached to finished structure
- **Equipment Placement**
  - Determine the Area of Operation
  - Range of Valid Data / Tolerance of equipment
  - Placement of control tripods, prisms, targets
  - Labeling of Surfaces, Targets
- **Setup of Hardware**
  - Pre-trial testing
    - Simulated Data Collection
    - Data processing
    - Lights, total stations, control points, and technician placement
- **Tie to control**
  - Surveyors performed data collection, students compiled computations and documentation

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Deformation/Displacement Measurement Using 3D Laser Scanning

TOTAL STATION – MEASUREMENT TECHNIQUES

- **Pre-trial data collection evaluation**
  - Set control and total stations to starting positions
  - Set total station and data collectors to zero position
  - Read, record and validate the starting & benchmark values
  - Turn to a known second control point
  - Read, record and validate the ending & elevation values
  - Ensure that no movement has occurred in local or control equipment

- **Pre-trial data processing evaluation**
  - Using recorded values, compute the displacement
  - Determine if control displacement value is within tolerance to measured displacement

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Deformation/Displacement Measurement Using 3D Laser Scanning

TOTAL STATION – OUTCOME / RESULTS

- **Data Obtained**
  - Surveyors performed setup of control, data collection; students performed documentation and data reduction
  - **3 Total Stations with 3 control points were established and read**
    - 5 tests each day for 2 days
    - 15 points per session
    - Measurements were verified to 0.06 (inches) or 0.005 (feet)
  - **Total Station Team Data Collection Work Process**
    - 3 teams of 2 persons (one surveyor / one documentation technician)
    - Data validated by taking multiple measurements, then verifying that results did not fall outside margin of error
  - **Total data collected (3 stations*15 points*5 tests*2 days = 675 data points)**
    - Data collected during two of three days of testing
    - Total Stations were removed from work area during destructive test sequence
    - All data point **WERE NOT** utilized by researchers in analysis
    - Field Data Collection Errors were detected during collection and 25 additional shots taken (total = 700)

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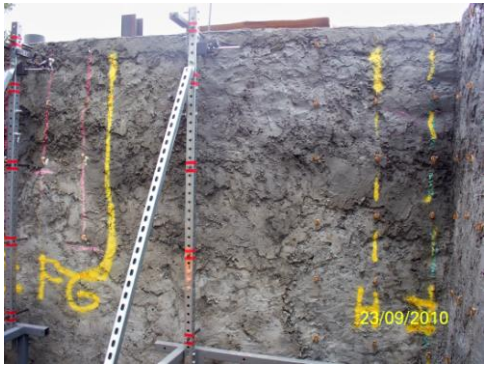
TOTAL STATION – COSTS

- **Costs**
  - **Total Costs = $4,300.00**
    - Equipment Rental Costs ($450.00 per total station package per day * 3 units * 2 days = $2,700.00)
    - Data Collection teams ($15/hr *80 hrs = $1,200.00)
    - Data reduction team & researchers ($15/hr * 20 hrs = $300.00)
    - Surveyor Review of data reduction ($100 /hr = $100.00)
  - **Research team ROI ($4,300 / 600 points = $7.17 / pt)**
    - Per collected data point
      - All 700 points reviewed for validity
      - 75 points were discarded due to incorrect back sight settings, 25 for operator or documentation error
    - Per analyzed data point
      - 600 points used for final analysis
  - **Total Station Team ROI**
    - Per collected data point ($4,300 / 700 readings = $6.15 / pt)
    - Per collection period ($4,300 / 80 hours = $53.75 / hr)
    - 6 technicians ($53.75 / 6 persons = $8.96 / hr)

Deformation/Displacement Measurement Using 3D Laser Scanning



Question and Answer Session

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Point Cloud Scanner Data Collection

Deformation/Displacement Measurement Using 3D Laser Scanning

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Deformation/Displacement Measurement Using 3D Laser Scanning

POINT CLOUD SCANNER - PROVISIONING

- **Design**
  - Use standard Point Cloud Scanner equipment package (Faro Focus 3D Laser Scanner) with tripod, location markers, scanning software, SD storage card, Dell notebook computer.
- **Construction**
  - Equipment and operators obtained from local companies (Faro.com, SPSU)
- **Placement**
  - Almost unlimited mobility, although equipment must be placed to see control and avoid interfering with pressure applicators but pressure equipment could move during loading
  - Equipment capabilities allowed for data collection from about 35 feet from work zone
  - Location markers cannot be moved during entire test process
  - Scanner cannot be moved during scanning process
- **Training**
  - Requires skilled operators to collect data
  - Eye Safety is critical and must be strictly enforced
  - RLS attention required during each measurement session

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Deformation/Displacement Measurement Using 3D Laser Scanning

POINT CLOUD SCANNER - PROVISIONING

SPSU

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Deformation/Displacement Measurement Using 3D Laser Scanning

POINT CLOUD SCANNER - PROVISIONING

SPSU

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POINT CLOUD SCANNER – SITE PREPARATION

- **Establish Control ahead of test session**
  - Location markers setup, Scan Run and Validated Before Test
  - Optional Reflector Targets obtained and attached to finished structure; if the data files are to be synchronized with total station data set
- **Equipment Placement**
  - Determine the Area of Operation
  - Range of Valid Data / Tolerance of equipment
  - Placement of location markers and optional targets
- **Setup of Hardware**
  - Pre-trial testing
    - Scanning Data Collection
    - Data processing
    - Review of scanned images to ensure that off-limit placement zone are marked
- **Tie to control**
  - Students performed data collection, students compiled computations and documentation

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Deformation/Displacement Measurement Using 3D Laser Scanning
POINT CLOUD SCANNER – MEASUREMENT TECHNIQUES

- **Pre-trial data collection evaluation**
  - Set location markers around site and position prisms on two control points
  - Scan and validate the starting & benchmark values
  - Ensure that scan includes at least one of the known control point and three of the location markers
  - Process the scan image and data file
  - Ensure that no movement has occurred in local or control equipment

- **Pre-trial data processing evaluation**
  - Using recorded values, compute the displacement
  - Determine if control displacement value is within tolerance to measured displacement

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Deformation/Displacement Measurement Using 3D Laser Scanning

POINT CLOUD SCANNER – OUTCOME / RESULTS

- **Data Obtained**
  - **Surveyors** performed setup of control markers; **students** placed location markers, performed the scan data collection and **students** performed final documentation and data reduction
  - **1 Point Cloud Scanner control area marked with 5 location spheres along with 3 control points were established and read**
    - 5 load increments each day for 2 days
    - 3,000,000+ points per test session
    - Measurements were verified to 2 (mm)
  - **Point Cloud Scanner Team Data Collection Work Process**
    - 1 teams of 2 persons (one scanner operator / one documentation technician)
    - Data validated by scanner, image shown to operator at the end of the scan
  - **Total data collected (1scanner*3million points*5 tests*3 days = 45,000,000 data points)**
    - Data collected during all three days of testing
    - Scanner was positioned outside the work area during destructive test sequence
    - All data point **WERE NOT** utilized by researchers in analysis
    - Initial scanner failed during pre-trial setup evaluation period, manufacturer supplied loaner

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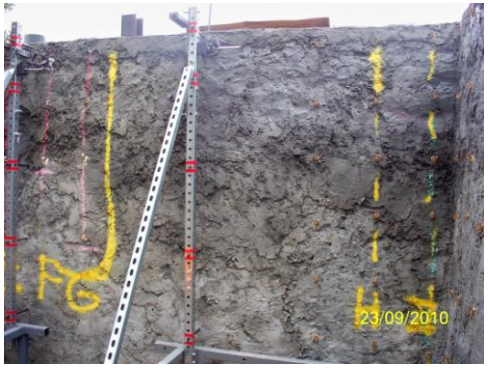
Deformation/Displacement Measurement Using 3D Laser Scanning

POINT CLOUD SCANNER – COSTS

- **Costs**
  - **Total Costs = $10,500.00**
    - Equipment Rental Costs ($3,000.00 per scanner package per day * 3 days = $9,000.00)
    - Data Collection teams ($100/hr *10 hrs = $1,000.00)
    - Data reduction team & researchers ($100/hr * 4 hrs = $400.00)
    - Surveyor Review of data reduction ($100 /hr = $100.00)
  - **Research team ROI ($10,500 / 4500 points = $2.33 / pt)**
    - Per collected data point
      - All 45,000,000+ points reviewed for validity
      - Some number of points were discarded due to equipment failure during day one.
    - Per analyzed data point
      - Of the 1,000,000 points specific to the areas under study, only 4500 of the points were used for final analysis
  - **Point Cloud Scanner Team ROI**
    - Per collected data point ($10,500 / 1,000,000 readings = $0.01 / pt)
    - Per collection period ($10,500 / 15 hours = $700.00 / hr)
    - 2 technicians and 1 Surveyor ($700 / 3 persons = $233.00 / hr)

Deformation/Displacement Measurement Using 3D Laser Scanning



Question and Answer Session

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Deformation/Displacement Measurement Using 3D Laser Scanning

Conclusions / Recommendations

- **Researcher's Recommendations**
  - Dr. Oncul / Dr. Barham / Dr. Meadati…???
- **Surveyor's Conclusions**
  - Am I ready to buy / rent new equipment to pursue this market?
- **Point Cloud Scanning Team Conclusions**
  - Is this equipment really ready for survey field conditions

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Deformation/Displacement Measurement Using 3D Laser Scanning

Parameters	Displacement Gauges	Total Station	Point Cloud Scanner
Data Collection Time (per pt)	6 minutes/pt (14 hrs / 150 pts)	2 minutes/pt (14 hrs / 600 pts)	16 seconds/pt (21 hrs / 4500 pts)
Skill Level (technician)	Minimal	Party Chief	Skilled Data Collection Tech
Field Time	80 hours - 66 hrs prep - 14 hrs of test observations	80 hours - 66 hrs prep - 14 hrs test observations	24 hours - 3 hrs prep - 21 hrs test observations
Number of Pts.	150 collected 150 used	700 collected 600 used	45,000,000+ collected 4500 used
Total Cost	Apprx $2,000 / job	Apprx $4,300/job	Apprx $10,000/job

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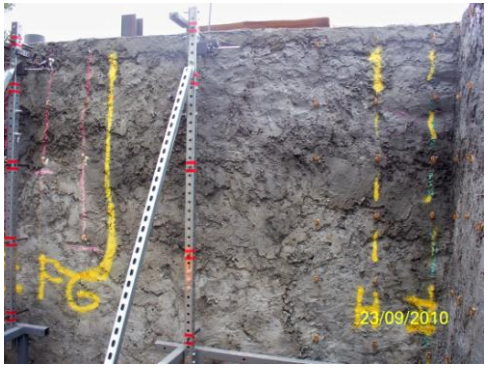
Deformation/Displacement Measurement Using 3D Laser Scanning



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Thank You for your attention to our presentation!