Haiti RAPID Projects: Structures

NSF HAITI RAPID PROJECTS: STRUCTURES		
TITLE	**PI/Research Team**	**Institutions**
Effects of the January 2010 Haitian Earthquake on Selected Electrical Equipment	Barry J. Goodno, PI N. C. Gould P. Caldwell P. L. Gould	Georgia Tech ABS Consulting Schneider Electric Washington University
Residential Housing in LÉOGÂNE: Post-Quake Damage Assessment and Perspectives on Sustainable Rebuilding	Tracy Kijewski-Correa, PI Alexandros Taflanidis Dustin Mix	University of Notre Dame
Urgent Collection of Perishable Condition Data from Structures Affected by the Haiti Earthquake	Laura Lowes. PI M. Eberhard, J. Pugh, J. Weigand R. DesRoches, I. Brilakis, S. German G. Parra-Montesinos D. Swanson K. Swensson	University of Washington Georgia Tech University of Michigan Reid-Middleton KSi/Structural Engineers
Laser Scanning Technology for Damage Assessment after the January 12, 2010 Haiti Earthquake	Khalid M. Mosalam, PI Shakhzod Takhirov Eduardo Fierro, Eduardo Miranda Mark Kelly	UC-Berkeley BFP Engineers Stanford
Collection of Field Data from Haiti for Calibration of Seismic Vulnerability Indices	Santiago Pujol Ayhan Irfanoglu, Marc Eberhard	Purdue University University of Washington
Evaluation of Analytical Assessment Tools through Comparisons to Observed Seismic Performance in the January 2010 Haiti Earthquake	Robert Fleischman, PI Giovanni Federico, Dichuan Zhang Andreas Schellenberg, Karl Telleen, Joe Maffei	University of Arizona Rutherford and Chekene

Project Description/Goals

Effects of the January 2010 Haitian Earthquake on Selected Mechanical and Electrical Equipment

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***Description*:** Performance of **critical mechanical and electrical equipment**, such as switchgear, motor control centers and inverters located in the Port-Au-Prince region, that were subjected to strong ground motion during the 12 January 2010 Haiti Earthquake, was investigated. The research effort began with surveys of both damaged and undamaged electrical equipment at **ten sites** in and around Port-au-Prince. Both **internal and external equipment damage states** were cataloged and documented in hundreds of digital photos.

Goals:

1. Catalog/document **damage** to selected non-structural elements/systems: focus on MEP (mechanical, electrical, plumbing)
2. Estimate local **ground motions** based on observed damage
3. Evaluate **consequences** of the loss of critical equipment at selected facilities in the Port-Au-Prince region (impact on response and recovery operations, business interruption, etc.)
4. Assess possible **implications for the seismic design** of critical non-structural components required for post-earthquake recovery operations *with emphasis on developing countries.*

Ten Sites Visited:

Center Petion Power Plant	Adventiste Hospital	ADRA Warehouse	University Adventiste	General Hospital
Union School	Prestige Beer Plant	U.S. Embassy	CDTI Hospital	Digicel

Initial Findings

- Absent or poorly implemented equipment seismic anchorage hampers ability to restore essential systems to operation after the event
- Root cause of poor performance: none of the various participants in the total life cycle of a critical facility have the collective knowledge to insure a high level of confidence in effective implementation of seismic restraint for equipment
  - **Structural engineers** do not design electrical equipment or their systems
  - **Electrical design professional** is unlikely to ever be an expert on the building seismic structural system behavior
  - **Electrical installer** is dependent upon guidance from the building design professional and equipment vendor
  - **Facility owner** is unlikely to be knowledgeable about effective seismic mitigation
- Fundamental understanding of how to **design, install and inspect** electrical equipment seismic restraint does not exist and as such poses a significant risk for the post event operability of critical facilities
- **Marginal installation** of elements such as emergency generators, invertors, and batteries could leave **critical facilities**, such as hospitals, aid organizations, and government facilities unable provide emergency response following a moderate to severe seismic event; design professionals should advocate for **construction observation** to be provided at these critical facilities to ensure proper installation of anchors and lateral restraining elements

Unanchored UPS system *(Digicel)*

Crushed outdoor HVAC condenser *(Digicel)*

Conduit separation *(General Hospital)*

Notre Dame: Project Objectives & Description

OBJECTIVE http://haiti.ce.nd.edu

To develop a plan for culturally-appropriate, long-term rebuilding of Léogâne's residential housing stock that is sustainable on locally available materials and construction practices and is resilient to both earthquakes and hurricanes.

SITE VISITS

March 8-10, 2010: Determine cause of poor performance/ collapse of buildings, primary focus on residential housing

August 18-22, 2010: Talk with (i) local architects and engineers to understand methods of knowledge dissemination and (ii) local families to understand housing requirements

WHY LEOGANE?

- Notre Dame has led a diverse, integrated approach to public health intervention focused specifically on lymphatic filariasis for over a decade
- Located approximately 20 km west of quake epicenter

- It is estimated that 62% of buildings in Léogâne collapsed and another 31% were damaged, making the need for assessment and rebuilding dire

Notre Dame: Initial Findings

CONSTRAINTS

- Lack of formwork (deforestation)

Size columns to CMU width (default formwork) ❷

- Sound design and construction is available but too costly

Compromise transverse reinforcement

- Higher quality materials available but too costly

Use of lower grade materials (aggregates, CMU)

DEFICIENCIES

- Cement Masonry Unit (CMU) as partitioning element ❶

Sufficiently stiff to attract forces, insufficient strength to resist them → wall fails in shear, immediately transfers forces and fails neighboring columns

- Undersized, inadequately detailed columns ❷

Generally results from using CMU as formwork

Economic constraints lead to widely spaced transverse reinforcement → lack of confinement

- Lateral systems not adequately tied together

Larger "mansions" employed same flat slab/column systems used in smaller homes, with slabs inadequate to engage undersized columns over plan and with insufficient reinforcement to facilitate transfer of shear from slab to columns

- Excessive mass

Heavy partitioning CMU walls, provision for adding floors later leads to use of heavy slab roofs

- Poor materials, construction practices, construction in stages with variable material quality and workmanship

Project Team, Goals and Activities

- **Project Team**
  - Faculty: L. Lowes (PI-UW), M. Eberhard (UW), R. DesRoches (GATech), I. Brilakis (GATech), G. Parra-Montesinos (UM)
  - Graduate Students: J. Pugh (UW), J. Weigand (UW), S. German (GATech)
  - Professional Engineers: D. Swanson (Reid-Middleton, Seattle, WA), K. Swensson (KSi/Structural Engineers, Atlanta, GA)
- **Project Goal**
  - To collect data to support on-going efforts to develop rapid, semi-automated, vision-based post-earthquake inspection of concrete buildings.
- **Project Activities**
  - Collect ***detailed*** damage and design data for five (5) engineered concrete buildings that were damaged during the Haiti earthquake. Data included
- For ***all*** structural components: geometry and location, measurement and documentation of damage sustained, still images of damage sustained, video of all structural components and damage sustained.
- Construction drawings
  - Organize data and provide the public with access to data via NEEShub.
  - Assess building response.
  - Apply automated post-processing algorithms to extract damage data (e.g. orientation, length and width of concrete cracks) from video data.
  - Evaluate automated damage extraction procedures using manually collected data.
  - Identify future research needs for semi-automated building inspection and assessment.

Initial Findings

- **Buildings for which damage data were collected**

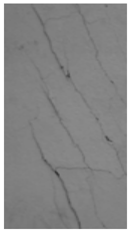
Union School (2 buildings)

Digicel office bldg. and parking garage

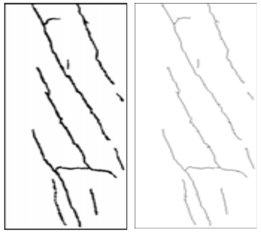
CDTI Hospital

- **Comparison of crack data collected manually and extracted from video**

video frame



crack identification



cracks

Difference between measured and extracted crack properties

	Orientation	Crack length / component dim.	Crack width / component dim.
Average	3.29°	2.21%	0.35%
Std. Dev.	2.70°	2.90%	0.49%

- **Initial conclusions and recommendations for future research**
  - Algorithms for extraction of concrete crack properties from video provide acceptable accuracy.
  - Similar algorithms are required to enable extraction of data characterizing the extent and severity of spalling, bar buckling and bar fracture.

Project Description/Goals

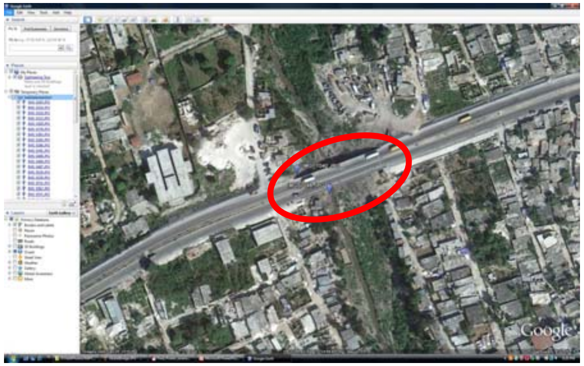
Laser Scanning Technology for Damage Assessment after the January, 12, 2010 Haiti Earthquake

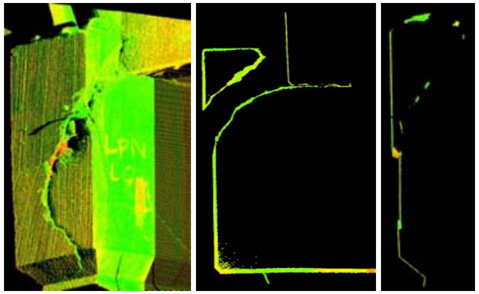
Khalid Mosalam, Shakhzod Takhirov, Eduardo Fierro, Eduardo Miranda, and Mark Kelly

Description: The project focuses on using laser scanner capable of measuring large objects in space, an important attribute for structural assessment after an earthquake event. A 3D point cloud representing the structure's surface is delivered as the outcome of the laser scanning. All laser scans are geo-referenced at surveying grade accuracy to allow creating a combined database of photo images and the laser scans. An array of structures in different damage states, including a city block in Port-au-Prince previously surveyed by both the World Bank from the aerial photos and by two members of the team using on-the-ground surveillance.

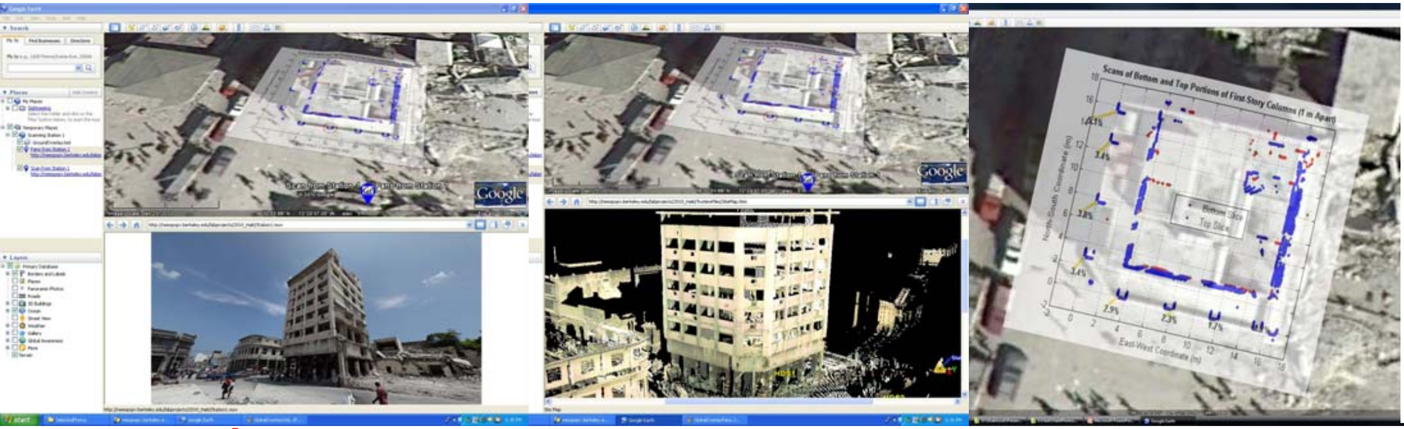
Goals: 1) To provide information for the first time on the use of high definition laser scanning and the merits and difficulties of using this advanced technology in a reconnaissance effort after a major disaster; 2) To evaluate if the scanning would be an appropriate way to corroborate damage from aerial surveys; 3) To use this unique deployment of field measurements to provide an important benchmark for image-based remote sensing evaluation and future advancement of our capabilities for damage assessment of structural systems using the collected detailed data in this project; 4) To improve our preparedness in situations of similar disasters in the US or worldwide where the information gathered will be instrumental in guiding the delivery of US aid for the reconstruction of Haiti.

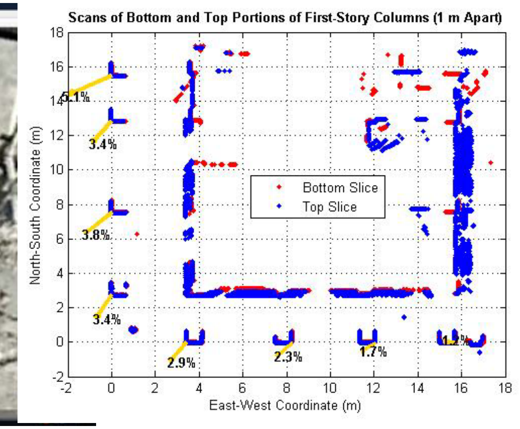
Initial Findings





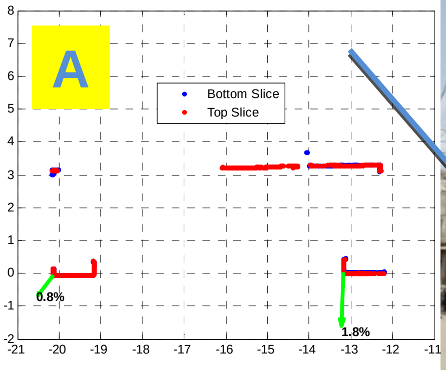
A damaged bridge scanned from 2 positions &
Shear key sections @ face & mid-plane

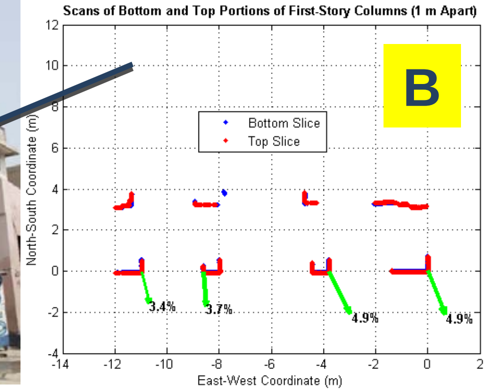




Cal balloon → Interactive panoramic movie of Asscotia Hotel & its surrounding & interactive image with links to points clouds from the laser scanner (TruView) to perform any measurements of the objects

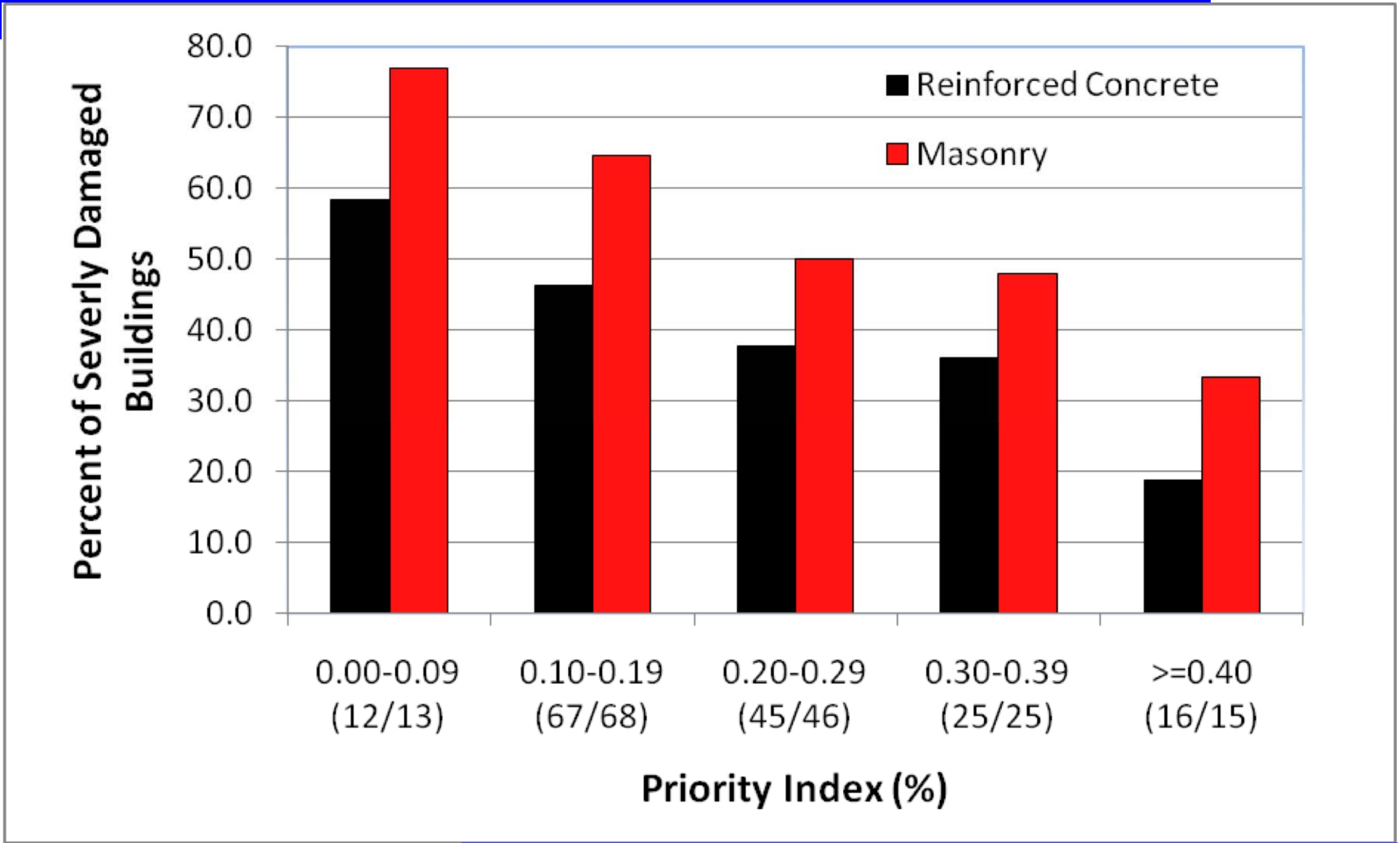
Ground observations by E. Fierro





Project Team: Ayhan Irfanoglu, Marc Eberhard, Santiago Pujol

MEASURES OF THE SEISMIC VULNERABILITY OF REINFORCED CONCRETE BUILDINGS IN HAITI



$$PI = (\sum A_w + \sum A_c / 2 + \sum A_m / 10) / \sum A_f$$

Initial Findings

Project Description/Goals

Evaluation of Analytical Assessment Tools based on Observed Performance

R. B. Fleischman[1],G. Federico[1], D. Zhang[1], J. R. Maffei[2], K. C. Telleen[2], A. H. Schellenberg[2]

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[2]Rutherford & Chekene*, San Francisco, CA, USA,*

Description: The January 12 2010 Haiti earthquake severely damaged several modern engineered buildings in the capital city of Port- au-Prince. Data gathered on the observed performance of a selection of these structures is being used for the purposes of comparison with, and calibration of, analytically-based predictions used in seismic assessment procedures.

Goals:

1. Identify and document candidate structures on the basis of damage state, available design information, and accessibility**;**
2. Document the design, site conditions, and observed damage of these structures with on-site visual inspection providing failure modes, damage intensity/patterns, and residual state;
3. Use available information to construct analytical models using state-of-the-art techniques for nonlinear dynamic analysis: research software (ANSYS, OpenSees), design office software (SAP-2000, Perform3D);
4. Estimate seismic hazard levels by indexing to the level of demand required to bring about the observed damage;
5. Predict observed response using accepted commonly used seismic assessment techniques in the U.S. and compare to the observed actual performance. In particular, evaluate the effectiveness of the structural models to produce similar behavior modes, overall patterns of damage, and appropriate assessment decisions;
6. Recommend improvements to building practice in Haiti;

The deliverable is a report documenting the structure and design information; the post-earthquake state; the modeling techniques; analytical results/comparison and evaluation of the methods.

Three Sites Visited:

Saint Louis de Gonzague School complex (cafeteria, classrooms, church and canopy)	**Teleco Building**	**Institution Mixte St Joseph de Petionville (classrooms)**

Initial Findings

Damage mapping


column shear failure


pounding damage


wall pier failure

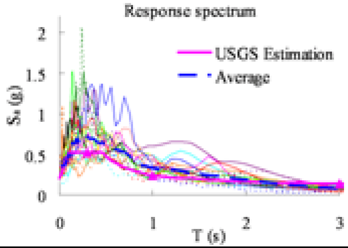

masonry wall failure


column shear cracking

Calibration/Selection of Ground Motion

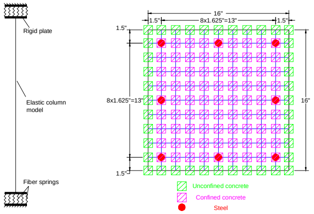
Select Ground Motions from PEER Database

- ✓Fault: Enriquillo -Plantain Garden Fault
- ✓Mechanism: Strike-slip
- ✓Distance: 25 km
- ✓Site: B, C or D
- ✓PGA: 0.3 to 0.42g
- ✓PGV: 20 to 80cm/sec
- ✓MMI: 7.0

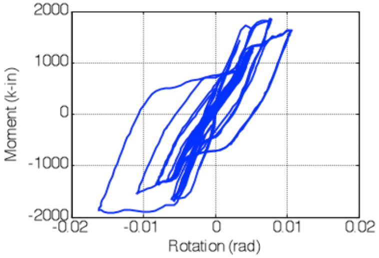


Calibrate Ground Motions from analyses of canopy


column base damage



column fiber model



hysteretic response at column base

Analytical Modeling

Employ existing models

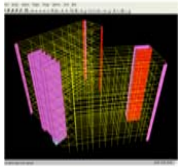
Column: Fiber model with axial and flexure coupling
Nonlinear shear limited state (Yavari et al. 2008)
Fiber model with axial, shear and flexure coupling
(Massone et al. 2006) (Ceresa et al. 2009)

Masonry wall : Nonlinear Strut-tie model with in-plane and out-of-plane behavior ((Mosalam 2007)

Beam & Shear wall: Concentrated plastic hinge

Material properties: Estimated from FEMA356 (2000)

Teleco Building – SAP 2000 Model



Saint Louis De Gonzague Cafeteria – ANSYS model