

# NEW TECHNIQUES FOR EARTHQUAKE RECONNAISSANCE

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## ABSTRACT

Earthquake reconnaissance provides primary data that drives the development of procedures and codes for earthquake engineering practices. Visual documentation of post-earthquake damage can validate code design provisions, or reveal flaws in structures that can lead to the enhancement of structural designs. This project explored a new technique for assessing post-earthquake damage to buildings and bridges. Canon EOS 5D Mark II camera photographs of damaged structures from the  $M_w$  7.0 2010 Haiti earthquake were stitched together using PTGui software to create spherical panoramas and three-hundred and sixty degree .mov files. Those photographs were also superimposed onto the Leica Scan Station 2's laser scanned images, using Cyclone software, to both mathematically and visually reflect the damaged state of the structures. The resultant images provide earthquake engineers with a true representation of the damaged structures and provide accurate measurements. This investigation suggests a precise method of analyzing earthquake damage to buildings and infrastructure. It offers government, construction companies, civil engineers, and architects a new tool to use when gathering data after earthquakes. The laser scanning and other conventional data also aims to improve our preparedness in situations of earthquake disasters worldwide. It is anticipated that techniques employed for this project in gathering and disseminating critical information will have a major impact on revolutionizing the reconnaissance efforts by the earthquake engineering community in the event of a major earthquake.

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## **INTRODUCTION**

On January 12<sup>th</sup>, 2010, a major earthquake struck the city of Leogane, Haiti. The earthquake measured 7.0 on the moment magnitude scale and devastated Haiti's infrastructure, economy, and population. It left buildings, bridges, and streets in ruins. The damage to the structures further impaired Haiti's already weak economy because its government now has the added burden of investing money to clear the debris, and demolish unusable structures and reconstruct them. The earthquake killed 230,000 to 300,000 people and left 1.6 million people homeless. Due to the vast scale of this disaster in Haiti, numerous earthquake reconnaissance research teams have gathered data from there.

Earthquake reconnaissance supplies hard data that drives the development of procedures and codes for earthquake engineering practices. Obtaining high resolution images and conducting a critical inspection of damaged structures aid in the validation of structural designs or improvement of current structural designs. Visual documentation can also reveal faults in a structure. Uncovering flaws in a structure's blueprint inspires the creation of safer and economic structural designs as more information and knowledge is gained. Illustrative data of earthquake damage also serves as a repository of results that can be disseminated and reviewed.

The introduction of a new method in evaluating earthquake damage offers government, construction companies, civil engineers, and architects a new tool to use when approving, building, or designing future structures. Refining post-earthquake structure damage analysis practices will aid in coming earthquake aftermath investigations. The objective of this research project was to explore new techniques for assessing building damage after an earthquake.

## **BACKGROUND**

There are various methods for post-earthquake visual documentation. Several techniques for assessing earthquake damage include extrapolating from on-the-ground estimates and using single-shot photos. Other methods include taking a three-hundred and sixty degree video of the affected area or running laser scans on the buildings. For these types of approaches, earthquake analysts must be present in the field to operate the instruments. However, with rapidly developing technology, it is not required to be on-site as earthquake damage is often recorded through satellites.

Satellites capture images of buildings and infrastructures, and thus structure analysis is conducted via those photographs. Similar images and measurements from the satellites can be acquired through laser scanners, high resolution cameras, and various software packages in the field. Yet, the majority of satellite images are limited to aerial views. Aerial views do not reflect the full scope of damage to a building after an earthquake (Fig.1 and 2). The top view of a building restricts the depth of analysis that can be conducted. The techniques used in this earthquake reconnaissance effort allow precision analysis to be performed.



**Fig. 1** Ariel view of Haiti's National Palace after the earthquake.



**Fig. 2** Aerial view of earthquake affected intersection.

## MATERIALS AND METHODS

### Data Collection

Eduardo Fierro<sup>2</sup>, Eduardo Miranda<sup>3</sup>, Khalid Mosalam<sup>4</sup> and Shakhzod Takhirov<sup>5</sup> went to Port-au-Prince, Haiti to collect data from the January 12<sup>th</sup>, 2010 earthquake. Under the funding of the National Science Foundation (NSF), the team of researchers spent eight days in Haiti. They collected 1,031 photographs with a Canon EOS 5D Mark II camera and their coordinates with a PhotoGPS, and fifteen scan positions and a total of nine scan projects with a Leica Scan Station 2. However, access to the extensively damaged structures was restricted and several buildings could not be thoroughly photographed or scanned.

### Technique I

**Canon EOS 5D Mark II.** The Canon EOS 5D Mark II, Fig. 3, is a digital, single lens camera that has 21.1 megapixel full-frame CMOS sensor with DIGIC 4 image processor, a ISO range of 100-6400, and contains EOS technologies such as auto lighting optimizer and peripheral illumination correction. This camera model produced high-definition photographs and when paired with a fisheye lens, it captured high quality qualitative data in fewer shots. The Fisheye lens, Fig. 4, gave approximately thirty percent overlap with the photos; this gave sixty degrees of a view angle. This degree of view resulted in twenty-six photographs being needed to capture a full three-hundred and sixty degree, dome view. In order to yield quality photographs using the fisheye lens, the nodal point of the Canon camera with the fisheye lens had to be calculated.

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**Fig. 3** Canon EOS 5D Mark II.



**Fig. 4** Fisheye lens for Canon EOS 5D Mark II.

**Nodal-point calculation.** To calculate the nodal point for the Canon camera, a laser pen, a template with angles marked on to adjust the laser beam, and a ruler were used. The nodal point for this camera was calculated by detaching the lens from the camera and creating a set-up similar to Fig. 3. To calibrate the set-up, the center line of the lens was aligned with the center line of the template. The center line of the scale was then aligned with the center line of the lens and the 0mm mark was aligned with the lens' front. The laser beam was projected along the center line through the lens. The beam at the zero degree line on the template was in line with the beam that was projected on top of the lens and the laser beam went through the lens. The level was then moved from the zero degree mark to the thirty degree mark because of the camera's sixty degree view and the desired thirty percent overlap. The level was adjusted until the laser beam showed behind the lens. The nodal point for the fisheye lens was calculated to be 19mm. Once the nodal point had been determined, the camera was then mounted onto the Manfrotto bracket (Fig. 4) and tripod (Fig. 5) to meet the 19mm difference from the lens and center of the tripod.



**Fig. 3** Set-up for calculating nodal points on cameras (*source: Thomas Schwenger*).



Fig. 4 Manfrotto bracket for camera.



Fig. 5 Tripod for camera.

**Tripod set-up.** To meet the 19mm nodal point of the fisheye lens with the Canon EOS 5D Mark II, the bracket was set-up as shown Fig. 2. In Fig. 3, the lower level of the bracket, the white arrow was placed on 102cm (The solid white line did not meet with the line that says, “Center”). For the second level of the bracket, the white arrow was on 106cm like in Fig. 3 (The clamp’s edges were on 90cm and 180cm). For the third level, the white arrow was on 39cm and the clamp’s edges were on 24cm and 108cm (Fig. 4).

This set-up was designed to collect a total of twenty-six photographs, a photo taken at every 45°. Eight pictures at the horizontal level, 0° (Fig. 5). Eight pictures at a tilted upward stance, at 45° (Fig. 6). One picture at 0°, pointed upwards (Fig. 2). Eight pictures, at a tilted downward stance, at 45° (Fig. 8). One picture pointed downward at 0° (Fig. 9).



Fig. 2

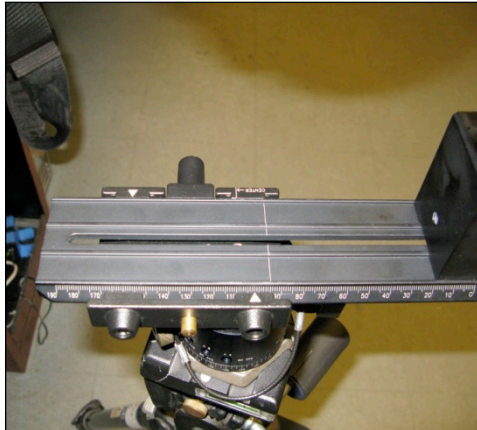


Fig. 3

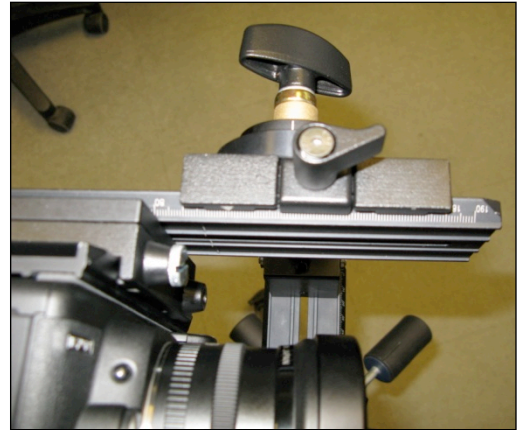


Fig. 4



Fig. 5



Fig. 6



Fig. 7



Fig. 8



Fig. 9

**PTGui Software.** PTGui is a panoramic stitching software for Windows and Mac OSX. PTGui stitches any number of photos into a panoramic image and creates three-hundred and sixty degree cylindrical panoramas, flat partial panoramas, and spherical 360x180 degree panoramas.

The photos from the Canon camera were uploaded onto a computer and then onto the PTGui software. Control points were created to stitch the images together (Fig. 10). Control points are common points between two photos where the software aligns the two images into one. The stitched image was then warped to create the spherical panorama. The warping of the image results in a full dome-view of the area. The panorama was converted from a .jpeg file into a .mov file, where one can rotate, zoom-in, and see the photographs as a full three-hundred and sixty degree video.

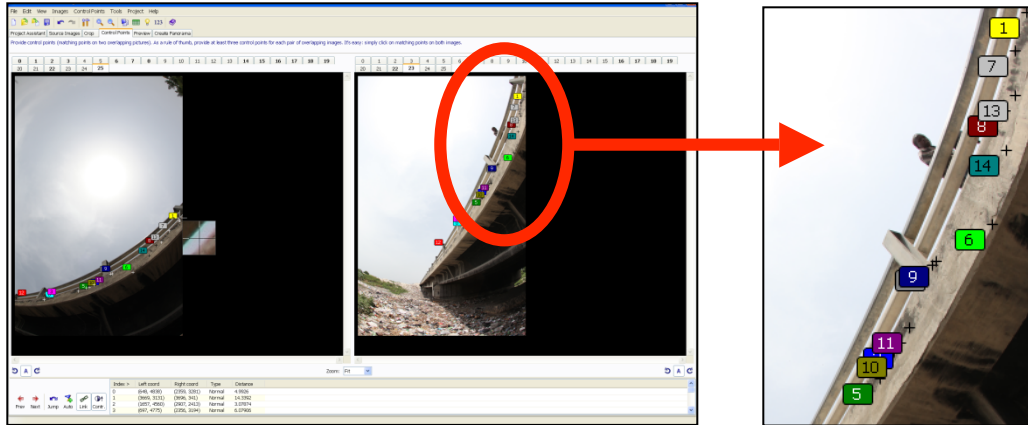


Fig. 10 Screen shot of photo stitching in PTGui software and zoomed-in section of control points.

## Technique II

**Leica Scan Station 2.** The Leica Scan Station 2 is a topographic surveying tool with 50,000 pts/sec maximum instantaneous scan speed. Each scanner position will generate a number of points in space called point clouds. A number of point clouds from different scanner positions around an object can be stitched together by means of reference points called targets. The fully stitched point cloud called registration represents the complete 3D image of the object in space.



Fig. 11 Set-up of Leica ScanStation 2

**Cyclone 7 Software.** Cyclone is a 3D point cloud processing software package. It is an application for point cloud acquisition, point cloud manipulation and presentation. The laser scans were imported onto a computer directly from the ScanStation on site. Once in the computer and software, the scans were able to be rotated, zoomed-in, and measured. The data obtained was manipulated to show the structures in different light intensities and cross sections were made to show the depth of the earthquake's damage.



### Technique III

Technique III is a combination of technique I and II. The spherical panorama, created from the photographs of the Canon camera, was superimposed upon the laser scanned images from the Leica ScanStation 2. This was done through the use of the Cyclone software, PTGui software, Panotools (a necessary plug-in for PTGui software), and Pano2QTVR Gui (for conversion of the equirectangular image into Cube Maps).

The spherical image created from technique I was converted into a Cube Map. The Spherical image was divided into six images: a top, bottom, front, back, left, and right view (Fig. 12). Once the Cube Map was created, it was imported onto Cyclone. In order to match the Cube Map and laser scan, three pairs of matching control points had to be created. For a detailed, step-by-step instructional guide, please see Manual for External Camera Workflow.

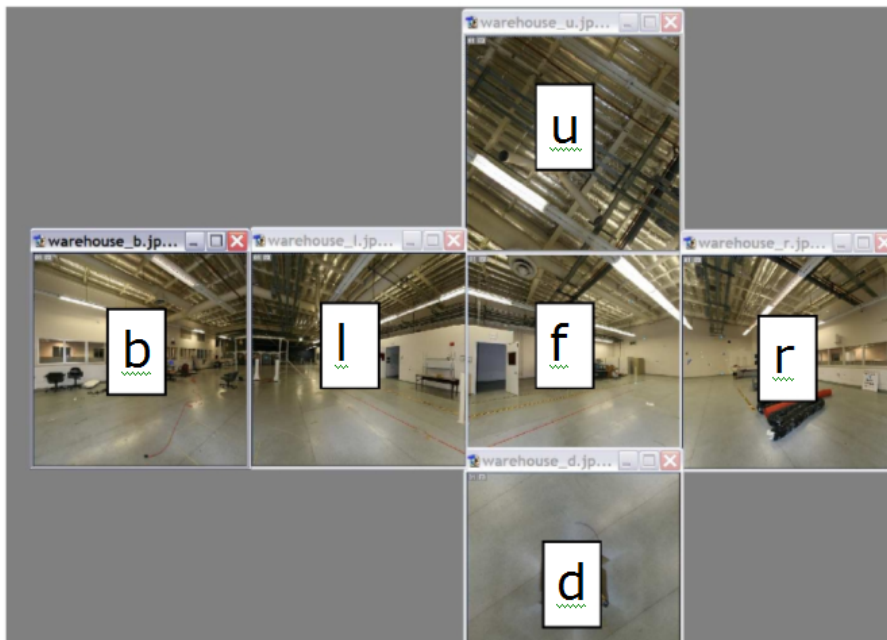


Fig. 12 Screen shot of a Cube Map (source: Leica Geosystems).

## RESULTS

The images, panoramas, and videos have been stored at the Pacific Earthquake Engineering Research (PEER) Center, where future researchers can use the data to investigate damaged structures from the Haiti earthquake. A total of 1,031 high-definition photographs were taken in Haiti (Figs. 13-18). Of those 1,031 photographs, five spherical images and panoramas were able to be created from technique I (Fig. 19). However, the qualities of three panoramas were hindered because people were in some pictures and not in others, so when the images were stitched together, the resultant panorama was inconsistent. The resultant images, of those three panoramas, contained blurred connections between photos (Fig. 20).



Fig. 13 Damaged first-level of a building in Haiti.



Fig. 14 Damaged house in Haiti.



Fig. 15 Collapsed building in Haiti.



Fig. 16 Close-up of collapsed building.



Fig. 17 Collapsed building in Haiti.



Fig. 18 Damaged Parking Lot in Haiti.



Fig. 19 Three-hundred and sixty spherical panorama of bridge.



Fig. 20 Three-hundred and sixty spherical panorama of an intersection in Haiti.

Technique I's images of Haiti serve as raw data of the catastrophe that struck Haiti. Detailed images were acquired and a full three-hundred and sixty degree view of the affected areas was obtained. Technique II, however, produced accurate laser scans and could also be zoomed in on (Figs. 21 and 22). Technique II also allowed for cross sections to be made and cracks to be measured (Figs. 23 and 24).

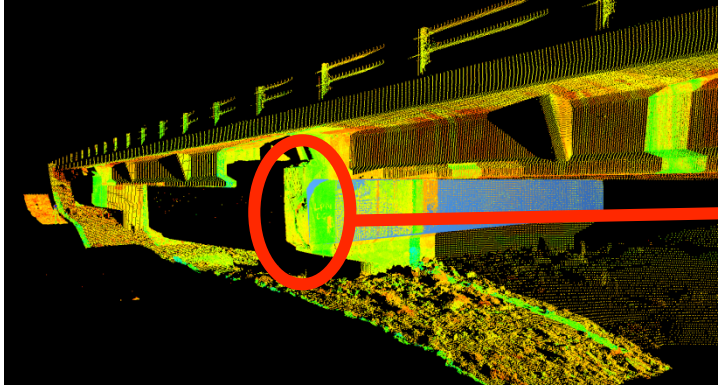


Fig. 21 Laser scan of bridge in Cyclone.

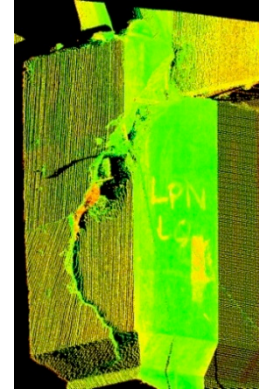


Fig. 22 Close-up of Bridge pier.

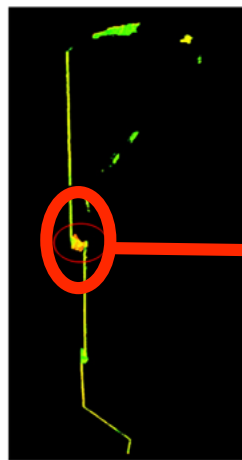


Fig. 23 Cross section of fig. 19.

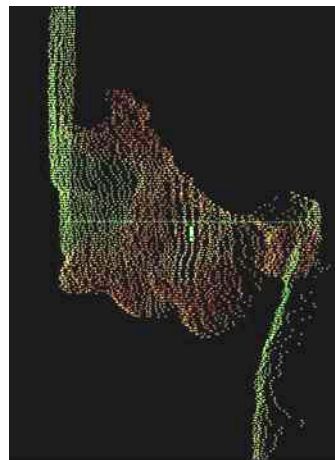


Fig. 24 Zoom-in of fig. 20.

The combination of the high resolution photographs and Leica laser both mathematically and visually reflect the damaged state of the buildings. Through this technique, cracks can be seen realistically and measured (Fig. 25). The blend of technique I and II shows a better display than the laser scan and unlike the Canon camera, it allows for calculations to be made. The images can be zoomed in and measurements can be displayed.

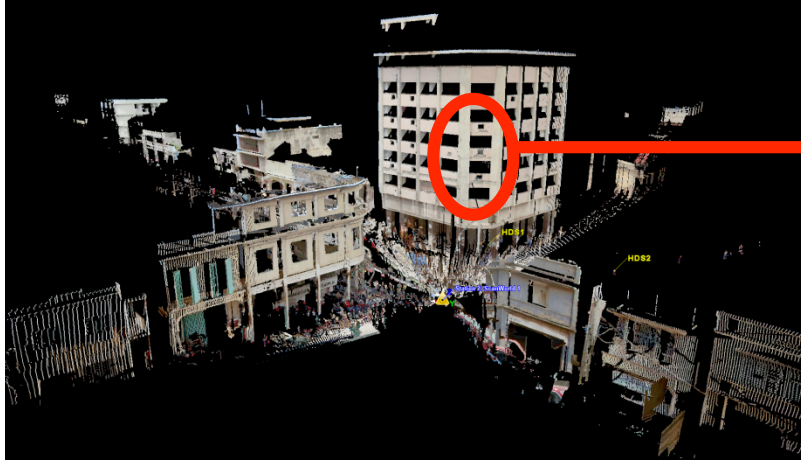


Fig. 25 Superimposed image of Asscotia Hotel in Haiti.



Fig. 26 Close-up of Fig. 25

Laser scan cross sections of the Asscotia Hotel were loaded onto MATLAB, where the coordinates of the hotel were graphed to produce Fig. 27. Fig. 27 shows story drift between the top and bottom portions of the columns, beams, and walls. Fig. 27a and Fig. 27b shows the residual displacement from the top and bottom portions of the columns. In Fig. 27a and 27b, the blue dots represent the top portion of the columns and the red dots are representations of the bottom.

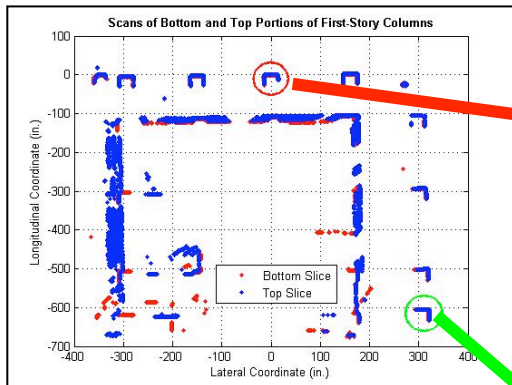
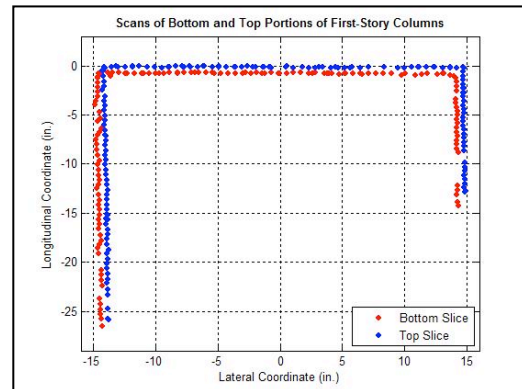
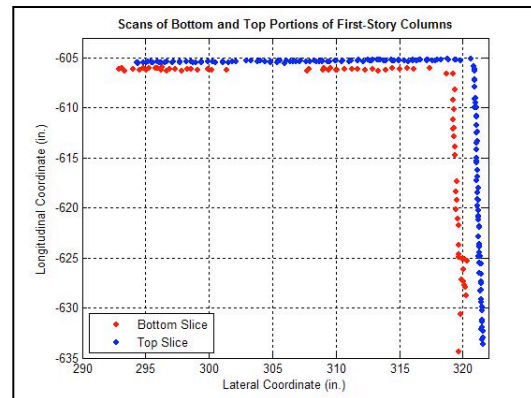


Fig. 27 Story drift shown in residual displacement graph produced by MATLAB.



(a)



(b)

In Fig. 27, the earthquake's effect on the Asscotia Hotel's structure can be seen. The gaps between the blue portions in Fig. 27 show where separation occurred between the material of the building. For example, between -400 and -300 longitudinal lines and -400 and -300 lateral lines, there is a portion missing. This means that part of the wall on the hotel is gone. The gap can be measured and the displacement can be measured for each column.

Technique III's advantages are clearly shown in comparison to satellite images (Figs. 28 and 29). The satellite's aerial view of the Mirand and Grand intersection does not show the extent of the earthquake's damage. Technique III, however, shows the horizontal view of the intersection; the viewpoint is of someone being in the center of the intersection. It gives details of the buildings because it is a composition of real-life shots from the high-definition images and laser scans.



Fig. 28 Google Map's image of Mirand and Grand intersection in Haiti.

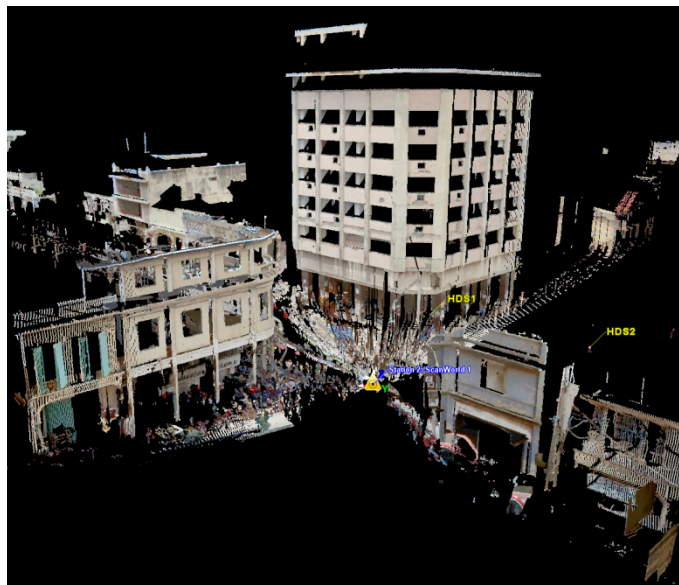


Fig. 29 Superimposed image on laser scan of Mirand and Grand intersection.

## DISCUSSION

The techniques of the project proved to be useful as researchers were able to obtain measurements and high quality qualitative data of buildings and bridges through photographs, laser scans, and software packages. This approach to assess earthquake damage resulted in a true visual and mathematical representation of the damaged structures. The techniques presented in this project give precise and accurate displays of the structures that earthquake analysts can utilize to evaluate a building or bridge's damage. The residual displacement can be calculated and the deformation measured in structural measurements through the techniques presented. A full scope of the damaged structure and surrounding area can be documented with this project's methodology.

Technique I showed the real-life damages done to cities and gave depth into the structures' damage. Its sharp images give vivid information on the structures that can be examined and assessed without needing to be on-site. While technique I shows the raw reality of earthquake

affected areas, technique II's laser scans show the areas in a mathematical perception. In technique II, 3D images are captured and the scale of the image is kept, and researchers can take measurements from the scan. The benefits of both techniques are seen in technique III, where techniques I and II are combined. Because technique III is a composition of those techniques, it holds both of their advantages such as extracting quantitative information from the images and displaying pure findings.

The techniques used in this project may also be applied to structures other than earthquake damaged buildings for analysis. For example, the .mov files that are created from Technique I may be used in presentations to show how a building looks on the outside and/or inside. It can also be used to create a three-hundred and sixty view of a laboratory set-up or construction site. Technique II can be used to show a structure's design through the cross sections that are able to be obtained. The laser scanned measurements can be compared to human acquired measurements. Technique III can be used on any structure to show a complete representation. Technique III is more versatile because of the information it is composed of, it serves as a realistic model and yields quantitative data.

Governments, construction companies, civil engineers, and architects now have a new tool to use when approving, building, or designing future structures. This project also helps in refining post-earthquake structure damage analysis practices because it will aid in coming earthquake aftermath investigations. The laser scanning and other conventional data also aim to improve our preparedness in situations of earthquake disasters worldwide. It is anticipated that techniques employed for this project in gathering and disseminating critical information will have a major impact on revolutionizing the reconnaissance efforts by the earthquake engineering community in the event of a major earthquake.

However, additional research is needed for post-earthquake reconnaissance. For example, the analysis on building damage after an earthquake demonstrated through these techniques may be possible through other software packages. Similar results may be possible through software packages such as Stitcher Unlimited or Image Modeler.

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