Three Dimensional Displacement Response Study of a Rubble-House Using a 3D Laser Scanner

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ABSTRACT

After the devastating earthquake that hit Haiti in January 2010, a number of non-profit organizations started building cost effective replacement homes for the needy using the rubble from collapsed buildings. Rubble-Houses are environmentally friendly structures with walls comprised of recycled loose rubble placed in welded wire baskets. Rubble-Houses are assumed to be earthquake resistant structures due to their improved damping and ductility characteristics arising from the rubble and welded wire basket, respectively. However, the response of such structures under static and dynamic loads has not been studied in detail. In order to have a better understanding of its behavior, a full-scale rubble-house was built in the middle of Southern Polytechnic State University campus and subjected to a series of in-plane and out-of-plane static loads. Wall displacements were recorded using a 3D laser scanning technique in addition to total station and displacement gauge measurements. 3D laser scanning is an effective and efficient approach for precise and dimensionally accurate as-built documentation. This paper presents and discusses the use of 3D laser scanning technique in measuring the displacement response of a rubble-house under static loads.

INTRODUCTION

A 7.0 magnitude earthquake struck Haiti on January 12th, 2010. The Haitian government estimates that 200,000 have died as a result of this sad incident, 2,000,000 people have been left homeless and 3,000,000 people are in need of emergency aid. The United States Geological Survey (USGS) reported that the earthquake was the strongest earthquake to hit the area since 1770.

Shortly after the earthquake, relief organizations from around the world joined forces to support the devastated communities in carrying out rescue operations and supplying food, shelter, medical aid and providing sanitation, etc. The most challenging issue was proving shelter to millions of people who lost their homes. Conscience International, a non-profit humanitarian and advocacy organization, started building homes for the Haitian out of the destroyed concrete, or rubble. Rubble-Houses are environmentally friendly structures that recycle the broken concrete from destroyed buildings to build the walls and are assumed to be earthquake resistant. The earthquake left huge quantities of rubble that could be used in the reconstruction of Haitians' homes.

Rubble-Houses' walls comprised of welded wire baskets filled with loose rubble seemed to be an inexpensive and immediate solution for the needy. Such structures are assumed to be earthquake resistant structures due to their improved damping and ductility characteristics arising from the rubble and welded wire basket. In August 2011, a collaborative research effort between Southern Polytechnic State University and Conscience International initiated to assess the seismic resistance of such rubble houses. A full-scale structure (14 ft. wide, 20 ft. long and 8 ft. tall), as shown in Figure 1 below, was built in the middle of Southern Polytechnic State University' campus and subjected to series of in-plane and out of plane static loads.

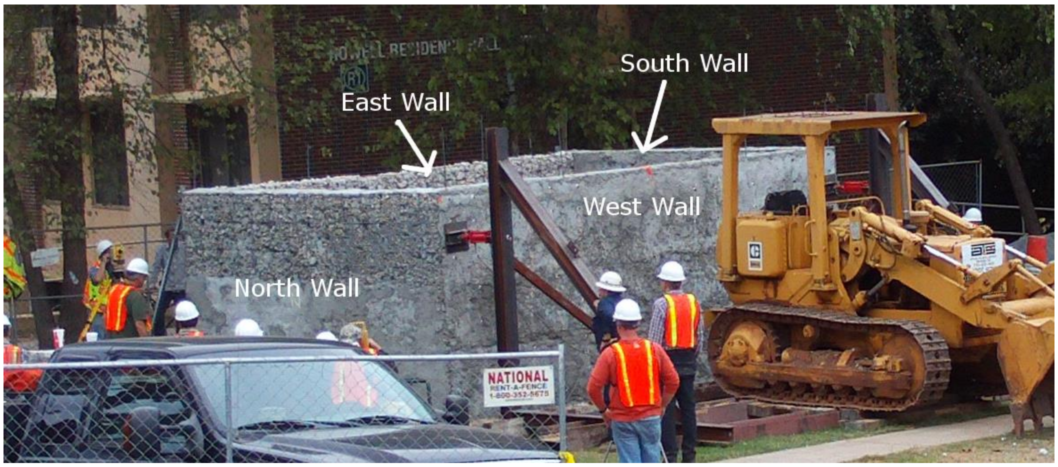


Figure 1. Rubble-House

In order to understand the mechanical behavior of the rubble walls, the displacement response map of the walls was recorded using a 3D laser scanning technique. 3D laser scanning is a very effective and efficient approach for precise and dimensionally accurate 3D as-built documentation. 3D laser scanning is a process of collecting the spatial coordinates of millions of points of an object by using lasers. The point clouds generated in this process are useful for measurement and visualization applications. This approach reduces errors and rework during documentation and enhances the productivity in a construction process.

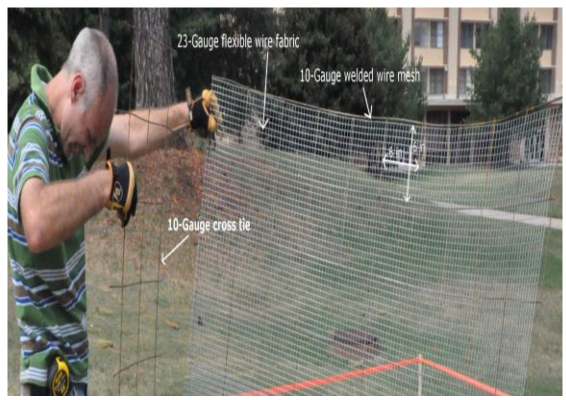
3D laser scanning technique has been successfully used for various architecture, engineering and construction applications (Shin and Wang 2004; Olsen et al. 2010; Jaselskis 2005). Walters et al. (2008) used laser scanners to determine the thickness of concrete pavement. Tsakiri et al. (2006) calculated the deformations through usage of surface reconstruction and deformation extraction techniques from laser scanner data. Gordon and Lichti (2007) used laser scanner data for modeling to calculate the precise structural deformation. Chang et al. (2008) used 3D laser scanner data for deformation calculations for evaluating the structural safety.

This paper presents and discusses the usage of the 3D Laser Technique in measuring the displacement response of structures under static loads.

RUBBLE HOUSE CONSTRUCTION

Rubble Homes are inexpensive and easy to build without power tools and skilled labor. A 6-in. deep foundation was first excavated and filled with rubble and concrete as shown in Figure 2, Stage 1. Next, a single wire basket was prepared for each wall separately. A wire basket consists of 10-Gauge 6-in. x 6-in. welded wire mesh and 23-Gauge flexible wire mesh fabric. As shown in Stage 2 of Figure 2, the sides of the basket are formed by tying 10-Gauge and 23-Gauge wire mesh together, then the sides are connected to each other by a 12-in. wide 10-Gauge cross tie at every foot along the length of the wall. Such an assembly creates 8 ft. tall compartments with 12 in. by 12 in. cross-sectional area. After erecting all four wire baskets, they are filled with crushed concrete, or rubble. Finally, the walls are covered with 1.5-2.0 in. thick cement finish as shown in Stage 5 of Figure 2. Each rubble house measures 14 ft x 20 ft. in foot print area and contains no bathroom, which is not uncommon in Haiti.

Stage 1: Foundation



Stage 2: Wire basket assembly

Stage 3: Wire basket erection

Stage 4: Pouring the rubble into the Basket

Stage 5: Finishing *rubble walls*

Figure 2. Construction Sequence of the Rubble House

RUBBLE HOUSE TESTING

The rubble houses are assumed to be earthquake resistant because of the ductile behavior of the wire baskets and the ability of the rubble to relocate its position without damaging the wall. However, behind its simplistic look and construction technique, a rubble wall possesses a highly complicated mechanical behavior due to its composite structure. Therefore, this experimental study was intended to be a preliminary research phase to gain a better understanding of Rubble-Houses. The objectives are: 1) evaluate current construction techniques and propose cost-effective improvements; 2) perform static load testing on a full-scale rubble-house; and 3) draft construction and design guidelines based on experimental and numerical findings. To achieve these objectives, the rubble house was subjected to a series of in-plane loads (Test-1), out-of-plane loads (Test-2) and a destructive test (Test-3) as shown in Figure 3.

Test 1: In-plane loading (North Wall)

Test 1: In-plane loading (South Wall)

Test 2: out-of-plane loading (West Wall)

Test 3: Destructive Test (South Wall)

Figure 3. Rubble House Testing

3D SCANNING RESULTS

3D scanning converts physical objects into digital 3D data. These scanners capture xyz coordinates of millions of points all over an object to recreate a digital image. In this project, FARO laser scanner Photon 20/120 was used for documenting the wall displacements for Test 2 and Test 3. It is a high accuracy, high resolution scanner. It scans at the rate of 976,000 points per second. It has range resolution of 0.07 mm. It has systematical distance error of ±2mm at 25 m. It has 320^{o} and 360^{o} field of view in vertical and horizontal directions, respectively (FARO, 2010). A 3D scanning for the house was performed after each loading step at three different locations. A total of 5 spheres have been used during the scanning process. These spheres were used for registering different scans during post data processing. FARO SCENE LT software is used for processing the scanned data. In order to determine the displacement response of each wall, a number of points on the wall were selected as shown on the West Wall in Figure 4. The displacement responses of the selected points were traced through the xyz coordinates. Mathematica software was used to fit the best surface between the scattered xyz displacements data points. Because of the limited space of this paper, only the results of Test 2 and Test 3 will be presented.

West Wall. The west wall was subjected to a series of out-of-plane loading at the mid point of the wall as shown in Figure 4. The selected mean points are also shown in the same figure. Figure 5 shows the displacement response of the wall for the load case of P=5000 pounds where Figure 5a shows the 3D scanning response of the wall compared to the original unloaded condition. In addition to the 3D scanning technique, the displacement response of the south wall was measured using displacement gauges placed inside the house. The displacement map of the inside surface of the wall using the displacement gauges and the outer surface using 3D scanning is shown in Figure 5b. The displacement map of the inner surface and the outer surface were overlapped as show in Figure 5c. Both maps are in great agreement.

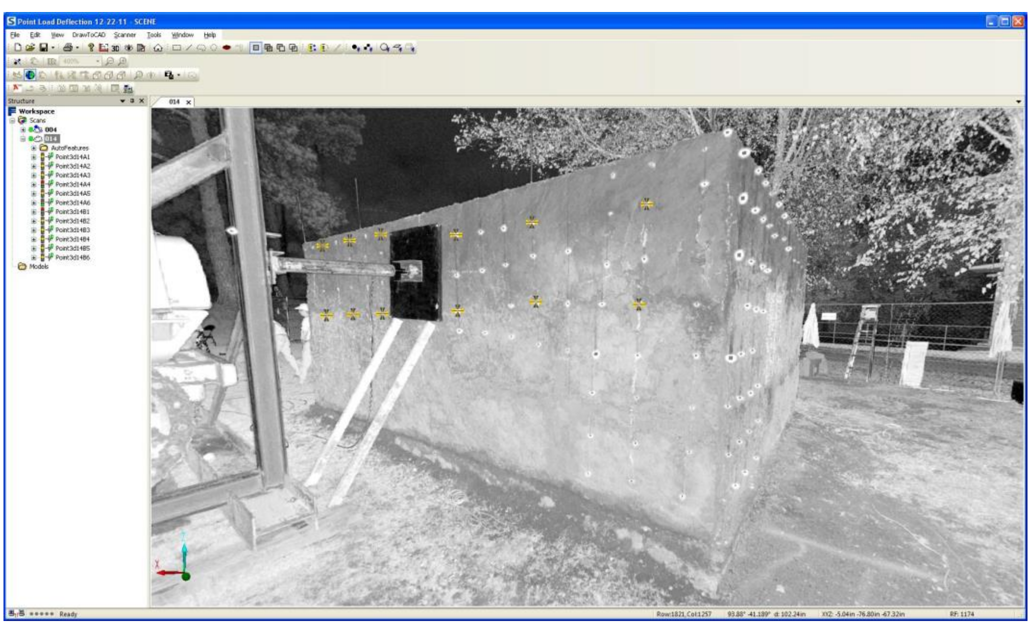


Figure 4. West Wall Mean Points

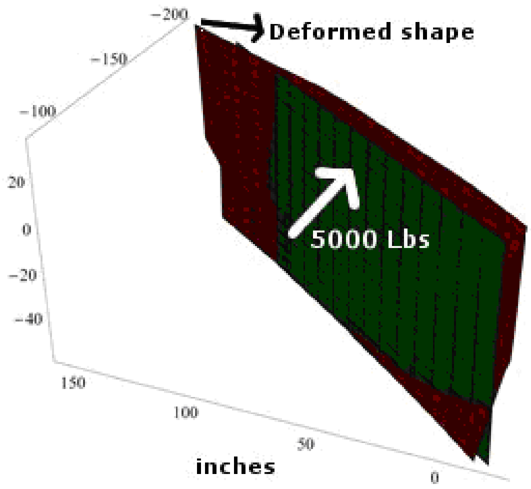


Figure 5a: Deformed shape vs. undeformed shape

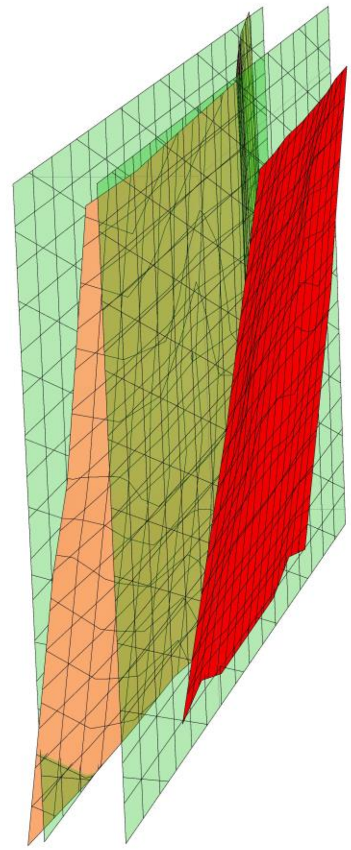


Figure 5b: 3D scanning results (outer surface) vs. displacement gauge results (inner surface)

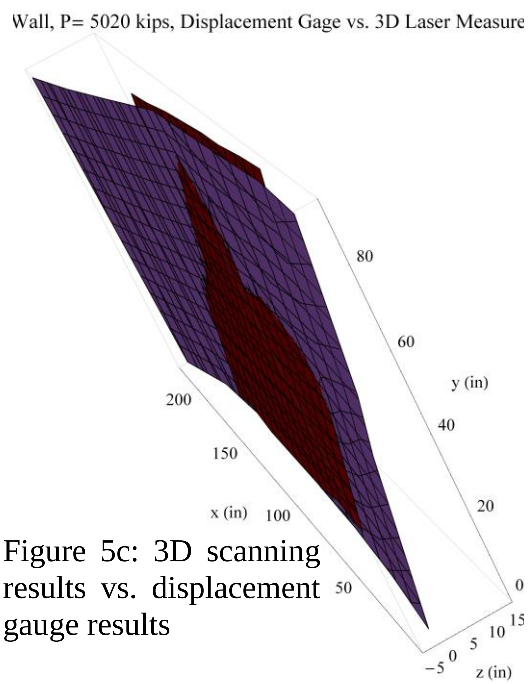
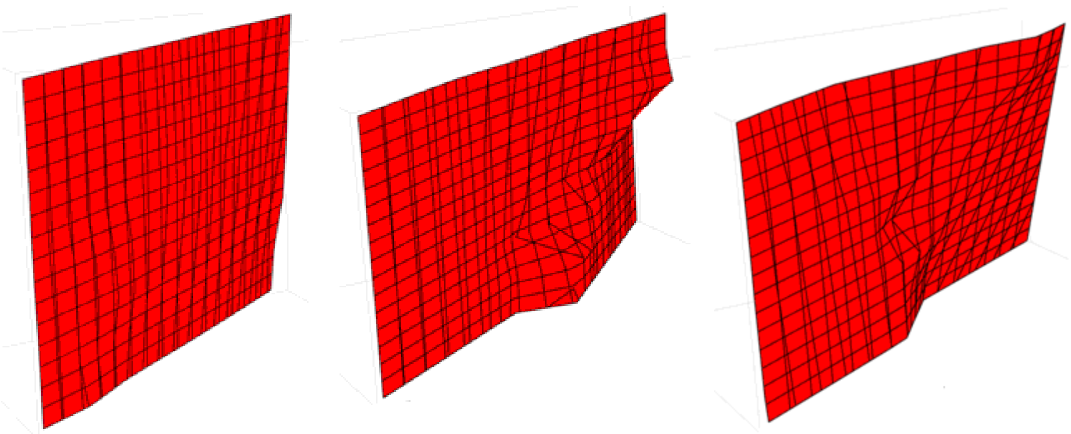


Figure 5c: 3D scanning results vs. displacement gauge results

Figure 5. Displacement response of west wall

South Wall. In the destructive test, the south wall was subjected to a pull from behind loading up to the collapse level. The displacement responses were recorded at three loading levels, namely 6 kip, 12 kip, and 15 kip (just before failure). Figure 6 shows the test setup and the selected mean points. The Displacement map is shown in Figure 7 for the three loading conditions. The walls of the rubble house sit on the foundation. A number of dowel rebars were embedded in each side of the foundation and extended inside the wall and that explains the out-of-plane displacements once the wall starts to slide.

Figure 6: South Wall Mean Points



P = 6 Kip **P = 12 Kip** **P = 15 Kip**

Figure 7. Displacement response of south wall

CONCLUSION

This paper presented the usage of 3D laser scanning technique to record the displacement response of a rubble-house under static loading. 3D scanning of an object produces millions of points stored in xyz coordinates format. To extract the deformed shape of each wall, sample area mean points were selected on each wall. After each loading, the displacements of the mean points were calculated by comparing the xyz coordinate of the current scan with the previous scan. Mathematica software was used to fit the best surface between the scattered xyz displacements data points. In one case, the displacement of 3D scanning was compared with the displacement obtained using simple displacement gauges. Although 3D scanning seems to be a very accurate technique in measuring the displacement response of structures, more work needs to be done to simplify the data extraction and manipulation.

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