SURVIVORS TALES: UNREINFORCED MASONRY AND THE 1886 CHARLESTON, SOUTH CAROLINA EARTHQUAKE

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ABSTRACT

Charleston, South Carolina is unique in both being near the epicenter of the largest earthquake on the east coast of the USA (M ~ 7, August 31, 1886) and having a large stock of unreinforced masonry (URM) buildings that were damaged by this earthquake, repaired, and in many cases still stand today. We are using historical photographs (both pre-and post-earthquake), an 1886 insurance report that describes damage to over 6000 commercial and residential buildings (~1800 URM), and a county-level parcel database to document these "earthquake survivors" and place them in a modern Geographical Information System (GIS). This will allow us to describe the building types in Charleston as they existed at the time of the 1886 earthquake. Changes in Charleston's street numbering system since 1886 make this effort somewhat challenging. We will describe the current state of this historic earthquake-damaged URM stock and efforts made to repair and reinforce these buildings, including the near ubiquitous use of "earthquake bolts" (rods and pattress plates) in the reconstruction after the 1886 earthquake. We are also using observations of URM damage in the 2010/2011 Canterbury, New Zealand earthquakes to reinterpret historic photographs and damage descriptions in terms of seismic ground motion. Our ultimate objective is to gather sufficient data to make the 1886 earthquake a "calibration event" for estimating building damage (to both historic and modern structures) in future earthquakes.

KEYWORDS: earthquake, unreinforced masonry

INTRODUCTION

Charleston, South Carolina is a major tourist destination in the southeastern USA. This year, the readers of one popular travel magazine voted it the number 1 travel destination in the USA. A large part of the city's charm lies in its history, which includes a large stock of colonial era unreinforced masonry (URM) buildings. Unique among colonial American cities, most of these buildings were damaged by earthquake shaking but were repaired and many still stand today. As evidenced by the 2010/2011 Canterbury, New Zealand earthquake sequence, this stock of historic URM structures is at great risk of loss in future earthquake events.

At 9:51 PM on August 31, 1886, a magnitude 6.7 [1] earthquake struck near Summerville, South Carolina, 30 kilometers from Charleston. Approximately 125 people were killed and two-thirds of Charleston's 60,000 residents were left temporarily homeless by severe building damage, particularly to URM structures [2]. During the ensuing 14 months much of this damage was repaired and many of these earthquake-damaged URM structures are currently used as residential and commercial space.

In the aftermath of the earthquake, several groups of investigators collected data related to the damage caused by the earthquake. A team of local and national scientists studied the earthquake, making it the first American earthquake systematically studied and resulting in one of the earliest United States Geological Survey publications on earthquakes [3]. In addition, a group of insurance companies commissioned a report on earthquake damage to commercial and residential structures [4]. Numerous photographs were taken of building damage caused by the earthquake [5, 6].

Several authors have used this historical information as a basis for studies of the relationship between earthquake damage and other factors. Robinson and Talwani defined earthquake damage as a function of building type and site conditions (natural versus made ground), finding that damage was predominantly to URM buildings but also that site conditions played a secondary role in the severity of damage [7]. Harlan and Lindbergh used a subset of data from the building damage report together with geotechnical borehole data to examine the relationship between site period and building damage, finding that damage levels increased as the site period decreased [8].

We are currently working towards improving our understanding of building damage during the 1886 Charleston earthquake by compiling relevant historical information into a Geographical Information System (GIS) database. Our main focus is on URM buildings, which suffered the greatest amount of damage [7] and therefore have the largest amount of information available (e.g., post-earthquake photographs) with regards to their performance. The aim of this work is to accurately capture the state of the built infrastructure in Charleston in the immediate aftermath of the earthquake, which will also help us ascertain the current state (i.e., degree of repair, etc.) of these historic structures. We will use this information to better understand what factors contributed to building damage in the 1886 earthquake plus create improved building fragility curves for these historic structures.

In the following sections we will review the materials available to analyze building damage in 1886, make several observations of damage style and repair mechanisms following the earthquake, and then discuss these findings in the context of recent earthquakes with substantial URM damage.

MATERIALS AND METHODS

A primary source for earthquake damage information is the Parkins and Stewart insurance report [4]. This report lists observations from 6956 commercial and residential buildings, with information on building materials, dimensions, condition of walls and chimneys, plus other observations (Table 1). In many cases the entries in this report can be compared to photographs of the buildings described in the report (Figure 1), to aid in interpretation of the entries.

As noted above, numerous photographs of building damage were taken in the aftermath of the earthquake. In addition, we have access to a series of photographs taken prior to the earthquake in 1883 [9]. The majority of these photographs were of the city's public buildings, which are not covered in Parkins and Stewart [4]. This allows for a direct comparison of the pre- and post-earthquake building stock (Figure 2). Many of these photographs are in the public domain and can be viewed online; the Lowcountry Digital Library (http://lowcountrydigital.library.cofc.edu/), a partnership between public libraries, educational and historical institutions in Charleston, has high-resolution scans of many 1886 earthquake photographs available for viewing.

Table 1: Example entry from 1886 Charleston earthquake insurance report for 21 East Battery; "Damages by Earthquake" are estimated repair costs in 1886 US dollars

Material		Dimensions			Condition of Walls				Condition of chimneys or flues	Damages by Earthquake	What should be done to make it safe
Building	Roof	Ft. Long	Ft. Wide	Ft. High	North	South	East	West			
Brick	Tin	125	60	40	Must come down	Badly cracked	Must come down	Badly cracked	Must be taken down	5330	By entire reno-vation

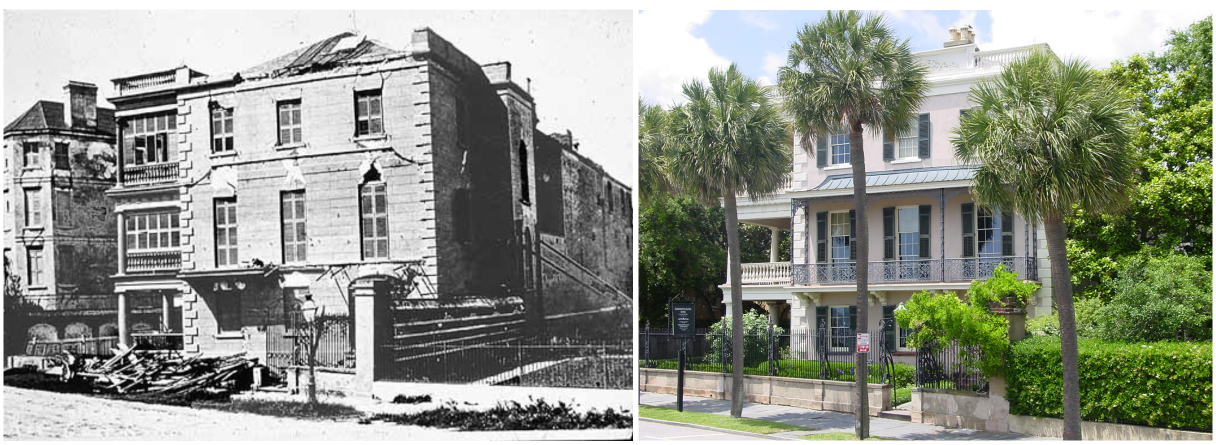

Figure 1: 21 East Battery, view from northeast: left) 1886 post-earthquake; right) in 2002.

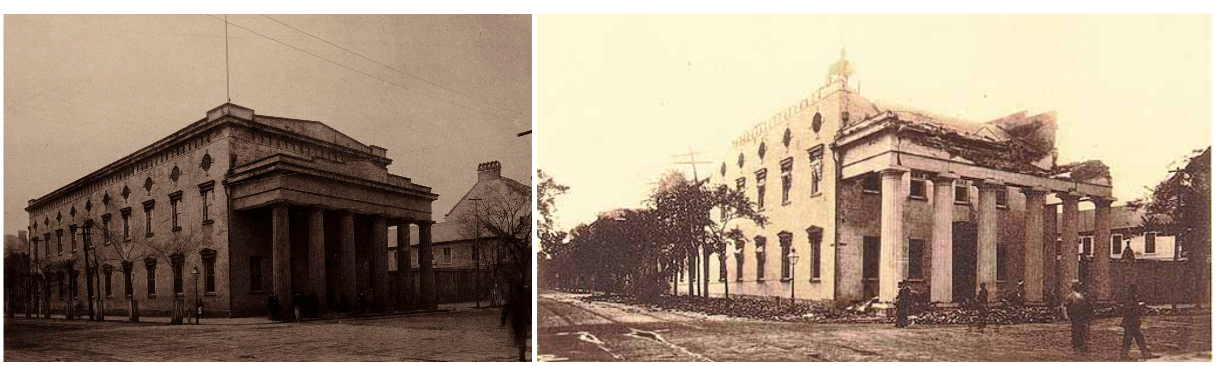

Figure 2: Main police station, corner of Meeting and Broad Street: left) 1883 pre-earthquake; right) 1886 post-earthquake.

An important part of our current work is placing these observations of earthquake damage in a modern geographical reference frame so they can be compared to existing geological and geotechnical information on site conditions in Charleston. A GIS building database created and maintained by the County of Charleston is the initial source of this information. This database includes the original date of construction for many (but not all) buildings, allowing us to identify a number of "earthquake survivors" (Figure 3). Publications on Charleston's historical architecture [10, 11, 12] allow us to fill in many gaps in the county buildings database and we are in the process of replacing the "Unknowns" in with the correct construction date.

One challenge in identifying buildings in post-earthquake photographs and finding the corresponding entry in the insurance report [4] is that the street numbering system has changed since 1886. Fortunately, in some parts of the city the insurance report is keyed to the 1884 Sanborn Fire Insurance maps, which have been digitized and are available via the University of South Carolina Library. In addition, historical researchers have documented some of these address changes [10], which is helping us properly locate observations of building damage.

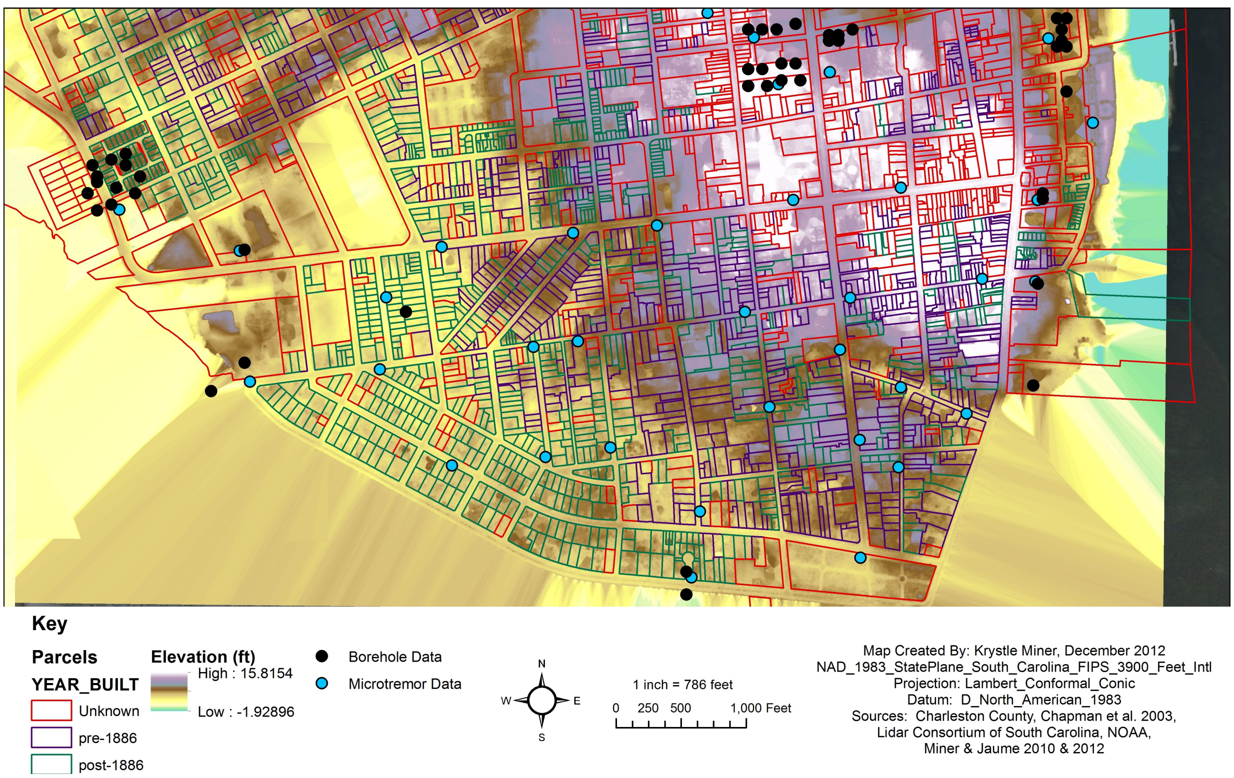

Figure 3: Map of the southern part of the Charleston Peninsula. The base map is a "bare earth" Lidar elevation map, with building parcel locations (color-coded by construction date), geotechnical borehole locations (black circles), and ambient seismic noise measurements (blue circles).

Besides the building information, we are adding geological, geotechnical and seismological data to create a comprehensive GIS product of information relevant to studying earthquake damage. Besides a surface geology base map [13], we have a two-meter resolution, "bare earth" Lidar image of the Charleston Peninsula that may prove to be a better indicator of the location and thickness of artificial fill. Geotechnical borehole data (provided by local geotechnical companies) in the historic part of Charleston consists primarily of Standard Penetration Tests (SPT), with a limited number of Cone Penetration Test (CPT) and Seismic Cone Penetration Test (SCPT) boreholes. We are supplementing this with ambient seismic noise measurements, which give information regarding the relative amplitudes and frequencies of the seismic site response. Figure 3 is a map of part of our study area showing the locations of relevant data.

Finally, one must never forget the importance of being a good observer of the built environment. As one walks around the older parts of Charleston looking at pre-1886 masonry buildings, one finds subtle clues in almost every building of the earthquake damage and subsequent repair. Further studies by the third author during restoration work on many of these historic structures show that the level of 1886 damage is made obvious when interior finishes are removed, providing those working on the buildings with clear maps of failures (Figure 4).

Figure 4: Interior view of the top (third) floor of an unreinforced masonry wall, originally built in 1785. Lower quality construction in the upper portion is the 1886, post-earthquake, reconstruction.

OBSERVATIONS

One aspect of damage to URM buildings observed both in historical and modern photographs is evidence of in-plane versus out-of-plane masonry wall failures. In-plane shear cracking (Figures 1 and 5) is often observed between windows and out-of-plane failure is seen in fallen gables and walls separating from buildings (Figure 2). A preliminary review of the insurance report and corresponding photographs suggest phrases such as “badly cracked” and “severely cracked” for walls with many windows imply in-plane failure. Phrases such as “top of wall down” appear to indicate out-of-plane failure.

Observation of 1886 post-earthquake photos, study of 1886 reports and present day knowledge of the structural damage to buildings built before 1886 all indicate that closely spaced pattress plates were tremendously effective in tying brick masonry walls to floor diaphragms, that is, in holding masonry buildings together during the 1886 earthquake. For this reason, in present day structural repairs and strengthening of historic masonry buildings, we generally favor them over stainless steel/epoxy/screen tube (resin) anchors. Their pullout cones are quite large, compared to the similar cones of resin anchors. Details of some modern pattress plate installations by the third author’s firm are shown in Figure 6.

Figure 5: Buildings on Glebe Street on the College of Charleston campus: left) 20 Glebe Street, showing typical post-event “earthquake bolt” (pattress plate) repair; right) close up of 12 Glebe Street showing mortar deterioration due to moisture migration through the wall.

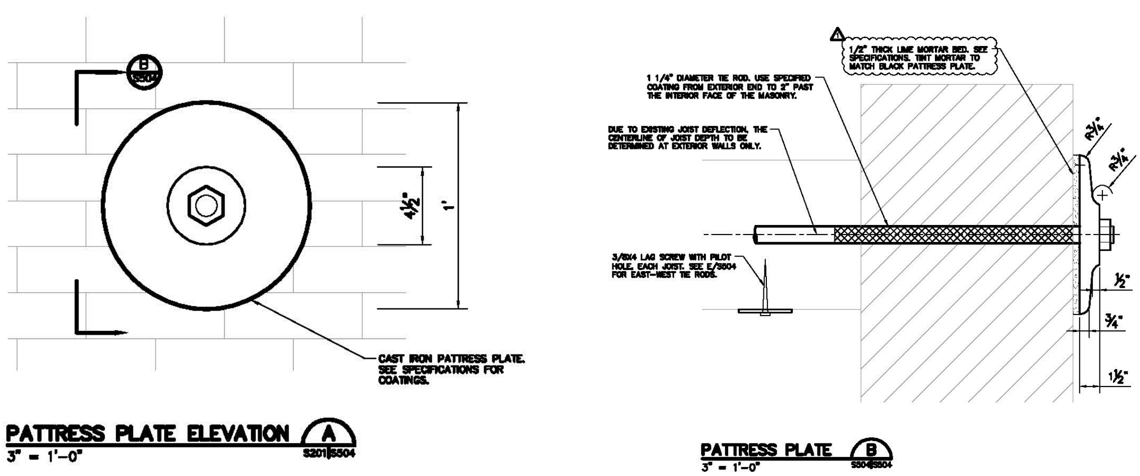

Figure 6: Diagram of typical pattress plate and rod system in current use by third author.

DISCUSSION

A major goal of our work is to interpret the historical earthquake damage information from the 1886 Charleston earthquake in light of what is now known regarding URM damage in earthquakes. We find that the 2010-2011 Canterbury, New Zealand earthquake sequence and the resulting damage in the city of Christchurch has many parallels to what happened to Charleston in 1886 [14]. Below we discuss some of our observations in light of findings from the Canterbury earthquake sequence, both in terms of the damage in 1886 and implications for damage in future earthquakes in the Charleston region:

a. Dizhur et al. [15] report that after the February 2011 Christchurch earthquake in-plane shear cracking was primarily observed on north and south facing walls while out-of-plane failure occurred on eastern and western walls, consistent with the predominant east-west strong motion during the event. We have also noticed regularities in in-plane versus out-of-plane URM damage in Charleston, but on a more localized basis. Damage to the main police station (Figure 2), St Michael's Church and the Charleston County Court House near the corner of Meeting and Broad Streets (near the highest elevations on Figure 3) appear to indicate the strongest shaking was in the east-west direction. However, damage in areas both south (Figure 1) and north (Figure 5) of that location is more consistent with the strongest shaking being in the north-south direction. One of our goals is to map the distribution and orientation of in-plane versus out-of-plane damage in Charleston, with the objective of determining any regularities in the orientation of strong ground motion and its relationship to either source or site properties.
b. Dizhur et al. [16] noted that poor quality mortar played a significant role in URM damage during the 2010 Darfield earthquake, with some mortar failing with finger compression. We have noted similar "finger compression failure" mortar in Charleston (Figure 5), particularly in the mortar used after the fire of 1837. Some of the mortar used in the repair after the 1886 earthquake had a Portland cement base and has held up better then some pre-1886 mortar.
c. Dizhur et al. [15, 16] also noted the performance of masonry wall anchors in URM buildings in Christchurch during the 2010 and 2011 earthquakes. In particular, Dizhur et al. [15] shows examples of both successful and unsuccessful wall anchorage. Given that similar wall anchorage systems are nearly ubiquitous in URM buildings in Charleston that were repaired, we are interested in the factors that governed the seismic performance of these systems, and expect to examine that in more detail in the future.

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