Smithsonian Institution
Scholarly Press

SMITHSONIAN CONTRIBUTIONS TO MUSEUM CONSERVATION • NUMBER 4



Unexpected—Earthquake 2011

Lessons to Be Learned

Edited by
A. Elena Charola,
Corine Wegener,
and Robert J. Koestler

SERIES PUBLICATIONS OF THE SMITHSONIAN INSTITUTION

Emphasis upon publication as a means of "diffusing knowledge" was expressed by the first Secretary of the Smithsonian. In his formal plan for the Institution, Joseph Henry outlined a program that included the following statement: "It is proposed to publish a series of reports, giving an account of the new discoveries in science, and of the changes made from year to year in all branches of knowledge." This theme of basic research has been adhered to through the years by thousands of titles issued in series publications under the Smithsonian imprint, commencing with Smithsonian Contributions to Knowledge in 1848 and continuing with the following active series:

Smithsonian Contributions to Anthropology
Smithsonian Contributions to Botany
Smithsonian Contributions to History and Technology
Smithsonian Contributions to the Marine Sciences
Smithsonian Contributions to Museum Conservation
Smithsonian Contributions to Paleobiology
Smithsonian Contributions to Zoology

In these series, the Institution publishes small papers and full-scale monographs that report on the research and collections of its various museums and bureaus. The Smithsonian Contributions Series are distributed via mailing lists to libraries, universities, and similar institutions throughout the world.

Manuscripts submitted for series publication are received by the Smithsonian Institution Scholarly Press from authors with direct affiliation with the various Smithsonian museums or bureaus and are subject to peer review and review for compliance with manuscript preparation guidelines. General requirements for manuscript preparation are on the inside back cover of printed volumes. For detailed submissions requirements and to review the "Manuscript Preparation and Style Guide for Authors," visit the Submissions page at www.scholarlypress.si.edu.

SMITHSONIAN CONTRIBUTIONS TO MUSEUM CONSERVATION • NUMBER 4

Unexpected—Earthquake 2011

Lessons to Be Learned

Edited by
A. Elena Charola,
Corine Wegener,
and Robert J. Koestler

Smithsonian Institution
Scholarly Press
WASHINGTON D.C.
2014

ABSTRACT
Charola, A. Elena, Corine Wegener, and Robert J. Koestler, editors. Unexpected—Earthquake 2011: Lessons to Be Learned. *Smithsonian Contributions to Museum Conservation*, number 4, viii + 105 pages, 86 figures, 3 tables, 2014.—This volume brings together nine reports and six short communications that describe damage and other problems caused for the Smithsonian Institution by the earthquake that occurred in the Washington, D.C., area on 23 August 2011. The first chapter is a summary of the presentation by Secretary G. Wayne Clough to the Smithsonian community nearly a month after the event, and the second gives an overview of the impact that the earthquake had on buildings and collections. The third chapter describes in detail both damages to and post-seismic stabilization of the Hempstead House, listed as a historic site on Smithsonian property in Maryland. The fourth chapter describes some of the damage to and subsequent conservation of fossils in the National Museum of Natural History; the next two chapters describe damages suffered by the Botany–Horticulture Library and the fluid collection located in this same building. The short communications report whether damage was suffered in six other Smithsonian museums. Chapter eight deals with the Smithsonian's Museum Support Center, describing damage suffered by collections in the pods of this center as well as the structure overall and, in particular, its roof, in which many previously undiscovered leaks were subsequently exposed (over offices and laboratories) by Hurricane Irene. The final chapter brings together recommendations for measures to be implemented based on the experience gained. An epilogue on the need for preparedness for unexpected emergencies and a bibliography close the volume.

Cover images (*from left*): Damages to Botany–Horticulture library stacks (see Juneau and Everly, Figure 1); damaged Smithsonian Castle towers and chimneys being stabilized (Clough, Figure 13); toppled ceramic artifacts in anthropology collections at the Museum Support Center (Homiak, Figure 8).

Published by SMITHSONIAN INSTITUTION SCHOLARLY PRESS
P.O. Box 37012, MRC 957, Washington, D.C. 20013-7012
www.scholarlypress.si.edu

Library of Congress Cataloging-in-Publication Data
Unexpected – earthquake 2011 : lessons to be learned / edited by A. Elena Charola, Corine Wegener, and Robert J. Koestler.
pages cm. — (Smithsonian contributions to museum conservation ; number 4)
Includes bibliographical references.
1. Smithsonian Institution—History—21st century. 2. Earthquakes—Washington Region—History—21st century. 3. Hurricanes—Washington Region—History—21st century. 4. Museums—Collection management—Washington Region. 5. Museum conservation methods—Washington Region. 6. Earthquake damage—Washington Region. 7. Hurricane damage—Washington Region. 8. Museum buildings—Washington Region—Earthquake effects. 9. Museum buildings—Washington Region—Hurricane effects. I. Charola, A. Elena. II. Wegener, Corine A. III. Koestler, Robert J. (Robert John), 1950–
Q11.S8U38 2014
069.09753'090512—dc23
2014013331

ISSN: 1949-2359 (print); 1949-2367 (online)

∞ The paper used in this publication meets the minimum requirements of the American National Standard for Permanence of Paper for Printed Library Materials Z39.48–1992.

Contents

Preface

Earthquakes on the East Coast! This thought rarely enters the mind of museum conservators, curators, or scientists when thinking about vibration mitigation in collections. We are all familiar with, if not quite always cognizant of, transmission of floor vibrations into cases and the dangers of free-standing pedestals or cantilever shelving that amplify local vibrations. Sure, we have seen objects "walk" if not anchored securely in exhibition cases, and we have seen minute pieces of objects, most often wood, appear underneath display objects, but we had not expected that our display or storage objects would be subjected to a significant earthquake! There was no institutional memory of damage from earthquakes in the mid-Atlantic or northeast USA, so it was a surprising event when on 23 August 2011 an earthquake, magnitude 5.8, hit the Washington, D.C., area. People who have experienced previous quakes elsewhere immediately recognized what was happening and knew what to do. The rest of us could think of only a human-caused accident or event. Fortunately, the earthquake was mild, the damage to the area was in the millions and not billions, and there were few injuries to people. The quake did serve as a wake-up call to museum personnel to reevaluate our emergency preparedness procedures and to reassess how well our collections were displayed and housed.

This volume brings together a set of papers to illustrate the type of damage that resulted from the earthquake, both to the buildings themselves and to the collections housed in them. The aim was to cover the wide variety of problems that resulted and explain the reasons for the damage. It is not an exhaustive listing of issues, since these were immediately assessed and documented in various internal reports. Instead these papers illustrate the damage found in various examples, ranging from the historic Homestead House acquired by the Smithsonian's Environmental Research Center in Edgewater, Maryland, only some months prior to the earthquake, to the collections in the National Museum of Natural History on the Mall and those stored at the Museum Support Center in Suitland, Maryland. They also describe the issues encountered during damage assessment and the measures undertaken in preparation for the arrival of Hurricane Irene, which struck a few days after the earthquake. The last chapter discusses important issues such as prompt assessment of structural damage to buildings and lessons learned from this experience that should improve our response in future catastrophic events. One of the most important lessons corresponds to the human reaction when subjected to such an event: while the first instinctive reaction is for self-preservation, the second one is to address the safety of the collections.

The first reaction in most museums was to evacuate the building, although this was not the correct one for an earthquake response. The inconsistency in this response among the various Smithsonian units contributed to a delay in organizing the damage assessment by less than a quarter hour—the time it took to reestablish communications.

The second instinctive reaction to check the safety of the collections cannot be undertaken individually because of the huge numbers and locations of collections at the Smithsonian. Depending upon the size and the storage conditions of the collections, such an effort requires mobilization of many individuals. Therefore, this second reaction requires prior organization and a concerted focus in order for it to be carried out rapidly and with maximum efficiently. For this purpose, training is required at all levels. This is one of the main lessons that was learned from this experience.

A. Elena Charola and
Robert J. Koestler
Museum Conservation Institute
Smithsonian Institution

Acknowledgments

We thank the collaborators to this volume for sharing their experiences and preparing the chapters included in this issue. Special thanks are owed to Lynn P. Campbell, private conservator from New Zealand, for her collaboration in compiling the bibliography. Further thanks are due to the many who indirectly collaborated in the preparation of this volume: John Yahner from the Office of the Secretary; Bayne Rector from the Office of Facilities Engineering and Operations; Mark Bretzfelder from the Office of the Chief Information Officer; Rick Fary from the Museum Support Center; and Katharine C. Wagner from the Smithsonian Libraries. Appreciated also are those who collaborated in identifying or contributing (or both) some of the many photographs included in this issue: from the Smithsonian Institution are Sylvia Kendra, Lee Robertson, Walter Ennaco, Britti N. Hammond, and Larry Varner (Office of Facilities Engineering and Operations), Kristin Quarles (National Museum of Natural History core facilities), Daniel G. Cole (National Museum of Natural History, Office of Information Technology); and from Virginia Polytechnic Institute and State University are professors James Martin and Martin Chapman and former students Betsy Godfrey and Morgan A. Eddy. We also thank Sasha Stollman, private conservator from New Zealand, for sharing her experience of the February 2011 Christchurch earthquake. Last but not least, Ann N'Gadi from the Museum Conservation Institute is thanked for her invaluable help with solving all the small details that otherwise take up so much time.

Back to Back: The Earthquake and Hurricane of 2011

G. Wayne Clough

ABSTRACT. This paper is based on a presentation given at the Freer Gallery of Art's Meyer Auditorium on 21 September 2011, nearly a month after an earthquake (23 August 2011) and Hurricane Irene (27–30 August 2011) passed through Washington, D.C. It briefly explains why this area suffered so much from an earthquake centered about 135 km (84 mi) to the southwest and describes the reasons for the damage to various Smithsonian Institution buildings as well as other important monuments in this area. The fact that Hurricane Irene hit the area only four days after the earthquake exacerbated problems caused by the earthquake. Because of design variations in a large number of Smithsonian buildings in the Washington, D.C., area and in the subsurface conditions beneath them, some buildings, and the collections within them, were more damaged than others by the earthquake. Cracking of museum walls was relatively common and offered avenues for water movement and leaks during Hurricane Irene. In the end, we were fortunate that the issues were not more severe. Experiences like these provide us with a teaching moment that we can use to improve our ability to respond in the future. It also allows us as scientists and engineers to take a moment to learn from the messages nature is sending us.

THE EARTHQUAKE

On Tuesday, 23 August 2011, an earthquake occurred some 135 km (84 mi) SW of Washington, D.C., at 1:51 PM. The epicenter was located 8 km (5 mi) SSW of Mineral, Virginia, and occurred at a depth of 5.95 km (3.7 mi) with a magnitude of 5.8 on the Richter scale (Figure 1).

The area is located in the middle of the North American plate where intense earthquakes are rare. Earthquakes are more likely to happen along the edges of neighboring tectonic plates when they shove and push against each other, as is the case along the coast of California. The bedrock in the epicentral area of the Virginia earthquake is riddled by faults, almost all of which are considered inactive (Figure 2).

However historical records show that an earthquake the size of the Mineral event occurs on average every one hundred years or so. The faults of this region trend along a northeasterly alignment that is directed toward our nation's capital. The earthquake on 23 August was generated on one of these faults, and the motions generated were directional, moving northeasterly toward the District of Columbia. The unique pattern of motion has been documented by

G. Wayne Clough, Office of the Secretary, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA. Correspondence: A. E. Charola, charolaa@si.edu. *Manuscript received 12 December 2013; accepted 18 March 2014.*

FIGURE 1. Area of Virginia showing the location of the town of Mineral, epicenter of the earthquake. (Data and map courtesy of Esri, 2011; map modified by Dan Cole, Smithsonian Institution.)

the U.S. Geological Survey (USGS) by means of strong motion measurements and through observed damage patterns (Figure 3).

It has been postulated that the directional nature of the event was caused either by a sequential occurrence of two earthquakes, one smaller that triggered a larger one to the east of the first one, or by a unique structure within the basement rocks in the area of Mineral, which blocked the motions from travelling to the west and amplified those to the east. As with many earthquake issues, we are just beginning to learn how earthquakes work, and it will take time to sort the mechanisms out.

The earthquake epicenter was relatively shallow occurring about 6 km (~4 mi) below the surface along a reverse fault. A mock up of this type of fault and earthquake are shown in Figure 4. An earthquake generates waves that dissipate the energy unleashed during the event. There are a number of such waves, but for this discussion the most relevant ones are the compression (P) and shear (S) waves (Figure 5).

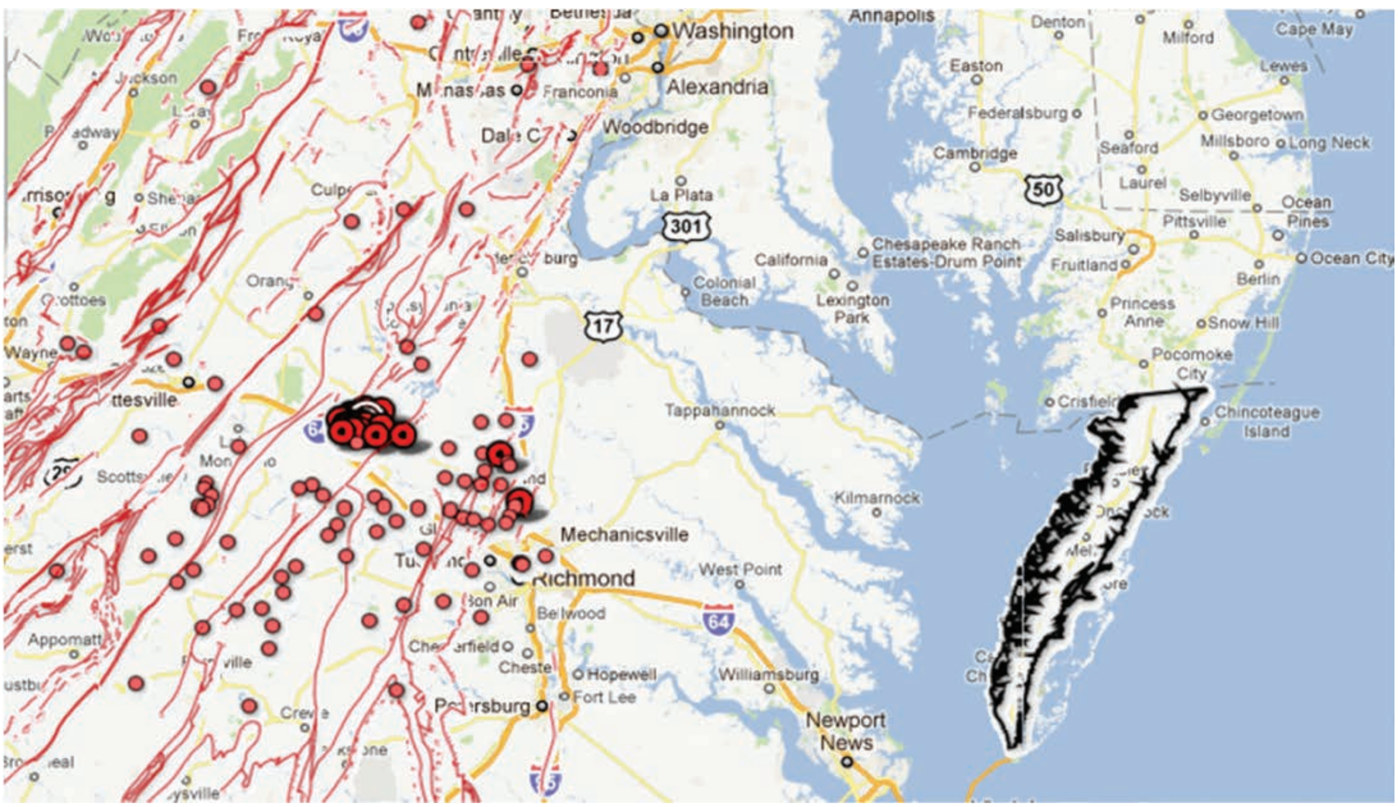

FIGURE 2. The Northeast region of Virginia has many faults (red lines); the red dots correspond to earthquakes. (Map courtesy of Virginia Department of Mines, Minerals, and Energy.)

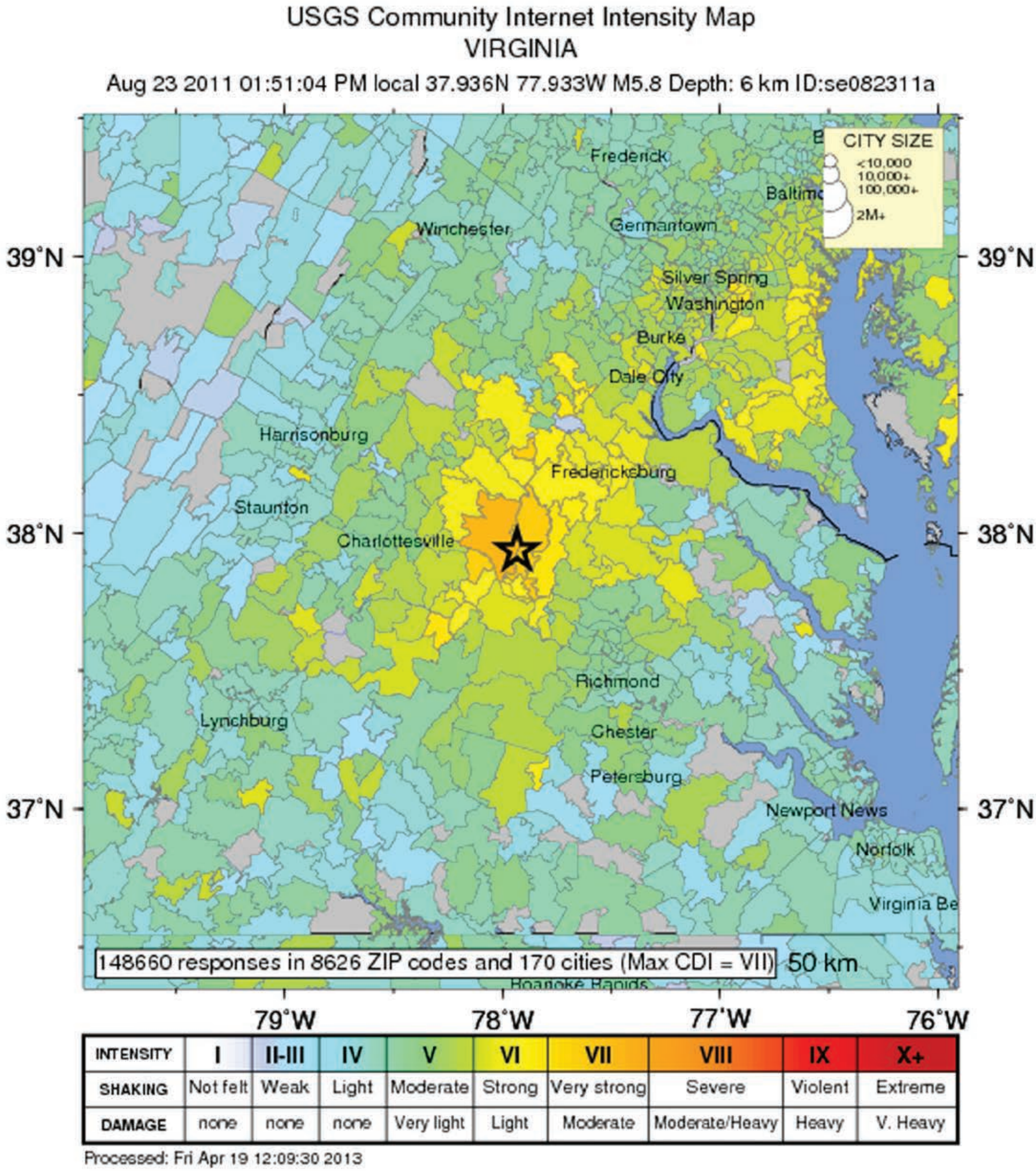

FIGURE 3. U.S. Geological Survey intensity map of the area around the earthquake epicenter at Mineral, Virginia. Note the higher intensity damage to the northeast of Mineral as a result of the aligned faults.

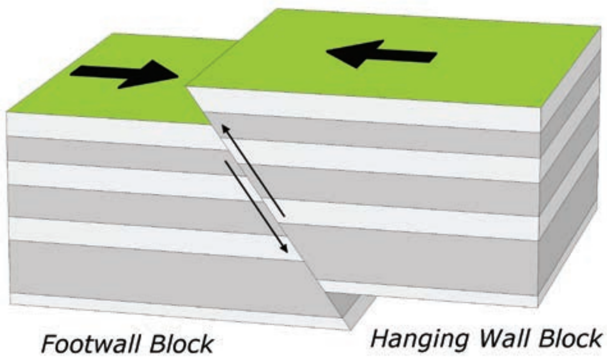

FIGURE 4. Depiction of rupture occurring along a reverse fault in the rock crust beneath the surface soil. (Diagram by Yun Liu, Smithsonian postgraduate Fellow, Museum Conservation Institute.)

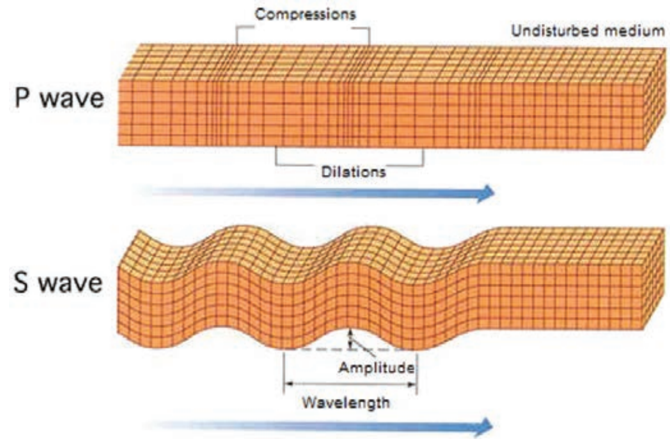

FIGURE 5. The two dominant waves generated by the earthquake: the compression wave (P) and the shear wave (S). (Diagram courtesy of AlabamaQuake, http://alabamaquake.com/education.html.)

The compression wave travels at a higher speed than the shear wave: 6.2 km/s and 3.6 km/s, respectively. This means that although they start at the same time, the wave fronts will separate from each other as they move farther from the epicenter. This is illustrated in four seismograms that were measured at different distances from the epicenter (Figure 6). The first wave arrival is the compression wave, and the second is the shear wave. The farther a given location is from the epicenter, the longer it takes for the shear wave to arrive and thus the greater the time delay between this arrival and that of the earlier compression wave. Because these phenomena are connected by the relative speed of the two waves, scientists and engineers have long used the time difference between the arrival of the shear and compression waves to calculate the distance back to the epicenter. The calculation depends a bit on the type of rock and its hardness, but roughly every second in separation corresponds to about 8.3 km distance from the origin.

As an engineer who has worked in the earthquake field, and having lived in California and travelled to earthquake sites around the world in time to experience many aftershocks, I have often used the time separation rule myself to calculate rough distances to epicenters. The key is to remain calm during the event itself so that you can note the arrival time of the compression wave and count the seconds till the shear wave arrives. Easier said than done, especially the first time, but with experience it becomes second nature. When the Mineral event occurred, I was holding a meeting in my parlor next to my office in the Smithsonian Castle (Castle). It took me a moment to realize we were having an earthquake since this was not California, but when it dawned on me, I asked those at the table to move under it or to get in the nearest doorway. I remained in my chair and counted, one thousand one, one thousand two, and so on until I felt the shear wave arriving at about 16 s. My guess was that the epicenter was 130 km, or 90 mi, away. In actuality it was 125 km (~84 mi) away—not bad for an out of practice earthquake guy.

The response of the Castle to the motions was interesting. The building is long and narrow and aligned roughly in an east–west direction, approximately in the direction of the earthquake waves as they travelled from the west toward the east through the District of Columbia region. As a result, when the earthquake hit the Castle, it was clear to me the motions were following a west–east pattern because I could feel the building wracking along its long axis. I heard blocks of the Seneca sandstone slide along their mortar joints. After the quake, the Parlor was filled with a light haze from the plaster and mortar particles that suffused the room, and there were diagonal cracks above the east–west doorways emanating from the corners of the door frames (diagonal cracks are sure evidence that the building was being shaken laterally along its long axis). In my office, the floor above the south wall had shifted enough to crack the plaster open along a line between the wall and the floor for the entire length of the wall. Sand and mortar particles covered my desk and computer cabinet. An engineering assessment showed that the

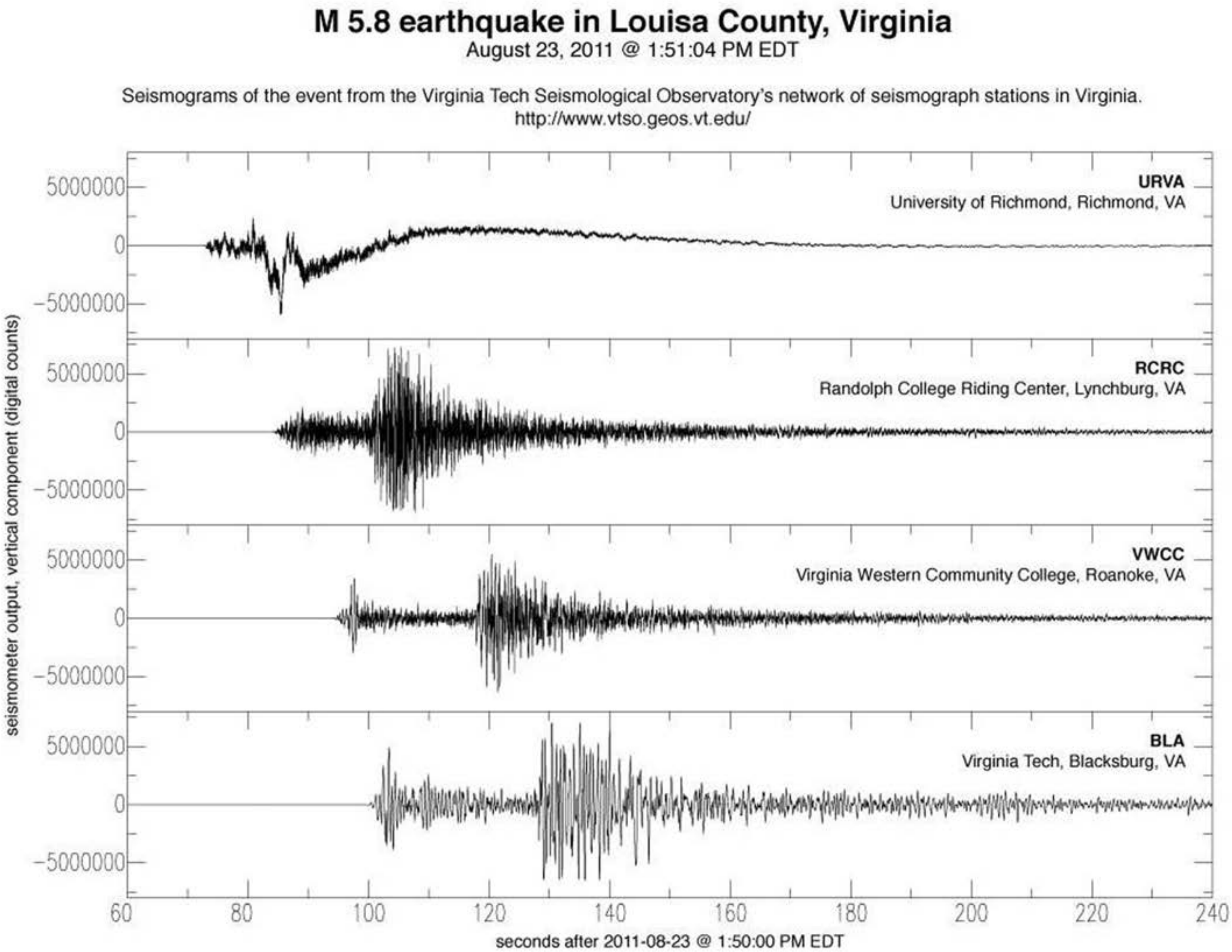

FIGURE 6. Seismograms showing how the initial compression (P) waves and subsequent shear (S) waves separate as they move away from the epicenter. Note that the time unit labels on the x-axis start at 60 seconds after the reference time of 1:50:00 PM. The P-wave arrival at station URVA (University of Richmond) is at 72 seconds on the plot, which corresponds to 1:51:12 PM. The URVA seismogram looks different from the other three because the recording instrument was overwhelmed by the earthquake and lost sensitivity. (Graph courtesy of Virginia Tech Department of Geosciences.)

wall and floor were still tied together and the damage was largely superficial, for which I was grateful. It took several weeks to repair the plaster, and during this time mortar and sand rained down regularly on my desk. I joked with my friends in the Office of General Counsel on the floor above me that they had to stop dancing until the building was repaired. When workers finally came to my office to repair the damages there and in the Parlor, I asked that they leave the diagonal cracks over the door that connects my office and the Parlor, feeling that the Smithsonian is all about history and that we need to leave some evidence for those who follow us to see. After all, it is a great conversation starter!

There are more lessons we can learn from this earthquake, and one of these relates to "soil or site amplification." Typically, as the waves travel away from the epicenter, the amplitude of the motions steadily diminishes. This is much like what happens when you throw a rock into a calm body of water and the ripples steadily diminish in amplitude with distance from the impact. The same occurs with earthquake waves; as they move farther away from the epicenter they spread out and encounter more and more mass, and because the energy in the waves remains roughly constant it has less influence on the ever-larger mass. But there is an exception to this rule and it occurs when the soil layers lying above bedrock have a natural frequency that closely matches that of the earthquake waves. This results in amplification of the bedrock motions at the ground surface. This occurred in the soils that underlie both the Castle and the Museum Support Center (MSC) in Suitland, Maryland. We cannot show definitive proof of this because we did not have an instrument to measure strong motions at the Smithsonian, but there were several instruments at locations nearby in Virginia that reflect similar conditions. Also, the stronger than expected damages at the Castle and at Suitland reflect this phenomenon. Thus, there is strong circumstantial evidence for soil amplification.

The two phenomena of wave attenuation and soil amplification are illustrated in the seismograms in Figure 6, where it can be seen that, as the waves travel away from the epicenter, the motions typically lose amplitude—for example, compare the seismograms at Lynchburg and Roanoke, Virginia. However, in the case of Blacksburg, Virginia, which is farther away from the epicenter than either Lynchburg or Roanoke, the waves suddenly show an amplitude level more like that found closer to the epicenter. This is caused by soil amplification at the Blacksburg instrument site.

Both the Castle and the MSC are about the same distance from the epicenter, as is an instrumented site in nearby Reston, Virginia (Figure 7). At this site, peak bedrock accelerations reached 0.02 g (1 g = the acceleration of gravity), but it can be seen that measured accelerations at the top of the soil column reached a peak of 0.09 g, that is about a fourfold amplification of bedrock motions. Similar conditions exist under the Castle, where there are three soil layers above the weathered rock, similar to those at the Reston site (Figure 8). Suitland conditions are also much like those at the Castle. So in both cases it is highly likely that amplification occurred and played a role in the damages that occurred.

As noted, the 2011 earthquake is not the first time this area has experienced a seismic event. In thinking about our recent event, it brought to mind the work I had done in the 1980s investigating the 1886 Charleston

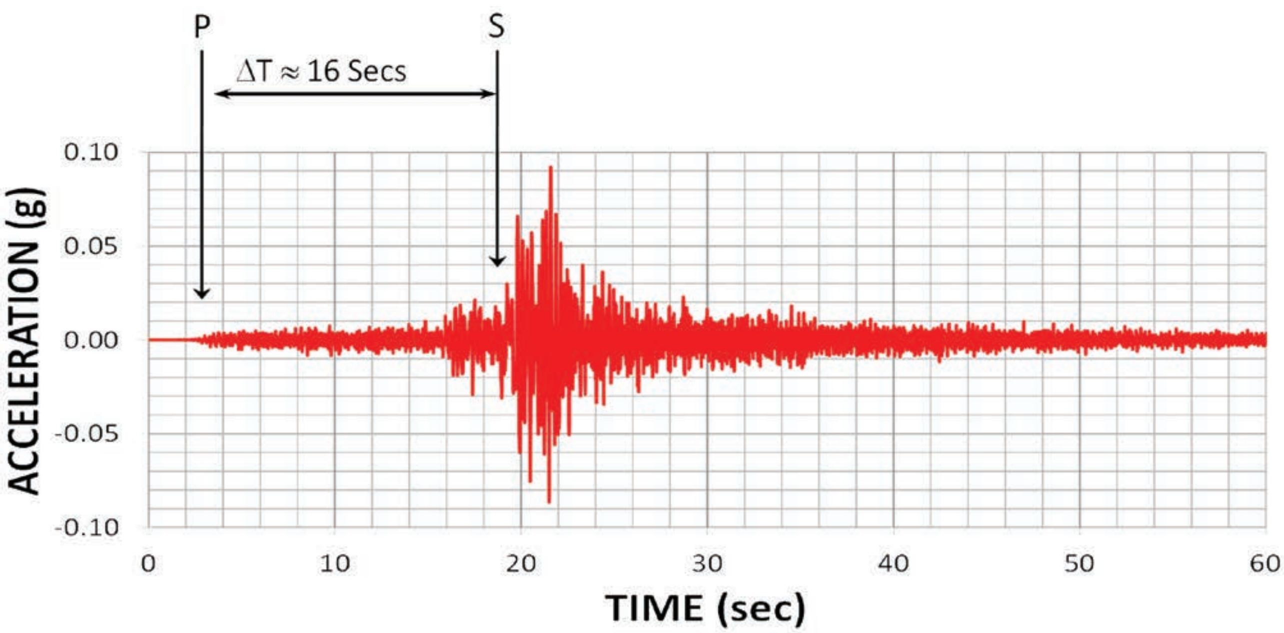

FIGURE 7. Seismogram for Reston, Virginia, which is a similar distance from the earthquake's epicenter as the Smithsonian Castle in Washington, D.C., and the MSC in Suitland, Maryland. Difference in time (ΔT) of onset of the compression (P) and shear (S) waves is indicated by the black arrows. (USGS seismogram modified by Morgan A. Eddy, Steele Foundation LLC.)

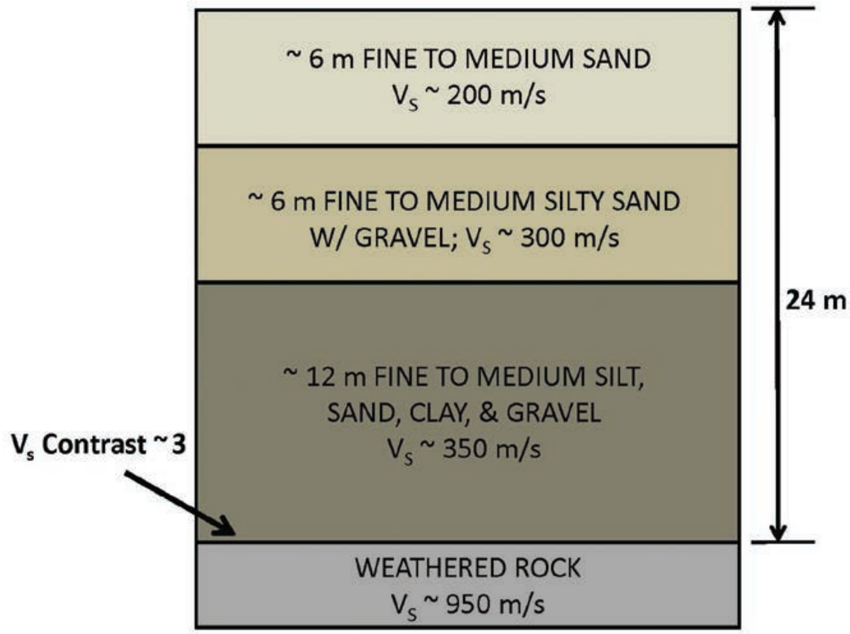

FIGURE 8. Cross section of the ground under the Smithsonian Castle. There are three different soils above the weathered rock with a total thickness of some 24 m (~80 ft); V_s stands for the speed of the S wave. (Diagram courtesy of Morgan A. Eddy, Steele Foundation LLC.)

earthquake. This earthquake was thought to be close to a magnitude 7, much larger than the Mineral earthquake. The epicenter was in Georgetown, S.C., 852.9 km (530 mi) to the south of the District of Columbia, and occurred at 9:51 PM on 31 August 1886. The event caused large and extensive damages in Charleston; at the time the damage was little understood but was fortunately well documented by the first-ever post-earthquake investigation by the USGS. Later investigations, including those I conducted with my students at Virginia Tech, showed much of the damage was caused by liquefaction of loose sandy soil deposits, some formed as ancient beach deposits and some created as developers dumped loose sand to expand the land mass in Charleston. What intrigued me about the Charleston event was that I had read years ago it was strongly felt in Washington, D.C., and New York City. I asked Pamela Henson, director of the Smithsonian Institution Archives' Institutional History Division, and her staff to investigate. They are always a fount of interesting information, and they discovered an article published by the *Washington Post* three days after the earthquake.

Mr. Lucien M. Turner, of the Smithsonian Institution, . . . noticed two additional shocks yesterday, the first occurring at 8:24 a.m. and the second at 5:15 p.m. . . .

[T]he first shock on Tuesday night occurred at 9:53:31. "I was sitting in the south tower of the Smithsonian building, with my chair tilted back and my heels resting on the table. . . . I recognized the cause, and looked at my watch. An old gas-fixture, shaped like an inverted T, suspended from the ceiling . . . served admirably as a seismometer. Its heighth from the floor is six feet six inches and sixty-six feet six inches from the surface of the ground.

The disturbance was so great as to cause the fixture to swing five inches. The oscillations . . . move[d] from west to east. The movements of the tremors were observed to last until 9:55 p.m. Several slight disturbances occurred until 10:04 p.m. . . . At 10:08 p.m. a second series of tremors began. The first of these moved from north northwest to south southeast; the middle tremors had a peculiar, circulatory motion, as though changing direction. The latter vibrations of this series were certainly from east to west, as indicated by the fixture. This lasted until 10:09 p.m. A third series occurred at 10:30:10 p.m., but were not so strongly characterized as the first, but were more severe than those occurring at 10:08 p.m. The third series lasted until 10:31:15 p.m." (*Washington Post* 3 September 1886)

So just when I thought I had been creative in observing our earthquake, it turns out Mr. Turner was right on the ball in 1886.

THE DAMAGES

The 23 August 2011 earthquake was strong enough to induce damage to several buildings and monuments in the District of Columbia, for example, the National Cathedral and the Washington Monument (Figures 9, 10).

FIGURE 9. The National Cathedral in August 2008 and detail of damage it suffered in August 2011 during the largest earthquake to hit the region in more than 100 years. Note that long and spiky objects tend to suffer more—three of the four high spires at the top of the cathedral were damaged. (Photos: Cathedral, courtesy NCinDC, http://www.flickr.com/photos/ncindc/2794096753; spire detail, REUTERS, Jason Reed.)

The Smithsonian Castle (Figure 11) and other Smithsonian buildings were affected by the earthquake; some of the damage will be briefly described in the following subsections. Also some of the objects in our collections were damaged, but that damage will not be addressed here because subsequent chapters address that issue, such as those by S. Jabo; S. Peurach; A. Juneau and R. Everly; and J. Homiak.

Smithsonian Institution Building (Smithsonian Castle)

A brief history of the Smithsonian Castle building is necessary to understand why the damage occurred where it did (Table 1).

The changes introduced in the East Wing of the Castle can best be appreciated by comparing the photographs taken before and after the reconfiguration (Figure 12). The main factors contributing to the damage suffered by the earthquake are the

- high, long, narrow shape of the building;
- tall, slender, unbraced towers and chimneys; and
- unreinforced masonry walls that are not tied to the floors and roofs.

Not only was there damage to the chimneys and towers (Figure 13) but also to walls as evidenced by cracks in the interior of the building (Figure 14).

National Museum of Natural History

The National Museum of Natural History (NMNH) (Figure 15) suffered damages, and again its construction history is relevant. The Main Building of the NMNH was completed in 1910, but it was soon realized that it was too small and four additions were made to it:

- The East Wing (completed by 1963)
- The West Wing (completed by 1975)
- The East Court infill (completed by 1990)
- The West Court infill (completed by 1998)

These additions are part of the problem that affected the building during the earthquake. The Main Building had not been designed to have additions attached to it. When the additions were made, each one used different structural systems and building standards, including seismological ones. Thus damage was induced as exemplified in Figure 16.

FIGURE 10. The Washington Monument in September 2005 (left) and detail of the crack that developed across one block on the pyramidion during the August 2011 earthquake (right). (Photos: left, courtesy Corey L. Kliewer, Washington, D.C., Convention and Tourism Corporation, www.washington.org [http://www.flickr.com/photos/wctc/79492470]; right, National Park Service.)

Donald W. Reynolds Center for American Art and Portraiture

The Donald W. Reynolds Center for American Art and Portraiture (DWRC) (Figure 17) houses the Smithsonian American Art Museum (SAAM) and the National Portrait Gallery (NPG). The building was originally constructed for the U.S. Patent Office. It is an excellent example of Greek revival architecture and was built with unreinforced stone and brick walls and column supported porticoes. The floor systems include both masonry arches (and vaults) and brick and concrete arched spanning iron beams that bear upon the unreinforced masonry. The center courtyard cover is constructed of structural steel and is independent of the surrounding older masonry structure. When constructed, a flexible joint was designed to separate the new steel frame from the older structure. Table 2 gives a brief chronology of the history of the building.

The damage was limited, with some cracks appearing in the Great Hall (Figure 18) of the NPG and the Luce Center of the SAAM (Figure 19). Because the cover structure of the central courtyard has a flexible joint it could move independently from the older masonry structure around it, avoiding significant damage.

FIGURE 11. The Smithsonian Castle (above) and damage that some of the towers suffered as illustrated by the displacement of blocks in the chimney (detail, left). These blocks are high-quality Seneca sandstone and each one weighs some 68 kg (150 lb). (Smithsonian Institution photos: Castle, Donald E. Hurlbert; chimney detail, Mark Avino.)

TABLE 1. Brief history of the Smithsonian Institution building, referred to as the Castle.

Year	Event
1846	Board of Regents select James Renwick Jr.'s plans for the building.
1847	Cornerstone of building laid on 1 May. Exterior of East Wing and Range complete by 31 December.
1848	West Wing and Range under construction, foundation of Main Building begun.
1849	East Wing and Range complete and occupied.
1850	West Wing and Range complete and occupied. Main Building roofed and towers partially complete.
1851	Exterior of building complete 31 December.
1855	Lower Main Hall open to public. Henry family apartments done in East Wing. Construction of the Castle complete.
1865	Fire destroys upper Main Hall and Towers.
1884	East Wing and Range reconfigured and enlarged and completed within that year.

FIGURE 12. The East Wing in 1883 (left) and after reconfiguration in 1884 (right). (Smithsonian Institution photos: left, SI negative 86-11899, probably taken by Thomas W. Smillie; right, Thomas W. Smillie.)

FIGURE 13. Stabilization of damaged stonework underway on 26 August 2011. (Smithsonian Institution photo by Eric Long.)

FIGURE 14. The Regent's Conference Room (above) developed a crack (detail, left) that runs through the beam over the bow window. (Smithsonian Institution staff photos.)

Museum Support Center

The MSC is located in Suitland, Maryland, southeast of Washington, D.C. (Figure 20). The layout in pods that intersect at mid wall is less than ideal for earthquake resistance since this does not support passage of structural forces at a strong point of the structure. The original construction took place in 1983, when earthquake loading was not taken as seriously as it is by today's codes. Finally, as illustrated for the case of the Smithsonian Castle (see Figure 8), the subsoil conditions at the site are conducive to amplification of bedrock motions in an event like Mineral. In 2007, Pod 5 was completed, and in 2010 Pod 3 was renovated. Both were built consistent with the

FIGURE 15. The National Museum of Natural History on the Mall. (Smithsonian Institution photo by Chip Clark.)

FIGURE 16. Damage to an original 1911 structural beam, basement of Main Building (left) and face brick separated where East Court building connects with Main Building at a bridge walkway (right). (Smithsonian Institution photos by James DiLoreto.)

FIGURE 17. The Donald W. Reynolds Center for American Art and Portraiture. (Smithsonian Institution photo by Ken Rahaim.)

TABLE 2. Brief chronology of the Donald W. Reynolds Center (DWRC) for American Art and Portraiture.

Year	Event
1865	Building completed.
1877	Fire starts at the West wing destroying other parts of the building.
1877–1885	Restoration of the fire damage and creation of the Great Hall.
1932	Patent Office moves out of the building, which is then used for the Civil Service Commission until 1963.
1958	Smithsonian Institution receives the building.
1964	Renovations of the interior begin to adapt it to museum use.
1968	SAAM[a] and NPG[b] move in.
2000–2006	DWRC renovations take place, including covering the center outdoor courtyard.

[a] Smithsonian American Art Museum.
[b] National Portrait Gallery.

FIGURE 18. Cracks in the Great Hall of the National Portrait Gallery, 26 August 2011. (Smithsonian Institution staff photo.)

FIGURE 19. Cracks in the Luce Center of the Smithsonian American Art Museum, 26 August 2011 (Smithsonian Institution photo by James DiLoretto).

provisions of an improved earthquake code for the Washington, D.C., region.

The structure suffered considerable damage as a result of the earthquake, but where it occurred is illustrative. Pods 3 and 5 were undamaged, both of which were upgraded to the new code, but Pods 1, 2, and 4, which were not upgraded, were damaged; Pod 2 suffered the most severe impact (Figure 21). Damages mainly consisted of cracking in nonstructural masonry infill walls, failure of steel stair framing connections to the structure, and broken pipes due to interaction with structural elements (Figure 22). Ironically, the new Smithsonian Gardens greenhouses located across the road from the pods, formed of steel framing and glass walls and roofs, did not suffer any damage because they were designed to the new codes and were built in a compact configuration (Figure 23).

HURRICANE IRENE

The damage induced by the earthquake was compounded by the arrival of Hurricane Irene on Saturday, 27 August, only four days after the earthquake. It spanned nearly the entire east coast of the USA, from North Carolina to northern Vermont and reached the Canadian border (Figure 24). A state of emergency was declared in 13 states, the District of Columbia, and Puerto Rico. Wind gusts reached 60 mph (approximately 97 km/h) during peak periods, and 3–6 inches (7.6–15.2 cm) of rain fell. It was one of the 10 most expensive catastrophes that the USA has suffered, and losses have been estimated to cost more than $10 billion. More than 5.8 billion customers lost electricity nationwide, in some cases lasting over several weeks.

The Smithsonian Institution Disaster Management Program worked well, and staff worked diligently to prepare for the worst, which luckily did not happen. With more than 1,000 full-time employees working, only five injuries were reported. Officers at both the Cooper Hewitt and the Heye Center in New York City sheltered in place for two days to give protection coverage until relief could report for duty.

The Office of Facilities Engineering and Operation as well as the Office of Protection Services successfully managed to keep different crews following each other over 24 hours a day to evacuate buildings and museums, fill and move over 1,000 bags of sand (20 total tons), and cut and remove more than 30 fallen trees. Maintenance, custodian, and security officers worked double shifts (16 hour days) to repair damaged structures and equipment, clean buildings and exhibits, and secure buildings and collections during evacuations and assessments.

CONCLUSION

The estimated required remediation that is to be implemented can best be assessed by putting numbers to it:

Earthquake total	$ 27,025,450
Hurricane total	$ 135,530

FIGURE 20. The Smithsonian's Museum Support Center in Suitland, Maryland. (Photo courtesy of Esri, 2014.)

The actions required for earthquake remediation can be subdivided into three categories:

- Immediate emergency: repairs, staffing, and material costs of remediation
- Required emergency: design and construction of seismic upgrades and structural remediation
- Future advances: correct structural conditions to diminish risk to staff and visitors and prevent damage to facilities and collections

Although damage did occur to some Smithsonian buildings and collections, put into perspective it can be said that fortunately the damage was relatively minor. This can be attributed to the short duration of the earthquake, quick intervention by staff to cut off pipes that were broken, the prompt evaluation that the Office of Facilities Engineering and Operation conducted of all structures and subsequent emergency repair, and the swift action of museum and conservation staff who worked tirelessly to document and repair as much of the damage as possible while preparing for the hurricane that arrived four days later. All of this was followed by extensive efforts to clean up and carry out minor repairs, work that was so competently done that our museums were closed for only the remaining hours of the day the earthquake hit.

Subsequent studies have been helpful for future design, and to this end we are grateful to the cooperation of USGS and the earthquake effects evaluation team of the National Science Foundation, led by Dr. James Martin of Virginia Tech. Without question, we can learn from every challenge, and the Mineral earthquake followed by Hurricane Irene illustrates that point well.

FIGURE 21. Pod 2 damage: (a) cracks along north wall; (b) bolts sheared off from floor; (c) a beam supporting another floor separated from its anchoring; and (d) one of the larger gaps that opened during the earthquake. (Smithsonian Institution photos by Office of Facilities Engineering and Operations staff.)

FIGURE 22. (a) G. Wayne Clough (second from left) and others examine a piece cracked off on “street” along Pod 3; (b) major crack along that same street; and (c) Clough examines an empty cabinet toppled over in mezzanine of Pod 1. (Smithsonian Institution photos (a, b) by staff and (c) by James DiLoreto.)

FIGURE 23. The Smithsonian Gardens greenhouses suffered no damage. (Smithsonian Institution staff photo.)

FIGURE 24. Hurricane Irene as it approached the eastern coast of the USA (National Aeronautics and Space Administration photo, http://www.nasa.gov/mission_pages/hurricanes/archives/2011/h2011_Irene.html.)

2011 Seismic Activity Quakes the Smithsonian: The Impact on Buildings and Collections

Elizabeth C. Sullivan and Mary Rogers

ABSTRACT. As a result of the 2011 earthquake, approximately 20 buildings in the Washington, D.C., area suffered some form of damage. Damages ranged from superficial plaster cracking to major structural issues. Within days of the earthquake, teams of engineers were assessing all of the Smithsonian buildings. For the most part, damage was determined to be repairable during the year or was postponed to coincide with either scheduled renovation or systems upgrade work in the next few years when funding would become available. While the structural evaluations and major work were carried out by personnel from the Office of Facilities, Engineering and Operations (OFEO) and contractors, all collections damage assessments were conducted mainly by Smithsonian collections management and conservation staff. Within hours of the earthquake, the National Collections Program (NCP) issued a request for a collections damage assessment to the heads of collections of each Smithsonian collecting unit. Within days, the NCP provided rolling updates to the Smithsonian's Emergency Operation Center to inform it regarding the immediate- and longer-term response effort that would be required to ensure the continued safety of collections. This report highlights the approach taken in evaluating the damage to both structures and collections to organize and efficiently prioritize the required actions to address the suffered damage.

INTRODUCTION

At 1:51 PM on the afternoon of 23 August 2011, a 5.8 magnitude earthquake struck the mid-Atlantic region. Although the earthquake was centered in Mineral, Virginia, it was felt from Alabama to Indiana to Ontario, Canada. It is said to have been felt by more people than any other earthquake in U.S. history. In total, four aftershocks also rocked the region, with the first occurring within 12 hours and the strongest (4.5 magnitude) in the early morning hours of 25 August.

ORGANIZATION OF THE ASSESSMENT FOR SMITHSONIAN BUILDINGS

The Office of Facilities Engineering and Operations (OFEO) in coordination with facilities staff at Smithsonian Institution locations along the eastern seaboard immediately performed assessments of all facilities for any damage. Facilities were inspected for extent of damage, if any, and whether the damage impacted the safety

__Elizabeth C. Sullivan,__ Contractor/Lend Lease, Manager, Office of Planning Design and Construction, Smithsonian Institution; and __Mary Rogers,__ Collections Program Specialist, National Collections Program, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA. Correspondence: E. Sullivan, sullivane@si.edu. *Manuscript received 12 December 2013; accepted 18 March 2014.*

of visitors and staff or required the facility to be closed until a more detailed assessment could be performed. Four engineering firms (Thornton Tomasetti, McMullen & Associates, AECOM, and KCE) were engaged to conduct expedited structural evaluations of facilities reporting damage.

Within hours it became clear that several locations would require immediate stabilization, such as the Smithsonian Castle (Castle) and Museum Support Center (MSC), necessitating closure of the buildings until structural engineers could completely assess the damage and construction workers could be brought in to implement the stabilization efforts. At the Castle, multiple masonry towers and chimneys on the east side were damaged and could potentially cause additional damage if they were not secured or stabilized as soon as possible. At the MSC, stabilization of the staircases along the interior "Street," or main corridor, was required as well as structural repairs to sheared bolts at various locations. It was also determined that the collections storage buildings, Pods 1, 2, and 4, had sustained extensive structural damage.

As multiple damage reports were verified and news of a hurricane hitting the metropolitan D.C. area within two days of the earthquake was received—a hurricane that could threaten the already damaged areas—the response to earthquake damage was divided into three categories:

1. Immediate emergency: repairs required for safety or to maintain open and operating conditions
2. Required emergency: design or construction of seismic upgrades and structural remediation
3. Capital projects to advance: projects previously identified in the five-year capital plan that would correct envelope and structural conditions, diminish risk to staff and visitors, and prevent additional damage to facilities and collections

By 29 August the Office of Facilities Management and Reliability (OFMR), Office of Protection Services, Office of Planning Design and Construction (OPDC; formerly Office of Engineering Design and Construction), and Office of Planning and Project Management had worked 550+ hours of overtime in conjunction with multiple contractors and structural engineers to inspect all facilities, install emergency stabilization at damaged areas, and reinspect facilities following several aftershocks and Hurricane Irene. This resulted in the reopening of all buildings with the exception of the Castle, which opened on the following day after confirmation from the structural engineer that it was safe to do so.

Within a week of the earthquake the multiple email reports from across the Smithsonian had been compiled into a comprehensive list of damages, and work was already in progress for those requiring immediate emergency repairs (category 1). Within this category were the Castle, the National Museum of Natural History (NMNH), and the MSC (see additional information in chapters by Clough and by DePriest et al., this volume). At the same time, required emergency repair (category 2) projects were established for design and construction of seismic upgrades and structural remediation, as in the case of the Smithsonian Environmental Research Center (SERC) (see additional information in chapter by Park, this volume). The OFEO also evaluated future capital projects to advance (category 3) for those facilities requiring envelope and/or structural corrections, such as the Arts and Industries Building (AIB) and the National Air and Space Museum (NASM) on the Mall.

Minor damage was reported at most buildings across the area and consisted of fallen ceiling tiles and light fixtures, plaster and mortar joint compound debris, collapsed shelving, fallen sprinkler escutcheon plates, water damage from a few broken sprinkler lines, and additional miscellaneous fallen debris. These minor damages were repaired quickly at each location and, therefore, were not included on the comprehensive list of damages. Also excluded from the large damage list were other damages also reported and resolved soon after the earthquake, including a damaged gas line at NASM–Udvar Hazy Center; a broken dielectric union in the boiler plant and one off-line elevator at the National Museum for the American Indian Cultural Resource Center (see additional information in chapter by Estoque, this volume); a roof expansion joint failure on the southwest side of the NMNH Mall building; and a potential gas leak at the new Smithsonian Greenhouses in Suitland, Maryland.

As time passed OFEO evaluated over 25 structural reports from some nine engineering and design firms (see Appendix for a list of the most relevant ones) to determine the extent of damage for each facility and developed a spreadsheet to facilitate tracking of the ongoing repairs. Projects were set up for those facilities requiring repairs, and a "crack team" comprising OPDC and OFMR personnel was established to physically evaluate each location reporting smaller-scale, nonstructural damage. The crack team determined the extent of damage at all reporting locations and established a schedule for repairs. After the team completed its review of nonstructural damage, the OFMR prioritized the list for repairs. The majority of the items on this list have been repaired.

Of all facilities reporting damage, the MSC, SERC, Castle, NMNH, NASM, and AIB (which was under restoration at the time of the earthquake) reported the most significant damage and required design services before construction could begin for any repairs. This damage was a mix of structural and nonstructural damage for which repairs have been completed for the Castle, AIB, and SERC. Design and construction costs to date for both earthquake and hurricane damage are approximately $4 million; an estimated $16.5 million more is needed to complete all the repairs.

ORGANIZATION OF THE ASSESSMENT FOR SMITHSONIAN COLLECTIONS

Because the general public of the Washington, D.C., metro area has a lack of familiarity with seismic events, buildings were evacuated immediately after the earthquake and many federal workers were sent home. Communication lines were quickly overburdened with area workers trying to contact family members and colleagues. Until the Smithsonian's Emergency Operations Center (EOC) was activated and fully operational, it took several hours before the Smithsonian's central collections coordination office, the National Collections Program (NCP), was able to issue a request to the heads of each Smithsonian unit's collections division for collections damage assessment information. From this information the NCP would report on the magnitude of damage across the Smithsonian to the EOC, consisting of the secretary and senior managers, as well as to potential insurance agents.

Within two hours of the distribution of the NCP request for collections damage assessment reports, the majority of collecting units had replied with information that over the next several days proved to cover the greater part of collections damage, some of which is described in other chapters in this volume. The damage ranged from slight movement of objects on storage equipment to their escape from housing materials, storage equipment, or exhibition mounts to their breakage; there was also damage from fire suppression systems that were compromised during the earthquake.

While the Smithsonian Institution's collections fared relatively well throughout the event, collections storage equipment sustained more extensive damage that required recovery beyond the time frame for collections stabilization. Mobile-aisle shelving became detached from rails; cabinet doors bent, rendering them unable to close or lock; and a collections elevator was disabled, making it difficult, if not impossible, to move collections in one primary location. Approximately 15,000 cabinets at the Smithsonian's MSC were misaligned and unbalanced as a result of the earthquake.

The collections damage assessments began immediately after staff were allowed to return to their facilities on the day of the earthquake. Smithsonian collections management and conservation staff surveyed exhibition galleries to ensure collections would not endanger either visitors or staff and surveyed collections storage space in primary and off-site locations. Depending on the complexity of the storage space configurations, some assessments required only a quick walk-through to ensure storage cabinetry was stable, whereas other assessments included opening individual cabinets and drawers to ensure the safety of individual collection items. In some cases it took several additional days to reach off-site locations because of staff limitations or lack of access to the facility due to ongoing structural assessments. Whereas facility assessments were contracted to structural engineers, the collections damage assessments were conducted, and continue to be conducted, mainly by Smithsonian collections management and conservation staff.

In the days following the earthquake, the NCP provided rolling updates to the EOC in order to inform the immediate- and longer-term response effort that would be required in order to ensure the continued safety of collections. The NCP and museum staff worked with the Smithsonian's Office of the Treasurer, Risk Management, to collect costs associated with collections stabilization in the event that the Smithsonian would decide to submit an insurance claim. Based on the experience gained, the following actions should be considered to enhance future response to earthquakes:

- Improve the proper designation and training of collections emergency response staff.
- Improve the ability to document efficiently and accurately the efforts put toward immediate collections assessment and stabilization as well as longer-term stabilization requirements.
- Ensure quality control during installation and periodic inspection of stability of collections storage equipment, ensuring suitability to withstand seismic events.
- Reassess current collections storage methodologies and preventive housing practices to minimize collections damage in the event of a future seismic event.
- Expand risk assessment for exhibition preparation to include equal emphasis on seismic events during development of exhibition mounts.

Although some Smithsonian collections were damaged, the number of collection items affected was minimal in relation to the magnitude of the earthquake and the sheer size of Smithsonian collections holdings. The Smithsonian is truly grateful for the dedication of its collections management and conservation staff who worked tirelessly around the clock to protect collections from harm in the wake of the earthquake and Hurricane Irene, which arrived four days later. The staff's daily professionalism and standards of practice assured the safety of and minimal damage to our collections during these events.

CONCLUSION

Of the more than 20 Smithsonian museums or units in or near the District of Columbia, only 6 suffered major damage. The remainder required only minor building interventions to repair cracks, which in most cases could be carried out in-house. Similarly, only a minimal number of collection items suffered damage relative to the actual size of the Smithsonian collections and most were repaired. The prompt response of the Smithsonian staff at all levels was fundamental for the timely evaluations carried out and the subsequent interventions.

APPENDIX

The following table provides a listing of the initial structural assessments across the Smithsonian. Additional structural reviews were required as well to inform structural and nonstructural scopes of work for necessary repairs.

TABLE A1. Main structural evaluation reports.</tab title>

Building	Contractor	Date of report
Arts and Industries Building	McMullan & Associates	29 Aug 2011
	McMullan & Associates	9 Jan 2012
Donald W. Reynolds Center for American Art and Portraiture	McMullan & Associates	6 Sep 2011
Freer Gallery of Art	McMullan & Associates	26 Aug 2011
Museum Support Center	Thornton Tomasetti	7 Sep 2011
	Thornton Tomasetti	19 Sep 2011
	Thornton Tomasetti	29 Sep 2011
	Ewing Cole	1 Aug 2012
National Museum of American History	McMullan & Associates	2 Sep 2011
National Museum of Natural History	McMullan & Associates	26 Aug 2011
	Ewing Cole	20 Jan 2012
	Ewing Cole	27 Jul 2012
	Ewing Cole	4 Dec 2012
National Museum of the American Indian—Mall	McMullan & Associates	26 Aug 2011
	URS Corporation	6 Jul 2012
National Museum of the American Indian—Cultural Resources Center	Thornton Tomasetti	29 Sep 2011
	Van Deusen & Associates	17 Feb 2012
	URS Corporation	22 Feb 2012
National Zoological Park (NZP-DC)	AECOM	26 Aug 2011
NZP-DC Elephant House	McMullan & Associates	15 Sep 2011
NZP-DC Pedestrian bridges and walkways	McMullan & Associates	15 Sep 2011
NZP-DC Vehicle bridges	McMullan & Associates	15 Sep 2011
National Zoological Park—Smithsonian Conservation Biology Institute, Officer's Quarters buildings 0740, 9800, 1180	McMullan & Associates	29 Sep 2011
Renwick Gallery	McMullan & Associates	6 Sep 2011
Smithsonian Environmental Research Center (SERC)—Homestead House	Thornton Tomasetti	31 Aug 2011
SERC—Mansion ruins	Thornton Tomasetti	31 Aug 2011
Smithsonian Institution Building (Castle)	KCE Structural Engineers	12 Sep 2011

Shake, Rattle, and Roll: Post-Seismic Stabilization of the Historic Homestead House at Smithsonian Environmental Research Center

Sharon C. Park

ABSTRACT. The historic Homestead House, on the campus of the Smithsonian's Environmental Research Center in Edgewater, Maryland, was damaged as a result of the unexpected earthquake of 2011. Preservation standards followed by the Smithsonian Institution call for the careful assessment of the historic character of a building in connection with a condition assessment to set parameters for interventions. Through a team approach using experienced historic preservation architects and a contractor with a long history of quality preservation work, the seismic repairs were undertaken to ensure that the proposed work maximized the retention of historic materials. Standard seismic repair approaches for newer construction with exposed bracing and substantial rebuilding was not appropriate for this structure, which is listed as a historic building by the state of Maryland. There are often conflicts between prescriptive building codes and the performance of historic building materials, and in this case the structural engineers initially were calling for more intense interventions based on conservative assumptions regarding materials. Ultimately, in-situ testing of the existing masonry walls was performed, and the historic building's structural resistance was found to be sufficient to perform adequately without a more extensive intervention. The overall project and the improvements to the building's future performance are outlined with examples of sound preservation treatments and approaches. At the time of preparing this report, the building repairs for the exterior restoration and the interior stabilization were recently completed.

INTRODUCTION

The historic Homestead House and its surrounding property (Figure 1) in Edgewater, Maryland, had been acquired by the Smithsonian's Environmental Research Center (SERC) in October 2010. Eight months later, on 23 August 2011, an earthquake struck the mid-Atlantic region of the USA. The epicenter of the 5.8 level earthquake was in Mineral, Virginia, about 200 km (125 mi) SW from Edgewater, Maryland.

The earthquake did enough damage to this almost 5,000 ft^2 (465 m^2) residence to disengage the front porch, dislodge chimney bricks, create diagonal cracking in brick mortar joints, damage interior plaster, and create some

__Sharon C. Park,__ Associate Director, Architectural History and Historic Preservation, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA; ParkS@si.edu. *Manuscript received 12 December 2013; accepted 18 March 2014.*

FIGURE 1. Aerial view of the Homestead House at SERC in Edgewater, Maryland, before the earthquake. (Google Earth Pro 2014; image U.S. Geological Survey 31 March 2005.)

transitional cracks in interior walls. This made the house immediately questionable for continued use. A team from the Smithsonian's Office of Facilities Engineering and Operations (OFEO), the on-site staff of SERC, the engineering firm of Thornton Tomasetti, and the Baltimore, Maryland, architectural firm of GWWO all came together to assess the damage and to propose solutions to any damage. Homestead House was the first of the Smithsonian's earthquake-damaged facilities to be fully assessed and was the first to undergo comprehensive stabilization directly related to the earthquake damage (P. H. Dawson, Global Forensic Investigations. "Structural Inspection after Earthquake, Smithsonian Institution Environmental Research Center," unpublished report, 16 November 2011; Z. D. Kates, Thornton Tomasetti, "Post-Seismic Event Structural Assessment, SERC–Homestead House," unpublished report, 31 August 2011).

The work, completed in the spring of 2013, benefitted from a building survey conducted prior to the earthquake in February 2011. The property was scheduled for a new roof and masonry repairs when the earthquake hit, which immediately delayed that work until a new assessment could be made. A key funding factor in moving forward with the expanded repair scope of work was the existence of an active insurance policy on the house from the previous owner; this policy contributed to the increased cost of the repairs. The post-earthquake stabilization work along with the new roof allows the building to stay in a sound condition until plans are completed for the integration of this structure into a proposed future visitors' center complex for SERC. As such, rehabilitation of the historic house's interior with upgraded services and renewed or restored historic finishes will be undertaken at a later date.

Historic buildings through their traditional materials are often difficult to assess for compliance with modern structural code requirements. However they often have surprising resilience due to the quality of their construction, such as self-healing lime rich mortars, and the substantial dimensions of materials, such as full-size lumber. Historic preservation approaches traditionally adopt the less-is-more philosophy—the minimal intervention criterion—that encourages the protection of historic materials and overall character to the greatest extent possible with minimal impact from modern interventions (Look et al., 1997). And yet safety is of the highest priority at the Smithsonian, so there needed to be assurance that the preservation approach would still reach the required level of code compliance. The results of the thoughtful analysis that has taken place at the Homestead House meets both the preservation objectives as well as code compliance. When the interior work is completed on the house, the intervention will be barely noticeable to the general public. Even in its interim stabilized condition Homestead House will be ready should there be another episode of shake, rattle, and roll in the future.

BACKGROUND HISTORY

The historic house (Figure 2) became part of SERC in 2010 when the terms of a life estate transfer for the neighboring property were fulfilled. The over 575 acres (233 ha) of the surrounding Contee Farm had already come into the Smithsonian in 2008 and are an important extension of the mission of SERC. The Homestead House is listed as an historic property—the Y. Kirkpatrick-Howat Residence—by the Maryland Historical Trust (1970s) and is significant because of its early architecture and the prominence of the families who had maintained farms on this site since colonial times. Additional research and oral histories are needed to expand upon pre–Civil War activities in the area as they relate to the enslaved population that worked the farms and later settled as freed persons in the area.

The Homestead House is the first structure a visitor sees upon entering the 2,650 acres (1,073 ha) of the

FIGURE 2. Photo montage of the west elevation. Left to right, the larger section of the structure is from 1841, the midsection is circa 1735, and the wooden frame section is from 1979. Note that the porch over the front doorway on the 1841 section has been removed as a result of earthquake damage. (Photos and montage by Sharon Park, Smithsonian Institution.)

research center, and it sets the tone for the significance of this property with its agricultural land and striking Rhode River escarpment. The shoreline of the Contee Farm property extended SERC's original shoreline and forms a contiguous watershed landscape for more than 4 mi (6 km) of fields, forests, and wetlands to the Chesapeake Bay. The Environmental Research Center's mission is to lead the nation in research on linkages of land and water ecosystems and to use its coastal zone property to study the critical environmental challenges of the twenty-first century. Defining the agricultural history of the property, of which Homestead House is a part, will complement the research on the natural environment of the region.

The house has an interesting and not fully explored history as it has not been part of the Smithsonian for very long. The current building is constructed of three parts (Figures 1, 2): an eighteenth-century dormered brick kitchen section, a nineteenth-century brick, three-story main residence, and a modern twentieth-century frame wing that replaced an earlier small nineteenth-century frame section. The aboveground composition sits above a stacked iron pyrite fieldstone basement foundation that is 20 × 42 ft (6 × 13 m) with an unusually wide perimeter wall section in addition to an oversized base at the north end, possibly for another chimney (Figure 3). The only section of the house that seems to fit right on the foundation is the middle kitchen section of circa 1735. This seems to indicate that portions of an earlier structure were lost, perhaps due to fire; this needs further study.

The earliest remaining section is the kitchen portion and is believed to be from 1731–1735 based on at least two exterior wall bricks pressed or marked with dates (Figure 4). The larger three-story section is typical of a vernacular Greek Revival brick structure with a side hall double parlor plan and was built by Daniel L. Fitzsimmons, a builder and carpenter from nearby Baltimore, who conveniently signed and dated his name on one of the attic joists (Figure 5).

The modern two-story section was constructed in 1979 and used many energy-saving solar gain features; it has living space on the ground floor and bedrooms above. It was built on raised piers and used modern frame construction. The flexible nature of the building handled the earthquake shaking easily, and there was no apparent damage. Therefore, this section of the house will not be discussed in terms of remediation or repair.

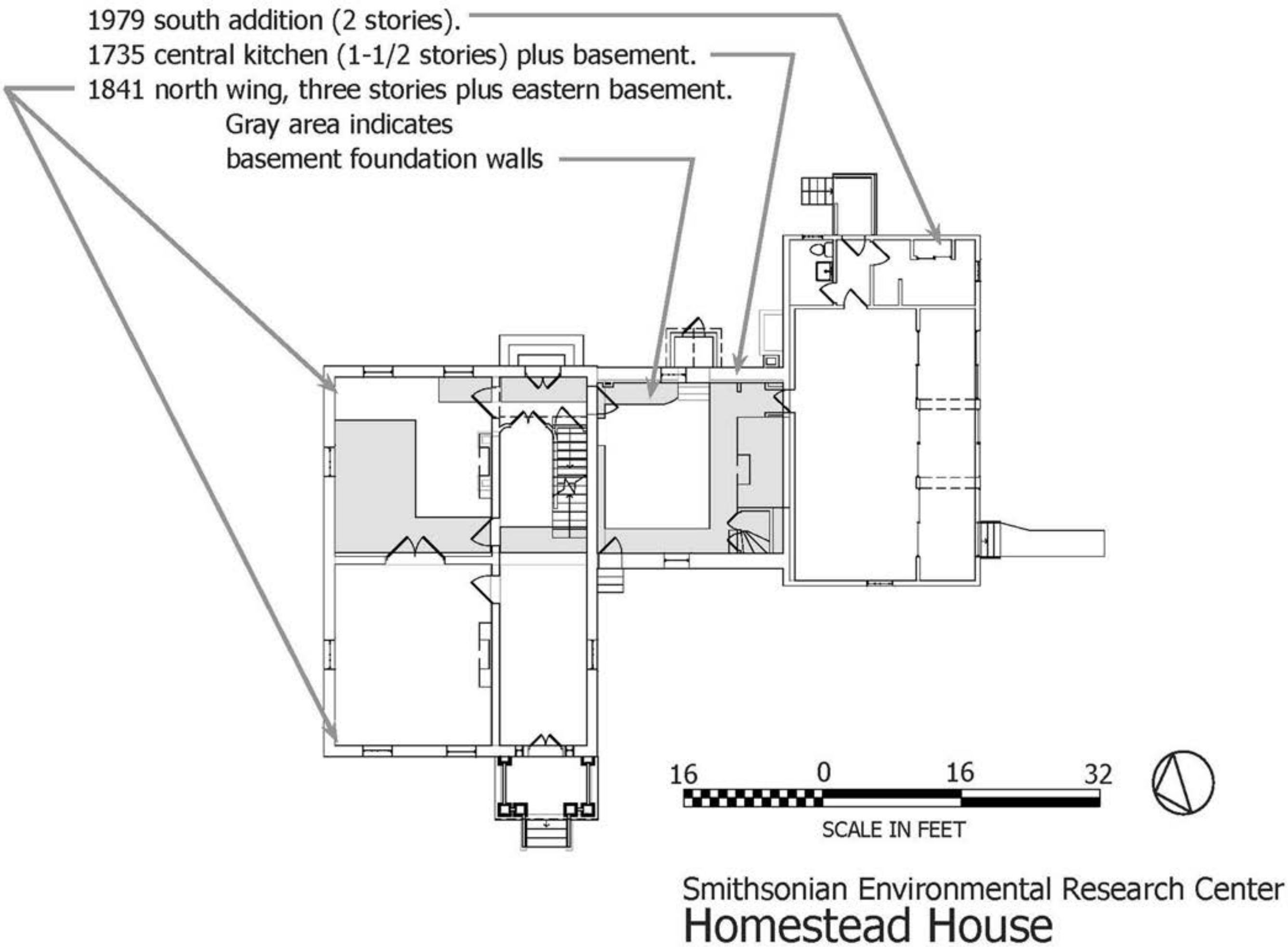

FIGURE 3. The plan of the first floor is superimposed on the existing basement foundation, shown with shading. The 1841 section sits only partially on the early foundations, which was of concern regarding its structural loading capacity. (Drawing by GWWO, Inc./Architects.)

FIGURE 4. An impression pressed into the historic brick prior to firing appears to be dated 1731 and may indicate the beginning of construction on this section. The historical record has dated this section circa 1735 for completion and is consistent with eighteenth-century structural and framing details found in the house. (Photo by Sharon Park, Smithsonian Institution)

FIGURE 5. Chalk markings in the attic on a wooden joist call out Daniel L. Fitzsimmons, Baltimore, 5 June 1841 as the builder. This date is consistent with construction and decorative details of the nineteenth century within the house. (Photo by Anson Hines, Smithsonian Institution.)

EXISTING STRUCTURAL CONDITION

The earliest section is of unreinforced brick masonry with glazed headers in a Flemish bond pattern (alternating long and short bricks), one and one-half stories high, and approximately 20 × 20 ft (~2 × 2 m). It is in remarkably good condition for its age. With its massive fireplace it serves as the kitchen on the first floor and houses a hall, closet, and bathroom above, which are accessed by a curved closet staircase. Historically this upper loft room would have been one space heated by a small fireplace there, which shares the large chimney but has its own flue. The first floor, served by the large cooking fireplace, has darkly stained woodwork trim from the nineteenth century (Figure 6). The original beam over the fireplace is intact and reveals that the original eighteenth-century fireplace opening was taller than currently exhibited with the circa nineteenth-century fireplace mantel. The small, curved closet staircase and second floor are decidedly original with hand riven, or split, wooden lathe and horse hair plaster, historic eighteenth-century paneled doors with wrought iron HL hinges, hand wrought rose-headed nails, and original pine flooring.

While the interior of this eighteenth-century section has undergone updating over time, the exterior masonry and window and door openings are original to the design. The tin roof, scheduled for replacement in 2011, was most likely a third generation roof—the original roofing having been of wooden shingles, some still remaining in the attic. This section's compact shape and good construction, along with its being nestled between two larger masses, resulted in only minor damage, that is, several dislodged chimney bricks, an easily repairable situation.

The brick main block, 29 ft 2 in × 42 ft 6 in (~9 × 13 m), the largest section of the house, was built circa 1841. With an elegant front entry porch it is of a style appropriate for a country house in this region (Figure 7). Three stories tall, the floor plan has a side hall with a handsome staircase (Figure 8a) and two large parlors, each having large masonry fireplaces. The wall between the two parlors on the first floor contains handsome double doors (Figure 8b), and it is this wall that was of greatest concern both to the structural engineers and to the historic preservation architects.

For the 1841 section, the exterior window openings and doorways are all original, and the standing seam metal roof is a second-generation roof over original wooden shingles. The unreinforced masonry exterior walls are 12 in (30 cm) thick and made of three wythes, or thicknesses, of brick. The wooden floor joists are a full 3 × 10 in (~8 × 25 cm) spaced 16 in (~41 cm) on center; the interior masonry-bearing walls are 8 in (20 cm) thick and made up of two wythes of brick. The roof trusses are 3 × 9 in (8 × 23 cm), taper to 3 × 5 in (8 × 13 cm) at the roof peak, and are connected to the third-floor ceiling joists. A rear porch has been missing since prior to the 1979 addition, and the front porch, original to the 1841 section, had serious enough earthquake damage to require the removal of its roof element.

A survey of the property, in preparation for the new roof and masonry repointing prior to the earthquake,

FIGURE 6. The oldest section has served as a modern kitchen for many years. It received dark trim and a wider mantel in the nineteenth century. The door, corner, leads to the upper level via a small curved stair. This portion of the house did not receive much damage as it was protected by the structures on either side. (Photo by Raymond Jones, Smithsonian Institution.)

revealed a number of deficiencies due to deferred maintenance while in a life tenancy situation. As such, particularly for the larger 1841 section, there were some settlement cracks on the exterior, some missing or weathered mortar, a few dislodged bricks, some intermittent leaks in the existing metal standing seam roofs, and original windows needing repainting and caulking (Figure 9). Even with these obvious deficiencies, including some earlier unsophisticated basement bracing to support aging floor framing, the house was in fair condition for its age. The earthquake exacerbated the existing condition and, therefore, required additional analysis and a larger scope for repairs.

STRUCTURAL ANALYSIS

Load-bearing unreinforced masonry structures are strong in compression and weak in tension. When subjected to lateral earthquake loading, masonry walls tend to crack on the diagonal along joint patterns and tend to pull away from floor joists unless adequately anchored. Historic buildings were not generally constructed with what are known today as shear walls and diaphragms, building elements used to resist lateral earthquake loading and transfer these loads to the building foundation. However, thick masonry walls have inherent shear strength and

FIGURE 7. Exterior of the 1841 section, shown several months before the earthquake, was stable, but the masonry was in need of repointing as a result of deferred maintenance. This work along with a new standing seam metal roof was in the planning stages but was delayed because of the earthquake. (Photo by David Wright, GWWO, Inc./Architects.)

can be used to withstand lateral loads and overturning caused by earthquake activity.

After the earthquake, all three sections of the house were studied for performance, not only for resistance to code level seismic and wind loads but also for floor gravity load capacity. The structural engineers used the *International Building Code* (IBC) of 2009 (International Codes Council, 2009), the American Society of Civil Engineers (ASCE, 2005) standard 7-05, and the American Institute of Steel Construction (AISC, 2006) manual as the controlling documents for compliance and guidance ("The Homestead House Structural Stabilization Report," unpublished report January 2012, can be obtained from the Smithsonian's Office of Architectural History and Historic Preservation upon request). As for historic preservation guidance, the Smithsonian's historic preservation policy (Smithsonian Institution, 2005) has adopted the Secretary of the Interior's Standards for the treatment of historic properties (Brown Morton III et al., 1997). These standards are a series of guiding principles that should be applied to decision making when historic properties are protected, preserved, rehabilitated, or restored. The standards call for minimal interventions, reversible interventions, repair over replacement of historic materials, and a

FIGURE 8. The interior after the earthquake. On the left is the handsome side hall staircase. On the right (above) is the wall between the two parlors showing the Greek Revival details of paneled doors, corner blocks in the door frames, and one of the black marble surrounded fireplaces. This wall was of concern as to its possible weakness in shear capacity structurally, but it had no visible cracks. (Photos: left, Raymond Jones, Smithsonian Institution; right, Sharon Park, Smithsonian Institution.)

FIGURE 9. The exterior and interior of the 1841 section had suffered from deferred maintenance while the house was in a life tenancy situation. The exterior brickwork (left) was in need of repointing; and the basement (right) had a number of temporary bracing supports, which luckily kept the house from having major structural damage during the earthquake. (Photos by David Wright, GWWO, Inc./Architects.)

differentiation between what is historic and what is new. There should be sensitivity when making alterations in order to protect historic materials and character-defining aspects of a property as well as an understanding of what might be a contemporary or added layer of treatment.

The analysis of the building began with an assessment of the gravity load-carrying capacities of the wood frame structural flooring system. It was determined by the structural engineers that the building had the loading capacity to handle typical office occupancies based on the IBC of 2009. In addition, the roof trusses were analyzed for wind load, uplift, snow, and other downward gravity forces and found to be deficient only in uplift in certain wind scenarios. As the roofing was to be replaced, there was the opportunity to make certain tie down connections of the structural members during the proposed roof work. If the building in the future will need to support higher live loads, such as addition of a library, floors would need further reinforcement.

To determine the ability of the building to resist lateral seismic and wind loads, the in-plane and out-of-plane lateral capacities of the masonry walls were evaluated, specifically in the 1841 section. The lateral movement of the earthquake created a racking effect on the unreinforced masonry walls and caused diagonal cracking. The diagonal cracking was most evident at weak points along the walls, such as over doors and windows and between windows. There had been some earlier settlement damage, probably from the poor engagement of the exterior walls with the stone foundation, and so there had been some minor diagonal cracking documented. During the earthquake additional diagonal cracks appeared and existing diagonal cracks were exacerbated, which further indicated that the integrity of the exterior wall was compromised. The front porch also pulled away from the masonry wall and had to be removed for safety reasons (Figure 10, left). On the interior, transitional cracking occurred where the front and back walls pulled away from the floor framing (Figure 10, right). There

FIGURE 10. Exterior damage from the lateral movement created by the earthquake is seen in the pulling away of the front porch (left). Interior damage resulted in the separation of front and back walls from interior bearing walls and floor framing (right). (Photos by Steve Groh, Smithsonian Institution.)

were new plaster cracks, particularly along the stair hall, probably as the lateral movement of the tall first-floor wall slammed into the stationary exterior wall of the smaller 1735 building. The analysis and repair recommendations called for reinforcing the horizontal floor diaphragms and anchoring connections between walls and flooring.

Extensive out-of-plane movement of the exterior bearing walls was observed (maximum of 2.5 in [6 cm] out of alignment at the second-floor level following the earthquake). The earthquake is believed to have exacerbated a slight bowing problem evident before the earthquake. The west and east exterior walls (front and rear) were most affected because the floor framing at both the first and second floors run parallel to these facades and are not laterally connected (or laterally braced) by these floor levels. This was particularly evident at the second-floor level where the maximum outward movement was observed. The unsupported length of the wall from the first-floor level to the second-floor ceiling is approximately 25 ft (~8 m). The out-of-plane bending stress in these walls exceeded the allowable tensile stress of unreinforced masonry, as determined by the structural engineers, which meant the walls would need to be tied into the floor framing to reduce the unbraced length of the walls and bring them into conformance. With input from the engineering team, it was concluded that repointing the masonry, even in the slightly bowed out condition, and tying the exterior walls into the floor framing would be sufficient stabilization (Figure 11).

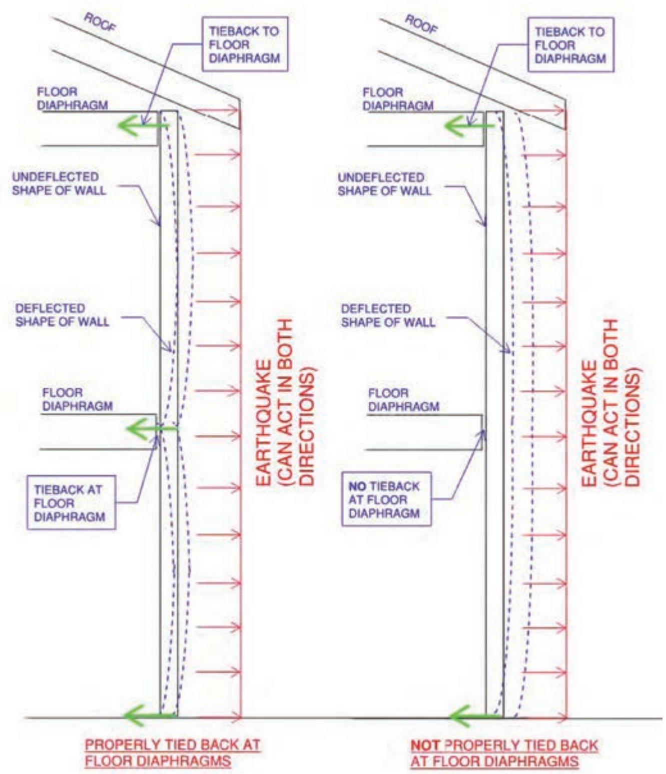

FIGURE 11. The diagram illustrates how floors need to be tied to exterior walls to reduce the amount of lateral deflection and therefore damage to the facades. There was extensive lateral cracking that occurred at the Homestead House because the second floors were not adequately connected. (Diagram by Thornton Tomasetti, Structural Engineers.)

The in-plane analysis, using modern computational models, looked at the masonry-bearing walls and found that only the internal north–south bearing wall between the two major rooms, the parlors, was deficient. This interior wall experienced, by technical computation, a shear stress of only 10 psi (pounds per square inch) whereas the code called for 19.9 psi. The predefined shear stress limit was determined using recommendations found in commonly used standards and is conservative due to the large variability in age of construction and material quality. Addressing this issue would require a major intervention: the construction of a new wood frame shear wall parallel to the existing masonry wall from the foundation to the third floor. The preservation architects asked for additional studies to be done to find a less invasive alternative.

It was determined that an in situ test could verify the actual shear strength of the masonry wall and determine whether or not the wall needed to be strengthened (i.e., could the wall perform at better than 19.9 psi). A masonry mortar joint shear strength test was undertaken on the 8 in (20 cm) thick interior masonry wall to see if the added interior shear wall would be necessary. The test followed method C as outlined by the American Society for Testing Materials standard (ASTM, 2009). It is a resistance test that uses a pressure pump and a flat jack plate inserted into narrow slots cut into the mortar joints on each side of selected bricks (Figure 12). The flat jack exerts increasing pressure on the side of the selected bricks until horizontal movement of the brick is observed. The actual shear stress in the horizontal joints is calculated and, based on established ASTM formulas and applying conservative safety factors, the allowable shear stress limit is determined. The results of the in situ testing concluded that the shear stress limit for the wall is 32 psi, not 10 psi as previously expected. Therefore the proposed new shear wall was eliminated from the scope of work.

FIGURE 12. The shear stress wall test (left) is a fairly nondestructive test. The several slots made in the walls to place the flat plate jacks (right) are easily repointed after the test. This pressure test proved that the wall, which had shown no visible cracking after the earthquake, was not in need of reinforcement, which would have been an extensive, invasive, and expensive undertaking. (Photos: left, FMC & Associates; right, Sharon Park, Smithsonian Institution.)

PROPOSED REPAIRS

It was clear that there needed to be a number of reinforcements to strengthen the 1841 section of the house. For example, at locations where the joists run parallel to the exterior walls, the walls needed to be tied to the floor framing to reduce the unsupported lateral height of the exterior walls. A system of metal tie bars and wall anchors, sometimes called patress (or pattress) plates, was designed. As this is a modern intervention, it was decided that the new exposed anchors would not mimic the historic black iron stars but would use small circular discs as the external elements to establish that they were new, subtle interventions. The anchors would be totally removable without damage (only a drill hole in the joists that could be plugged) and clearly contemporary, thereby meeting goals of historic preservation to be differentiated from the historic and reversible. The end plates selected are stainless steel to ensure a long life and avoid future corrosion (Figure 13).

Due to the significance of this property and the fact that so many of the original features were still in place, options were discussed as how best to preserve the greatest amount of historic material and details. In order to minimize the visual effect of the reinforcements being added, particularly the exposed wall plates, the anchorage would be concealed in the joists themselves and not with added interior shelf angles or new beams visible in the historic rooms. By using the space between the floors, the old growth historic wood flooring could be protected but the plaster ceilings would be disturbed. It was decided that it was better to invade the ceilings, which could be repaired more easily than the floors. Likewise with the plaster walls, it would be best to remove the plaster only around the affected cracking to make repairs and then to replaster to match the visual appearance of the historic

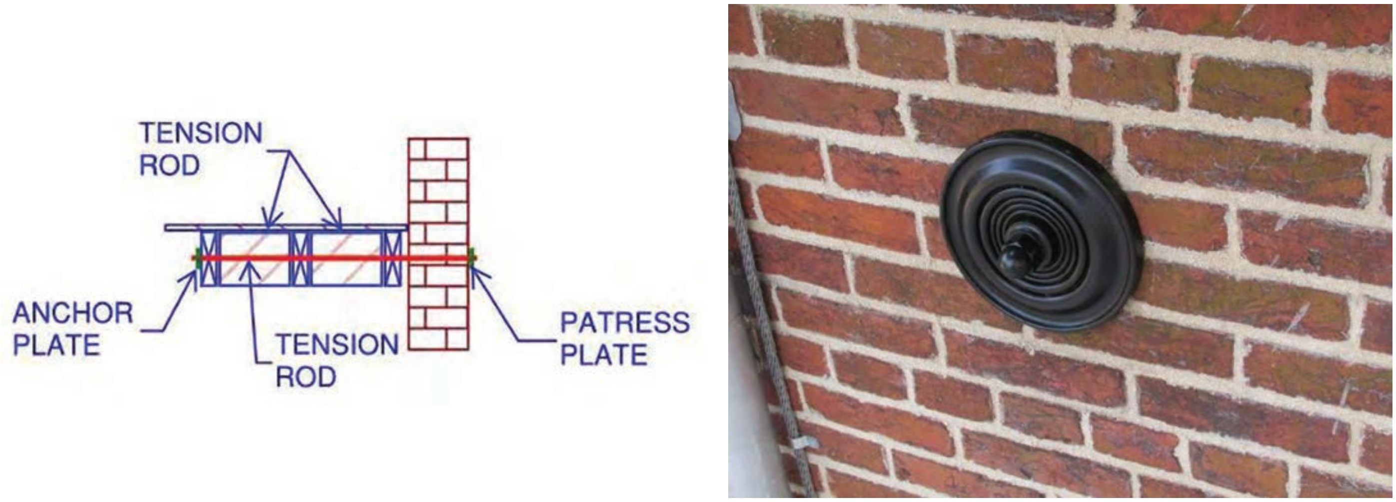

FIGURE 13. In order to tie the floor framing to the exterior walls, the 3 × 10 in (~8 × 26 cm) joists closest to the affected exterior walls were drilled from below to thread new 4 ft (~1 m) long tension rods every 4 ft or so to be anchored by a bolt on one end and a decorative disc plate on the exterior (left). The stainless steel disc has a black baked on finish (right). (Diagram, left: Thornton Tomasetti, Structural Engineers; photo, right: Sharon Park, Smithsonian Institution.)

FIGURE 14. Images, once plaster was removed, show the diagonal cracks over a doorway before (left) and after (right) repointing. As with other interior repairs, the plaster will be replaced at a later date. (Smithsonian Institution staff photos.)

walls (Figure 14). In less sensitive areas, such as the basement, the structural repairs could be more visually obvious; in this case all the historic timbers were saved even though many were strengthened with visible new adjacent framing members.

Preservation principles also directed that new mortar to replace the deteriorated exterior mortar would match the historic in composition, color, and pointing details. This was important as the two different periods of older construction, circa 1735 and 1841, respectively, had differing conditions and details. Interestingly, both sections had mortar of similar color, which is mostly derived from the sand and aggregate that historically was generally from a local source. The compositions also contained shell fragments consistent with being located along a river and tidal area. The 1841 section, unfortunately, had been selectively

FIGURE 15. The image on the left shows the two eras of brick and mortar work. Mock-ups were developed to test for specific composition and appearance to match each era. On the right is seen a sample for the 1841 section with the bottom two courses of new lime-rich mortar with shell aggregate to match the upper course by the blue tape. The 1735 section had a slightly different aggregate mix and a tooled joint detail. (Photos: left, Raymond Jones, Smithsonian Institution; right, Bryan Fisher, GWWO, Inc./Architects.)

repointed in the twentieth century with very hard Portland cement-based mortar, which was causing additional spalling decay of the bricks. So the repointing of the exterior walls to strengthen them would also be corrective and extend the future of the brickwork by using an appropriate softer, pliable lime-based mortar. For the most part, the old mortar was removed by hand (no grinders or power tools to avoid damaging the brick joints) and replaced by masons experienced in working with lime mortars on historic buildings. The brick surfaces were washed using a garden hose, natural bristle brushes, and water (no power washing or chemicals) to remove surface dirt prior to repointing and to prepare the brick for the lime mortar.

The replacement mortar for historic buildings needs to be weaker in composition and more porous than the bricks so that moisture in the walls can evaporate through the mortar as part of the natural performance of the wetting and drying of masonry walls. This is particularly important in the mid-Atlantic region where freeze–thaw action can result in spalled bricks when too hard a mortar mix has been used. As such, the mortar mix mimicked the historic mortars, which were rich in natural hydrated lime and sand and aggregate from a local source and contained no cement. The repointing of the majority of the exterior will unify the exterior walls in a way to strengthen them and to distribute stresses throughout the wall. The color of the sand and the tooling of the joints have been designed specifically for each of the two sections of the house to match their unique historic appearance. Missing bricks at the chimney, entrance porch, and window heads used bricks reclaimed after the earthquake or from nearby salvage supplies. Several of the cracked or aged stone window sills were repaired or replaced with matching stone sills to ensure a complete exterior refurbishment (Figure 15).

The roof was already scheduled for replacement. The old metal roofing and sheathing was stripped off, additional ventilation was discreetly added to the gable ends to extend the roof's life, and the roof rafters were strapped to the second-floor ceiling joists to complete the structural tie downs recommended by the engineers. The new roof is of a similar standing seam configuration as before the earthquake. Figure 16 shows a view of the house after completion of the intervention in spring of 2013.

CONCLUSION

The Smithsonian undertook this work with a team of seasoned professionals in an expedited manner. As some design work had already been undertaken for the new roof and masonry repointing prior to the earthquake, a design assist contract was established with the contractor to facilitate integrating the seismic repairs. To that end, the Smithsonian, the architectural firm, the structural engineers, and the contractor worked together to refine details as the work was underway. The project was initiated

FIGURE 16. The Homestead House after completion of the intervention in spring 2013. (Photo by Sharon Park, Smithsonian Institution.)

in the spring of 2012, and most of the stabilization and exterior work was completed by the end of that same year.

And so the lesson learned in this exercise was that the most affected part of the historic house, even though over 170 years old, performed better than modern assessment formulas anticipated. The repair and strengthening work followed sound preservation principles, and the OFEO team took care to give the contractor good direction. While the house did need additional connections to tie the walls to the floors and to tie the roof framing to the ceiling joists, on the whole the interventions are modest and not particularly visible. The interventions go through the more repairable materials, and the proposed major new interior shear wall was eliminated after physical testing of the lateral strength of the wall. The repointing of the masonry corrects earlier damage from inappropriate use of hard mortar and gives more homogeneity and a better appearance to the wall surfaces. The new rod and plate wall anchors tie the walls and framing together, and the interior transitional cracks, now stabilized, can be cosmetically repaired at a later date. The new roof, flashings, gutters, and downspouts for all three sections provide a sound top to the house and management of rainwater away from the basement. The structural strengthening of the first floor framing now meets code requirements as well. The new rebuilt entrance porch gives a fine appearance from the road as well as a welcome entrance once the house is refurbished as part of the future visitors' center. The house will be safe and should survive another round of shake, rattle, and roll with strength and dignity.

Acknowledgments

I acknowledge and thank the following three teams for their collaboration in the project:

1. The Smithsonian team: Anson Hines, Director, SERC; Bob Gallagher, Deputy Director, SERC; Steve Groh, Project Manager, Office of Planning and Project Management (OPPM); Sharon Park, Associate Director Architectural History and Historic Preservation, OPPM; Raymond Jones, Construction Manager, SERC; and Kenneth Williams, Office of Facilities Management and Reliability
2. The GWWO team: David Wright, Principal and Senior Preservation Architect; Bryan Fisher, Preservation Architect; and Mark Tamaro, Zachary Kates, and Neil Satrom of Thornton Tomasetti, Structural Engineers
3. The Construction team; Worcester Eisenbrandt, specialists in historic preservation projects; and Edifice Group, general contractor.

REFERENCES

American Institute of Steel Construction (AISC). 2006. *Steel Construction Manual*, 13th ed. Chicago: AISC.

American Society for Testing Materials (ASTM). 2009. "Standard Test Methods for In Situ Measurement of Masonry Mortar Joint Shear Strength Index." ASTM C1531-09. West Conshohocken, Pa.: ASTM.

American Society of Civil Engineers (ASCE). 2005. *Minimum Design Loads for Buildings and Other Structures*. ASCE 7-05. Reston, Va.: ASCE.

Brown Morton III, W., G. L. Hume, K. D. Weeks, H. Ward Jandl, and A. E. Grimmer. 1997. *The Secretary of the Interior's Standards for Rehabilitation and Illustrated Guidelines for Rehabilitating Historic Buildings*. Washington, D.C.: U.S. Department of the Interior, National Park Service, Heritage Preservation Services.

International Codes Council. 2009. *International Building Code (IBC)*, 6th printing, Washington, D.C.: International Codes Council.

Look, D. W., T. Wong, and S. R. Augustus. 1997. The Seismic Retrofit of Historic Buildings: Keeping Preservation in the Forefront. *Preservation Briefs* 41. Washington, D.C.: National Park Service. http://www.nps.gov/tps/how-to-preserve/briefs/41-seismic-retrofit.htm (accessed 27 December 2012).

Maryland Historical Trust. 1970s. Inventory of Historic Properties: Y. Kirkpatrick-Howat Residence. Maryland State Archives. http://www.mdihp.net/dsp_county.cfm?criteria2=AA&criteria1=Y (accessed 22 May 2014).

Smithsonian Institution. 2005. *Historic Preservation Policy*. Smithsonian Directive 418. Washington, D.C.: Smithsonian Institution.

Examination, Repair, Consolidation, and Conservation of the Natural History Museum's Fossil Specimens

Steve Jabo

ABSTRACT. Among the myriad of concerns after the Mineral, Virginia, 2011 earthquake was the large and storied fossil collections at the National Museum of Natural History in Washington, D.C., and the Museum Support Center in Suitland, Maryland. These collections consist of over one and one-half century's worth of collecting of over 40 million specimens of fossil vertebrates, invertebrates, paleobotanical samples, microfossils, tracks, burrows, and dung spanning 3.1 billion years of geologic history. Many of these specimens are holotypes (first published name bearers) and are very brittle and fragile, so damage due to vibration was a real concern and a real possibility. The day after the quake, Department of Paleobiology personnel began examining and assessing the fossil collections, starting with the exhibit specimens. Overall, the fossils sustained very little damage from the earthquake. A few specimens fell or cracked, but there were no catastrophic events. The design and composition of various brackets, as well as how a bracket was fastened to the wall, factored into why some specimens were damaged. These same factors also determined why some specimens were spared significant damage. Most of the specimens that fell out of their brackets did not have a holder at the top, and they fell forward during the shaking. Other brackets were not secured well enough in the wall and vibrated out or rotated. The vertebrate fossil mounts did not sustain much damage because, in part, of the springiness of the steel armature. The steel flexed and absorbed much of the energy of the quake. Another probable reason of less damage is that the paleobiological collections and exhibits are on the first and ground floors, sustaining less vibration than did higher floors.

HISTORY OF THE NATIONAL MUSEUM OF NATURAL HISTORY'S FOSSIL COLLECTIONS

The National Museum of Natural History (NMNH) retains over 40 million fossil specimens of vertebrates, invertebrates, paleobotanical samples, microfossils, tracks, burrows, and dung spanning 3.1 billion years of geologic history, fossils that have been collected dating back to the mid-1800s. Throughout this over a century and one-half period, a variety of storage, conservation, and exhibition techniques have been employed on these specimens, almost always with the long-term durability of them as the primary consideration. However, there is a high probability that guarding against a fairly strong, local earthquake never entered the thought processes regarding these considerations.

One of the public's major misunderstandings about many types of fossils regards their inherent fragility and instability. It is sometimes assumed that fossils

__Steve Jabo,__ Museum Specialist, Department of Paleobiology, MRC-121, National Museum of Natural History, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA; jabos@si.edu. *Manuscript received 12 December 2013; accepted 18 March 2014.*

are just a type of "rock," that they are virtually indestructible. But the reality is that a majority of fossils—fossil bones, especially—are extremely brittle and susceptible to damage by chronic ambient building vibration, acute visitor vibration, and chemical alteration due to reactions with water vapor in a high humidity (>50% relative humidity) environment. Over the millennia, iron sulfides, alkali salts, and other compounds that are fairly stable at low humidity get deposited in bones and react with water vapor to produce substances, such as sulfuric acid salts, that grow within the bone interstices and slowly and irreversibly destroy the bone material from the inside out. The presence of these aggressive compounds makes the fossils much more susceptible to damage from vibration.

To try to stabilize and preserve them, a wide variety of compounds such as shellac, varnishes, beeswax, nonarchival resins, plasters, and home-cooked brews of organic glues have been indiscriminately applied to fossils since they were first collected. The chemistry of fossils was virtually unknown in the past, so fossils were treated more like modern wood or rock rather than permineralized organic material. Fortunately, the field of fossil conservation and preservation has advanced by leaps and bounds since the 1840s, especially in the past couple of decades. Unfortunately, protecting the NMNH fossil collections with the latest conservation techniques presents an enormously challenging undertaking. Great progress is being made, but complete coverage of all the fossils in all of the collections has not yet been achieved. For vertebrates, professional conservators today recognize just a few compounds suitable for archival consolidation and adhesion. For consolidation, polymers dissolved in acetone or alcohol, such as polyvinyl butyral B-76, ethyl methacrylate copolymer B-72, and polyvinyl acetate B-15 are acceptable; for adhesion, archival compounds are limited to the same polymers at a higher viscosity, as well as some slow-setting epoxies. And these compounds should be applied only when consolidation or adhesion is necessary, not as a common practice on all specimens all the time. Over-applying consolidants on bone surfaces can cause differential torsion on the bone as the solvent volatilizes and consolidant sets, creating more damage than if no consolidant had been applied.

Storage techniques, especially for vertebrates, have historically ranged from placing fossils as-is on a wooden shelf with no support along the length of the bones, imbedding them in a plaster base, placing them directly onto a plaster base without padding, making rudimentary plaster cradles (padded and unpadded), and mounting them in a skeleton by drilling holes through the bones to bolt them directly to steel armature to today's method of making custom-fit padded plaster clamshell jackets for individual bones (Figure 1).

FIGURE 1. Padded storage jacket containing a theropod dinosaur leg bone from the collection. (Photo by Steve Jabo, Smithsonian Institution.)

Non-vertebrate specimens, such as rock slabs containing trilobites or fossil wood, are generally more stable and require less complex conservation methods. However, silicified invertebrates that have been dissolved out of carbonate rock are extremely fragile and require special care in the collections and exhibit.

THE FIRST DAYS AFTER THE EARTHQUAKE

On the afternoon of 23 August 2011, after a brief period of "sheltering in place" while it was being determined there were no immediate hazards to personnel from falling building materials, museum staff were evacuated from the NMNH. They were not allowed to return to the building until the next morning, after the internal architecture had been deemed safe by structural engineers. During the following five days, the following activities took place.

Assessment of the Exhibit Halls' Specimens

Starting on the morning of 24 August and continuing through the next several days, staff from the Vertebrate Paleontology Preparation Lab began to assess the condition of the fossil specimens. In order to open as much of the museum as soon as possible, assessments started with the exhibit specimens, specifically the large vertebrate mounts with skeletal elements overhanging the visitor passageways that might cause a hazard to anyone below. Surprisingly, there was very little damage to the mounted fossil vertebrates, some of which had been installed for 70 or 80 years.

The damage found was relatively minor, such as a broken tooth on a Pleistocene giant ground sloth, a broken femur on the *Allosaurus* dinosaur, a chipped leg bone and broken neural spine on the *Diplodocus* dinosaur, and other small breaks on fossil mammals. In total, seven vertebrate mounts or bones on exhibit were damaged. None of the damage created a visitor hazard.

Further assessment of the Paleontology Hall and the Sant Ocean Hall revealed some damage and jostled invertebrate and paleobotanical specimens, none of which was catastrophic. Two upright fossil tree trunks (*Araucarioxylon*) were cracked through in a couple places but were stable in their brackets. A Devonian plant (*Zosterophyllum*) on small slab of rock behind a Plexiglas vitrine appeared to be broken but was stable in its bracket. (As of this writing, the slab had not yet been examined, and the supposed crack or break could be an old repair.) Some very delicate silicified Permian marine invertebrates etched out of limestone were jostled out of position in their brackets and slightly damaged. Two relatively small specimens in the Ocean Hall, a Cambrian Burgess Shale *Wiwaxia* specimen and a Silurian *Eurypterus* on slabs of rock, were broken when they fell out of their brackets (Figures 2, 3, respectively).

The causes of the damage—and the reason why some of it wasn't as bad as possible or expected—are relatively straightforward. Damage occurred because fossil bones are extremely brittle and susceptible to cracking from torsion and uneven stresses along their length. High neural spines on the back of a sauropod dinosaur would be susceptible to damage as the mount shook back and forth and so forth. Bracketed specimens vibrated in their brackets, sometimes causing the bracket to loosen from the wall, or rotate or sometimes work its way out of the

FIGURE 2. Broken slab of Burgess Shale rock containing a 500-million-year-old soft-bodied *Wiwaxia* fossil. (Photo by Steve Jabo, Smithsonian Institution.)

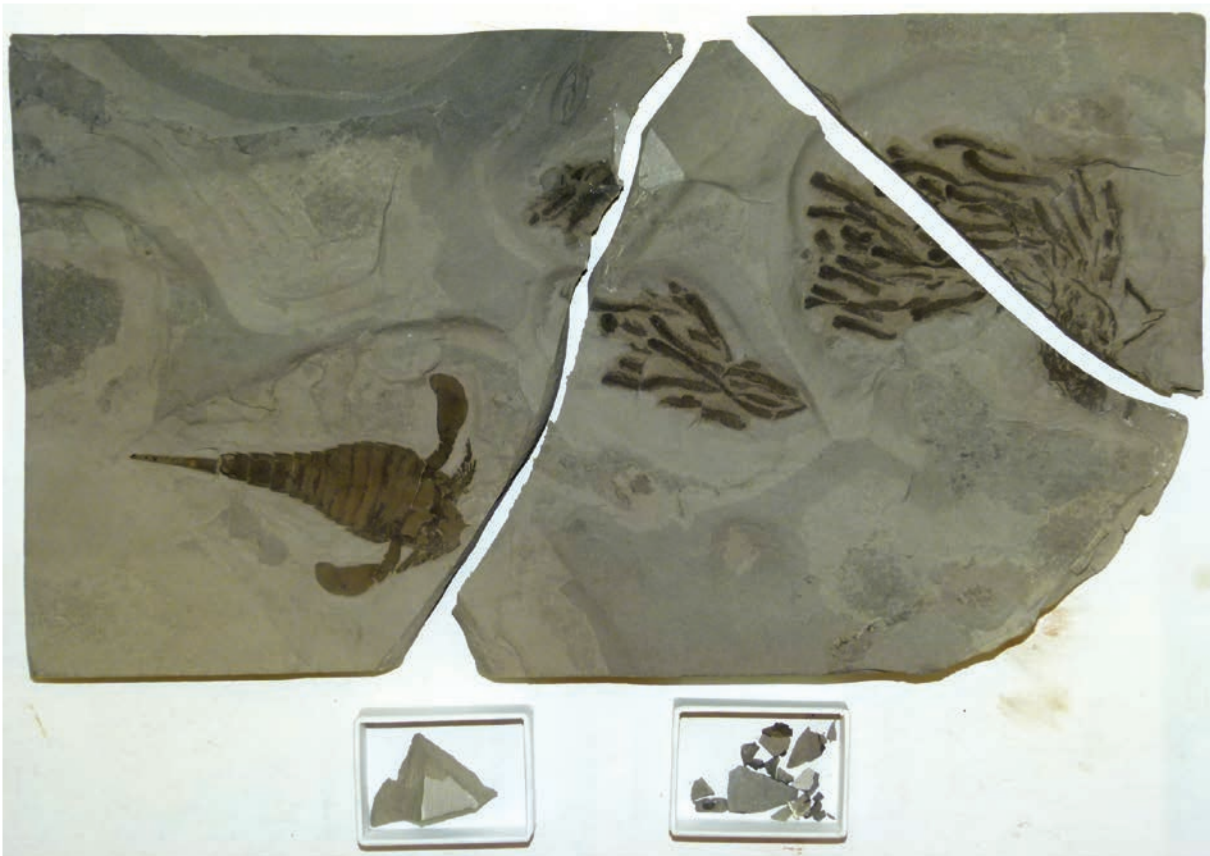

FIGURE 3. Broken slab of limestone containing a 425-million-year-old *Eurypterus* (sea scorpion) fossil. (Photo by Steve Jabo, Smithsonian Institution.)

wall. The first reason the damage was minimized is probably because the Paleontology Halls are on the first floor, and the effects of the earthquake were less pronounced there than on the higher floors. Additionally in the case of the vertebrate mounts, the armature design and the flexibility of steel appear to be the main contributing factors as to why the bones were minimally damaged. Despite the fragility of fossil bone, the energy of the earthquake was dissipated in the spring of the bent steel between the limb elements; they seemed to have been able to "ride it out" on the steel for the most part. Some damage did occur at areas where the armature was fixed and rigid and not able to flex. For example, cracks occurred in a foot bone of the *Edmontosaurus*, in the femur of the *Allosaurus* (Figure 4), and at the base of an antler of the Irish elk (Figure 5).

If the bone elements weren't mounted too closely together, there was not much contact by them or grinding as the steel flexed. In the case of the La Brea giant ground sloth, it appears the spring of the steel worked against the specimen, allowing the lower jaw to "chatter" against the maxilla and knock off a canine (eye tooth) (Figure 6).

However, any positive flexure characteristic of these armatures is not a full endorsement of their mounting materials and methods. For instance, many mounts have drilled bones held in place by bolts and nuts, and there is no padding of felt or urethane between the steel and the bones. These will have to be corrected in any future re-mounting projects. Newly installed mounts of real bone, such as the *Triceratops, Diceratops,* and *Centrosaurus* skulls and the juvenile *Brachyceratops* skeleton, have rubber shock absorbers between their bases and the floor, and the bases are physically separated from the exhibitry decking with a small gap on all sides. Even though these features were designed to eliminate the ambient, chronic building vibrations, they also seemed to have worked well for acute, higher-amplitude shaking during the earthquake.

FIGURE 4. The broken femur on the exhibit *Allosaurus* dinosaur. (Photo by Steve Jabo, Smithsonian Institution.)

The majority of the damage to the invertebrate fossil specimens in the Paleontology Halls happened to the silicified specimens. Silicified fossils that have been etched out of limestone blocks, such as Permian bryozoans, brachiopods, and mollusks, are by their nature extremely fragile and vulnerable to breakage at the slightest touch. The original calcite and aragonite that comprised their structures has been dissolved out and incompletely replaced with silica over the millennia. When the specimens are acid etched out of the limestone what remains is a very light, airy, and brittle cast of the original. As these exhibits were vibrated and bounced in their brackets, they were abraded and pieces broke off and fell to the floor of the case (Figure 7).

The only real damage to the paleobotanical specimens appears to have been when two trunks of *Araucarioxylon*, a Triassic conifer, were each cracked through while standing upright in the exhibit (Figures 8, 9). These fossils were formed when the original plant cells were replaced by agate, microcrystalline quartz, at the molecular level. They were strapped into place with steel bands and apparently succumbed to the vibrations.

The bracket design of the slab mounts in the Sant Ocean Hall was at fault for the resulting damage there. Though the brackets were held tightly to the wall, the specimens were supported by only two arms at the bottom and stayed in place by gravity. As they shook during the earthquake, the specimens simply fell forward and flipped out of their brackets. The problem was solved by attaching a small bracket arm over the top of the specimen.

Assessment of Specimens in the Collections and the Director's Office

Examination of the fossil collections, the bulk of which dealt with the more vulnerable oversized fossil vertebrates, occurred immediately after the exhibit hall examinations were completed. Although specimens were jostled a bit on

FIGURE 5. Pleistocene-aged Irish elk with a crack through the base of its antler. (Photo by Steve Jabo, Smithsonian Institution.)

FIGURE 6. Pleistocene-aged giant ground sloth with a broken canine (eye tooth). (Photo by Steve Jabo, Smithsonian Institution.)

FIGURE 7. A group of silicified fossils that were acid etched out of limestone bounced out of their cradle and abraded against the display case. (Photo by Steve Jabo, Smithsonian Institution.)

FIGURE 8. A trunk of a 240-million-year-old fossil *Araucarioxylon* tree with a crack through it. (Photo by Steve Jabo, Smithsonian Institution.)

FIGURE 9. Another trunk of a 240-million-year-old fossil *Araucarioxylon* tree with a crack through it. (Photo by Steve Jabo, Smithsonian Institution.)

their shelves, very little damage was found. Several factors appear to have contributed to this. Since the fossil collections are located on a lower floor of the museum, that is, the first floor, the effects of the earthquake were not as intense as would have been experienced on the higher floors. Another reason that damage was minimized is that many of the oversized vertebrates have been conserved and are protected in form-fitting, padded plaster jackets. Also, all of the oversized shelving is covered in 1 in (2.5 cm) Ethafoam, which dampens any vibrations. Almost all, if not all, drawers in the storage cabinets are lined with 0.25 in (0.6 cm) Ethafoam or polyester felt.

The few vibration-related issues that were found in the collections were limited to the shifting of an upright *Triceratops* skull on its plaster base, the exacerbation of some of the skull's existing cracks, and the movement of some other specimens on the shelving. Discoveries of some broken specimens in drawers, such as fragile *Stegosaurus* plates, have subsequently been reported; more finds like these in drawers and on shelves undoubtedly will continue as work on the collections continues.

Several esthetically pleasing paleobiological specimens are on display in a large case on the top floor in the director's office. Damage to two of these specimens was observed soon after the earthquake. A crinoid on a slab of limestone fell and damaged a mammoth jaw, from the Department of Anthropology, below (Figure 10).

Again, the reason for the damage in the director's office was the design and installation of the fossil's brackets. The bracket holding the crinoid slab consisted of eight, 0.125 in (0.3 cm) diameter brass rods that were flattened and slightly curved inward at their ends. Each rod was held in place by the mild pressure of its hole in the backboard. As the rods vibrated during the quake, some became loose in their holes and either rotated or fell out. Other specimens in multi-armed brackets affixed to the backboard as described above merely rotated from their original position. Fortunately, nothing fell out of the rotated brackets. In defense of the bracket makers, these brackets worked very well for years and were perfectly capable of holding their specimens but were not designed for fairly strong earthquakes given their rare occurrence in the Washington, D.C., area.

FIVE DAYS TO FIVE MONTHS AFTER THE EARTHQUAKE

In the days and months following the earthquake, Department of Paleobiology staff conducted repairs, consolidation, and conservation on the damaged specimens and continued assessing the vast collections in the NMNH building and at the Museum Support Center (MSC), the storage facility in Suitland, Maryland.

Consolidation and repairs to the vertebrate specimens were done with polyvinyl butyral B-76 (Butvar) dissolved in acetone to different viscosities—low viscosity as a consolidant and higher viscosity as an adhesive—and with

FIGURE 10. A fallen slab of limestone containing a crinoid (sea lily) lying in the bottom of the display case in the director's office. The slab hit and damaged the mammoth jaw, on the right, as it fell. There is a divot in the gravel at the bottom of the case where the rock landed. (Photo by Steve Jabo, Smithsonian Institution.)

marine-grade, slow-setting epoxy. Repairs to the invertebrate rock slabs were done with Butvar, slow-setting epoxy, and cyanoacrylate adhesive (super glue). These repairs were reported to the department's collections manager to be entered into the database as part of each specimen's record.

There was very little, if any, damage found in the collections stored at the MSC. The first, obvious thing observed was that some of the rows of storage cabinets were out of alignment due to the shaking. And while the contents of every drawer of every case have not been examined, overall the specimens appear to have survived intact. There are a couple of reasons for this: the storage facility is relatively new, less than 20 years old, and modern storage techniques have been implemented at the MSC from its beginning. All the cabinet drawers are lined with Ethafoam, the drawers are not so overcrowded that specimens are touching each other, and most of the specimens in drawers are well supported. The oversized specimens that have been moved to the MSC are all in padded storage jackets, so they are well supported and protected. Those jackets are strapped to wooden pallets and stored on high-bay shelving. Some of the pallets moved a bit on the shelving, but none of them fell.

PREPARATIONS FOR THE FUTURE

Monitoring and Maintenance of Collections

Conservation of the fossil vertebrates is ongoing with the construction of padded storage jackets, stabilization and support of specimens in padded drawers, and regular monitoring and assessments of the collections. Major renovations of the Department of Paleobiology's fossil collection storage areas in the NMNH are scheduled to begin in the next decade and will provide an opportunity to house the specimens in state-of-the-art archival cabinets and compactors in a climate-controlled space.

New Exhibit and Armature Designs

Upcoming renovations of the paleobiology exhibit complex provide an opportunity to re-mount some of the exhibit skeletons with armature and bases that mitigate earthquake vibrations. As has been done with more recent exhibit installations, such as the ceratopsian skulls, bases will be physically separated from the surrounding floor, if possible, and have shock absorbing features added to them. The steel armatures will be padded with felt or rubber against the bone and remain flexible to dampen shock and vibration. Brackets for wall-mounted specimens and slabs will be bracketed on all sides to prevent them from falling out of the mounts in the event of an earthquake or other sustained vibration.

There were many lessons to be learned from the 23 August 2011 earthquake regarding the effects of strong vibrations on fossil specimens. The Department of Paleobiology intends to incorporate those lessons into its collection storage and exhibition methodology to protect and preserve the fossil specimens for many years of further research.

Braced for Disaster: But the Botany–Horticulture Library Shelves Weren't

Ann Juneau and Robin Everly

ABSTRACT. The Botany–Horticulture Library's shelving structure suffered significant damage due to the 23 August 2011 earthquake. Shelving that had been moved 10 years prior was not cross braced properly when reinstalled. Quick action and a well-organized recovery effort allowed for efficient action when part of the collection had to be housed in another library. Other National Museum of Natural History libraries sustained minor damage, which was quickly addressed. Many lessons were learned about properly bracing shelving and ensuring the safety of staff when a natural disaster occurs. For the Botany–Horticulture Library, this incident also became an opportunity to rethink how the collection is housed and how library space for staff and library users is designed.

INTRODUCTION

The Smithsonian Libraries consists of 20 branch libraries within the Smithsonian Institution museum complex. Together, the libraries hold approximately two million printed items. The National Museum of Natural History (NMNH) building houses three branch libraries, which are staffed full time, and several smaller libraries (referred to as sublocations), staffed on an as-needed basis. The libraries serve NMNH departmental staff and are open to visitors by appointment. One of these branches, the Botany–Horticulture Library, is located within the Department of Botany. Established in 1965, it is the third largest book and journal collection in NMNH with approximately 100,000 items. The primary purpose of the library is to serve the information needs of the Department of Botany, Smithsonian Gardens, and other science departments in NMNH.

The library is located on the fourth floor of the West Wing of NMNH along a span of windows facing Constitution Avenue. The floor loads of the library cannot support compact shelving; instead, the shelving consists of upright, double-sided, cantilever-type metal shelving, 2 m (84 in) in height. At the time of the earthquake, the shelves were at 100% capacity with books and journals. The shelves are not mounted to the walls, but there are metal bars at the top of the shelving connecting the ranges together to provide stability. It was thought that the cross bracing on the individual tiers was secure. At the time, a small library carrel with a personal computer was stationed within one of the aisles. When the earthquake occurred, an intern was working in this area.

__Ann Juneau,__ Department Head, Natural and Physical Sciences, Smithsonian Institution Libraries, and __Robin Everly,__ Branch Librarian, Botany–Horticulture Library, Department of Natural and Physical Sciences, Smithsonian Institution Libraries, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA. Correspondence: A. Juneau, juneaua@si.edu. *Manuscript received 12 December 2013; accepted 18 March 2014.*

Out of all the libraries in the building, the Botany–Horticulture Library suffered the most damage. The following is a report of how both library and NMNH staff responded to the damage in the Botany–Horticulture Library, damage in the other two NMNH libraries, and lessons learned from the incident.

THE EARTHQUAKE

Fortunately, the intern working alone in the library at the time of the earthquake was quickly and safely escorted out of the building by Department of Botany staff. Upon reentry, staff discovered that several ranges of shelving had collapsed, including one of the ranges in the aisle where the intern had been working. All the damaged ranges were leaning toward the windows. Some of the twisted metal ranges pressed against the Constitution Avenue plate glass windows (Figure 1). Books were supporting the shelving structure and were wedged in tight (Figure 2).

Later that same day the building staff determined that all the damaged stack ranges leaning against the windows and walls had to be emptied. The Smithsonian Libraries director, who was the only library staff person remaining in the building at the time the decision was made, and approximately 10 museum staff worked into the evening to empty the shelves of several thousand books. The books were carefully placed in call number sequence, some in vertical and others in horizontal piles in the aisles of the stable shelf ranges. Clean herbarium paper blotters were placed on the floor beneath the books. Carts were used to shuttle books into the herbarium range, where they were placed in order on countertops and again on clean blotters on the floor between herbarium cabinets. The paper blotters were marked with the corresponding aisle numbers indicating the shelves from which the books came. This gave library staff an idea of the books' call number ranges. Keeping this order proved beneficial when the books were loaded onto large carts days later and moved to the NMNH main library for temporary storage.

OTHER SMITHSONIAN LIBRARIES

Of the two other libraries in the NMNH, the Anthropology Library located on the third floor of the Main Building suffered the more noticeable effects from the shock. The shelf bracing detached from the walls, but the 3.4 m (11 ft) shelving remained upright in spite of the earthquake. When the assessment was done, few items were found on the floor. While waiting for building management staff to reattach the bracing bolts to the walls, staff carefully returned books to their rightful places and roped off the affected areas with caution tape. However, during the interim period, the library staff pulled requested books from the cordoned off areas, hoping that there would not be any new aftershocks.

FIGURE 1. Left, twisted and broken shelving. Right, stacks shifted and distorted, leaning perilously against glass windows overlooking Constitution Avenue. (Smithsonian Institution photos by M. Kalfatovic; see more at http://www.flickr.com/photos/travelinglibrarian/sets/72157627394103839/with/6077290443/.)

FIGURE 2. Images of twisted and distorted shelving kept in place by the weight of the books. (Smithsonian Institution photos by M. Kalfatovic; see more at http://www.flickr.com/photos/travelinglibrarian/sets/72157627394103839/with/6077290443/.)

LESSONS LEARNED

With regard to the Botany–Horticulture Library the first and most important lesson learned is not to have library carrels or desks embedded in the aisles of the stacks. Desks and tables where people work and use the library's resources should be placed in open areas, away from the stacks. The library carrel mentioned in this article has been removed and relocated to open space in the reading room area. We also learned about the importance of properly braced shelving. The eight double-sided ranges that sustained damage were all located in one section of the library. This shelving had been moved about 10 years earlier because of a sprinkler installation project; the installation allowed books to be housed on the upper shelves while retaining a 46 cm (18 in) clearance for the sprinklers. Apparently during this move the cross bracing was not properly anchored again, which allowed the shelving to shift from side to side. Also, some of the ranges that shifted were standing alone without top metal bracing rods anchoring them to other ranges. The entire affected area had seventeen doubled-sided ranges at the time, and approximately 18,000 books had to be temporarily stored in the NMNH main library. To make matters worse, the affected shelves housed the most heavily used section of the collection, the botany journals. The journals are used daily by the Department of Botany and circulate frequently for intralibrary loans within the Smithsonian Institution and interlibrary loans to other libraries throughout the USA.

The other lesson learned is that when a library responds to a disaster, keeping books as much as possible in call number order is of fundamental importance. The librarians and collection managers carefully maintained books in call number order, on the floor, countertops, and carts. This saved a tremendous amount of staff time when putting the books on carts and moving them to another location.

To fully assess any damage that might have occurred at various other sites, the head of natural and physical sciences created a nine-question survey and sent it to several of the Smithsonian branch librarians in the Washington, D.C. area (NMNH: Anthropology, Botany–Horticulture, Main, and Joseph F. Cullman 3rd libraries; National Museum of American History: Main and Dibner libraries; Smithsonian American Art Museum; Sackler–Freer Galleries of Art; National Portrait Gallery; National Museum of African Art; National Air and Space Museum; National Zoological Park; and Anacostia Community Museum) as well as both the Museum Support Center in Suitland, Maryland, and the Pennsy Collections and Support Center in Landover, Maryland. The questions sent out are as follows:

1. At which library branch are (were) you located?
2. Where were you when the earthquake occurred?
3. What were you experiencing during the earthquake?
4. If you were in the library at the time, what did you observe about the book stacks and other fixtures in the library as the earthquake was occurring?
5. What damage did your collection or library space incur?
6. How long after the earthquake did you return inside?
7. How long after the quake did you survey your library for damage? What precautions did you take?
8. Did you gain any lessons from your experience?
9. Are there other observations you wish to contribute?

Apart from the general recommendations that in the event of an earthquake it is important to take cover under doorways, tables, or desks and stay there until the tremors have stopped (Clough, 2014, this issue), the most relevant points are the following:

- If the building is evacuated, make certain all staff gather in a preassigned location and all persons at work are accounted for.
- Upon evacuation, make sure to take your necessary personal belongings, such as house keys, as you may not be allowed back in the building that day.
- Communication systems may break down, so the best tool for monitoring breaking news is Twitter on a smartphone because of the limited bandwidth it needs.
- Compact shelving appears to be much more stable than stationary shelving. Moveable stacks appeared to perform well. In all cases, bracing must be secure and periodic checks every couple of years are required.
- It is important to have book ends on the shelves to secure the books and prevent them from falling.

CONCLUSION

The 23 August 2011 earthquake caused no lasting damage to the Botany–Horticulture Library's physical collection. Some books had dented covers and a ripped page here and there, but none was beyond repair. The shelving was quickly dismantled and replaced in a matter of weeks. What the earthquake did do was create the unique opportunity for Smithsonian Libraries management and the Department of Botany to rethink the Botany–Horticulture Library, considering what collections should be housed there and the appropriateness of the design of staff and library user space. It has truly been a silver lining in all the hard work that went into cleaning up and moving the collection days after earthquake. Before the earthquake, there were a variety of small book collections in call number order but shelved separately from the main collection based on plant type (e.g., algae, ferns, lichens, and grasses). This incident allowed for library staff to finally consolidate the botany–horticulture collection into two major sections, one section for the journals and one section for the books and floras. Most botanical libraries in the USA and Europe are organized in this matter, and it is now easier to find and reshelve books and journals used in the collection. Also, the work spaces and reading room have been redesigned to be user friendly and serve multiple functions.

In general, all the Washington, D.C., based library staff learned many lessons that day that they will carry throughout their careers. During times of confusion and danger, self-preservation and safety of personnel must be our highest concern. It is most critical to remain calm because typically after a disaster persons are not themselves. For this purpose, disaster training is fundamental to prepare us for these events. The overall Smithsonian disaster control plan worked, although there was some difference in response among the institution's buildings. The unexpected breakdown in communications points to the requirement for better preparation for what might happen, an important lesson to be taken into account. And it clearly suggests that we all should be more knowledgeable and self-reliant about emergency responsiveness and prepare contingency plans for future events of communication loss.

Acknowledgements

The authors thank Deborah Bell from the Department of Botany, Jerry Conlon and Chun-Hsi Wong from the NMNH, and Nancy E. Gwinn from the Smithsonian Libraries for their help in providing details about the occurrences during the earthquake and the immediate response that allowed the authors to provide a better description of the events.

REFERENCE

Clough, G. W. 2014 (this volume). "Back To Back: The Earthquake and Hurricane of 2011." In *Unexpected—Earthquake 2011: Lessons to Be Learned,* ed. A. E. Charola, C. Wegener, and R. J. Koestler, pp. 1–18. Smithsonian Contributions to Museum Conservation, No. 4. Washington, D.C.: Smithsonian Institution Scholarly Press.

When Things Get Tipsy in the Fluid Collections: Addressing What Went Wrong and Preventing Future Damage

Suzanne C. Peurach

ABSTRACT. The fluid-preserved specimen collections in the National Museum of Natural History, Division of Mammals, suffered significant damage due to the earthquake that occurred in August 2011. Even though our newly renovated fluid storage bunkers were equipped with earthquake bars, these bars came loose on many shelves, resulting in toppled and shattered jars of specimens littering aisles in each of the three rooms. Quick action and a well-organized recovery and reorganization effort resulted in minimal damage to our specimens, but we learned much in the process about improving layout and design, preventing occurrences such as this in the future, and, most importantly, considering first the safety and well-being of staff if and when a disaster strikes.

INTRODUCTION

The Division of Mammals (DOM) of the National Museum of Natural History (NMNH) houses a world-class collection of mammals, with approximately 600,000 cataloged specimens, by far the largest maintained in any natural history museum. Many of the specimens were collected in the eighteenth and early nineteenth centuries, and it is not uncommon to see names on specimen labels of some of the nation's most iconic individuals and renowned biologists, such as Theodore Roosevelt, C. Hart Merriam, and the second secretary of the Smithsonian Institution, Spencer Fullerton Baird. The over 90,000 specimens stored in fluid constitute a large and special subset of the DOM's holdings. Fluid-preserved specimens were historically fixed in 10% formalin and then transferred into 70% ethanol for long-term storage. The DOM also houses special collections that include cleared and stained specimens stored in glycerin and treated with thymol as a preservative and anatomical preparations stored in a variety of chemical solutions (e.g., brains stored in unbuffered 10% formalin and genitalia stored in a mixture of glycerin and ethanol). The entire fluid-preserved collection was inventoried, data-captured, reorganized, and rehoused prior to 2002. This included replacing the fluid in each jar of the main fluid collection with fresh 70% ethanol cut with deionized water. The special collections also were rehoused and the preservation media replaced. The DOM moved the entire collection to the Smithsonian Museum Support Center (MSC) in Suitland, Maryland, in 2004 to facilitate HVAC (heating, ventilation, and air conditioning) renovations downtown and to comply with newly established

Suzanne C. Peurach, Collections Manager, Division of Mammals, U.S. Geological Survey Patuxent Wildlife Research Center, National Museum of Natural History, Smithsonian Institution, P.O. Box 37012, MRC 111, Washington, D.C. 20013-7012, USA; peurachs@si.edu. *Manuscript received 12 December 2013; accepted 18 March 2014.*

safety regulations applying to alcohol-stored collections. Because of space limitations and safety concerns, most of our fluid-preserved specimens have been retained permanently at the MSC. Some parts of the fluid collection being used by research staff and visiting researchers were moved back to the NMNH and installed into newly renovated alcohol storage bunkers. The only fluid-preserved mammal specimens now stored within the NMNH on the Mall are small insectivores, microchiropteran bats, and small rodents. All special collections, including those stored in mixed-media solutions, were retained at the MSC.

THE EARTHQUAKE

When the earthquake struck on 23 August 2011, the DOM staff and visitors rapidly evacuated from the sixth floor of the West Wing of the NMNH. During evacuation, no damage to collections was apparent, even though several staff offices were in close proximity to the alcohol bunkers on the sixth floor. The NMNH staff waited outside about an hour until it became apparent that employees were not going to be let back into the building anytime soon; most people then headed home. The security force allowed one visiting researcher who needed to retrieve personal possessions to return to the museum quickly as long as he was escorted by a staff member. At that time, a quick walk-through of the collection areas revealed that many jars of fluid-preserved specimens had toppled, smashing many of them on the floor in each of our newly designed alcohol bunkers (Figure 1).

The building management staff was immediately alerted. Representatives from the NMNH administration, conservation staff, and collections managers from several departments and divisions, including the DOM, pitched in to help that same afternoon. Absorbent “snakes” were placed where pools of alcohol had collected, doors were propped open, and buckets, hand brooms, and dustpans were brought into each of the rooms (Figure 2).

Everyone worked quickly to rescue exposed specimens and return them to fluid storage as soon as possible. To keep specimens sorted, we used a single bucket per aisle and placed all specimens and jar labels from each aisle into it. The bucket was topped with 70% ethanol, marked according to the aisle where it was found, and covered with cheesecloth and plastic sheeting to limit evaporation until specimens could be re-jarred. Locating and retrieving all the specimens required hands-and-knees inspection to check under the bottom shelves of each row, where many specimens had traveled. Once all specimens were gathered and in fluid, hand brooms and dustpans were used to sweep up as much broken glass as possible and to deposit

FIGURE 1. Two views of some of the central aisles of the Division of Mammals’ fluid storage bunkers. Above, bat specimens that had been in the bottles are lying on the floor among the glass shards. (Photos by Suzanne C. Peurach, USGS Patuxent Wildlife Research Center.)

FIGURE 2. Absorbent snakes (left) soak up pools of alcohol, and (above) specimens along with paper jar labels from each aisle are gathered into buckets. (Photos by Suzanne C. Peurach, USGS Patuxent Wildlife Research Center.)

all solid debris into specially marked, rolling hazardous material cans. After the rooms were cleared of specimens and broken glass, we rolled the hazmat cans out of the building and into the open air of the parking lot for disposal by building management staff.

During the following weeks, the DOM staff worked to sort and organize specimens so that they could be rejarred and reinstalled into the collection (Figure 3). An estimated 50 jars containing about 2,000 specimens were broken during the earthquake. Because every individual specimen in the collection is uniquely labeled by its catalog number and data captured, and shelf arrangement is based on scientific name, country and state, and catalog number sequence, it was fairly simple to generate printouts to organize the sorting process. In the end no specimens had suffered long-term damage, and data loss was limited to two individuals that had been disassociated from their labels.

FIGURE 3. (Right) Linda Gordon and Craig Ludwig work to sort specimens recovered from broken jars damaged by the 2011 earthquake. (Photos by Suzanne C. Peurach, USGS Patuxent Wildlife Research Center.)

LESSONS LEARNED

Fluid collection shelving at the NMNH was equipped with earthquake bars when the storage areas were renovated by 2007. The bars are positioned by sliding them into grooves cut into either side of each shelf support. While many bars held, some became dislodged under the movement during the earthquake. The problem was easily fixed by installing clips, hairpin cotter pins, to hold the bar to the side brackets on each shelf (Figure 4).

During the recent curation of the DOM fluid-preserved specimens, completed by 2004, jar sizes were standardized to maximize available space on the shelves, to reduce costs, and to simplify jar storage. The shelves were spaced to accommodate the largest jar size permitted under safety standards (3 liter Le Parfait jars), and the DOM opted for the smallest footprint and tallest jar sizes that could be accommodated for each jar type. Unfortunately the earthquake toppled these top-heavy jars easily. Wider, shorter jars with the same capacity for fluid would likely have fared much better in an earthquake but would sacrifice maximizing storage capacity.

Many more toppled and broken jars were found in the center of each room than along the outer walls, and more damage occurred to jars on the upper shelves than to those closer to the floor (Figure 5). Shelving along the perimeter of the room is attached to the cinderblock wall, which undoubtedly enhanced stability.

Lastly and most importantly, although we used nitrile gloves to protect our hands, no one working to rescue these specimens, including this author, thought protection from fumes created from the large volumes of spilled ethanol was necessary. By the time we left for the evening, however, I had a headache, sore throat, burning eyes,

FIGURE 4. Earthquake bars were originally designed to slide into slats on each side of every shelf. Hairpin cotter pins were applied to fasten the bars into place and prevent future failure. (Photos by Suzanne C. Peurach, USGS Patuxent Wildlife Research Center.)

FIGURE 5. Jars on perimeter shelving had much less damage than those located in the central aisles of each alcohol storage bunker. (Photos by Suzanne C. Peurach, USGS Patuxent Wildlife Research Center.)

and undoubtedly an elevated blood alcohol level; yet it had never occurred to any of us to use respirators. The problem of accumulated fumes was likely exacerbated because following the earthquake the air handling system was shut down. Using fans to increase ventilation in these rooms would have dissipated some of the accumulating fumes.

CONCLUSION

The 23 August 2011 earthquake caused minimal lasting damage to the fluid-preserved collections stored at the NMNH, but there were considerable costs to the DOM and the NMNH in terms of personnel costs associated with cleanup, jar and alcohol replacement, and specimen reorganization. We developed a method for securing the earthquake bars in all three alcohol storage bunkers and recognize that respirators must be used when cleaning up large amounts of spilled alcohol within confined spaces.

On the positive side, our situation could have been much worse, disastrous even, if the DOM had not already completed an extensive recuration of the collection in 2004. If the earthquake had occurred in 1991 (instead of 2011)—when our entire collection was still on the Mall and stored on open shelves lacking any earthquake bars, in various states of organization, and in a variety of chemicals with many uncatalogued and non-individually labeled specimens—we would have been confronted with a chaotic situation in terms of specimen conservation and data loss, disorganization of the fluid storage area, and decidedly greater safety concerns for museum staff.

Communication: Earthquake Damage Report from the National Portrait Gallery

Nik Apostolides

The 2011 Washington, D.C., earthquake shook the National Portrait Gallery at the Smithsonian, but the building stood up very well to it. For example, staff in the Kogod Courtyard reported seeing the Norman Foster designed glass canopy swaying considerably from side to side. This is exactly how it was designed to respond in order to avoid collapsing, and the design proved sound, even under such unusual and unexpected conditions. Nonetheless, other areas of the building experienced significant shaking; in the Great Hall in the south wing this shaking resulted in a cracked steel plate on one of the third-floor mezzanine stairways and other cracks on various arches and architectural elements in that space (Figure 1). The large stone lintels in the west wing shifted considerably during the earthquake, but no structural damage was observed.

Immediately following the earthquake, visitors and staff were evacuated from the museum building. On the G Street side of the building, the police were concerned about possible structural damage to other buildings around the museum. The public and staff were unsure whether it was safer to stand on the sidewalks or in the middle of the street or to find other more open public spaces.

Inside the museum, I went to the Office of Protection Services' (OPS) control room in the basement to find the security manager on duty and to establish our Emergency Command Center (ECC). In the control room, I found the deputy security manager, and we discussed the situation and began the process of assessing any damage and locating other members of our ECC team. Surprisingly, we were unable to use the voice over internet protocol telephones to reach the Smithsonian's emergency operations center, so I left a message on the chief of OPS' cell phone to let him know that we were not able to reach him.

Due to questions about the impact of the earthquake on the building's structure, we moved the ECC upstairs to the G Street lobby of the museum. There we were able to locate the deputy director of the American Art Museum and the building manager, both of whom are also members of the ECC. We established communications from that location and began to address the main questions: the extent of any induced damage and the timing and safety of letting critical staff back into the building to secure dangerous materials, collect any personal belongings, and await word on the possible reopening of the building when safe.

Nik Apostolides, *Associate Director, National Portrait Gallery, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA; correspondence: apostolidesn@si.edu.*
Manuscript received 12 December 2013; accepted 18 March 2014.

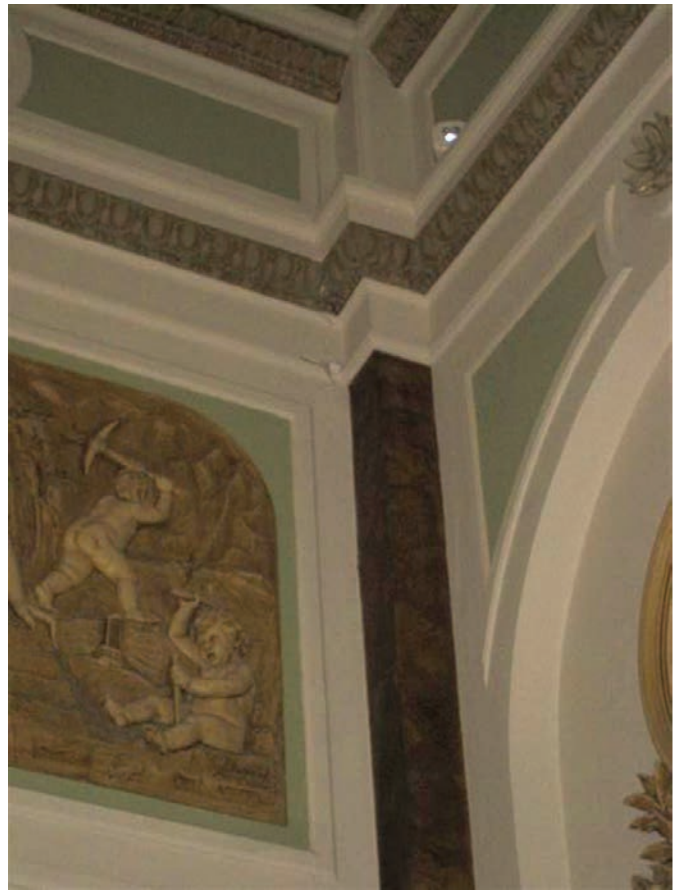

FIGURE 1. One of several cracks in the arches around the Great Hall (above) and its pilasters (right). (Smithsonian Institution photos by Office of Facilities, Management and Reliability staff.)

Within approximately an hour or less, teams of the Office of Facilities Management and Reliability and OPS staff were permitted back into the building to do a quick survey of any damage and to begin to assess the safety of the building for staff, and eventually visitors, to return. Some museum staff were also allowed back into the building in order to secure hazardous materials that were in use at the time of the earthquake—for example, in the conservation departments. Eventually other museum staff were permitted in to assess any collections damage, which was minimal in the National Portrait Gallery.

Communication: Earthquake Damage Report from the Smithsonian American Art Museum

Lynn Putney

The American Art Museum collections suffered no catastrophic damage as a result of the earthquake. A number of items in the display cases of the Luce Foundation Center at the museum shifted position or fell over (Figure 1), such as the Roman vases acquired in the 1920s (before the museum's collecting goals were redefined to focus on American art and artists). But only eight works were damaged to a degree that warranted removing them from public view, and none were irreparably damaged.

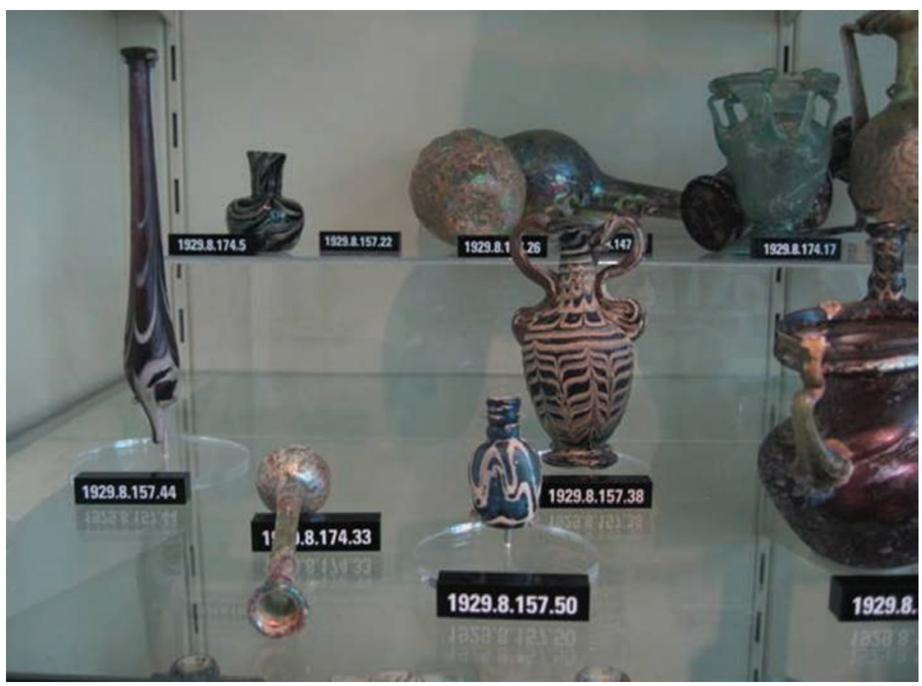

FIGURE 1. Roman glass vases toppled over during the earthquake but suffered no significant damage. (Smithsonian Institution staff photo.)

Lynn Putney, Associate Registrar, Smithsonian American Art Museum, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA; putneyl@si.edu. Manuscript received 12 December 2013; accepted 18 March 2014.

In the Lincoln Gallery the Jenny Holzer electronic artwork *For SAAM* suffered crossed LED strands and stressed solder joints, and a few television sets shifted position on the armature for Nam June Paik's *Electronic Superhighway.* Both of these problems were quickly resolved by our conservation and exhibitions staffs.

Some cracks in the walls of the second-floor galleries at the museum, and a broken cornice in a second-floor gallery at the Renwick, were the most worrisome damage. The cornice was stabilized a few months after the earthquake (December 2011), and repair of the wall cracks at the museum began in 2013.

Communication: Earthquake Damage Report from the Hirshhorn Museum and Sculpture Garden

Susan Lake and Keri Towler

***Susan Lake,** Director of Collection Care and Management, and **Keri Towler,** Collection Registrar, Hirshhorn Museum and Sculpture Garden, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA. Correspondence: S. Lake, lakes@si.edu.* *Manuscript received 12 December 2013; accepted 18 March 2014.*

On 23 August 2011 at 1:51 PM EDT, an earthquake with a magnitude of 5.8 and centered near Mineral, Virginia, 135 km (~84 mi) SW of Washington, D.C., shook Smithsonian Institution buildings, including the Hirshhorn Museum and Sculpture Garden (HMSG) on the Mall and its off-site storage facility on the ground floor of Pod 3 (rooms 110, 111, and 112) at the Museum Support Center (MSC) in Suitland, Maryland.

At the HMSG, staff and visitors were evacuated by 2:30 PM; the staff was dismissed. Engineers then inspected the building for damage and by the next day declared it structurally sound. The engineers noted that several cracks in the ceiling of the lower level sculpture storage appeared to have widened, although this could not be quantified. Increased water penetration into that area during the following winter months indicated that the overhead plaza dam may have been breached. Despite a leak abatement project carried out through the remainder of the year, water penetration has continued.

The HMSG storage areas at Pod 3 in MSC suffered more structural damage—a series of vertical cracks in the walls of all rooms (Figure 1). Additionally, sprinkler heads in the overhead second-floor storage rooms were damaged and activated; it took almost three hours for the main valve to be located and deactivated. By that time, cascades of gray-colored water had entered through ceiling cracks in the small sculpture storage area (room 112) along the west and north walls and via an overhead trap in the oversized sculpture storage (room 111). In room 112, water pooled on the floor to a depth of 2.5 to 3.8 cm (1–1.5 in) and on the surfaces of palletized and crated objects located adjacent to the west and north walls (Figure 2). Fortunately, no water penetrated through the areas of ceiling over the compact shelving system, although it did flow under the shelving system and into the two adjacent rooms (110, 111). Several objects stored on the compact shelving toppled but were not damaged. One sculpture on the top shelf in the large sculpture room broke its tether, toppled from its palette, and would have fallen to the floor had it not caught on the edge of the wire shelving (Figure 3).

By late afternoon that same day, as water continued to flow from overhead, a museum registrar and conservator moved exposed objects away from falling

FIGURE 1. Cracks in the wall of Pod 3 at the MSC. (Smithsonian Institution staff photo.)

FIGURE 2. Dirty water pooled on the surfaces of floor and in packing crates. (Smithsonian Institution staff photo.)

FIGURE 3. A sculpture perilously toppled from its palette. (Smithsonian Institution staff photo.)

streams of water, wiped standing water from the surfaces of exposed objects, and covered vulnerable objects with plastic wrap. To the extent possible, MSC staff and building management directed standing water to a recently opened drain pipe in the adjacent hall. Eventually, they removed the water with a wet–dry vacuum.

The following day (24 August), a five-member team comprising museum conservators, registrars, and interns (team composition varied over the course of several days) began to examine the objects in each room and mopped any still-standing water from under the compact shelving system and from the floors of the painting and large sculpture storage. This required removing all bottom shelves of the compact shelving and opening the painting screens (Figure 4). Ultraviolet germicidal lamps, to reduce airborne fungal spores, that were supplied by Museum Conservation Institute were installed and ran continuously for almost five days until data loggers indicated that the environmental conditions had returned to normal. Two mid-sized sculptures suffered water damage and were later treated by conservators.

When the earthquake struck, the museum was still in the process of relocating its collection to Pod 3. The extent of the damage would likely have been more serious had more objects been installed at the MSC at that point in time. Emergency efforts the afternoon and evening of 23 August were hampered by several issues:

1. Staff could not enter the storage spaces until they were deemed safe, and throughout this period water continued to flow into the spaces;

FIGURE 4. Cleanup following the earthquake and flood from the sprinkler system. (Smithsonian Institution staff photo.)

2. floor drains had not been installed when the storage spaces were redesigned; and
3. at that phase of the relocation no emergency supplies—such as a wet–dry vacuum, plastic wrap, absorbent pads and snakes, or sponges—had been moved into the collection spaces.

Requests from the HMSG and other units to MSC staff for such supplies surpassed the available stock. Since the earthquake, the cause of the sprinkler head failure has been remedied and the MSC and HMSG have stockpiled additional emergency supplies.

Communication: Earthquake Damage Report from the National Museum of the American Indian

Justin Estoque

The earthquake of 23 August 2011 and a magnitude 5.8 quake along the New York–Ontario border in 1944 were the largest to have occurred in the USA east of the Rocky Mountains since 1897. The 2011 quake was felt across more than a dozen U.S. states and in several Canadian provinces. No deaths and only minor injuries were reported. The earthquake shook Smithsonian Institution buildings, including the National Museum of the American Indian on the National Mall (NMAI-DC), the Cultural Resources Center (NMAI-CRC) located next to the Museum Support Center in Suitland, Maryland, and the George Gustav Heye Center in New York City (NMAI-NY). The NMAI-NY did not suffer any damage during the earthquake or from the subsequent Hurricane Irene. Several aftershocks, ranging up to 4.5 in magnitude, occurred after the main tremor. As soon as it was realized that an earthquake had occurred, staff and visitors were evacuated from both the NMAI-DC and the NMAI-CRC. Two hours later, by 4 PM, all Smithsonian staff were dismissed.

During the inspection carried out immediately following the earthquake, the engineers discovered cracks on the curved wall of the Potomac Atrium, near the east entrance of the NMAI-DC, but declared the building structurally sound. Also noted was the slight shifting of horizontal blocks of stone outside the windows of the third-floor Family Activity Center. In the 1491 wall of the "Our Peoples" exhibit, an Arkansas ceramic jar and a Campeche, Mexico, ceramic fell off their mounts and were broken into many pieces. A Mexican stone figure and a Peruvian ceramic pitcher sustained abrasions and chips from the falling ceramics (Figure 1). And in the "Window on Collections" exhibit, a wooden Tsimshian headdress twisted off its mount, damaging some of the wood.

The NMAI-CRC building suffered more structural damage, especially on higher floors, and staff were concerned that they might not be able to enter the building the next morning. However, inspections conducted by a structural engineer determined that staff could return to work. At the NMAI-CRC no objects suffered damage. However, the freight elevator became inoperable, and 11 of the electronic control boards for the compactor storage units were damaged, likely from the units going into fire configuration mode while swaying after the fire alarm was pulled to evacuate the building. While awaiting shipment of

__Justin Estoque,__ Assistant Director, National Museum of the American Indian, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA; estoquej@me.com.
Manuscript received 12 December 2013; accepted 18 March 2014.

FIGURE 1. Falling ceramic objects caused abrasion and chips to a Mexican stone figure and a Peruvian ceramic pitcher. (Smithsonian Institution photo by Gail Joice, NMAI.)

replacement control boards, collections staff had to hand crank the affected units.

A summary of repairs to be carried out after the earthquake is given below:

- NMAI-DC: Damage was relatively minor, concentrated primarily in upper areas of the Potomac Atrium. The design for repairs started in May 2012.
- NMAI-CRC: Cracks were found in 10 areas of the CRC—the mechanical/electrical rooms, the freight elevator lobby walls and adjoining stairway door, the conservation wet-cleaning area, and 7 areas in collections storage.
- In addition, the integrity of the collections' hoist had to be recertified, which required an additional engineering review. The hoist was recertified in 2013 as part of the earthquake repairs.

Aftermath: Unfortunately, these repairs were very disruptive to the work of collections management and required the closing of the NMAI collections during renovations. To allow the repair contractors access to the affected walls to use large lift equipment, at least 45 mostly oversized objects were moved or protected from dust or abrasion, including 23 large Northwest Coast house posts (as tall as 5.5 m) and a house front. On the northwest wall of the NMAI-CRC only the two largest totem poles remained in place. Two bulk storage racks and the 21 large objects they contain were moved, while an art rack system and a large bulk rack containing objects were protected from dust. The moved objects were stored horizontally on the floor of the NMAI-CRC collections in areas away from the repairs, thus severely limiting movement in collections storage.

Communication: Earthquake Damage Report from the Freer–Sackler Galleries of Art

Bruce Young

The Freer–Sackler Galleries of Art did not suffer any object damage from the August 2011 earthquake, neither in their exhibitions on the mall in Washington, D.C., nor in the storage area at the Museum Support Center (MSC) in Suitland, Maryland. At the MSC the rooms show minor damage that is no doubt repeated throughout Pod 3. In this pod, the Arthur M. Sackler Gallery's space is located on the ground floor, in rooms 120 and 121. The earthquake opened some cracks running roughly north–south in the ceiling of room 120 but with no discernible debris or dust. However, one sprinkler head was activated on the top level, and the resulting water trickled downward, finally emerging through the cracks in our ceiling and dripping on top of several rows of Viking metal cabinets that are installed in a compact storage system by SpaceSaver. The cabinets are gasketed so there was no water damage to the objects inside. Collection Support Services staff placed plastic sheets over the cabinets affected so that we had a second level of protection. Otherwise, we suffered no damage that I could see to either rooms or collections.

Bruce Young, *Registrar, Freer–Sackler Galleries of Art, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA; youngbr@si.edu.* *Manuscript received 12 December 2013; accepted 18 March 2014.*

Communication: Earthquake Damage Report from the Paul A. Garber Facility

Charles Fry

In response to the 23 August 2011 earthquake, Smithsonian staff completed visual inspections, structural analyses, and air monitoring in selected Smithsonian Institution buildings to determine whether asbestos-containing materials in the buildings could have been dislodged and rendered airborne as a result the earthquake. Visual inspections revealed no evidence of dislodged asbestos-containing debris at these buildings. Included in the inspections were buildings at the Paul E. Garber Facility in Suitland, Maryland. Three of the buildings at the Garber Facility have ceilings lined with asbestos-containing materials. The ceilings in these buildings are covered with layers of polyethylene sheeting that were previously installed to protect stored collections in the buildings from possible asbestos contamination. Due to the asbestos-lined ceilings in these buildings, air monitoring was also conducted to determine if any fibers were present in their environment. All air samples were analyzed by transmission electron microscopy, a fiber-specific analytical method, and revealed that no airborne asbestos fibers were present.

Charles Fry, Industrial Hygienist, Office of Safety, Health, and Environmental Management, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA; FryC@si.edu. *Manuscript received 12 December 2013; accepted 18 March 2014.*

When a Tempest Breaks your Teapots: Seismic Events and Museological Lessons

John P. Homiak

ABSTRACT. The staff of the Anthropology Collections and Archives Program (CAP) cares for more than 2.5 million extremely diverse artifacts, specimens, and archival materials at the Smithsonian's Museum Support Center (MSC) in Suitland, Maryland. During the 1990s the Department of Anthropology's holdings were moved from the National Museum of Natural History in Washington, D.C., to the MSC, where the collections were housed in state-of-the-art storage equipment. Since that time, the CAP staff has continued to make selective improvements to storage and access. Staff, however, had never considered the potential impact of a seismic event. This essay reviews procedures related to the damage assessment of the diverse and varied anthropological collections and the lessons learned from this assessment by the CAP director and staff in the aftermath of the earthquake of 23 August 2011.

THE EVENT

On 23 August 2011, at roughly 2:00 PM, I was standing outside my office near the doorway to the Department of Anthropology collection spaces in the Smithsonian's Museum Support Center (MSC). I started to hear—and then feel—a low rumble. I have experienced at least six earthquakes while previously residing in California or doing fieldwork in the Caribbean, and the onset of each one has had exactly the same confusing cognitive and physiological effect on me. In the first few seconds I find myself trying to identify the source of the low rumbling or growling sound as something mundane and explainable. Perhaps it is a giant generator that has lost its bearings or a nearby train arriving. Only as those mental suggestions fail to fit and the mounting vibrations turn into tremors does my mind relinquish the search for easy answers and submit to the surprise of having the earth move underfoot. In this case, I wondered if all around me might not be coming down. Each time the event has been startling, uncomfortable—even frightening.

This experience was all of that, yet different. In each of the other instances none of the quakes was so severe that I couldn't resume what I was doing almost immediately. This time, however, I was responsible not merely for myself but for a staff of 15 plus the priceless anthropological collections amassed during more than 150 years by the Smithsonian Institution. After the concerns of human safety and security had been dealt with in the ensuing 48 hours, it became

John P. Homiak, Director, Anthropology Collections and Archives Program, Department of Anthropology, Museum Support Center, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA; HOMIAKJ@si.edu. *Manuscript received 12 December 2013; accepted 18 March 2014.*

clear that the next step would have to be a comprehensive survey of the physical state of our collections. The fact that the quake was severe enough to crack walls and split blocks gave us pause. What might be waiting for us inside the collection storage areas where tens of thousands of unique cultural artifacts were housed?

With holdings that include more than 250,000 ethnology artifacts ranging from totem poles to Zuni ceramics and cradleboards to carved Chinese ivories, 2.5 million archaeological artifacts, and extensive archival collections that included over 30,000 glass plate negatives—we needed to evolve a triage approach quickly to determine what had suffered damage. Fortunately, some collection spaces—those with large oversized objects on cantilever shelves—could be eyeballed and dealt with quickly. But with the majority of collections housed on shelves and drawers within closed cabinetry, the survey of those collections would be time consuming and, in some instances, labor intensive.

ARCHITECTONICS AND LAYOUT OF THE STORAGE SPACES

It is perhaps useful to understand that when funding was secured from Congress to begin construction of the Smithsonian's MSC in the early 1980s, little or no consideration was given to the potential impact of seismic events. Southern Maryland, where the MSC is located, is not considered a seismic zone and, in speaking with colleagues who were involved during this period, no one considered the possible impact of a seismic event on the building, not to mention collection storage (G. Hansen, Smithsonian Institution, personal communication, October 2011). I am speaking here of a footprint essentially the size of a football field that is devoted entirely to the housing of anthropological collections. With respect to building construction, two of the five pods that presently form the overall storage areas for the MSC contain three levels of floors. In each, the second and third floor levels are not attached to the walls. Rather, they are supported by 46 parallel rows (roughly 55 m [180 ft] long) of rectangular steel posts anchored in the concrete floor. The stability of these posts is enhanced by additional posts that run the perimeter of the floors. The posts—roughly 2 m (84 in) apart, are themselves connected by 5 cm (2 in) cross-member struts that are welded to them to enhance their stability. The torqueing, deforming, and, in some instances, severing of these steel components was immediately apparent during our early walking inspections. In some cases, the expansion bolts were either snapped or torn from their concrete moorings (Figures 1, 2). Reports from the structural engineers who subsequently made several examinations of the pods and their supports assure us that these storage areas, and the buildings as a whole, performed as expected during the earthquake without significant structural damage. Despite this, given the visible signs of fallen debris from ceilings and cracks in our masonry walls, it was disconcerting to consider the possible state of collections—particularly ceramics and fragile objects—within the storage units.

FIGURE 1. Space between wall and floor of Pod 1. (Smithsonian Institution photo by David Rosenthal, National Museum of Natural History, Department of Anthropology.)

Because of the construction technique—floors supported by a myriad of steel posts—it seemed apparent that the movement of storage units would be the greatest on the third floor, less on the second, and least on the first. Although I am not a seismologist, a visual inspection easily confirmed this intuition. Of the roughly 3,150 storage

FIGURE 2. Bolts sheared off or torn from Pod 1 floor. (Smithsonian Institution photo by David Rosenthal.)

cabinets in Pod 1, those on level one remained roughly in place where they had been originally aligned and leveled, while those cabinets on level two showed modest signs of "walking," sometimes 5 to 10 cm. Those on level three exhibited the greatest extent of walking, moving in some cases up to 20 cm (8 in). We had staff on the first floor of the pod when the quake struck, which, because of the low 2.4 m (8 ft) ceilings on each floor, must have been a very disconcerting experience. "It was really loud in there" during the event, reported Felicia Pickering, our ethnology specialist who at the time was showing Southwest materials to two researchers from Arizona. "You could hear the cabinets clanging into each other. There was a tremendous amount of banging and noise and you could see cabinets shake. We were watching to make sure nothing fell from the ceiling." Based on Ms. Pickering's anecdotal experience and how our cabinets shifted, we more-or-less determined that the shaking forces of the quake moved roughly in a north–south orientation (Figures 3, 4).

It would be two full days (25 August) until my staff and I were allowed back into the building to begin conducting visual checks in our storage spaces to determine damage. These initial surveys included checks in four of the five pods (1, 2, 3, and 4) within the MSC. Pod 4, the storage area equipped with large, cantilevered, heavy-duty shelves constructed for loads of up to 4.5 metric tons (5 tons) per shelf, revealed no damage to objects. As with our storage cabinets, however, a number of objects (all of which are housed on and strapped to specially designed aluminum pallets) evidenced signs of walking (Figure 4). These were easily returned to their original positions by use of a forklift, and the (uncompromised) structural integrity of the shelves was determined by two teams of engineers.

Pod 3, a newly renovated facility that now holds both our physical anthropology collections in compactor storage equipment and film and video in cold storage, also experienced impacts that were relatively minor and easily

FIGURE 3. Shifting of shelf cabinets, Pod 1, level three. (Smithsonian Institution photo by David Rosenthal.)

FIGURE 4. Walking of large palletized objects on cantilever shelves, in Pod 4. (Smithsonian Institution photo by David Rosenthal.)

managed. Because of the manner in which these physical collections (human skeletal remains) are housed—in the interior drawers with Ethafoam cushioning in sealed cabinets—there was negligible impact to the collections. The single notable event in this pod was that the cabinetry—which reaches almost to the ceiling of the pod—moved on its compactor tracks and severed the heads of a number of fire-suppression sprinkler units. This caused a discharge of black brackish water that spewed over the new cabinetry and much of the space. Aside from the inconvenience of the cleanup, the discharge soaked two collections of associated archival materials that required conservation attention. Pod 2, a space that the Anthropology Collections and Archives Program (CAP) shares with several other natural history divisions, was initially a source of concern if only

FIGURE 5. National Anthropological Archives glass plate negatives in Pod 2, level one. (Smithsonian Institution photo by David Rosenthal.)

because it contains the collections of our National Anthropological Archives, which includes over 30,000 priceless glass plate photographic negatives created during the last quarter of the nineteenth century. In addition to other things, this collection represents the visual legacy produced by the Smithsonian's Bureau of American Ethnology (1878–1964) and includes thousands of historical images of Native American Indians and their traditional cultures and environments. Thanks to the manner in which these plates are housed—each in an archival Tyvek sleeve and slotted in groups of 8–10 between metal dividers—these treasures were unaffected by the event (Figure 5).

It was principally in Pod 1—particularly on level three of that pod—that we would realize that the seismic event was much more than a "tempest in a teacup." On this level, where Viking storage cabinets once marched precisely down long aisles in marionette fashion, they were now consistently out of alignment and askew (Figure 6).

FIGURE 6. Shelf cabinets out of alignment in Pod 1, level three, following the earthquake. (Smithsonian Institution photo by David Rosenthal.)

The CAP areas at the MSC utilize mainly four types of Viking cabinets: an oversized, four-door cabinet for large flat objects; a standard-sized cabinet with deep shelves that can be adapted with shelves or drawers, depending on the size of objects to be housed; a "220" or steel cabinet modeled after the traditional museum "quarter unit" or "half unit"; and a standard-sized cabinet of shallow depth with door windows that we have adapted to the storage of our archival materials. Given the extent of observable movements of our cabinets—sometimes as much as 15–20 cm (6–8 in)—as well as our knowledge of the kinds of artifacts present on this level, my staff and I began our condition survey there.

AN UNCERTAIN LANDSCAPE OF CABINETRY AND OBJECTS

The plan for our survey was relatively simple. With support from the CAP staff, the Department of Anthropology, and four staff from the Museum Conservation Institute, we paired off in teams of two and three across the space of the pod. Each team positioned itself at one of the 44 rows of cabinets in the pod and proceeded down the length of that row—roughly 55 m (60 yd) of cabinets. When inspection of the cabinets in that row was completed, the team moved to the next unvisited row with teams hopscotching over each other in the process. In all, the survey took five full work days (25–31 August) and involved more than 800 hours of staff time.

Each team was equipped with a mobile cart holding a laptop, camera, and supplies (e.g., sealable plastic bags in which to include any small broken shards or artifact pieces). One person would call out the cabinet number and location being surveyed, and the other would record that information on a spreadsheet in the laptop. This was followed by a visual examination of the interior shelves or drawers. It there were no detectable signs of disturbance, the doors were simply closed and relocked. If objects had been toppled or damaged, the catalog numbers of those objects were called out to the recorder. All objects were then set upright, any broken parts were associated with the relevant object, and any small pieces were placed in a sealable plastic bag. Care was taken in the pairing of team members to ensure that one individual was familiar with the cabinet nomenclature and the collections. At the end of each day our data manager, Carrie Beauchamp, copied the data from the 8–10 laptops that we used into a master Excel spreadsheet she had devised. One of the fields she used recorded the photograph numbers (as enumerated by the camera) associated with toppled or broken objects as a way to cross-reference the survey shot with a particular catalog number. Once the whole survey was complete (a process that as noted took five working days), a shorter list was produced that included 137 damaged objects, the majority of them broken ceramics.

While seemingly straightforward, this process was not always as simple. As one might imagine, museum objects come in all sizes, weights, and shapes. With some notable exceptions (e.g., oversized objects like totem poles, monumental Olmec sculptures, and outrigger canoes; large rolled textiles; and long, thin objects like spears, paddles, harpoons, or hoes) the Department of Anthropology houses its objects by cultural area rather than "type." As a consequence, a given storage cabinet may house fairly large and heavy objects and relatively small and fragile ones on the same shelf. This turned out to be the case for many parts of our Asian ceramics collection in which tall cloisonné vases find themselves side-by-side with small cups and bowls of Fujina ware. Indeed, most of the damage discovered within our Japanese, Korean, and Chinese ceramics collection resulted from the toppling of tall cylindrical vases into each other or falling on smaller ceramic objects or figurines. In addition, we found that light thin-walled ceramics with small bases were also unstable as were small vases that might only be 10 to 13 cm high.

The toppling of these smaller and lighter objects sometimes caused them to roll to the front of the shelf even though each shelf had an Ethafoam liner. We realized the consequences of this the hard way when, upon opening a door, one such small ceramic dropped onto the concrete floor and broke. This happened even though we were very cautious in opening cabinet doors, doing so slowly, to ensure that objects that had moved would not drop. Realizing the possibility that this could happen multiple times, we regrouped and came up with the idea of placing foam pads that were as wide as the cabinets on the floor at the base of each cabinet before we continued to open additional doors (Figure 7). Then, as a door was opened slightly, one team member would attempt to peek into the cabinet to determine if there were any "hanging objects" (Figure 8). If one was sighted, an attempt was made to reach in and secure it or push it back onto the shelf. This further slowed the work of the survey, but it saved an estimated 10–12 artifacts that might have broken on the concrete floor. Even with this care, however, it was at times impossible to keep a small object from dropping to the next level and striking the metal edges of the cabinet, something that damaged at least three other small ceramics vases (Figure 9).

FIGURE 7. With foam in place, staff checking for hanging objects as shelf cabinet is opened. (Smithsonian Institution photo by David Rosenthal.)

LESSONS LEARNED AND REINFORCED

As my staff and I worked through our collections on each level of the three levels of Pod 1 (and to a lesser extent, level two of Pod 2 where we also have anthropology objects stored), it became clear that the greatest damage had occurred on the upper two levels of the pod. On the first level a few objects had shifted on their shelves, but there was virtually no damage to any object. Intuitively this seemed to make sense in terms of how the structure of the pods themselves functioned during the earthquake. But during post-assessment when we began to discuss informally the uneven impact of the event on collections housed on different levels of the pod, it became clear that other factors accounted for the fact that our holdings fared better on the first level—and this included our entire collection of more than 7,000 Southwest ceramics.

FIGURE 8. Examples of hanging ceramic artifacts. (Smithsonian Institution photos by David Rosenthal.)

FIGURE 9. Japanese vase that toppled, causing rim breakage. (Smithsonian Institution photo by David Rosenthal.)

What accounted for this difference in impact, we now feel, is that during the transfer of collections from the National Museum of Natural History to the MSC—a process that took more than a decade, from the late 1980s through the 1990s—our own collections and housing practices evolved considerably (Hansen and Sawdey, 1999). At the front end of this move—which had begun with our Asian collections—staff had attempted to maximize the use of shelf space in our cabinets. As we continued through the process of moving the collections, however, it became apparent that some decompression of the spacing of objects might be warranted. North American materials—which are among those collections most utilized by researchers—came during the second half of the move and benefitted from our own collective reflections upon how best to use cabinet space. With respect to our Southwest ceramics it was determined that they should be decompressed. Rather than being lined up in two rows per shelf, a decision was made to stagger them in a kind of diamond pattern, providing more space between each object so that they could be more easily removed for study and research (F. Pickering, Smithsonian Institution, personal communication, November 2011). In addition, nearly all of these ceramics were fitted with an Ethafoam ring or "doughnut" to stabilize the object on the shelf. While some of these objects actually did tilt in their doughnuts during the earthquake, not a single one suffered damage (Figures 10, 11).

All of these stabilizing measures proved to be well worth the time and effort. But it also seems reasonable to suggest that our Southwest ceramics fared better during the earthquake for reasons that perhaps had more to do with the nature of the objects than to these stabilizations. Water jars and bowls from the Pueblo people can be more-or-less easily grouped into objects of similar size and shape, and we had housed them in this way. By contrast, our Asian ceramics represent a myriad of sizes, shapes, and weights that caused them to interact with much more apparent energy during the earthquake.

The lessons learned from this event now seem rather straightforward. We clearly had not anticipated dealing with an earthquake and, except perhaps fortuitously, we had not incorporated preventive measures for seismic events into our storage practices. The fact that no shelf cabinets themselves toppled (excepting one that was empty and had not been balanced), appears to have reflected the

FIGURE 10. Example of crowded Japanese ceramics. (Smithsonian Institution photo by David Rosenthal.)

careful manner in which the Collections Support Staff had aligned and balanced the cabinets at the time our collections moved into the facility. With regard to all of our Asian ceramic collections—which were among the first to have been moved to the MSC back in the late 1980s—we now need not only to restore those objects that were broken but to implement a decompression of the collection. In the process of doing this we anticipate developing stabilizations (e.g., bases and cradles) for specific objects such as tall cylindrical ceramics and other objects that may be top heavy due to their shape or design. Decompression will likely cause us to think further about the relationships among the size, weight, and shape of objects on a given shelf to insure that larger objects do not roll, topple, or impact smaller fragile ones. Small fragile ceramics will need to be appropriately grouped and placed in blue board trays or other housings that will prevent them from rolling and serve to buffer them from the movement of any larger adjacent objects in the event of a future seismic event (Figure 12). Currently there is also consideration for equipping some cabinets—those containing fragile, high-value objects—with glass portals that would allow staff to view the objects housed therein. In the future, this could prevent accidental damage that might be caused by an object falling when a door is opened.

While the staff of the CAP contemplates how we will implement these preventative improvements, we also find ourselves preparing for a structural refit of Pods 1 and 2 as well. At a minimum, this will mean removal (by either torching or cutting) of some 75% of the metal

FIGURE 11. Zuni ceramics with stabilizing Ethafoam rings. (Smithsonian Institution photo by David Rosenthal.)

FIGURE 12. Japanese Fujina dish shattered by impact from larger toppled object. (Smithsonian Institution photo by David Rosenthal.)

strap cross-struts that were designed to stabilize the metal posts supporting the floors on levels two and three of these pods. To ensure the continued structural stability of the storage areas, these struts will be replaced by metal cables tensioned with turnbuckles. For our staff this will mean moving at least half of the more than 1,000 cabinets in Pods 1 and 2. This task issues from the fact that the rows of storage equipment are created by placing cabinets back-to-back separated by the narrow space occupied by each line of steel posts in the pod, and most of the cross-members can be accessed only by moving the cabinets. In some instances, this will also mean removing the objects in these cabinets before they are moved and then reloading the objects when the cabinets are realigned and releveled. With such a significant investment of time, funds, and labor involved in this effort, we have sought to be proactive and forward looking. We have invited a seismic expert working with museums to visit the MSC and provide consultation on both the arrangement of our storage equipment and our storage practices. We do all of this with the hope that the next seismic event we experience will amount to only a tempest in a teapot.

REFERENCE

Hansen, G., and C. Z. Sawdey. 1999. A Moving Experience: Thirteen Years and Two Million Objects Later. *Curator: The Museum Journal* 42(1): 13–36. http://dx.doi.org/10.1111/j.2151-6952.1999.tb01126.x.

Compounded Damage at the Museum Support Center: Hurricane Irene after the Earthquake

Paula T. DePriest, Elizabeth Dietrich, Odile Madden, Elizabeth Sullivan, and A. Elena Charola

ABSTRACT. On 23 August 2011 a 5.8 magnitude earthquake, centered in Mineral, Virginia, shook the Smithsonian Institution's Museum Support Center building in Suitland, Maryland. Because of the building's design and construction, the moderate earthquake caused significant structural damage and flooding. On 27 August 2011, Hurricane Irene brought 10 cm (4 in) of rain into the area, causing the aging and earthquake-damaged roofing system to leak in multiple areas. In less than a week the building constructed in the 1980s as a model for collection preservation had sustained an estimated $11 million in needed structural repairs and seismic upgrades.

INTRODUCTION

The Museum Support Center (MSC) in Suitland, Maryland, was originally constructed in the early 1980s to provide the optimum conditions for both the preservation and study of the Smithsonian Institution's collections. The building is composed of modules called pods, each with a collection storage space separated from offices and laboratories by a wide central corridor or "street." The building currently has five pods arranged in a unique zigzag-shaped pattern and covers 1.8 ha (4.5 acres) of land (Figure 1). Because less than 2% of the Smithsonian's collections are on exhibit at any time (Smithsonian Institution, 2013), the MSC and its large pods were designed to keep the collections in an appropriate climate-controlled environment for long-term preservation and storage, with modern pest management and security as well as continual on-site access. The building is in constant use by staff and visitors throughout the year for inventory, survey, conservation, and research on the collections.

Approximately 40% of the Smithsonian's 137 million objects and specimens (Smithsonian Institution, 2013), that is, more than 54 million, are located at the MSC (Smithsonian Institution, 2009). Although the majority of the collections are natural history and anthropological collections from the National Museum

Paula T. DePriest, *Deputy Director, Museum Conservation Institute, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA;* ***Elizabeth Dietrich,*** *Program Manager, Museum Support Center, Smithsonian Institution;* ***Odile Madden,*** *Research Scientist, Museum Conservation Institute;* ***Elizabeth Sullivan,*** *Contractor/Lend Lease, Manager, Office of Planning Design and Construction, Smithsonian Institution; and* ***A. Elena Charola,*** *Research Scientist, Museum Conservation Institute. Correspondence: P. DePriest, depriestp@si.edu.* *Manuscript received 12 December 2013; accepted 18 March 2014.*

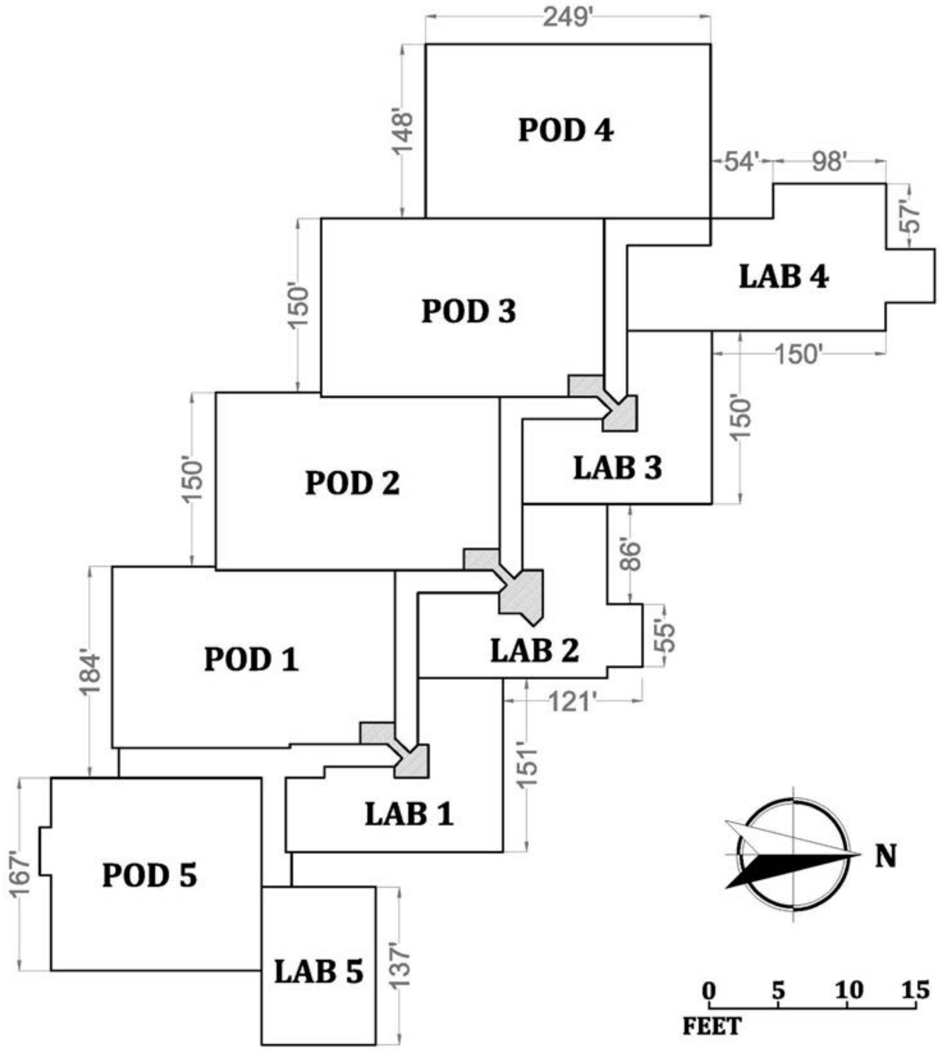

FIGURE 1. Simplified plan of the first floor of the Museum Support Center building showing the relative locations of the five collection storage pods and the associated office, laboratory, and conservation spaces. Numbers are length measurements in feet. Areas marked in grey are stairwells that suffered structural damage. (Drawing courtesy of Yun Liu, MCI Post-graduate Fellow.)

of Natural History (NMNH), the National Zoological Park, and the Smithsonian Environmental Research Center, the MSC also houses fine art and historical objects from the Freer Gallery of Art and the Arthur M. Sackler Gallery (FSGA), the National Museum of African Art, the Hirshhorn Museum and Sculpture Garden (HMSG), the National Museum of American History (NMAH), and the National Postal Museum. The MSC also houses the Museum Conservation Institute (MCI), the center for specialized technical collection research and conservation for all Smithsonian museums and collections, and a branch of the Smithsonian Institution Libraries (SIL).

However, despite being designed for preservation of collections, the building was susceptible to a pair of catastrophic events. On Tuesday, 23 August 2011, just after 1:51 PM, a 5.8 magnitude earthquake centered at Mineral, Virginia, rolled through the MSC building. Staff in the office and laboratory areas reported a loud boom, followed by shaking and secondary (sine) waves on a north–south axis. Staff in the pods reported violent shaking and swaying; metal groaning, rattling, and banging; an empty cabinet falling over; and water rushing from the sprinkler systems in the upper levels of Pods 2 and 3. The first photographs of the damage showed heavy bolts sheared off posts, structural damage visible as cracks in stairways, and nonstructural damage to some masonry walls (Clough, 2014, this volume). The initial official report mentioned only minor damage to all Smithsonian facilities because those reporting were unaware of the severity of damage to the MSC (E. Dietrich, Smithsonian Institution, "Earthquake Log of Actions 23 Aug 2011," unpublished). Later that week, on Saturday, 27 August, Hurricane Irene would bring torrential wind and rain to the Washington, D.C., area. In a few days, the very strong earthquake and hurricane caused an estimated $11 million cost in structural and nonstructural damage that required seismic improvements and repairs to this multi-use building. The earthquake and hurricane endangered the preservation of Smithsonian collections and required certain collections' displacement.

EARTHQUAKE DAMAGE ASSESSMENT

In the immediate aftermath of the earthquake, it was clear that the MSC had sustained significant damage. Although a water-flow alarm was activated, no general evacuation alarm could be given, and shaken staff and visitors evacuated the building as soon as the earthquake subsided. No injuries to staff or visitors were reported. The MSC remained closed to all but emergency staff and recovery teams for two days, 24 and 25 August, to allow time for assessment of the damage and to ensure that the facility was safe for occupancy. Building engineers turned off the air handling units to protect them from damage during the anticipated aftershocks. Small teams worked to recover collections from broken jars in the NMNH's fluid (alcohol) collection in Pod 5 and to move some HMSG and NMNH collections in Pod 3 to drier areas and cover them with plastic. Emergency staff and collections recovery teams that ventured into the building to check on collections also reported structural damage to the stairwells, elevators, walls, and ceilings and water damage from broken sprinkler heads in multiple areas of Pods 2 and 3.

On the evening of the earthquake the Office of Facilities Engineering and Operations (OFEO) design and construction managers and contracted structural engineers, along with staff from the MSC, NMNH, and Office of Protection Services, began preliminary assessments to separate "cosmetic" damage from major structural damage in the building. Along the central corridor, or street, there was significant nonstructural cracking in the concrete masonry unit of the interior partition walls that divide the office and storage spaces. The three cast-in-place staircases to the street's elevated walkways, or "catwalks," (see shaded areas in Figure 1) had cracking and spalling of varying degrees, while some columns and beam interfaces had surface detachments and spalling (Thornton Tomasetti, "MSC Building, Post-Seismic Event Structural Assessment," unpublished report, 2011; Ewing Cole, "Part 1. MSC Damage Assessment," unpublished report, 2012; and briefly discussed elsewhere [Clough, 2014, this volume]).

In storage Pods 2 and 3, three sprinkler heads were sheared off and water from the sprinkler systems was released over the collections, storage cabinets, and shelving. In Pod 2, a sprinkler head was knocked off by the swaying of a roof member during the earthquake. Rusty colored water from pipe corrosion sprayed over collections cabinets (Figure 2) and open storage on the third level and ran down to the first and second levels. In Pod 3, two sprinkler heads were broken off on the upper level when they banged into ceiling beams as the sprinkler lines swung back and forth during the earthquake (Figure 3) The water had a blackish color due to the presence of iron corrosion products and iron-related bacteria (S. Storke, Mid Atlantic Laboratories, unpublished report, 2011). Since there were no floor drains on the upper level, water flowed down through the floor and stairs to the first level where about 7.5 cm (3 in) of water accumulated (Figure 4). Turning off the water line to the damaged sprinkler had taken about 20 minutes for Pod 2, which was the first to be identified, and about 1.5 hours for Pod 3. Initially facilities staff did not realize that there were sheared sprinkler heads in Pod 3 until water began collecting in its first level (Lake and Towler, 2014, this volume). Shutting down these sprinkler lines was further delayed by some problems in the automated fire detection system; problems were subsequently rectified.

On the evening of the earthquake the structural engineers cleared the OFEO's Office of Facilities Management and Reliability (OFMR) to take basic steps in disaster recovery. Immediate steps included removing loose and unsupported concrete that presented a falling hazard, shoring up damaged stairways, and cleaning up water as long as no heavy equipment was used in the Pods, 1, 2, and 4, which had the greatest structural damage. By the afternoon of 24 August, the day after the earthquake, some recovery work was allowed in Pod 2 as well as immediate structural stabilization of the stairwells. That evening all water was removed from the floors, and open shelves on the upper level were covered. In Pod 3, all the water that had been released from broken sprinkler heads was removed. The following day, 25 August, collections management recovery teams were allowed to enter Pods 1 and

FIGURE 2. Rusty-colored water on case tops in Pod 2. (Smithsonian Institution photo by Catharine Hawks, NMNH.)

3, although Pods 2 and 4 were closed for additional days until further structural assessment was completed. Recovery teams from NMNH, MCI, FSGA, NMAH, HMSG, and SIL worked over the next few days to check collection storage for damage, especially on the upper levels of the pods where collection storage cabinets shifted and even tipped over. Fortunately, there was no widespread damage to the art work or collections in the pods. In addition to structural and collection damage, NMNH and MCI staff examined their sensitive analytical instrumentation for

FIGURE 3. Above, sprinkler head as installed; right, sprinkler head in Pod 3 sheared off during the earthquake. (Smithsonian Institution photo by Catharine Hawks, NMNH.)

damage. The MCI alone estimated immediate repair costs of almost $30,000.

In-depth structural surveys and computer modeling after the earthquake revealed more significant damage to the building in addition to that already noted for the stairways. Both the interior and exterior concrete masonry unit walls had experienced out-of-plane movement, and several columns and trusses on the office, laboratory, and conservation side of the building were damaged (Ewing Cole, "Part 2. MSC Building Evaluation," unpublished report, 2012). The five pods (Figure 1) differed in their degree of structural damage: Pods 1, 2, and 4 were more damaged than Pods 3 and 5. For example, during the earthquake, the inverted tee beam between Pod 1 and Pod 2 shifted 5 cm (2 in) to the west. Pods 1–4 originally were built in the early 1980s. Pod 3 was rebuilt completely between 2007 and 2009. Pod 5, which suffered the least damage (Figure 5), was an addition to the original building and completed in 2007. In the period between the construction of the original structure and the construction and renovation of Pods 5 and 3, respectively, seismic design requirements increased to improve earthquake performance of structures.

One factor in the increased damage inside three of the older pods was the subsequent addition of two mezzanine floors in each of the high-bay structures of Pods 1 and 2 and half of Pod 4 to increase their storage capacity. These steel-framed floors were constructed as self-sustained, isolated units that did not connect to the building envelope or rely on it for support. A 5 cm (2 in) gap around the perimeter of each mezzanine floor was designed to accommodate movement during seismic events. Because of the detailing of the connections (tension straps and cross-braces between posts), the mezzanine did not perform as designed, and the system's resistance to lateral force was compromised. An estimated 75% of the tension straps permanently buckled or ruptured, allowing the mezzanine structures to rock back and forth during the earthquake and bang into the surrounding structures (Ewing Cole, "Part 1. MSC Damage Assessment," unpublished report, 2012), Repair of the damaged mezzanines may require moving approximately 10,000 storage cabinets, more than 65% of the estimated 15,000 cabinets, and the collections they contain and then returning them into their original positions.

PREPARATIONS FOR HURRICANE IRENE

Over the week following the earthquake, roof leaks, both new and compounded damage to existing leaks, became evident as Hurricane Irene brought torrential rains to the area. As there was advance notice of the approach of Hurricane Irene on Saturday, 27 August, the earthquake-damaged building was prepared for further water damage and power outages. Collections, open shelving, scientific instruments, office furnishings, and so forth, including the open stacks and shelves of the SIL branch library, were covered with plastic sheeting to protect against potential roof leaks and blown-in water. Because of the impact of environmental conditions, especially high humidity and

FIGURE 4. Cabinets stained by the blackish water released from the broken sprinkler heads in Pod 3. (Smithsonian Institution photo by Catharine Hawks, NMNH.)

FIGURE 5. Minor, superficial damage in Pod 5. (Smithsonian Institution photo by Catharine Hawks, NMNH.)

moisture, on collection safety, the MCI staff prepared equipment—such as ultraviolet C lamps, fans, shop vacuums, and an argon treatment system—to control potential mold and mildew problems after water damage. Additionally, the expected hurricane-associated power outages threatened many of the sensitive analytical instruments and freezers that were not protected by an emergency back-up generator system at the MCI and MSC-NMNH units. These instruments were shut down preemptively and, where possible, frozen materials and samples were consolidated into freezers on emergency power systems. Interruption in electrical power and building systems during the earthquake and hurricane highlighted the need for increased emergency generator capacity and greater reliability and stability of the power supply.

Hurricane Irene brought 64–97 kmh (40–60 mph) winds gusts and 10 cm (4 in) of rain that continued from Saturday, 27 August, until Tuesday, 30 August, in Suitland, Maryland (NASA and Acker, 2011). The torrential rains revealed earthquake-related damage to the roof system—damage to expansion joints, flashing and caulking around seams, and pipe and ductwork penetrations (Ewing Cole, "Part 1. MSC Damage Assessment," unpublished report, 2012)—when leaks appeared in parts of the MSC building during the hurricane. These leaks were concentrated over offices, laboratories, and the central streets; none developed over the pods. The severity of leaks ranged from small puddles discovered on desks to those so large that water continued to be collected for many months in rolling, plastic dumpsters approximately 2 m^3 (60 ft^3) in volume (Figure 6). In some office, laboratory, and conservation areas, water continued to drip for over a year after the hurricane (with Hurricane Sandy contributing more damage in October 2012), during both dry and rainy days, until the roof was repaired. These repairs fixed all but a few persistent leaks associated with air handler units sitting on the roof over the MCI. The MCI staff worked with OFMR to document and assess damage to the roof.

FIGURE 6. One of the most persistent leaks in the Museum Conservation Institute, still unresolved when photo was taken in January 2013. (Smithsonian Institution photo by E. Keats Webb, MCI.)

ROOF ASSESSMENT

On 30 September 2011, one month after the hurricane, the OFMR MSC building manager and engineers as well as MCI scientists and conservators investigated the roof's condition and causes of the ongoing leaks. The MSC's roof is cast concrete with a waterproofing membrane that helps seal all the roofing penetrations such as duct work, plumbing vents, and exhaust fans. On top of this membrane is insulation covered by another single-ply membrane. This outer single-ply membrane also seals all the roof penetrations. When the roof's original outer membrane deteriorated, a choice was made not to remove it but rather to install a new one on top. In 1999, the MSC roof was refitted with a Stevens EP Vented Roof System. According to the manufacturer, the system consists of a roof membrane, described in the product specifications as ".045-in. or .060-in. nominal thickness overall scrim-reinforced, Ethylene-Propylene-based sheet" (Stevens Roofing Company product specifications) plus adhesives and underlayment (Stevens, n.d.). The specifications also approved placement beneath the membrane of loose-laid insulation with a minimum of 1.3 cm (0.5 in) thick moisture-resistant gypsum board overlay. At the time of the earthquake and hurricane, the MSC roofing system was still under a warranty that covered all the subsequent necessary repairs.

The roofing membrane has penetrations of regularly spaced round, capped aluminum vents that extend 15–29 cm (6–12 in) above the membrane to vent the space below the membrane. The roof itself is penetrated by pipes and ductwork that allow water to drain from the roof and also air to vent from the work spaces below. The latter openings for vents are common above laboratories and areas with plumbing fixtures (common rooms and restrooms). In contrast, the roofs of the pods are clear expanses of evenly sloped white membrane with the regularly spaced aluminum capped vents and, toward the bottom of the slope, drains. There are no penetrations through the roofs of the pods.

At the time of the inspection, the roof surface was covered entirely with the 1999 membrane, the sections of which are adhered with overlapping seams. The underlying old membrane and concrete structural roof were hidden from view. The newer membrane, which consists of a supporting woven mesh coated with a bulked polymeric matrix, exhibited significant localized deterioration; in many areas, the polymeric matrix was chalking, cracked, and lost, which exposed the supporting open mesh within (Figure 7). This deterioration often was observed in areas of the roof with standing water. Clearly, this membrane no longer was impermeable to water and would have allowed rain to infiltrate the roof sublayers.

Deterioration of the membrane was most pronounced on the north side of an air-handling unit that had lost its metal underpan. A small sea of water had accumulated beneath the air handler on top of the membrane (Figure 8), and an alarming amount of water also had accumulated under the membrane in this area. Though the source of the water was not investigated in detail, it seemed most likely that it was an accumulation of rain water onto a low area of the roof, possibly combined with condensation from the decommissioned air handler above (Browning, 2004). Large sections (approximately 1.2 m^2 [4 ft^2]) of a solid board material, consistent with the loose-laid hard insulation installed under the membrane, were floating under the membrane such that the roof surface undulated underfoot like a floating raft. This condition extended across an area estimated to exceed 37 m^2 (400 ft^2). If the depth of water beneath the membrane is assumed to have been 10 cm (4 in), the total amount of rain that fell during Hurricane Irene in this area (NASA/SSAI and Pierce, 2011), then that section held more than 3.77 m^3 (996 gallons) of water, with an estimated weight of more than 3,774 kg (8,320 lb). This area of the roof appears to be slightly lower than the surrounding area and could have collected

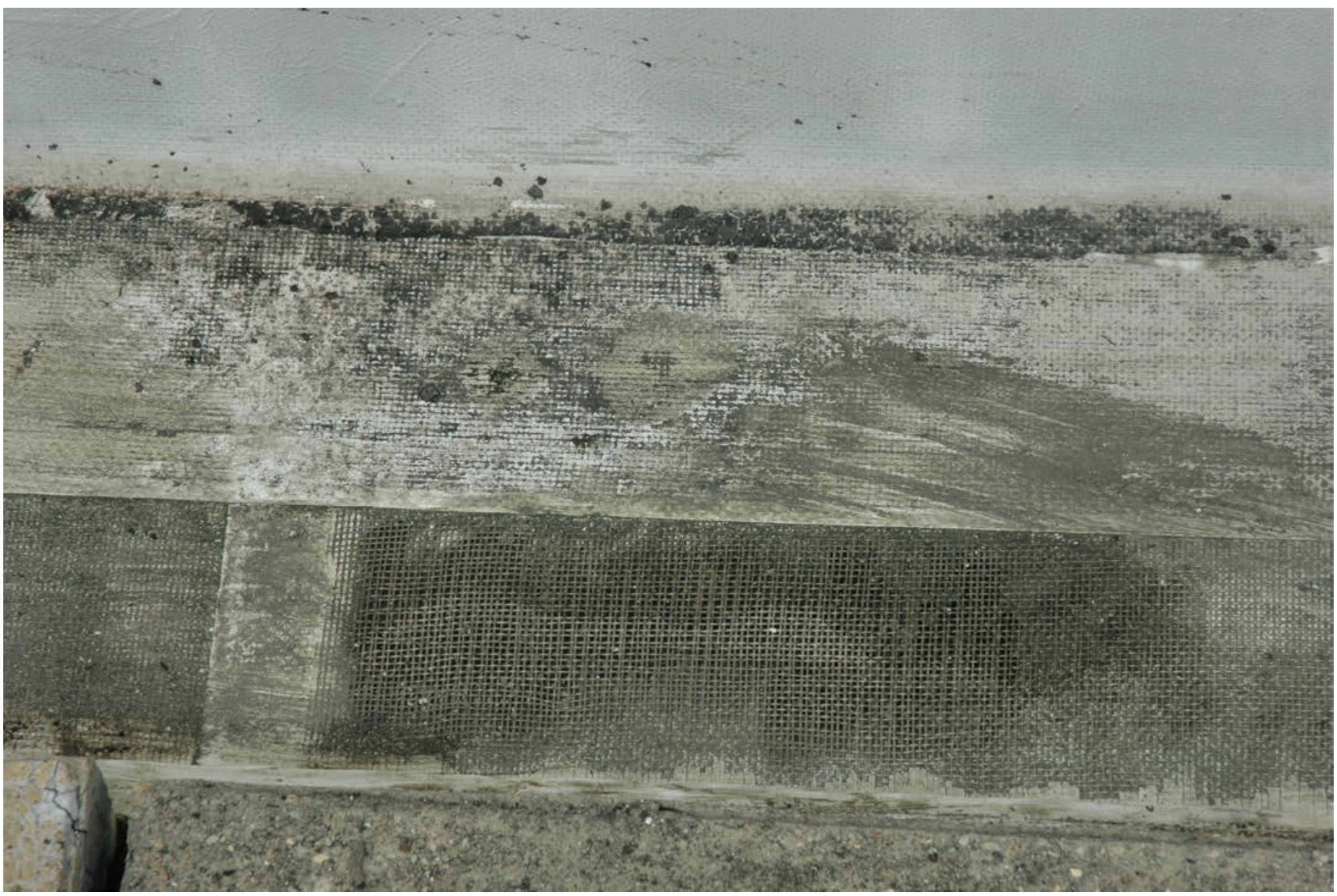

FIGURE 7. Detail of the eroded membrane leaving the woven support exposed. (Smithsonian Institution photo by Carol A. Grissom, MCI.)

FIGURE 8. Top, large pool of standing water under air handling unit; bottom, detail of standing water with algae and gray-colored deteriorated roof membrane. A hanging piece of the corroded metal underpan is visible at the top center of the image. (Smithsonian Institution photo by Carol A. Grissom, MCI.).

shedding rainwater, which would contribute to the large water accumulation and might explain the persistent leak below this area that lasted well over a year.

Smaller pools of standing water had collected in other locations across the roof. The bottoms and edges of the puddles often appeared red, green, or blue in color (Figure 9), and in some instances a thicker green-black film was present, all of which suggested a biological origin. Analysis of the green-black film showed the presence of carotene pigments (Madden, internal Smithsonian Institution report, unpublished, 2011) that would be consistent with the presence of algae or bacteria, such as *Trentepohlia* sp. or *Micrococcus roseus,* respectively. Though the organisms were not identified definitively, it was clear that their growth indicated a longer-term problem with standing water in those localized low-lying areas.

These observed conditions beg the question of drainage. The component sub-buildings of the MSC complex each have a gently sloped flat roof surrounded by low parapet walls. Water is removed from each roof through a network of drains that span the roof surface at the level of the membrane. Weep holes in the parapet walls also help with drainage in some areas. Each drain is a shallow "basin" with a vertical pipe opening at the center that is covered with a cage-like plastic cap to keep out debris (Figure 10). Two different configurations of drains were observed. For most drains above the pods the mouth of the drain is flush with the bottom of the basin. On other drains, the mouth of the vertical iron drain pipe stands proud of the roof membrane by at least 2.5 cm (1 in), and a significant amount of water can collect in the basin without draining. Some of the older flush-mounted drains, including those over the laboratories and offices, also exhibited heavy corrosion on the iron plates that secure the plastic cap. This corrosion was sufficiently bulky to inhibit drainage, and when drains do not shed water effectively the deterioration of the roof membrane may be accelerated.

FIGURE 9. Red staining in standing water presumably resulting from microorganism growth. (Smithsonian Institution photo by Carol A. Grissom, MCI.)

Because the drains were designed for water shedding off the roof surface, there is no drainage for water that seeps beneath the membrane. This condition was most obvious near the sea of water with floating insulation described above. During the inspection, some small openings (about 5 cm [2 in] long) were cut into the membrane at a nearby drain basin. The water that gushed out was cloudy and white, possibly due to gypsum powder washed loose from the underlying insulation (Figure 10). In essence, the membrane behaved like a bladder that trapped and prevented evaporation of the water that had seeped beneath it.

The condition of the roof membrane, the roof's uneven slope, and the drainage issues contribute to the accumulation of standing water that makes its way into the MSC buildings through damaged sealing around roof penetrations. The presence of microorganism growth in standing water suggests that drainage has been an ongoing problem on the MSC roof. The original outer roof membrane, which was not removed when the vented roof system was installed, probably continued to offer some protection to the concrete structural roof despite its deteriorated state. It seems likely that the earthquake created new openings in this membrane, which can reasonably be expected to have become brittle with age.

The torrential rains of Hurricane Irene tested the MSC's aging and earthquake-damaged roofing system. Whereas the roofs of the pods appear to shed water well, the roof above the laboratories and offices of the MSC has an uneven grade and does not direct all water effectively toward roof drains, which themselves do not shed water efficiently. Some roof drains will not allow water to enter the drain until at least 2.5 cm has collected on top of the membrane in the surrounding basin. During the hurricane, once the rainwater penetrated below the membrane, the drains became useless, and thousands of gallons of water had nowhere to go but into the building through the underlying old membrane and earthquake-damaged expansion joints, flashing, and caulking. This condition was far worse above the MSC laboratories and offices, where the roof is perforated by many ducts and drains. Few leaks,

FIGURE 10. Left, typical roof drain in a shallow, membrane-lined basin that may collect rain water and allow it to seep under the membrane; right, a cut was made into the membrane and the water that had collected beneath spurted out. (Photos by Odile Madden.)

if any, were found in the pods, which have far fewer roof penetrations. The prolonged leakage observed in several areas of the MSC building is a reminder that maintenance of flat roof systems with caulked seals is an on-going task.

CONCLUSION: ESTIMATES OF DAMAGE

The 5.8 magnitude earthquake on 23 August 23 hit the MSC building especially hard, causing major structural and cosmetic damage to the building envelope and some breakage of collections and their containers. Of the five collection storage pods, three experienced significant movements and slippage of their supporting structures and roofs (Clough, 2014, this volume). In addition, broken pipes and fire suppression sprinklers caused flooding in two of the pods. A strong hurricane on 27 August compounded the damage by causing roof leaks in multiple areas of the bulding. On the basis of the engineering surveys, the Smithsonian requested from the U.S. Congress a total of $11,250,000, most of it required for moving the collections during repairs and making seismic upgrades of the MSC's existing structure and roofing systems (Smithsonian Institution, 2012:219–220). The request noted that although the structure had avoided total failure during the earthquake, its original seismic design was compromised and there was no guarantee that it would withstand another earthquake. The MSC required repairs and upgrades to prepare for the next earthquake and to continue to fulfill its mission of safeguarding the Smithsonian's collections.

Acknowledgments

The authors gratefully acknowledge the extremely helpful comments, suggestions, and information received from Nancy Bechtol (OFEO), Kendra Gastright (OFMR), Keith Keyes (Contracting Officer Technical Representative), Rick Fary (OFEO-OFMR, Suitland), David Hay (Office of Engineering, Design and Construction), and Molly McGrath (MCI Postdoctoral Fellow).

REFERENCES

NASA and J. Acker. 2011. "3-hourly TMPA-RT 00Z25Aug2011-18Z28-Aug2011 Accumulated Rainfall [mm]." Graphic from website: *Hurricanes/Tropical Cyclones. Latest Storm Images and Data from NASA. August 30, 2011. Goodnight Irene: NASA's TRMM Satellite Adds Up Irene's Massive Rainfall Totals*. R. Gutro, H. Pierce, J. Acker. National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md. http://www.nasa.gov/mission_pages/hurricanes/archives/2011/h2011_Irene.html; http://www.nasa.gov/images/content/583114main_IMAGE3-irene_maryland_rainfall_labeled.jpg (accessed 4 February 2013).

Browning, B. K. 2004. "Museum Archive Dehumidification in Hot and Humid Climates." In *Proceedings of the 14th Symposium on Improving Building Systems in Hot and Humid Climates, Richardson, Texas*. College Station, Tex.: Texas A&M University, Energy Systems Laboratory. http://hdl.handle.net/1969.1/4606 (accessed February 5, 2013).

Clough, G. W. 2014 (this volume). “Back To Back: The Earthquake and Hurricane of 2011.” In *Unexpected—Earthquake 2011: Lessons to Be Learned,* ed. A. E. Charola, C. Wegener, and R. J. Koestler, pp. 1–18. Smithsonian Contributions to Museum Conservation, No. 4. Washington, D.C.: Smithsonian Institution Scholarly Press.

Lake, S., and K. Towler. 2014 (this volume). “Communication: Earthquake Damage Report from the Hirshhorn Museum and Sculpture Garden.” In *Unexpected—Earthquake 2011: Lessons to Be Learned,* ed. A. E. Charola, C. Wegener, and R. J. Koestler, pp. 65–67. Smithsonian Contributions to Museum Conservation, No. 4. Washington, D.C.: Smithsonian Institution Scholarly Press.

NASA/SSAI and H. Pierce. 2011. “August 20–29, 2011 Rainfall Accumulation (mm).” Graphic from website: *Hurricanes/Tropical Cyclones. Latest Storm Images and Data from NASA. August 30, 2011. Goodnight Irene: NASA’s TRMM Satellite Adds Up Irene’s Massive Rainfall Totals*. R. Gutro, H. Pierce, J. Acker. National Aeronautics and Space Administration and Science Systems and Applications, Inc., Goddard Space Flight Center, Greenbelt, Md. http://www.nasa.gov/mission_pages/hurricanes/archives/2011/h2011_Irene.html; http://www.nasa.gov/images/content/583120main_irene_rain_20-29aug11.jpg (accessed July 12, 2013).

Smithsonian Institution. 2009. “Fact Sheets: Museum Support Center.” *Newsdesk: Newsroom of the Smithsonian,* SI-410-2009. http://newsdesk.si.edu/factsheets/museum-support-center (accessed 20 August 2013).

———. 2012. “Fiscal Year 2013 Budget Justification to Congress.” Submitted to the Committee on Appropriations, Congress of the United States. Washington, D.C.: Smithsonian Institution. http://www.si.edu/content/pdf/about/FY2013-BudgetRequest.pdf (accessed 11 July 2013).

———. 2013. “Fact Sheets: Smithsonian Collections.” *Newsdesk: Newsroom of the Smithsonian,* SI-379-2013. http://newsdesk.si.edu/factsheets/smithsonian-collections (accessed 5 June 2014).

Stevens, n.d. “Stevens EP™ Roofing Membrane.” Stevens Roofing Systems. Norfolk, Va.: Stevens Roofing Corporation. http://www.championservicesinc.net/Roofing/Stevens/EP.htm (accessed 21 December 2012).

Conclusions and Recommendations

Nancy Bechtol, William Tompkins, Kerry Button, Catharine Hawks, and A. Elena Charola

ABSTRACT. A brief overview is presented of the immediate actions undertaken to evaluate the damaging effects of the 2011 earthquake that resulted in the closing of two buildings, the Museum Support Center and the Smithsonian Castle, which were subsequently opened two and six days later, respectively. Despite initial communications problems, the prompt activation of the Emergency Operations Center permitted the coordination of the building damage evaluation. Nonetheless, the experience served to highlight areas that need to be improved in the case of a similar event. Among them is the need for better training of staff, that is, to improve preparedness. A list of recommendations has been put together to improve response to similar emergencies.

INTRODUCTION

The "After Action Report" compiled following the earthquake of 23 August 2011 summarizes the institutional response to this event ("After Action Report," Smithsonian Office of Facilities Management and Reliability, unpublished, 2011). Museums located toward the east end of the Mall, such as the National Air and Space Museum and the National Museum of the American Indian, suffered minor damages as compared with those closer to the west end, such as the Smithsonian Castle and the National Museum of Natural History.

Immediately after the earthquake, most Smithsonian Institution (SI) facilities were evacuated for both public and staff. Shortly thereafter, select Office of Facilities Engineering and Operations (OFEO) and unit staff re-entered some facilities to assess both building and collections damage. The Office of Protection Services (OPS) immediately activated the Emergency Operations Center (EOC) in its primary location in the Capital Gallery building. The Emergency Command Center (ECC) from the OPS started to contact all SI units. However, depending on individual SI units, wireless phone communications were down for the first quarter of an hour after the earthquake and radio systems also had periods of poor communication, whereas e-mail and the voice over internet protocol telephone service appeared to work normally during this first period. (We subsequently learned that this system did not work consistently for all SI units). All SI facilities were immediately closed to the public, and nonemergency staff were excused for the rest of the day.

Nancy Bechtol, *Director, Office of Facilities Engineering and Operations, Smithsonian Institution, P.O. Box 37012, Washington, D.C. 20013-7012, USA;* ***William Tompkins,*** *Director, National Collections Program, Smithsonian Institution;* ***Kerry Button,*** *Supervisory Museum Program Specialist, National Museum of Natural History, Smithsonian Institution;* ***Catharine Hawks,*** *Collections Program Conservator, National Museum of Natural History; and* ***A. Elena Charola,*** *Research Scientist, Museum Conservation Institute. Correspondence: N. Bechtol, bechtna@si.edu.* *Manuscript received 12 December 2013; accepted 18 March 2014.*

The following day, all SI facilities were open to the public and staff with exception of the Museum Support Center (MSC), the SI Castle, and select Garber facilities, where structural damage had been the worst. However, after further evaluation and cleaning, the MSC and Garber Facility were reopened by 25 August 2011. Six days later, after emergency measures were taken, the SI Castle was reopened to the public and staff.

STRENGTHS AND WEAKNESSES

The prompt reaction in activating the EOC despite initial communication problems is likely to have been one of the most important decisions because it permitted coordination in the evaluation of damage through the prompt action of the Office of Engineering, Design and Construction (OEDC) and the Office of Facility Management and Reliability (OFMR), both within OFEO. After the initial disruption, communications were quickly re-established through SI mobile alerts, SI-wide e-mails, the SI public website, and the SI alert website followed by public communications about museum status and interviews with Secretary Clough. These communication systems served well in preparation for Hurricane Irene.

Even with this level of communication, many units felt they were not prepared for an earthquake. The earthquake was a regional and Smithsonian-wide event for which the SI was not completely prepared since earthquakes have not been part of our emergency preparedness plans. Some felt that training for earthquake emergency management should be improved; others deemed that this might be an overreaction as earthquakes are not so frequent on the East Coast. Nonetheless, regular updates and guidance of what to do in emergency events, including earthquakes and hurricanes, is required.

The response of the National Museum of American History (NMAH) can be considered a good example for the SI facilities on the Mall. Following the alarm sounded by the OPS, the building was evacuated in a safe manner. The zone manager notified the OFMR leadership immediately. The West Mall Zone put a team together to inspect exterior windows and any visible structure damage. Subsequently, the NMAH building management staff, after coordinating with the OPS and the NMAH associate director, sent an ad hoc team into the museum to inspect broken glass, fallen objects, water pipes, kitchen burners, fire pumps, and utilities such as natural gas, water, and electric and then notified the OFMR leadership of actions taken. After inspection, the team confirmed that there were no problems associated with the utilities or with broken glass, and this information was passed to the NMAH director and the OPS. At this point the director allowed employees back into the museum to retrieve personal items and released everyone for the day, except select curatorial and collections management staff who were going to inspect for any collections damage.

An important point to remember is that immediate evacuation of both public and staff from buildings is not the proper protocol during an earthquake. Lack of experience prompted the immediate evacuations, and these were poorly managed. The designated gathering places were not generally known by staff, and this was compounded by the initial lack of communication systems. The response of OPS staff in the evacuations was not uniform: in some buildings they evacuated both staff and visitors but not in others. Therefore, training for this type of disaster needs to be addressed, in particular the evacuation of public from the museums, and especially those with disabilities.

LESSONS LEARNED: WHAT NEEDS TO BE IMPROVED

While overall the response to the earthquake was appropriate and efficient, the following points listed below will help in improving future response to unexpected events:

- Reinforce that human safety always takes precedence over collections assessment and recovery, including the necessity for some buildings to undergo more extensive assessments of structural integrity than others, rendering them closed to collections responders for a longer period of time than are other buildings.
- Develop a standard protocol regarding what OPS units must do in case of earthquake emergencies so that they are better equipped to take charge and lead.
- Arrange for critical facilities staff to access the buildings immediately in order to assess damages.
- Improve communication between the OEDC and the OFMR, especially with regard to assessments and repairs, for example, regarding what structural engineers should see and evaluate.
- Improve communication between units within the OFEO.
- Define the chain of command. In some cases, employees were not sure whether to follow instructions from the OPS, the specific unit, or the OFMR.
- Clearly designate incident command post locations both inside and outside each facility so staff know where to report new information and receive status updates.

- Set up guidelines and protocols for emergency situations along with an incident command system, then train SI staff to follow them.
- Coordinate with other federal agencies and sister institutions, especially on or near the Mall, as their evacuation plans may directly impact SI procedures and protocols.
- Do not make decisions based on incomplete information. The central EOC made some initial decisions, such as that it was safe to re-enter buildings, without having full information available from non-Mall facilities where it was *not* safe to enter the buildings.
- Share immediately structural analysis reports once received by the OEDC with all members of the integrated facility team.
- Resolve electronic communication issues. There was limited cell phone coverage inside buildings, and maintenance staff did not have radio communication. These problems were reported at the MSC in Suitland, Maryland, various SI sites on the National Mall, and at the National Zoo. Building management could not reach the OPS or museum staff. Verizon seemed to be the best carrier, while Sprint and AT&T were less reliable for cell phone communication.
- Expand risk assessment for exhibition preparation to include seismic events during development of exhibition mounts.
- Ensure quality control during installation and periodic inspection of stability of collections storage equipment.
- Reassess current collections storage, exhibition methodologies, and preventive housing practices to minimize damage to collections in the event of a future seismic event; understand that adjustments may involve associated costs.
- Establish better guidance regarding the funding of collections storage equipment repairs or replacement and collections-specific actions to support immediate and short-term unit recovery efforts.
- In shared facilities, ensure emergency plans address prioritization of critical needs and orchestration of available resources so response is coordinated in the most effective manner.

SUGGESTIONS FOR FUTURE APPROACHES

The low incidence of significant earthquakes on the eastern coast was the main reason the Disaster Management Program (DMP) did not emphasize specific awareness and training regarding such an event. Nonetheless, the DMP allowed for adequate management of the emergency. It has become evident that information regarding earthquake preparedness is necessary, but it should be in proportion to that required for more frequent natural disasters, such as hurricanes or snow storms.

Based on the gained experience, the following recommendations are offered:

1. Prepare and distribute informative material regarding earthquakes and correct response procedures.
2. Develop and implement emergency preparedness and response training courses for diverse natural disasters, including earthquakes.
3. Improve SI collections emergency management, planning, preparedness, and response.
4. Establish indefinite delivery–indefinite quantity contracts for a variety of services to ensure emergency response and recovery is without delay.
5. Improve communication among all members of the central EOC.
6. Improve communications between the central EOC and the SI units, especially in the case where evacuation of one or more units is considered necessary.
7. Standardize check-in procedures between central EOC and unit–facility ECC staff to ensure that all units have reported conditions at their facilities in a consistent manner.
8. Standardize forms for recording events and updates from the SI Disaster Management Program and business continuity plan and ensure that forms are readily available to report damage.
9. Improve radio communications.
10. Provide Office of the Chief Information Officer with backup telephone numbers for use during emergencies as current capacity cannot handle the increase of calls.
11. Create a less cumbersome all-directors teleconference system.
12. Provide regular communications with emergency information via OPS to all SI staff.
13. Publicize the SharePoint website dedicated to the Disaster Management Program.
14. Arrange for EOC to set up emergency contact organizationally, not geographically, as some unit directors do not share facilities.
15. Send periodic reminders to SI staff and volunteers to subscribe to the SI alert system.

To address the development of training courses to prepare staff for emergencies, a list of entities that provide training alternatives for self-reliance during emergencies is provided in an Appendix at the end of this chapter.

Acknowledgments

The collaboration of Paula T. DePriest, Ann Juneau, Mary Rogers, and Elizabeth Dietrich in providing suggestions and recommendations included in this chapter is gratefully acknowledged. The information presented in the Appendix was kindly provided by Ann Juneau.

APPENDIX: TRAINING ALTERNATIVES FOR SELF RESILIENCE DURING EMERGENCIES

Community Emergency Response Team

The Community Emergency Response Team (CERT) was originated in 1985 by the Los Angeles Fire Department to train private citizens and government employees to help themselves, their neighbors, and first responders. There are now community training groups across the country. The Federal Emergency Management Agency (FEMA) recognizes the importance of preparing citizens. The Emergency Management Institute and the National Fire Academy adopted and expanded CERT materials believing them applicable to all hazards. The basic training components of CERT include disaster preparedness, disaster fire suppression, disaster medical operations, light search and rescue operations, disaster psychology and team organization, course review, and disaster simulation.

Local CERT groups can be found in Montgomery County, Prince George's County, City of Laurel, Anne Arundel County, and City of Annapolis in Maryland and Arlington County, Fairfax County, Falls Church, and City of Alexandria in Virginia.

Red Cross CPR, First Aid, and Automated External Defibrillator Certifications

Red Cross certification is valid for two years. In person and web-based training is available. Red Cross first aid, CPR, and automated external defibrillator training incorporates the latest scientific guidelines and aligns with the Occupational Safety and Health Administration's best practices for workplace first aid training programs. The Red Cross has an app that can be downloaded to smartphones and other such devices from their web page on earthquakes: http://www.redcross.org/mobile-apps/earthquake-app.

Ready

Sponsored by Homeland Security and FEMA, the Ready (*Listo* in Spanish) website (http://www.ready.gov/) is a national public service campaign to educate the public about how to prepare and respond to emergencies. Emergencies of all flavors are included.

National Library of Medicine's Disaster Information Management Center

This website (http://disaster.nlm.nih.gov/) has up to the minute information for disasters and health conditions making the daily news, providing quick access to hazardous materials (HazMat) databases for first responders. Designed for librarians and first responders in the medical and disaster response communities, it has a very broad content including that of cultural heritage workers.

Disaster Information Management Research Center

Sponsored by the National Library of Medicine's Disaster Information Management Center, the DISASTR-OUTREACH-LIB listserv (http://sis.nlm.nih.gov/dimrc/dimrclistserv.html) is very active with a widespread membership from the library, medical, public health, environmental, first responder, and other communities. As described in the website, "As a participant in this listserv, you can stay informed about current disaster-related resources, connect to colleagues in the field, engage in information exchange and learn about new ideas, trends, training opportunities, and conferences in the area of disaster health information. Click here for a list of the news sources scanned for weekly news updates sent on this listserv."

Epilogue: Ask Yourself "What if . . . ?"

By failing to prepare, you are preparing to fail.—Benjamin Franklin

Smithsonian staff and other volunteers working in Haiti after the devastating 2010 earthquake were amazed at the bravery and resilience of our Haitian colleagues. We knew that staff at the Centre D'Art (Haitian Art Center) in Port-au-Prince began working very quickly after the earthquake to salvage thousands of works of art of critical importance to Haiti's cultural patrimony from their damaged building. In those same dark days, members of the Nader family salvaged thousands of paintings from the Nader Museum, rehousing them in their gallery in Pétion-Ville. My personal inspiration was architect and artist Patrick Villaire, who took it upon himself immediately following the quake to check in with the owners of some of the most important public and private collections around Port-au-Prince. Using his own truck and work crew, he helped many of these owners salvage and rehouse collections of rare books, paintings, and works of art.

Those of us volunteering at the Cultural Recovery Center after the earthquake often gathered in the evenings after dinner, and sometimes the conversation came around to the "what if?" question: "What if I found myself in such a disaster? How would I react? What if that was my collection? Could I make those hard decisions about which objects to save and which to leave behind?" As so often happens when contemplating the worst case scenario, some of us retreated, shaking our heads and saying, "Let's hope I never have to worry about something that bad." Unfortunately, hope is not a plan. While the 5.8 Mineral, Virginia, earthquake that struck on 23 August 2011 caused a mere shadow of the devastation caused by Haiti's 7.0 earthquake, it was a reminder that even so-called "once in a lifetime" events require appropriate risk assessment and planning to mitigate their effects on people and collections.

This series of essays provides an overview of how the Smithsonian Institution's various museums and storage areas were affected by the 2011 earthquake. If you read between the lines, you can also get a sense of how it affected the staff. Everyone reacted quickly and for the most part correctly, yet there were plenty of important lessons learned. Remember that an earthquake means shelter in place; increase the space between objects in storage cabinets so there is less chance of breakage; ensure the rails on fluid collections storage shelves are secured; and so forth. All of these are fairly easy to comply with, but one thing we know about human behavior is that lessons learned often become "lessons identified" over time. Sometimes even the easy fixes don't get accomplished as we return to our normal routines. Those who directly experienced the disaster move on to other jobs, and the daily demands of the job take over. It doesn't take long before hope, once again, becomes the plan.

One of the best ways to prevent this vicious cycle is to set aside a specific time of year to update as well as *train and exercise* the emergency plan. Most institutions have a written emergency plan, but few regularly communicate that plan to staff; even fewer actually carry out training drills. Emergency response professionals, the military, and law enforcement all know that training, drill, and repetition are necessary elements for teams to ensure quick reaction time, better teamwork, and increased resiliency after the disaster. One way to get into a routine about emergency planning is to observe the annual "May Day" campaign promoted by Heritage Preservation ("Do One Thing for Emergency Preparedness" at http://www.heritagepreservation.org/mayday/). Planning time to plan is the first step.

It may be an old adage in the disaster preparedness field, yet it remains true no matter how many times we hear it: we do not have control over the disaster, but we DO have control over how we prepare.

Corine Wegener
Cultural Heritage Preservation Officer
Office of the Under Secretary for History, Art, and Culture
Smithsonian Institution

Bibliography

Buildings

Amaratunga, D., and R. Haigh, eds. 2011. *Post-Disaster Reconstruction of the Built Environment: Rebuilding for Resilience*. Chichester, UK: Wiley-Blackwell. doi.org/10.1002/9781444344943.

Asia-Pacific Cultural Centre for UNESCO (ACCU). 2007. *1st International Conference on Risk Management: Is the World Heritage Endangered Today*? Nara, Japan: ACCU, Cultural Heritage Protection Cooperation Office.

———. 2009. *3rd International Conference on Risk Management: Reducing Vulnerability to Disasters in Historic Cities*. Nara, Japan: ACCU, Cultural Heritage Protection Cooperation Office.

Government of Spain. 2012. Patrimonio en riesgo: Seismos y bienes culturales [Heritage at risk: Earthquakes and cultural property]. *Revista Patrimonio Cultural de España* 6. Madrid: Ministerio de Educación, Cultura y Deporte. http://www.calameo.com/read/000075335fb4cfb209514 (accessed 2 June 2014).

Matthews, G., Y. Smith, and G. Knowles. 2009. *Disaster Management in Archives, Libraries and Museums*. Farnham, UK: Ashgate Publishing.

Stewart, D., and D. Tremain. 1996. *Emergency and Disaster Preparedness for Museums*. Ottawa: Department of Canadian Heritage, Canadian Conservation Institute.

United Nations Educational, Scientific, and Cultural Organization (UNESCO). 2010. Managing Disaster Risks for World Heritage. Paris: UNESCO. http://whc.unesco.org/en/activities/630/ (accessed 2 June 2014).

Collection Display and Storage

Accardo, G., A. Altieri, A. Cacace, E. Giani, and A. M. Giovagnoli. 2003. "Risk Map: A Project to Aid Decision-Making in the Protection, Preservation and Conservation of Italian Cultural Heritage." In *Conservation Science 2002*, eds. J. H. Townsend, K. Eremin, and A. Adriaens, pp. 44–49. London: Archetype Publications.

Berke, P., and T. Beatley. 1992. *Planning for Earthquakes: Risk, Politics, and Policy*. Baltimore: Johns Hopkins University Press.

Dorge, V., W. Faulk, and J. M. Martínez. 2002. "Emergency Planning for Cultural Institutions: The Process and Some of Its Challenges." In *13th Triennial Meeting, Rio de Janeiro: International Council of Museums Committee for Conservation Preprints*, ed. Roy Vontobel, pp. 27–33. London: Earthscan.

Erturk, N. 2005. "Earthquake Preparedness at the Istanbul Museums." In *Preparing for the Worst, Planning for the Best: Protecting Our Cultural Heritage from Disaster,* ed. J. G. Wellheiser and N. E. Gwinn, pp. 53–59. *International Federation of Library Associations and Institutions Publication* 111. Munich: De Gruyter Saur.

Government of Spain. 2012. Patrimonio en riesgo: Seismos y bienes culturales [Heritage at risk: Earthquakes and cultural property]. *Revista Patrimonio Cultural de España* 6. Madrid: Ministerio de Educación, Cultura y Deporte. http://www.calameo.com/read/000075335fb4cfb209514 (accessed 2 June 2014).

Lowry, M., B. J. Farrar, D. Armendariz, and J. Podany. 2007. "Protecting Collections in the J. P. Getty Museum from Earthquake Damage." *Western Association for Art Conservation (WAAC)*

Newsletter 9 (3): 16–23. http://cool.conservation-us.org/waac/wn/wn29/wn29-3/wn29-305.pdf (accessed 2 June 2014).

Norris, D. H. 1998. *Disaster Recovery: Salvaging Photograph Collections*. Philadelphia: Conservation Center for Art and Historic Artifacts. http://www.ccaha.org/uploads/media_items/technical-bulletin-salvaging-photographs.original.pdf (accessed 2 June 2014).

Rebière, J., ed. 2003. *Congrès International: Prévention 2000: La prévention des sinistres dans les aires de stockage du patrimoine* [Prevention of disasters in cultural heritage storage areas]. Draguignan, France: Centre Archéologique du Var. http://www.art-conservation.fr/colloques/2000/prevention_2000.pdf (accessed 2 June 2014).

Disaster Planning

Ashley-Smith, J. 1999. *Risk Assessment for Objects Conservation*. Oxford, UK: Butterworth-Heinemann.

Asia-Pacific Cultural Centre for UNESCO (ACCU). 2008. *2nd International Conference on Risk Management: Planning Risk Preparedness for Cultural Heritage Against Natural Disasters*. Nara, Japan: ACCU, Cultural Heritage Protection Cooperation Office.

Cornu, E. 1991. "Seismic Disaster Planning: Preventive Measures Make a Difference." *Western Association for Art Conservation (WAAC) Newsletter* 13 (3): 13–19. http://cool.conservation-us.org/waac/wn/wn13/wn13-3/wn13-306.html (accessed 2 June 2014).

Dorge, V., and S. L. Jones, compilers. 1999. *Building an Emergency Plan: A Guide for Museums and Other Cultural Institutions*. Los Angeles: Getty Conservation Institute. http://www.getty.edu/conservation/publications_resources/pdf_publications/emergency.html (accessed 2 June 2014).

Edwards Information. 2011. *Edwards Information Emergency Planning and Disaster Recovery Sourcebook*. Ashton, Md.: Edwards Information.

Feilden, B. M. 1987. *Between Two Earthquakes: Cultural Property in Seismic Zones*. Rome: International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM); Marina del Rey, Calif.: Getty Conservation Institute. http://www.getty.edu/conservation/publications_resources/pdf_publications/between_two.html (accessed June 2 2014).

Government of Spain. 2012. Patrimonio en riesgo: Seismos y bienes culturales [Heritage at risk: Earthquakes and cultural property]. *Revista Patrimonio Cultural de España* 6. Madrid: Ministerio de Educación, Cultura y Deporte. http://www.calameo.com/read/000075335fb4cfb209514 (accessed 2 June 2014).

Handmer, J. W., and S. Dovers. 2007. *The Handbook of Disaster and Emergency Policies and Institutions*. London: Earthscan.

Hawks, C. A., and S. H. Butts, eds. 2011. *Health & Safety for Museum Professionals*. New York: Society for the Preservation of Natural History Collections; Washington, D.C.: American Institute for Conservation of Historic and Artistic Works, Health and Safety Committee.

Heritage Preservation. 2006. *Field Guide to Emergency Response*. Washington, D.C.: Heritage Preservation.

International Council of Museums (ICOM). n.d. *Guidelines for Disaster Preparedness in Museums*. http://icom.museum/fileadmin/user_upload/pdf/Guidelines/guidelinesdisasters_eng.pdf (accessed 2 June 2014).

Jenner, S.-J. 2006. "From disaster plan to action plan." In *Proceedings of the International Symposium: The 3-D's of Preservation: Disasters, Displays, Digitization,* ed. C. Koch, pp. 34–38. *International Preservation Issues* 7. Paris: International Federation of Library Associations and Institutions Core Activity on Preservation and Conservation. http://archive.ifla.org/VI/4/news/ipi7-en.pdf (accessed 2 June 2014).

Jigyasu, R., and K. Masuda, eds. 2005. *Cultural Heritage Risk Management. World Conference on Disaster Reduction, Kyoto & Kobe, Japan, 15th-22nd January, 2005: Proceedings*. Kyoto: Rits- DMUCH (Ritsumeikan Daigaku Research Center for Disaster Mitigation of Urban Cultural Heritage).

Jirasek, P. 1997. Prevention and emergency plans in museums, historic monuments, churches and libraries. *ICOM International Committee on Museum Security Study Series* 4:9–12.

———. 2004. "Museum Security and Disaster Preparedness." In *Running a Museum: A Practical Handbook,* ed. P. J. Boylan, pp. 177–193. Paris: International Council of Museums (ICOM) and United Nations Educational, Scientific, and Cultural Organization (UNESCO). http://unesdoc.unesco.org/images/0014/001410/141067e.pdf (accessed 2 June 2014).

Jones, B. G. 1986. *Protecting Historic Architecture and Museum Collections from Natural Disasters*. Boston: Butterworths.

Knight, B., and S. P. Floray. 2005. Museum Staff Emergency Procedures: A Sample Emergency "Flip Chart." *Conserve O Gram* 21/11. Washington, D.C.: U.S. National Park Service. http://www.nps.gov/history/museum/publications/conserveogram/21-11.pdf (accessed 2 June 2014).

Lewitt, A. M. 1997. *Disaster Planning and Recovery: A Guide for Facility Professionals*. New York: John Wiley and Sons.

Liston, D., ed. 1993. *Museum Security and Protection: A Handbook for Cultural Heritage Institutions.* International Council of Museums (ICOM) International Committee on Museum Security. London: Routledge.

Lord, A., C. Reno, and M. Demeroukas. 1994. *Steal This Handbook! A Template for Creating a Museum's Emergency Preparedness Plan*. Columbia, S.C.: Southeastern Registrars Association.

McIlwaine, J. 2006. "International Federation of Library Associations Disaster Preparedness and Planning: A Brief Manual." *International Preservation Issues* 7. Paris: International Federation of Library Associations and Institutions Core Activity on Preservation and Conservation. http://www.ifla.org/files/assets/pac/ipi/ipi6-en.pdf (accessed 2 June 2014).

Meister, P., ed. 1991. *1991 Disaster Preparedness Seminar Proceedings*. Baton Rouge, La.: Southeastern Museums Conference and Institute of Museum Services.

Menegazzi, C., and I. Brianso, eds. 2004. *Cultural Heritage, Disaster Preparedness and Response.* Paris: International Council of Museums (ICOM). http://archives.icom.museum/disaster_preparedness_book/index.html (accessed 2 June 2014).

Merrill, A. T., ed. 2003. *The Strategic Stewardship of Cultural Resources: To Preserve and Protect*. New York: Haworth Information Press.

Ramroth, W. G. 2007. *Planning for Disaster: How Natural and Man-Made Disasters Shape the Built Environment*. New York: Kaplan Publishing.

Stovel, H. 1998. *Risk Preparedness: A Guide for Museums and Other Cultural Institutions*. Rome: International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM). http://www.iccrom.org/ifrcdn/pdf/ICCROM_17_RiskPreparedness_en.pdf (accessed 2 June 2014).

Verberne-Khurshid, F., R. Boitelle, D. Ormond, and R. van Gulik. 2008. "Disaster Is Just a Step Away: Working at Being a Step Ahead." In *15th Triennial Conference, New Delhi, International Council of Museums Committee for Conservation Preprints*, ed. J. Bridgland, pp. 798–807. Paris: International Council of Museums Committee for Conservation.

Weise, K., and A. S. Weise, eds. 2010. *Proceedings of the International Training Course on Disaster Risk Management of Cultural Heritage: 2010, 5th Year, 13th to 26th September 2010, Kyoto, Kobe, Sasayama, Japan.* Kyoto: Rits- DMUCH (Ritsumeikan University Research Center for Disaster Mitigation of Urban Cultural Heritage and International Council of Monuments and Sites [ICOMOS]).

Wellheiser, J. G., and J. Scott. 2002. *An Ounce of Prevention: Integrated Disaster Planning for Archives, Libraries, and Record Centres,* 2nd ed. Lanham, Md.; Scarecrow Press; Toronto: Canadian Archives Foundation.

General

AlabamaQuake.com. 2014. "Locating Earthquakes." *Earthquake and Seismic Education*. http://alabamaquake.com/education.html (accessed 2 June 2014).

Government of Spain. 2012. Patrimonio en riesgo: Seismos y bienes culturales [Heritage at risk: Earthquakes and cultural property]. *Revista Patrimonio Cultural de España* 6. Madrid: Ministerio de Educación, Cultura y Deporte. http://www.calameo.com/read/000075335fb4cfb209514 (accessed 2 June 2014).

International Council of Museums (ICOM). 2011. Haïti, Cultural Heritage and Reconstruction. *Museum International* No. 248 (Vol. 62, Issue no. 4, December 2010): 5–124. (Some articles can be downloaded from http://onlinelibrary.wiley.com/doi/10.1111/muse.2011.62.issue-4/issuetoc.)

Haiti Cultural Recovery Project. 2010. Bibliographie. Aide d'urgence pour le patrimoine culturel haïtien [Bibliography. First aid for Haitian cultural heritage]. Port au Prince: International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) and Smithsonian Institution. http://www.iccrom.org/ifrcdn/fra/prog_fr/01coll_fr/archive-haiti_fr/2010_09HaiticourseBiblio.pdf (accessed 5 June 2014).

Koch, C., ed. 2008. "Proceedings of the International Symposium: The 3-D's of Preservation: Disasters, Displays, Digitization." *International Preservation Issues* 7. Paris: International Federation of Library Associations and Institutions Core Activity on Preservation and Conservation. http://archive.ifla.org/VI/4/news/ipi7-en.pdf (accessed 2 June 2014).

Human Reactions

Alcántara, I., and A. Goudie, eds. 2010. *Geomorphological Hazards and Disaster Prevention*. Cambridge, UK: Cambridge University Press. http://dx.doi.org/10.1017/CBO9780511807527.

Dörner, D. 1996. *The Logic of Failure: Recognizing and Avoiding Error in Complex Situations*. Translated by R. and R. Kimber. Cambridge, Mass.: Perseus Books; New York: Metropolitan Books.

Klein, N. 2007. *The Shock Doctrine*: *The Rise of Disaster Capitalism*. New York: Henry Holt and Company/Picador.

Massey University, School of Psychology. 2011. A Focus on the Canterbury Earthquakes. *Australasian Journal of Disaster and Trauma Studies* 2011-2, Special Issue. Palmerston North, New Zealand: Author. http://www.massey.ac.nz/~trauma/issues/2011-2/contents.htm (accessed 2 June 2014).

REQUIREMENTS FOR SMITHSONIAN SERIES PUBLICATION

ALL MANUSCRIPTS ARE REVIEWED FOR ADHERENCE TO THE SISP MANUSCRIPT PREPARATION AND STYLE GUIDE FOR AUTHORS (available on the "Submissions" page at www.scholarlypress.si.edu). Manuscripts not in compliance will be returned to the author. Manuscripts intended for publication in the Contributions Series are evaluated by a content review board and undergo substantive peer review. Accepted manuscripts are submitted for funding approval and scheduling to the Publications Oversight Board.

MINIMUM MANUSCRIPT LENGTH is thirty manuscript pages. If a manuscript is longer than average, an appropriate length will be determined during peer review and evaluation by the Content Review Board. Authors may be asked to edit manuscripts that are determined to be too long.

TEXT must be prepared in a recent version of Microsoft Word; use a Times font in 12 point for regular text; be double spaced; and have 1" margins. Each chapter/section must be saved in a separate file.

REQUIRED ELEMENTS are title page, abstract page, table of contents, main text, and reference section. See the SISP Manuscript Preparation and Style Guide for Authors for the order of all elements.

HEADINGS should be styled so different levels of headings are distinct from each other and so the organization of the manuscript is clear. Insert one line space above and one line space below all headings.

FRONT MATTER should include title page, abstract page, and table of contents. All other sections are optional. Abstracts must not exceed 300 words. Table of contents should include A-, B-, and C-level headings.

TABLES (numbered, with captions, stubs, rules) should be submitted in separate MS Word files; should include footnotes, if appropriate; should have rules only at top, bottom, and beneath column heads. Print outs of each table should accompany the manuscript to ensure correct layout of data. Tabulations within running text should not be numbered or formatted like formal tables, and should be included in the text of the manuscript.

FIGURE CAPTIONS should be provided in a separate MS Word file.

FIGURES (e.g., photographs, line art, maps) should be numbered sequentially (1, 2, 3, etc.) in the order called out; be placed throughout text, not at end of manuscript; have all components of composites lettered with lowercase letters and described in the caption; include a scale bar or scale description, if appropriate; include any legends in or on the figure rather than in a caption.

ART must not be embedded in the main text.

Figures must be original and submitted as individual TIFF or EPS files. Resolution for art files must be at least 300 dpi for grayscale and color images and at least 1200 dpi for line art. Electronic images should measure no more than 100% and no less than 75% of final size when published. JPG files will not be accepted. Color images significantly increase costs so should be included only if required. Funding for color art is subject to approval by SISP and the Publications Oversight Board.

IN-TEXT REFERENCES should be used rather than bibliographic notes and should follow the author-date system in the following format: "(author last name, year)" or ". . . author (year)"; "(author, year:page used within the text)" or ". . . author (year:page)." A full citation should be included in a "References" section.

ENDNOTES are to be used in lieu of footnotes and should be keyed manually into a separate MS Word file, in a section titled "Notes". Notes should not contain bibliographic information. Manually type superscript numerals in text and use full-sized numerals at the beginning of each note in the "Notes" section. SISP will determine the best placement of the notes section, either at the end of each chapter or at the end of the main text.

REFERENCES should be in alphabetical order, and in chronological order for same-author entries. Each reference should be cited at least once in main text. Complete bibliographic information must be included in all citations (e.g., author/editor, title, subtitle, edition, volume, issue, pages, figures). For books, place of publication and publisher are required. For journals, use the parentheses system for volume(number):pagination [e.g., "10(2):5–9"]. Do not use "et al."; all authors/editors should be included in reference citations. In titles, capitalize first word, last word, first word after colon, and all other words except articles, conjunctions, and prepositions. Examples of the most common types of citations are provided in the SISP Manuscript Preparation and Author Style Guide.

For questions regarding the guidelines, please email SISP at schol.press@si.edu.