Department of Defense
Legacy Resource Management Program

PROJECT 15-707 s

20th-CENTURY BUILDING MATERIALS AND SUITABLE SUBSTITUTES: EXTERIOR MATERIALS

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January 2017s

20TH-CENTURY BUILDING MATERIALS AND SUITABLE SUBSTITUTES: *Exterior Materials*

PREPARED FOR:
Department of Defense
Legacy Resource Management Program
[Project 15-707]

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JANUARY 2017

Executive Summary

The Department of Defense (DoD) owns or manages over 340,000 buildings, of which approximately 140,000 are 50 years of age or older; the majority of these buildings were constructed during the twentieth century (Aaron & Childers 2011:1). Within the past two decades, many of these twentieth-century buildings and complexes have been determined eligible for listing in the National Register of Historic Places (NRHP), as mid-century buildings are reaching the 50-year age threshold. Throughout the DoD, these twentieth-century historic buildings are facing a critical point as the materials used in their construction reach the end of their serviceable lives, and true replacement in-kind is not an option due to product unavailability, regulatory requirements, or inherent flaws in construction. These constraints, in turn, require a creative approach to determine sensitive replacement options when dealing with character-defining features of historic buildings, as the work undertaken on these buildings is subject to federal preservation standards and review procedures under Section 106 of the National Historic Preservation Act of 1966 (NHPA; as amended).

A 2013 survey of DoD Cultural Resources Managers (CRMs) in the Mid-Atlantic and New England regions identified some of the greatest challenges to maintaining historic twentieth-century DoD buildings. A.D. Marble and Naval Facilities Engineering Command, Mid-Atlantic (NAVFAC MIDLANT) submitted the FY13 Legacy Resource Management Project (Legacy Project) 20th-Century Building Materials and Suitable Substitutes: Windows (Legacy Project 13-707) in 2014, which focused on suitable substitutes for twentieth-century window types, including steel, corrugated wire glass, and glass block, which are identified as character-defining features of historic twentieth-century DoD buildings. The 2013 survey of DoD CRMs also identified the problematic repair and replacement of several exterior cladding materials: cast-in-place and precast concrete, corrugated metal siding, and asbestos-cement roof panels and siding. The FY15 Legacy Project 20th-Century Building Materials and Suitable Substitutes: Exterior Materials (Legacy Project 15-07) investigates problem areas associated with repair or in-kind replacement of these materials and addresses possible suitable substitute materials. This report also presents the history of each material, identifying its unique characteristics and special circumstances that led to its development. When an adverse effect cannot be avoided, it is the intent of this report to utilize the history presented to prepare mitigation documentation.

The aim of this report is to serve as a useful tool that will assist DoD CRMs, facility planners, architects, and engineers responsible for the maintenance and repair of historic twentieth-century buildings in expediting and complying with

Section 106 of the NHPA. This report provides a summary of evaluating repair versus replacement options for historic exterior materials. When replacement is warranted, this report identifies acceptable substitute materials that meet the Secretary of the Interior's Standards for the Treatment of Historic Properties, as well as minimization measures that are acceptable to respective State Historic Preservation Offices (SHPOs), thereby avoiding or minimizing adverse effects to historic properties and ultimately preserving their historic integrities while enhancing future sustainability.

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ABBREVIATIONS/ACRONYMS

ACM	Asbestos Containing Material
AT	Antiterrorism
ATFP	Antiterrorism/Force Protection
ATSDR	Agency for Toxic Substances and Disease Registry
BTHL	Building Technology Heritage Library
BRAC	Base Realignment and Closure
CAA	Clean Air Act
CAD	Cartridge-Activated Device
CNRMA	Commander, Navy Region Mid-Atlantic
CRM	Cultural Resources Manager
CWA	Civilian Works Administration
DoD	Department of Defense
EPA	Environmental Protection Agency
FY	Fiscal Year
HABS	Historic American Buildings Survey
HAER	Historic American Engineering Record
HEPA	High Efficiency Particulate Air
ICRMP	Integrated Cultural Resources Management Plan
Legacy	Legacy Resource Management Program
MHT	Maryland Historical Trust
NAVFAC MIDLANT	Naval Facilities Engineering Command, Mid-Atlantic
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NHL	National Historic Landmark

NHPA	National Historical Preservation Act
NJHPO	New Jersey's Historic Preservation Office
NMRI	Naval Medical Research Institute
NNMC	National Naval Medical Center
NNSY	Norfolk Naval Shipyard
NSA	Naval Support Activity
NSF	Naval Support Facility
NSFC	Naval Support Facility Carderock
NSWC, IHEODTD	Naval Surface Warfare Center, Indian Head Explosive Ordnance Disposal Technology Division
NPS	National Park Service
NRHP	National Register of Historic Places
NSW	New South Wales
PCA	Portland Cement Association
psi	Pounds per square inch
SHPO	State Historic Preservation Office
SOI	Secretary of the Interior
SOI Standards	The Secretary of the Interior's Standards for the Treatment of Historic Properties
UFC	Unified Facilities Criteria
UV	Ultraviolet
VOC	Volatile Organic Compound
WPA	Works Progress Administration
WRNMMC	Walter Reed National Military Medical Center

Acknowledgements

This project and subsequent report were funded by the Department of Defense (DoD) Legacy Resource Management Program (Legacy) in fiscal year (FY) 2015 (Legacy Project 15-707). A.D. Marble and Naval Facilities Engineering Command, Mid-Atlantic (NAVFAC MIDLANT) would like to acknowledge the following for their support and assistance in completing this project: Jason Huggan, Picatinny Arsenal; Karrie Reckley, Naval Support Activity (NSA) Bethesda; Thomas Wright, Naval Support Facility (NSF) Indian Head; Jennifer Pipe, NSF Carderock; Heather Robbins and Katherine Childs, NAVFAC MIDLANT; Julie Darsie, Naval Facilities Engineering Command, Washington (NAVFAC Washington); the remaining Cultural Resources Managers (CRMs) and their designates throughout the Northeast and Mid-Atlantic regions who responded to our initial survey; Amanda Apple of the Maryland Historical Trust (MHT); Emma Diehl of the Pennsylvania Historical and Museum Commission (PHMC); and Michelle Craren of the New Jersey Historic Preservation Office (NJHPO).

1.0 Introduction

A.D. Marble, under sponsorship from the Naval Facilities Engineering Command, Mid-Atlantic (NAVFAC MIDLANT), received funding from the Department of Defense (DoD) Legacy Resource Management Program (Legacy) to develop a tool to assist DoD Cultural Resources Managers (CRMs), facility planners, architects, and engineers in the maintenance of the vast number of historic twentieth-century buildings within the DoD real property inventory. This project is a follow-up to the FY13 Legacy Project, *20th-Century Building Materials and Suitable Substitutes: Windows* (Legacy Project 13-707), which focused on suitable substitutes for twentieth-century window types, including steel, corrugated wire glass, and glass block, which were identified as character-defining features of historic twentieth-century DoD buildings. During that study, problematic twentieth-century exterior materials, specifically concrete, corrugated metal, and asbestos-cement, were identified as part of a survey of DoD CRMs. The subsequent research and report were carried out under Legacy Project 15-707 and Cooperative Agreement HQ0034-15-2-0019, from September 2015 to May 2016.

Wartime construction efforts associated with World War I through the Cold War dramatically shaped the built environment at many DoD installations. Within the last two decades, many of these often hastily constructed buildings have been listed in or determined eligible for listing in the National Register of Historic Places (NRHP), either individually or as contributing resources to historic districts. Consequently, the DoD, as a federal agency, has management responsibilities concerning the protection and preservation of the historic properties on land it controls or uses.

Federal statutes require all branches of the DoD to consider the effects of their projects on historic properties and ensure that preservation values are factored into project planning and decisions. While the Department of Defense UFC 1-200-02 report *High Performance and Sustainable Building Requirements* is focused on sustainability, Appendix D of the report provides guidance on the application of SOI Standards in repair, maintenance, and renovation projects (Unified Facilities Criteria [UFC] 2014: 59-63). An overview of the rules and restrictions specific to the Navy and Marine Corps can be found in SECNAV Instruction 4000.35A, which outlines the Department of the Navy Cultural Resources Program and applicable legislation, regulation, directives and guidance (Secretary of the Navy 2001:1-13). An overview of the rules and restrictions specific to the Army can be found in Army Regulation 200-1, which includes an outline of regulations to ensure that installations make informed decisions regarding the cultural resources (Department of the Army 2007:28-30). Instruction regarding the management of cultural resources in the Air Force can be found in Air Force Instruction 32-7065, which outlines required actions and processes for managing and protecting cultural resources (Secretary of the Air Force 2014:1-20). Guidelines for design are available in the Department of Defense Legacy Resource Management Program Project 07-382, Design Guidelines for Department of Defense Historic Buildings and Districts, which is an overview of cultural resource management within the DoD (McDonald and Michael 2008).

Problematically, many of the historic twentieth-century buildings are reaching a point of uncertainty, as materials utilized in their construction reach the end of their serviceable lives. Product unavailability, cost prohibitive reproduction, regulatory restrictions, flawed replacement options, or a combination thereof have resulted in feasibility issues for maintenance, repair, or replacement. In instances where in-kind replacement is not possible, creative approaches are needed to determine sensitive replacement options.

In architecture, exterior materials like roofing and cladding are often the defining characteristic of a style, time period, or method of construction. In particular, for buildings that are not high style, exterior cladding or roofing can sometimes be the only character defining feature. Although materials like concrete, corrugated metal, and asbestos-cement were designed for utility and not for aesthetics, they are character-defining features on countless buildings of the twentieth century. Buildings of this kind were the face of military architecture in the twentieth century. The military embraced high style architecture for important or public buildings, but proportionally, military architecture was defined by secondary or support buildings. These necessary buildings housed functions related to technology, research, artillery, and ordnance through World War I, World War II, and the Cold War. The utilitarian buildings are important to United States history for their functionality, which provided a platform for major United States military successes. The three materials of concrete, corrugated metal, and asbestos-cement were invented, utilized, and maintained due to their inherent practicality. With characteristics like strength, durability, economy, and availability, these materials were integral to the feasibility of wartime construction. Post-war, the buildings were reused for the same characteristics. Although secondary, utilitarian buildings have existed through history, the materials of concrete, corrugated metal, and asbestos-cement are unique in that they represent important technological advancements of their time.

This report is intended to improve the efficiency and effectiveness of compliance with federal regulations concerning historic properties by assisting DoD services in justifying the use of replacement materials for historic twentieth-century buildings. This report focuses specifically on twentieth-century exterior material types utilized in DoD buildings, including concrete, corrugated metal, and asbestos-cement. The purpose of this report is to identify acceptable repair or replacement materials for historic twentieth-century exterior material types that meet the Secretary of the Interior's Standards for the Treatment of Historic Properties (SOI Standards) and State Historic Preservation Office (SHPO) approval. This will help avoid adverse effect findings and lengthy consultations in accordance with the National Historic Preservation Act (NHPA) of 1966, as amended, which includes Section 106 compliance.

This report also provides a detailed history of concrete, corrugated metal, and asbestos-cement as historic twentieth-century DoD building materials (Section 3.0). The history details the development of each material type and addresses its primary use, qualities, characteristics, and architectural impacts. The intent is that this information can be used in the preparation of mitigation documents, such as Historic American Buildings Survey (HABS) or Historic American Engineering Record (HAER) documentation packages, when suitable substitute materials are not available and NHPA Section 106 consultations result in a finding of adverse effect.

The continued use of DoD buildings often necessitates upgrades and changes in order to comply with federal regulations and DoD standards, or to adapt to new uses; consequently, substitute materials are being used more frequently due to cost effectiveness and longevity. With the proper planning, substitute materials can be used successfully in the rehabilitation of a historic building. It is the aim of this report to increase the efficiency of the planning and design process for projects involving adaptive reuse of historic twentieth-century buildings by providing a readily available source of information that will preserve the historic integrity or assist in the recordation of a historic building while providing for its future sustainability.

2.0 Methodology

This project is a follow-up to the FY13 Legacy Project *20th-Century Building Materials and Suitable Substitutes: Windows* (Legacy Project 13-707) that focused on window materials: steel, corrugated wire glass, and glass block. This follow-up study addresses additional examples of twentieth-century exterior cladding materials commonly used at DoD bases that have experienced problems because of repair issues, a lack of suitable replacement materials, or cost issues associated with replacement materials. The materials investigated are concrete (cast-in-place and precast), corrugated metal, and asbestos-cement. As a continuation of the previous study, this report follows the same basic methodology. The geographical limits of study remained confined to the Northeast and Mid-Atlantic regions, from Maine to Virginia, though it is anticipated that the findings presented herein will generally be applicable to other geographic areas that use concrete, corrugated metal, and asbestos-cement in their historic twentieth-century buildings.

The approach to this project was an extension of the methodology of the previous report, in which a CRM survey questionnaire, on-site research, and installation visits identified exterior materials as problematic. The next step was a review of National Park Service (NPS) briefs and other documentation regarding the rehabilitation or replacement of twentieth-century building materials. On-site investigations were completed at various DoD installations, and the corresponding SHPOs were contacted for further information. The methodology took into account lessons learned from the previous project, which guided the organization of this report.

2.1 PRELIMINARY WORK

2.1.1 REVIEW OF EXISTING DOCUMENTATION

A.D. Marble conducted preliminary background research into existing documentation and articles relevant to building materials prior to preparation of the initial project, FY13 Legacy Project *20th-Century Building Materials and Suitable Substitutes: Windows* (Legacy Project 13-707). The purpose of this precursory review was to assess the range and focus of previously published information while avoiding a duplication of efforts and existing products. This task began with the identification and review of previously published resources regarding the history of twentieth-century building materials, including windows, exterior cladding, and roofing.

For the FY15 Legacy Project, researchers reviewed the online library catalogs of multiple research repositories that were determined to have the most extensive architectural collections for sources on exterior cladding and roofing, including the Free Library of Philadelphia, the libraries of the University of Pennsylvania and the University of Maryland, and the Building Technology Heritage Library (BTHL). For a complete list of the previous studies, reports, and publications relevant to this project, consult the Bibliography found in Section 9.0 of this report.

2.1.2 CULTURAL RESOURCES MANAGERS QUESTIONNAIRE

A questionnaire was distributed to DoD CRMs in the Northeast and Mid-Atlantic regions as part of the FY13 Legacy Project *20th-Century Building Materials and Suitable Substitutes: Windows* (Project 13-707). The questionnaire was intended to first identify DoD installations that have historic twentieth-century buildings, then use those results to provide a better understanding of twentieth-century building materials; the problems with those materials; the challenges in finding suitable substitute materials; and also identify success stories regarding rehabilitation. Researchers aimed to not only refine the list of twentieth-century materials for the study, but to also identify key installations for conducting on-site case studies. A.D. Marble developed a survey comprised of ten questions, most of which were multiple choice. The survey questionnaire was distributed to 29 CRMs by NAVFAC MIDLANT in November 2013, including regional- and installation-level personnel representing the Navy, Air Force, Army, and Marine Corps. Eighteen responses were received, and based on the results of the questionnaire, the primary element of concern was windows. As a result, the FY13 Legacy Project *20th-Century Building Materials and Suitable Substitutes: Windows* (Legacy Project 13-707) was prepared. Following windows, the next major concern recorded on the questionnaires was exterior materials; specifically, concrete, corrugated metal, and asbestos-cement, which became the subject of this follow-up report *20th-Century Building Materials and Suitable Substitutes: Exterior Materials*. Appendix C includes a copy of the distributed CRM questionnaire, as well as a summary of the results.

2.2 INTENSIVE WORK

2.2.1 INSTALLATION VISITS

The results of the CRM questionnaire not only helped in refining the scope of work, they also assisted in identifying relevant installations to visit. These visits provided a context within which to evaluate the existing conditions, repairs, replacements, uses, and feasibility of substitute materials (particularly within a larger historic district), and assisted in documenting key factors to consider when assessing project effects with regard to Section 106.

On-site research and documentation was carried out in 2015-2016 at the following DoD installations: Naval Support Activity (NSA) Norfolk Naval Shipyard and St. Juliens Creek Annex (Navy; Virginia); NSA Bethesda

(Navy; Maryland); Naval Support Facility (NSF) Indian Head (Navy; Maryland); Picatinny Arsenal (Army; New Jersey); and NSF Carderock (Navy; Maryland). Each installation's CRM, or the individual acting in this capacity, offered case studies for at least one, if not all three, of the exterior materials. Materials gathered from each installation included copies of Integrated Cultural Resources Management Plans (ICRMPs), building studies, project details, and information regarding SHPO consultation for repair and replacement projects. Photographs of representative examples were taken and are included throughout this report. More information regarding the installations visited as part of this study can be found in Sections 5.0 and 6.0 of this report.

2.2.2 INTENSIVE RESEARCH

Intensive research as identified in the initial task was undertaken concurrently with the installation visits. General and specific archival and documentary records were consulted in order to prepare as comprehensive a history as possible for each exterior material type.

Based on a review of online materials and repository consultation, it was determined that the bulk of materials and sources pertaining to the exterior material types could be located online, including an extensive collection of trade catalogs and manuals available on the BTHL, which was accessed online (BTHL, accessed March 2016). In addition to installation and repository research, other NPS publications were consulted after the refinement of the scope. Specifically, NPS Brief No. 16: *The Use of Substitute Materials on Historic Building Exteriors*; No. 15: *Preservation of Historic Concrete*; and No. 4: *Roofing for Historic Buildings* (Park 1986; Gaudette and Slaton 2007; Sweetser n.d.). Appendix B contains copies of these briefs.

3.0 History of Twentieth-Century Exterior Materials

3.1 INTRODUCTION

The exterior materials of concrete, corrugated metal, and asbestos-cement represent technological advancements in building materials. Each material has a unique history of development, and each was a revolutionary and defining building material of the twentieth century. The principle of "form follows function" defined the Modernist movement, an architectural style that influenced first industrial, then military architecture in its practical efficiency. Concrete, corrugated metal, and asbestos-cement were not designed for aesthetics, but rather for functionality. Military installations are generally defined by the high quantity of support and secondary buildings. The buildings that housed the necessary operational tasks, technology, research, artillery testing, and ordnance storage that supported the United States through World War I, World War II, and the Cold War, were utilitarian, and thus used utilitarian materials.

The movement toward Modernism had begun in Europe and the United States by the end of the nineteenth century. Steel and reinforced concrete structural frames for buildings had been developed, allowing large expanses of glass and more open floor plans (Hampton et al. 2012:10). The first type of architecture in the United States to embrace Modernist ideals was industrial architecture, which developed into Industrial Modernism and utilized the technological advancements of the period. The restrained, practical forms became linked with mass production. This type of building construction was relatively low in cost as well (Hampton et al. 2012:13-14).

The practical approach influenced U.S. military architects during World War I, with a wartime focus on efficiency and budget. The design influences of Industrial Modernism corresponded perfectly to the utilitarian buildings needed on military installations, as well as the availability of common materials like concrete, corrugated metal, and asbestos-cement. Additionally, the World War I era had brought along the development of standard architectural drawings for common building types across the U.S. military to meet the needs of rapid wartime construction, allowing for a mass production of practical, functional utilitarian buildings across U.S. military installations. Industrial Modernism in the U.S. military was adopted for practicality, functionality, and affordability (Hampton et al. 2012:15-18).

Exterior materials like concrete, corrugated metal, and asbestos-cement continued to be primarily used on utilitarian buildings after the war. The uses of these materials on U.S. military bases stayed consistent. As World War II approached and rapid, temporary construction began, the same needs arose for cost efficient, utilitarian structures. The ideals of Industrial Modernism continued using the technology and materials available. The practical materials, like concrete, corrugated metal, and asbestos-cement, made for strong, resilient buildings appropriate for a wide array of uses. As such, many temporary construction buildings intended to only last until the end of the war continue to be in use today (Hampton et al. 2012:32).

The World War II-era mass production techniques and temporary mobilization structures were identified as possibilities for the private sector's focus on prefabrication. The temporary construction efforts of World War II taught the benefits of mass production, standardization, and prefabricated standardized materials (Hampton et al. 2012:32).

The demobilization from World War II occurred during 1946, and the start of the Cold War began in 1947. A large amount of construction occurred across the military in the 1950s as temporary buildings were replaced and new facilities were needed for new technologies (Hampton et al. 2012:37). However, the previous utilitarian buildings, with practical materials, layout, and spaces, were often reused within the military installations.

Concrete, corrugated metal, and asbestos-cement, through their sheer presence and commonality, became integral to U.S military architecture. In order to preserve the integrity of historic twentieth-century buildings, it is imperative to understand the history and development of these building materials, which are detailed in the following sections.

3.2 CONCRETE

Concrete is a versatile composite material made from a mix of cement, aggregate, and water. Cement (a combination of calcium, silica, alumina, iron, and gypsum) has occurred naturally for millions of years as a result of reactions between limestone and oil shales, and concrete is an ancient invention. When aggregate is mixed with cement and water is added, a chemical reaction occurs that hardens the mixture, creating concrete. Historic concrete often had admixtures, which are defined as anything added to concrete that can aid setting properties based on use and environment (Gaudette and Slaton 2007:1; Malhotra and Mehta 1996:1; Gromicko and Shepard n.d., accessed March 2016; Croft 2004:9). The vast improvements to concrete technology through the invention of reinforced concrete and advancements in cement production in the nineteenth century led to concrete becoming the exemplary building material of the twentieth century. Concrete was quickly recognized for its utilitarian benefits as a flexible, versatile, and cost-effective material (Croft 2004:12-14). Concrete was used for a wide array of building types, including military facilities. The popularity and prevalence of concrete continues well into the twenty-first century (Illustrations 1 and 2).

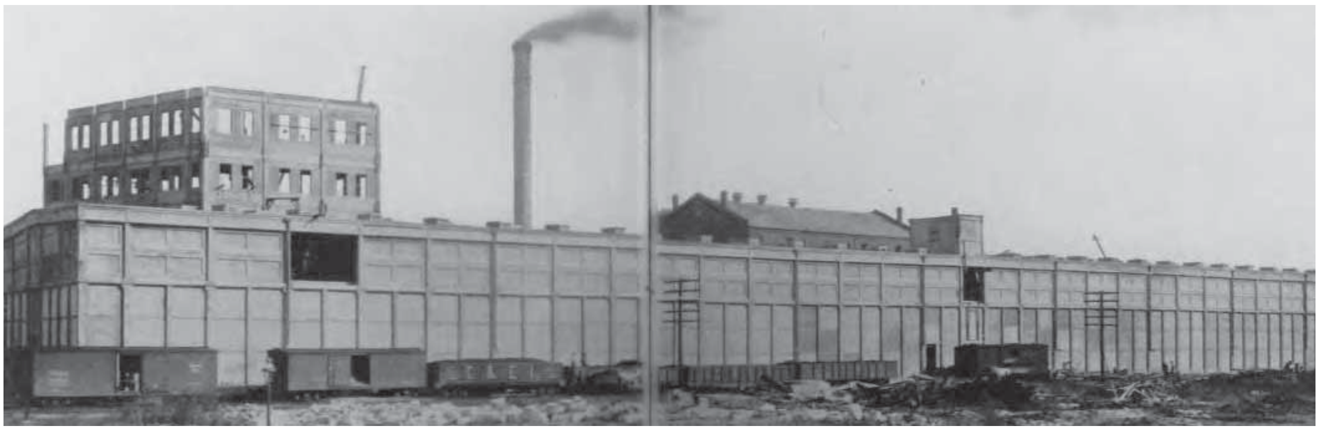


Illustration 1: The exterior of a building within the National Lead Company complex in St. Louis, which was constructed with reinforced precast concrete panels (Unit Construction Co. 1913:16).

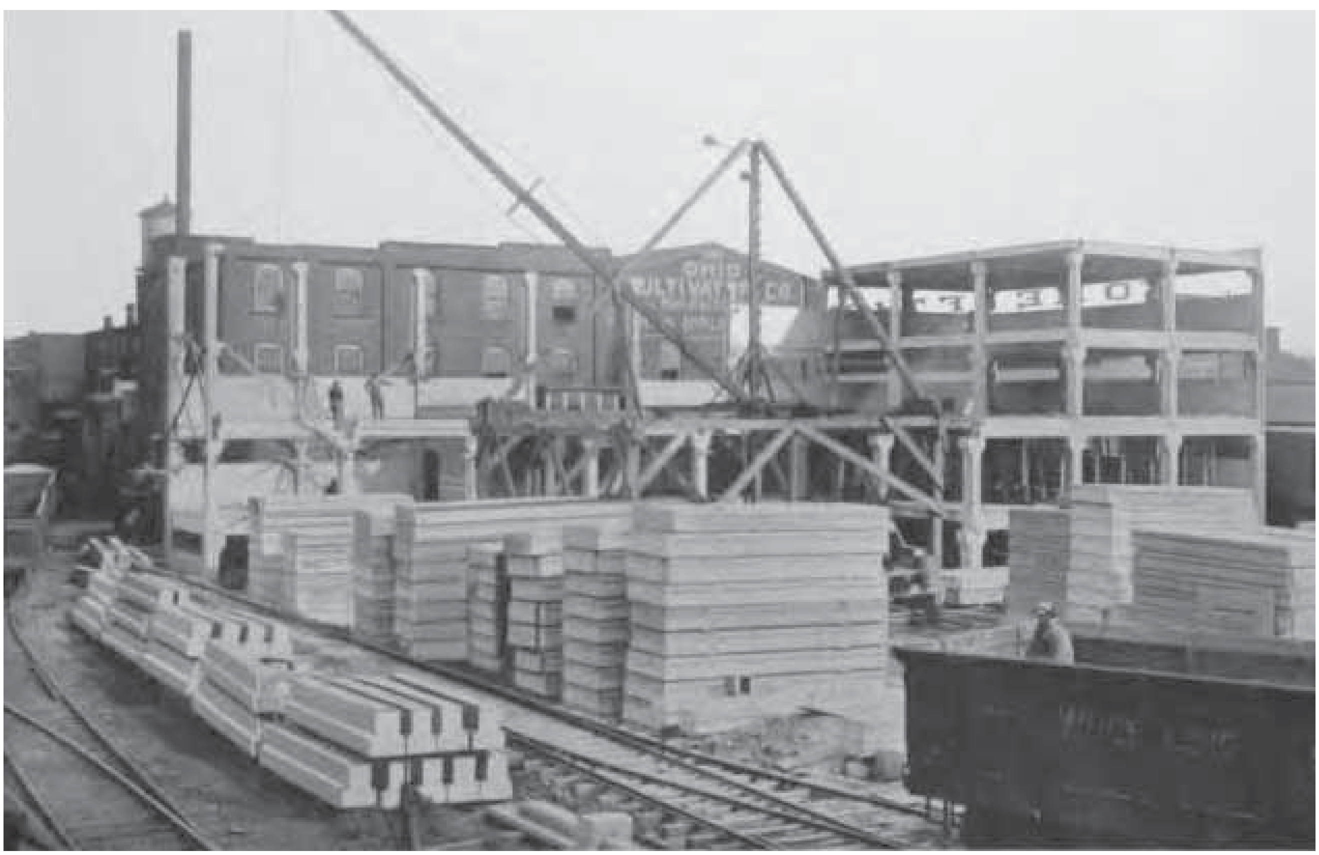


Illustration 2: A precast concrete building within the Ohio Cultivator Co. complex in Bellevue, Ohio, during construction. The precast concrete elements stacked in the foreground were delivered to the site and moved into place by a crane (Unit Construction Co. 1913:4).

3.2.1 HISTORY OF CONCRETE

Early concrete was created from gypsum and limestone, crushed and burned, then combined with sand and water to make mortar. Kilns to produce mortar are recorded as early as 700 B.C. (Gromicko and Shepard n.d., accessed March 2016). By 200 B.C., the Romans used various types of concrete in building, creating designed mixes to suit each use. Common construction used cemented rubble. Large spans, marine structures, bridges, and docks each utilized different mixes of volcanic sand which, when combined with lime and water, created rock-like solidity. Roman admixtures included animal fat, milk, and blood. Eventually, the Romans discovered the technology to manufacture artificial clay and stones that mimicked volcanic sand, called “pozzolan” cement (Gromicko and Shepard n.d., accessed March 2016). After the fall of the Roman Empire in 476 A.D., the Roman technique for making “pozzolan” cement was lost. The manuscripts of Roman Pollio Vitruvius, which describe the process, were rediscovered in 1414. The first “modern” use of concrete occurred in 1499 with the construction of the pier of the Pont Notre Dame in Paris by Fra Giocondo (Gromicko and Shepard n.d., accessed March 2016; Concrete Contractor website, accessed January 2016).

The next major advancement in concrete technology occurred almost 300 years later. An English engineer named John Smeaton was working with quicklime to find a material not adversely affected by water. In 1793, he discovered the calcinations of limestone, which contained clay, produced hydraulic lime, a material that hardened under water (Concrete Contractor website, accessed January 2016). Smeaton fired the limestone until it became “clinker” (ash or residue), and he ground the clinker into a powder (Gromicko and Shepard n.d., accessed March 2016). Smeaton had identified the compositional requirements needed for lime to harden underwater. His work began the widespread use of concrete and led to further advances in technology. In 1796, natural hydraulic cement was patented by James Parker, an English cement manufacturer. Natural hydraulic cement used natural limestone containing clay, which was ground and burned into a fine powder. Many engineers then attempted to make an artificial version (Concrete Contractor website, accessed January 2016). In 1817, French engineer Louis Vicat invented an artificial cement by mixing powdered lime with clay, which would set in water. Vicat never filed a patent for his invention, and it eventually led to the creation of Portland cement using Vicat’s methods (Vicat website, accessed April 2016).

Portland cement was invented in 1824 by English cement manufacturer Joseph Aspdin using Vicat’s artificial cement methods (Concrete Contractor website, accessed January 2016; Vicat website, accessed April 2016).

Portland cement, named for its resemblance to the building stones of Portland, England, was created by burning finely ground chalk and clay in a kiln to remove the carbon dioxide. Joseph Aspdin heated the alumina and silica materials to the point of vitrification (fusion), which caused the materials to become glass-like. The compressive and tensile strength of different mixes were tested through the nineteenth century, and the modern composition of Portland cement was first produced in 1860 (Gromicko and Shepard n.d., accessed March 2016). The first American patent for the production of Portland cement was received by David O. Saylor in 1871 (Concrete Contractor website, accessed January 2016).

Another major step in concrete technology was the invention of reinforced concrete. Concrete is strong in compression but weak in tension. The addition of steel rods, strong in tension, could offset deflection and make a more flexible material (Croft 2004:9). William Boutland Wilkinson received an English patent for a reinforced concrete beam in 1854 (Croft 2004:13). S.T. Fowler obtained a U.S. patent for a reinforced concrete wall in 1860. The technology did not truly take off until English engineer Ernest L. Ransome developed a method of using twisted reinforcing bars to improve the bond between concrete and steel, which he patented in England in 1884 and in the United States in 1894 (Illustration 3; Gaudette and Slaton 2007:2; U.S. Patents 1894: 516113 A). Between 1880 and 1900, engineers developed calculations for the use of reinforced concrete in buildings for industrial and agricultural uses (Croft 2004:13).

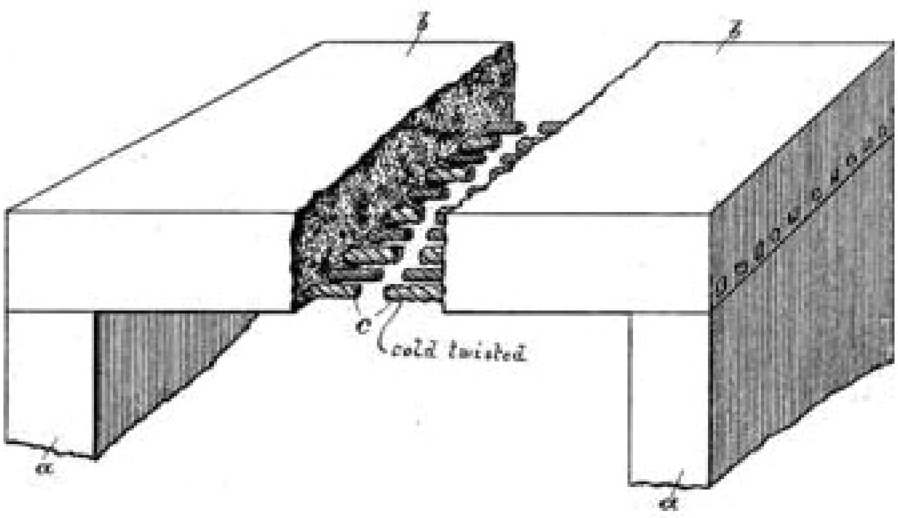


Illustration 3: Ernest L. Ransome's patented design for cold-twisted iron reinforcement in concrete (U.S. Patents 1894:516113 A).

Within two years of his reinforcement patent, Ernest L. Ransome introduced his rotary kiln to the production of cement in the United States. The earlier kilns in cement production were vertical and stationary, and cooled between each production. The rotary kiln allowed the material to move from one end to the other, burning it more thoroughly and uniformly. The process made a less expensive and more reliable cement. Cement is an ingredient for concrete, along with aggregate and water, so a more reliable cement meant a more reliable and consistent concrete (Gaudette and Slaton 2007:2; Boateng 2008:1-2; Concrete Contractor website, accessed January 2016). The increased efficiency of the rotary kiln led to a sharp increase in production of Portland cement between 1880 and 1890 (Boateng 2008:1-2; Concrete Contractor website, accessed January 2016). By the turn of the twentieth century, testing and manufacturing methods of concrete were standardized (Gromicko and Shepard n.d., accessed March 2016). Improvements in concrete production, largely influenced by Ransome, led to a greater acceptance of concrete in the twentieth century (Gaudette and Slaton 2007:2).

Although both cast-in-place and precast concrete methods date to ancient times, cast-in-place concrete was more common before 1905. John Alexander Brodie and Yannick Macken developed precast paneled buildings in 1905, allowing for cheaper and quicker application (Del Zotto Products website, accessed April 2016). By 1913, precast concrete was advertised as a more efficient method for concrete construction due to ease and completeness of inspection; certainty and accuracy of product; simplicity of design; uniform quality; minimal shrinkage; and advanced planning of joints. Reinforcement could be located directly as designed, with a greater speed of erection (Unit Construction Co. 1913:5-7).

By 1945, concrete was one of the most valuable building materials; in simple form, it replaced stone masonry, and in complicated designs, it replaced steel and timber (Gibson 1945:i). Among its numerous applications was its use as concrete panels for cladding. Although these vertical walls, or panels, were not intended to carry weight, they were made of reinforced concrete. The panels were intended to fit between the post and girders that created the skeleton of a building. Exterior panels were specially designed for wind pressure (Gibson 1945:312-14). The application of concrete became popular, and even embraced by high-style architecture as well. Concrete was an exemplary material of twentieth-century architecture.

Air-entrainment was invented in the 1930s, and was the process of adding microscopic air bubbles to the concrete, which provide protection against the freeze and thaw cycle. The air-entraining agents are added to concrete during mixing, which causes small, loosely spaced air bubbles that remain once the concrete hardens. The tiny bubbles can compress and absorb the stress of the freezing water's expansion, therefore reducing the threat of cracking (Gaudette and Slaton 2007:5; Gromicko and Shepard n.d., accessed March 2016).

3.2.2 CONSTRUCTION

Concrete exterior cladding is either precast or cast-in-place. Cast-in-place concrete is transported in a pre-mixed, proportioned, and unhardened state to a construction site. The primary uses for cast-in-place concrete include foundation, floors, walls, beams, columns, roofs, and infrastructure. Precast concrete is poured and cured in molds at a different location, then delivered in ready-to-use components. Precast concrete is often used for cladding panels, bricks, blocks, paving stones, bridge girders, and structural components. Cast-in-place and precast concrete types both have high energy performance, environmental durability, low volatile organic compound (VOC) emission, and are recyclable (Portland Cement Association [PCA] website, accessed January 2016). The choice of cast-in-place or precast concrete is project specific and relies on a large number of factors.

Cast-in-place concrete is durable and works well for structural support. The mix of cast-in-place concrete must consider the appropriate concrete properties for the project. Cast-in-place concrete is subjected to a “Slump Test” in which the consistency of the product is tested by being placed into a cone-shaped mold and then tamped with a rod. The mold is removed and the settlement of the concrete is measured (Illustrations 4 and 5; Atlas Portland Cement Company 1927:11-13). It is important that the placement of cast-in-place concrete be consistent, continuous, and maintains the speed in which it can be spread, cut, and consolidated. Cutting is the trimming or shaping of the poured concrete. Consolidation refers to the process of compacting the poured concrete to mold around reinforcements as well as prevent air pockets. This process is often completed through vibration, although

Illustrations 4 and 5: The images show the “Slump Test” inspection method for cast-in-place concrete, which is conducted on-site (Atlas Portland Cement Company 1927:12).

self-compacting concrete is also available. The concrete must be cured for approximately three days, but the time frame varies due to the environment, temperature, use, and application. The curing is needed for the material to develop strength and durability. Monitoring of moisture loss must be undertaken to maintain ideal conditions. Following the curing process, the concrete is finished with surface treatments to protect it from deterioration from loose surface aggregate and to add colors or textures. On-site stress tests are performed at the completion of construction (PCA website, accessed January 2016; Advance Concrete Products Co. website, accessed January 2016).

Precast concrete is ideal for projects that involve repetitive shapes. Precast concrete is mixed, measured, and cured in molds in a controlled, supervised plant. The forms (usually wood) are created and lubricated, and then the concrete is poured. The concrete cures in place, and the process is repeated for mass production. The concrete elements are also finished in-house and then strength tested for quality control. This is not only cost effective, but ensures consistency and uniformity. The delivery and installation is also less labor intensive than that of cast-in-place concrete, and thus reduces construction time. Precast concrete beams can also be pre-stressed to allow for long-span applications (PCA website, accessed January 2016; Advance Concrete Products Co. website, accessed January 2016).

3.2.3 ARCHITECTURAL IMPACT

The early twentieth century was called "The Cement Age" (Moyer 1905:1). Concrete became the exemplary building material of the twentieth century. Concrete was quickly recognized for its utilitarian benefits: flexible, versatile, and cost effective; however, it was also considered visually unappealing. In the nineteenth and early twentieth centuries, it was not considered a suitable material for prestigious buildings, unless covered by exterior cladding. Architects cited its poor surface, poor color, and common cracking, and suggested concrete should be covered by veneers. While the architectural aesthetic was argued, concrete became the quintessential material for defense structures, roads, power stations, and other utilitarian architecture. By 1900, it was universally agreed that concrete was ideally suited for industrial buildings and infrastructure (Croft 2004:12-14).

Concrete remained an aesthetically controversial material throughout the first half of the twentieth century. Utilizing the acceptance in industrial architecture, Ernest Ransom, Albert Kahn, and Richard E. Schmidt promoted a "factory style" utilitarian architecture that used a concrete frame and wide expanses of glass (Gaudette and Slaton 2007:3). The first concrete skyscraper in the United States was the Ingalls Building, designed by the firm Elzner & Anderson, and built in Cincinnati, Ohio, in 1903. In 1904, Albert Kahn designed the concrete

Burroughs Company Building in Plymouth, Michigan. Frank Lloyd Wright began his pioneering use of concrete in 1906 (Croft 2004:16).

After World War I, concrete became associated with innovative developments in architecture. The use of concrete became a pillar of the architectural style of Modernism (Croft 2004:15-16). Modernism appeared after World War I, and was classified by the utilization of new technology, rejection of ornamentation, and belief that function should dictate form. The materials to suit these tenets were primarily glass, steel, and concrete (Bose 2008:n.p.). The popularity of Modernism in the United States during the 1920s and 1930s again reiterated the arguments of the aesthetics of concrete. Even Frank Lloyd Wright, a pioneer of concrete in the United States, called concrete "artificial stone at best, or a petrified sand heap at worst" (Croft 2004:16). Concrete's aesthetic values only further decreased in public opinion by the end of the 1930s. Concrete was seen as cold, patchy, and prone to darkening through weathering. With the onset of World War II, concrete was widely used for various defense buildings. It was then used as a main material for the rapid reconstruction of European cities affected by the war (Croft 2004:18). The public's recognition of concrete as only for utilitarian buildings was amplified by these wartime associations.

In the United States, Modernism was followed by the popularity of the International Style in the 1940s and 1950s. The International Style was categorized by open spaces, no ornamentation, and a weightless quality developed through cantilevered construction. Although concrete continued to be used, it often formed the "skeleton" of the building, and thus was not visible (Architectural Styles of America and Europe website, accessed April 2016; Encyclopaedia Britannica, accessed January 2016). In the late 1950s and 1960s, the material's popularity reappeared in the New Brutalism movement, which used monolithic, geometric swaths of poured, unfinished concrete. Brutalist architecture, like concrete itself, was criticized aesthetically by architects and the general public, but was recognized for its functionality and utilitarianism (Croft 2004:20; Styleture website, accessed January 2016).

Concrete commonly had variations of color, discolorations, and imperfections, but there were various surface treatment options for concrete (Illustration 6). Some of the most popular finishes are described below.

Rubbed

Concrete would often have evidence of lines from the wood form in which it cured. Once hardened, the form could be removed and the surface rubbed with carborundum brick and water to create a smooth appearance.

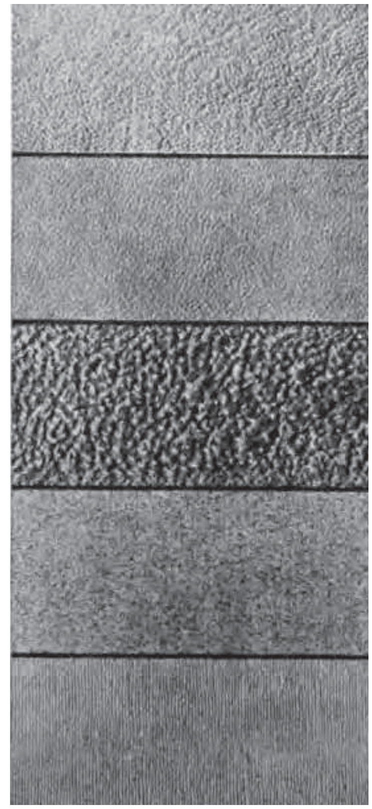


Illustration 6: Concrete could be finished in various ways. Shown here are examples of hammer finished (top three) and bush-hammered (bottom two). The rougher textures are best adapted to coarse aggregate (Atlas Portland Cement Company 1927:37).

Plastered or Painted

Mortar made from Portland cement could be used in lieu of plaster, but offered similar results. Portland cement paint was created from Portland cement and lime-proof and sun-proof pigments. The paint easily bonded with the damp concrete surface.

Picked

A "picked surface" was a treatment created by brushing, hammering, or tooling a seasoned concrete surface, often revealing the color of coarse aggregates.

Pebble

A "granolithic" or pebble finish was made by applying 8 inches of mortar to the form itself, letting it dry, and then pouring in the concrete. When the concrete was hardened and the form removed, the mortar was washed off, leaving the small stones and gravel of the aggregate exposed.

Acid

The concrete could be washed with a diluted acid, which removed cement and exposed the aggregate. An alkaline solution was then applied to remove the acid, and the concrete was washed with water.

Masonry Facing

The concrete could also be made to represent ashlar masonry by manipulating forms. This was often done with extra pieces of wood used to create V-shaped depressions in the concrete to simulate joints.

Cast-Slab Veneer

A concrete slab could be made in any thickness, size, or shape. The slab could then be adhered to the concrete wall in a continuous slab or used to represent masonry.

Coloring

Coloring material, made from pure mineral colors, could be mixed into the concrete. The coloring was recommended to never be more than 10 percent of the cement used to avoid reducing the strength of the concrete. Historically, blues used ultramarine blue pigment; browns used pure brown oxide of iron; buff colors used a synthetic oxide of iron or a natural yellow oxide; grays used pure black iron oxide or Germantown lamp black; greens used pure green chromium oxide; and reds used pure red oxide of iron or a natural Spanish red oxide (Gibson 1945:357-366).

3.2.4 CONCRETE AND THE U.S. MILITARY

The first foray of the U.S. military into the use of concrete came just after the Civil War. The Quartermaster General's Office of the War Department used a "poured gravel wall" and "lime-grout" construction as the material of choice for several frontier military posts. By the 1890s, the U.S. government used concrete for the coastal fortifications along the Atlantic, Pacific, and Gulf coasts (Gaudette and Slaton 2007:2). By 1900, the popularity of concrete for industrial, utilitarian buildings was adopted by the U.S. military.

While also used in more high-style architecture, concrete was largely used on military installations as a functional material on utilitarian buildings. The use of concrete became more popular in military installations through the embrace of the Modernist influences of "form follows function." This meant that buildings should reflect their structure and that simplicity was favored over the more ornate details of previous styles. The Modernist ideas were based in the technological advances of materials like iron, steel, glass, and concrete (Hampton et al. 2012:10). Section 3.1 includes a discussion of the military's embrace of the Modernist ideas and how it relates to the study materials. Concrete was used in a multitude of styles on residential, administrative, and support buildings across the U.S. military, and continues to be a key material for utilitarian buildings.

3.2.5 QUALITIES AND CHARACTERISTICS OF CONCRETE

Fire Resistance

Concrete was noted to resist burning, which offered protection of both lives and property (Atlas Portland Cement Company 1927:1). Reinforced concrete buildings were tested, and it was proven that any damage to the concrete occurred within 1 inch of the surface at temperatures of 1,400 to 1,900 degrees Fahrenheit. Even then, the structural integrity of the concrete was not affected (Gibson 1945:69). Concrete often results in reduced insurance rates.

Strength and Durability

Concrete had great load capacity, and reinforced concrete was designed for the heaviest loads. Concrete could accommodate longer spans than other materials, allowing maximum window space for daylighting. Concrete buildings were noted to allow 50 to 85 percent greater window area than other types of construction in 1927. Concrete was able to meet all architectural and engineering requirements of the time (Atlas Portland Cement Company 1927:1-2). The inherent strength of the material created a safe and secure construction.

Economical

Concrete construction cost the same, if not less, than other construction methods. The material was more cost effective than other fire-resistant construction options in the first half of the twentieth century, such as stone or brick (Atlas Portland Cement Company 1927:1-2). Concrete was promoted as rot-resistant – an important quality for military, industrial, agricultural, and commercial settings. Concrete did not require upkeep like painting or refinishing, which also made it less expensive overall (Atlas Portland Cement Company 1927:1).

Sound Control

Excess noise can be common in any building type, but especially in industrial architecture. Concrete was able to reduce sound transmission (Atlas Portland Cement Company 1927:1-2).

3.2.6 CONCLUSION

Concrete's durability is one of its key character-defining features. As such, concrete tends to have a long life with minimal preservation issues. When preservation and upkeep issues occur, they often do not result in structural failure and can be corrected through non-evasive methods. When repair is not an option, concrete continues to be widely produced. Concrete can be replaced in-kind, and physical characteristics like aggregate and color can be customized.

3.3 CORRUGATED METAL

Corrugated metal siding and roofing is an oft-overlooked staple of industrial, commercial, and military architecture of the twentieth century. Developed in the first half of the nineteenth century in England, the material uses metal (historically iron or mild steel) gauged sheets that were "crimped" to become corrugated. The corrugations made the metal sheets stiffer and stronger, allowing a structural stability not available in flat metal sheets (Newton and Partington 1829:234-235). Corrugated metal was used throughout the nineteenth and twentieth centuries on a wide variety of buildings, but most commonly on utilitarian buildings (Illustration 7). Today, corrugated metal remains common worldwide in various applications due to its strength, span, durability, accessibility, and economy.

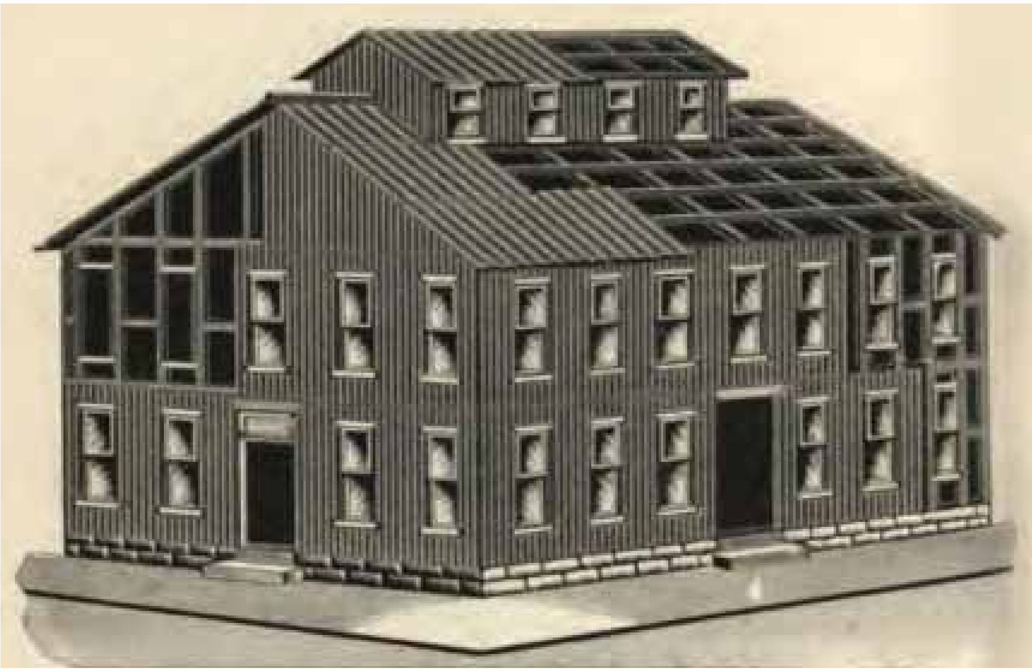


Illustration 7: An example of corrugated metal roofing and siding used on a skeleton frame building (Milwaukee Corrugating Co. 1920:154).

3.3.1 HISTORY OF CORRUGATED METAL

Sheet metal of uniform thickness is a product of the rolling mill. By the seventeenth century, rolling mills produced thin sheets of gold for coins. In the eighteenth century, lead and semi-finished steel was rolled into a number of shapes and sizes. At the start of the nineteenth century, rolling mills used steel cylinders that could be adjusted by a screw to set thicknesses (Metalworking World Magazine website, accessed January 2016). In 1829, Henry Robinson Palmer, architect and engineer for the London Dock Company, submitted a patent for iron "fluted, indented or corrugated plates or sheets." The invention of corrugated iron sheets for the construction of warehouses, sheds, and other buildings could be used as roofing, cladding, doors, shutters, or partitions. The corrugated metal sheets gained additional strength from the corrugations, requiring less support from the frame of the building than that needed by flat sheets (Newton and Partington 1829:234-235).

Palmer's 1829 patent gave corrugated metal sheeting two principal uses: as cladding on a supporting framework or as self-supporting sheets spanning spaces without framing. The self-supporting sheets as roofing were revolutionary, and had a distinctive barrel shape, making them easily recognizable (Mornement and Holloway 2007:14). The patent describes that in the use of roofing, the corrugated metal sheets were designed to be riveted at the upper ends to a crown plate, and the lower ends riveted to a metal gutter. The metal gutters were to be connected to gutter plates, which would counteract the horizontal thrust of the roof. The use of the corrugated metal sheets as cladding, partitions, doors, or shutters required the sheets to be riveted or connected to a frame, preferably of metal (Newton & Partington 1829:235-236). The early process involved passing iron sheets through fluted rollers, with the rollers sometimes heated. The width of the rollers determined the maximum length of the sheets (Mornement and Holloway 2007:11).

Palmer sold the patent to Richard Walker in 1830. The ability to mass produce corrugated iron sheets created a market for prefabricated iron buildings in Great Britain by the 1840s. The strong, easily transportable material was ideal for colonization efforts in Australia and South Africa (Nicholson n.d., accessed January 2016). In the 1840s and 1850s, the material was used on a number of British factories (Mornement and Holloway 2007: 10).Walker's patent expired in 1843, and the market was subsequently flooded with corrugated metal (World Archaeology website, accessed January 2016). The United States began to produce corrugated metal by the mid-nineteenth century (NPS website, accessed January 2016).

However, corrugated iron was subject to corrosion. British patent holder Richard Walker recommended the material could be weather proofed with a thin coat of paint, but the salty air of coastal cities and the corrosive interiors of factory buildings were causing the sheets to deteriorate rapidly (Mornement and Holloway 2007:10-14). The answer to deterioration was galvanization. Galvanization was first invented in 1742 by French chemist P.J. Malouin, though it was not patented until 1836 by French engineer Stanislas Sorel. Galvanizing is a method of protecting metals susceptible to rust by coating them in a bath of molten zinc, at which time a thin protective coating of zinc is bonded to the metal (Leeds Galvanizing & Powder Coating website, accessed January 2016; NSW Heritage Office website, accessed January 2016). The galvanizing process greatly improved iron and steel durability and was in use by the 1840s. The corrugated galvanized iron sheets were strong, durable, relatively light, and transportable. Manufacturing processes improved throughout the nineteenth century, allowing larger sheets to be produced (NSW Heritage Office website, accessed January 2016). By 1854, Marshall Lefferts & Brother were advertising "Patent Galvanized Iron" in the United States (NPS website, accessed January 2016).

By 1899, corrugation of galvanized iron sheeting was done by a machine in which two dies were fit into each other. The bottom die was wider on each side by half a corrugation. The upper corrugating die was turned by a cranked shaft. The machine was operated by two men: the corrugator and his underhand. The corrugator pressed the sheet towards the die, and the underhand pulled it forward in the same direction. Without a fixed method, the corrugations would vary in width and depth. Uniformity was a challenge; as the corrugating machines became worn, the gauges would widen. The remedy was to have a steel template of the correct gauge, and to regularly plane the dies to match. The dies most commonly created a 3-inch corrugation, though other sizes were available from 1 inch to 9 inches (Illustration 8). The ideal size of a sheet was 10 feet, 6 inches in length. Machines were available up to 12 feet, but the highest demand was for sheets 6 to 8 feet in length. Multiple sheets could also be corrugated at one time (Davies 1899:49-53).

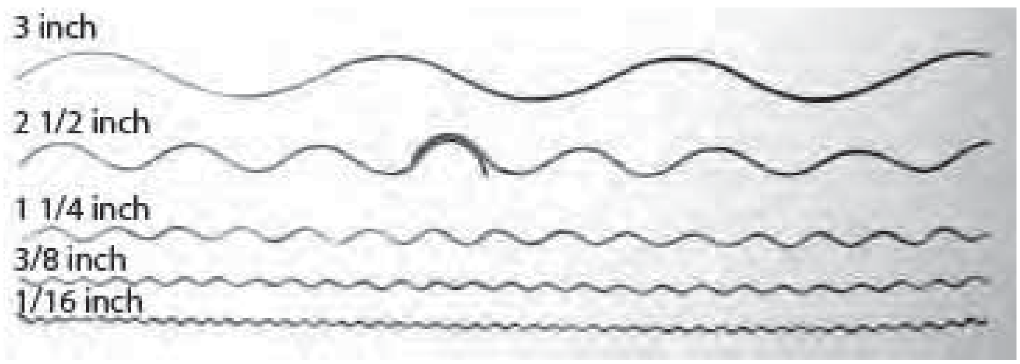


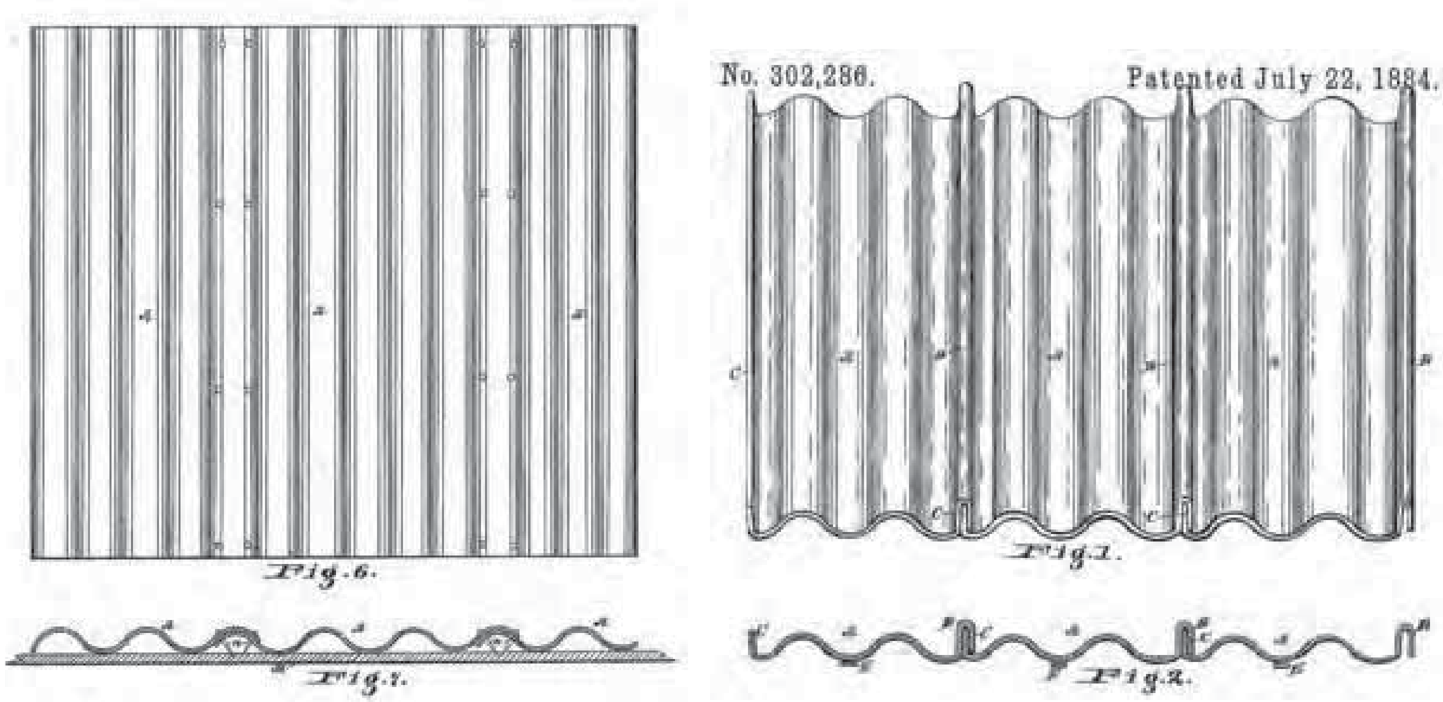
Illustration 8: The various corrugation sizes offered in 1893 by the Cincinnati Corrugating Company (Cincinnati Corrugating Company 1893:4).

Corrugated galvanized iron was made from wrought iron until the late nineteenth century. The improvements in the production of steel from 1890 to 1910 replaced the use of wrought iron with mild steel, but other metals were also used (NSW Heritage Office website, accessed January 2016). After World War II, aluminum became a popular choice due to corrosion resistance. The development and refinement of corrugated metal in the nineteenth century led to widespread use throughout the twentieth century and into the present day. Corrugated metal is still widely used and produced in the United States and worldwide.

3.3.2 CONSTRUCTION

Until 1900, corrugated sheet metal roofing and cladding was mainly only used for commercial and industrial purposes. When installed, corrugated metal sheets are laid similar to tiled shingles, which utilize an overlap between neighboring sheets (Illustration 9). When laid correctly, the roof is waterproof (Corrugated Metal Roofing website, accessed October 2015).

Illustration 9: Corrugated roofing was specified to have one and one-half corrugations overlap, as shown in this diagram (Milwaukee Corrugating Co. 1920:146).



Illustrations 10 and 11: Comparison of the overlapping corrugation connection method (left) and the "V-crimp" connection method (right). The overlapping corrugation method remains the preferred connection method (U.S. Patents 1884:302286 A).

For roofing, corrugated metal was to be started at the eave, with 4 to 6 inches of projection. Side-by-side panels were lapped by one corrugation. The sheets were nailed in the lap, 8 inches apart. Flat roofs required thick metallic paint between the laps, while pitched roofs required the use of a metal ridge cap. The construction method for the use of corrugated metal as siding was to start at the bottom of the wall. The side-by-side sheets would also lap by one corrugation. Heavier gauges were necessary for buildings that needed exterior durability (Globe Iron and Corrugating Company 1890:32). The lapped method was historically the more common application. In 1884, L. Lewis Sagendorph invented a "V-crimp" connection, creating a corrugated metal roof with distinct seams (Illustrations 10 and 11; U.S. Patents 1884:302286). The simple construction methods using corrugated metal quickly led to its popularity (Illustrations 12 to 15).

Illustration 12: Corrugated metal roofs required a cap along the ridge (Globe Iron and Corrugating Company 1890:25-26).

Illustration 13: Corrugated siding was specified to have overlapping corrugations and nailed approximately every 6 inches, as shown in this diagram (Milwaukee Corrugating Co. 1920:146).

Illustration 14: An example of corrugated siding, with application beginning at the bottom of the wall (Milwaukee Corrugating Co. 1920:146).

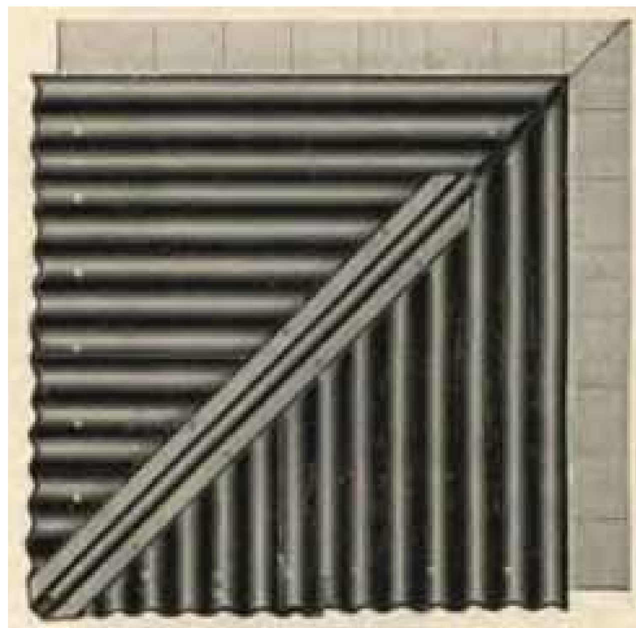


Illustration 15: A roof plan view of corrugated metal roofing on a hipped roof with a ridge cap (Milwaukee Corrugating Co. 1920:147).

3.3.3 ARCHITECTURAL IMPACT

Corrugated metal was quickly recognized as an efficient material for various building types. Metal roofing was popular in the United States throughout the nineteenth century. In 1834, just five years after its invention, architect William Strickland proposed a corrugated metal roof for a marketplace design. By the 1850s, the material was used on train sheds, factories, custom houses, and post offices (Sweetser n.d.:4). Metal roofing's popularity was due to three main factors: it was lighter than slate, more fireproof than wood, and less expensive than most other options (NPS website, accessed January 2016).

Corrugated metal was a material of necessity and efficiency, and not high-style. Although it did appear in residential architecture in the United States, it was most commonly used as roof material, as it was an inexpensive and durable alternative to slate, asphalt, or wood roofing. As siding, corrugated metal was often used in temporary housing or agricultural outbuildings. In 1890, English architect William Morris remarked that corrugated metal was "now spreading like a pestilence over the country" in England (World Archaeology website, accessed January 2016). Corrugated metal was also increasing in popularity in the United States at that time.

Corrugated metal has been continuously used since its invention, but was only adopted for public or residential architecture with the eventual embrace of the industrial architectural styles. In the 1920s, architects Walter Gropius and Buckminster Fuller experimented with corrugated metal in their Modernist style buildings. In the 1950s, it was made popular in California (especially in Palm Springs) by avant-garde architects, such as John Lautner, Donald Wexler, Albert Frey, and E. Stewart Williams. The use of corrugated metal has remained a traditional and beloved architectural material internationally in places like the Caribbean, South Africa, and Australia (World Archaeology website, accessed January 2016; Palm Springs California website, accessed April 2016).

Corrugated iron and steel were prone to corrosion, so it was recommended that the corrugated metal sheets be painted or galvanized. Iron oxide metallic paint was created from ground iron oxide and linseed oil. It was ideal as roofing paint, and in 1890 was advertised only in red or purple. Galvanized metal could be scratched or damaged, which could remove the galvanized layer, so galvanized metal sheets were still recommended to be painted (Globe Iron and Corrugating Company 1890:43). By 1920, paint colors were offered in black, red, graphite, or galvanized (Milwaukee Corrugating Co. 1920:142).

The material was most popular in industrial, military, and commercial architecture because of its utilitarian nature (Illustrations 16 and 17). For roofing, light yet strong qualities of the material made it ideal for long spans. For roofs or cladding, it was fireproof and needed minimal maintenance. Corrugated metal roofs were used for factories, train stations, airplane hangars, or large-scale production facilities. The overwhelming use of corrugated metal in the industrial sector inspired the invention of corrugated wire glass. Corrugated metal was exceptionally popular until the invention of corrugated asbestos-cement sheathing, which became a substitute for corrugated metal roofing in industrial applications (NPS website, accessed January 2016). However, corrugated metal was sometimes used in conjunction with corrugated asbestos-cement sheets (U.S. Patents 1929:1732368 A). Using

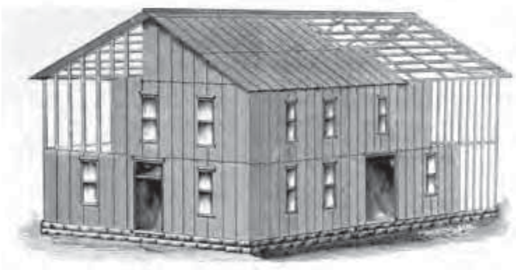


Illustration 16: *An example of a simple building covered with both corrugated metal roofing and siding (Cincinnati Corrugating Company 1893:7).*

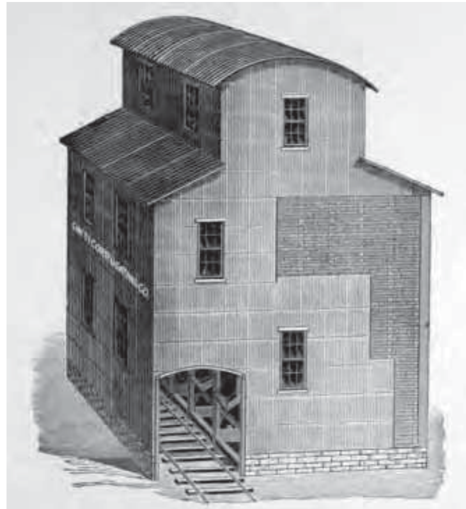


Illustration 17: An example of a simple building covered with corrugated metal siding and an arched roof (Cincinnati Corrugating Company 1893:7).

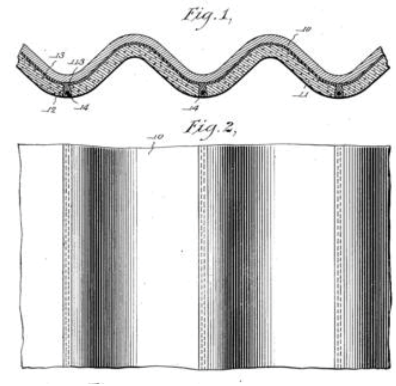


Illustration 18: Corrugated metal sheets could be layered with asbestos-cement sheets to offset the weaknesses of each material (U.S. Patents 1929:1732368 A).

corrugated metal and asbestos-cement sheets together offset each material's weaknesses, as corrugated metal lacked insulation and asbestos-cement lacked waterproof protection (Illustration 18). Corrugated metal continued to be used in the same applications throughout the twentieth century and into the twenty-first century.

3.3.4 CORRUGATED METAL AND THE U.S. MILITARY

Corrugated metal became synonymous with the military in the twentieth century (World Archaeology website, accessed January 2016). Its primary use on military installations was as a functional material on utilitarian buildings for roofing, cladding, and often both. Its use originates in the military's embrace of Modernist influence of "form follows function." This meant that buildings should reflect their structure and that simplicity was favored over the more ornate details of previous styles. (Hampton 2012:10). Section 3.1 includes a discussion of the military's embrace of the Modernist ideas and how it relates to the study materials.

As World War I began, Captain Peter Nissen of the British Army noticed a lack of simple housing for troops. In 1916, he designed the Nissen Hut, a semicircular structure that could be shipped in pieces, erected quickly, moved, and dismantled (Illustration 19). The hut design was a wood and steel skeleton, covered in corrugated iron (Van Dulken 2002:44-45). During the war, the British government shipped Nissen Huts to the United States (Van Dulken 2002:44).

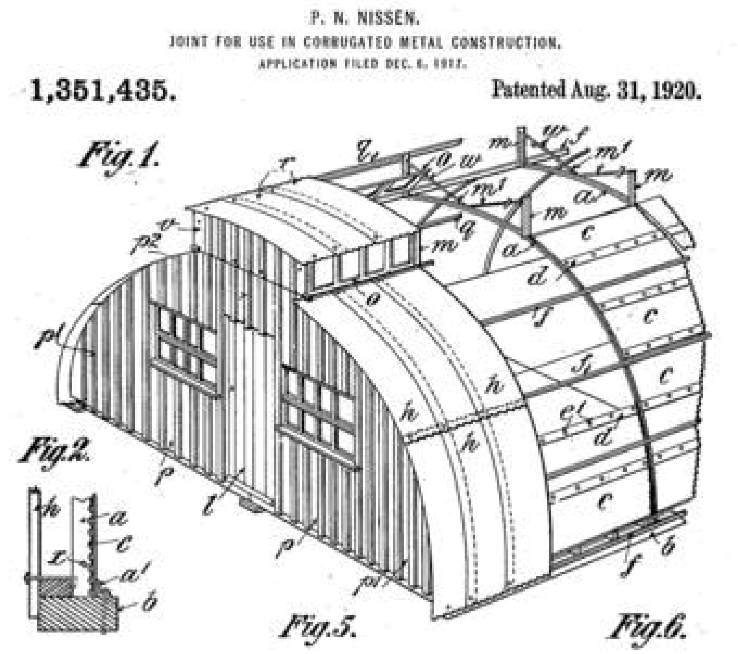


Illustration 19: Captain Peter Nissen first developed the Nissen Hut in 1916, fabricated with corrugated iron. The U.S. patent was filed in 1917 (U.S. Patents 1920:1351435 A).

The George A. Fuller Construction Company developed an improved Nissen Hut, the Quonset Hut, at the beginning of World War II. Quonset Huts were prefabricated shelters with steel skeletons and semicircular corrugated metal roofs. They were inexpensive, mobile, and incredibly strong. Quonset Huts were used for barracks, mess halls, aid stations, and supply depots. In 1941, the U.S. Navy began to ship Quonset Huts abroad. The United States constructed 150,000 to 170,000 Quonset Huts throughout the duration of World War II (Military Brat Life website, accessed January 2016).

The World War II era mass production techniques and temporary mobilization structures were identified as possibilities for the private sector's focus on prefabrication. At the close of World War II, there was a housing shortage caused by the returning troops. Surplus Quonset Huts were sold to the public. The Public Housing Authority created Quonset Hut subdivisions near major cities, and civilians converted them into businesses, dormitories, and single family homes (Quonset House website, accessed January 2016). The temporary construction of World War II taught the benefits of mass production, standardization, and prefabricated standardized materials (Illustrations 20 to 22; Hampton 2012:32). Corrugated metal continues to be used in industrial, military, and commercial architecture; to provide shelter in cities of South America, the Caribbean, Africa, and Asia; and to serve as temporary housing for disaster relief (World Archaeology website, accessed January 2016).

Illustrations 20–22: A sample of corrugated iron sheets for roofs, siding, partitions, awnings, or other (unspecified) applications (Globe Iron and Corrugating Company 1890:25–26).

3.3.5 QUALITIES AND CHARACTERISTICS OF CORRUGATED METAL

Affordability

While already an affordable material, as corrugated metal became more popular, more techniques were found to reduce overlap, reducing the quantity needed. The material was advertised as a covering for steel superstructures. The application cost was estimated at 50 percent cheaper than any other cladding material (Pedlar People Limited 1911:27). Corrugated metal siding was touted as the best material for structures of moderate cost that are intended to be fireproof (Milwaukee Corrugating Co. 1920:142). "When applied over a light, inexpensive framing, it makes a cheap, substantial, fire-proof building" (Wheeling Corrugating Company 1911:17).

Ease of Application and Upkeep

In addition to being affordable, corrugated metal was easy to install. The sheets could be overlapped as roofing or siding with minimal connections (Pedlar People Limited 1911:27). While corrugated metal was not always painted, it was recommended to preserve the iron or steel from long-term rust or corrosion. Galvanized metal could be scratched or damaged, which could remove the galvanized layer, so galvanized metal sheets were still recommended to be painted. The quality of paint was important, and the recommendation was often for a paint mixture of dry iron-ore and pure linseed oil, and only one coat. The paint was then to be dried slowly. All painted corrugated metal was recommended to be repainted upon installation and then periodically to prevent spots from appearing that would then be susceptible to corrosion. If galvanized, the metal could be painted several weeks after installation or as soon as a slight discoloration occurred. It was noted that paint adhered to galvanized metal better after it was seasoned than when freshly galvanized (Wheeling Corrugating Company 1911:14; Globe Iron and Corrugating Company 1890:43).

Strength and Durability

Corrugated metal was designed for strength and rigidity. The sheet would be gauged at each corrugation and appropriate pressure applied to maximize the strength. The result was complete uniformity. The corrugations made the material the strongest known form of siding at the time (Pedlar People Limited 1911:3-31). Corrugated metal was stronger than sheet metal due to its lineal rigidity (Milwaukee Corrugating Co. 1920:142).

Long Span

The rigidity of the lightweight material makes the corrugated metal sheet practically self supporting. As such, only a light, inexpensive frame is needed (Milwaukee Corrugating Co. 1920:142). The combination of strength and lightweight nature of corrugated metal made it ideal for long-span construction.

Fireproof

Corrugated metal was fireproof, which was of an inestimable value to its use in industrial facilities. The use of corrugated metal roofing reduced average insurance rates by one third, due to the recognized fire resistance (Wheeling Corrugating Company 1911:14). Corrugated iron and steel sheets will buckle under extreme heat, but the material will confine flames and heat for a prolonged amount of time (Freitag 1899:40-42; Global Asset Protection Services LLC n.d.:1).

3.3.6 CONCLUSION

Today, corrugated metal remains common worldwide in various applications due to the strength, span, durability, and inexpensive accessibility of the material. The major issue is corrosion and rusting of the metal. While corrugated metal can be maintained and protected simply through paint, corrugated metal is largely used on utilitarian buildings. As such, utilitarian buildings are not always given preference in maintenance schedules, and inevitable lapses in upkeep occur. This leaves the material prone to corrosion. While sometimes correctable, the most common solution is replacement in-kind. Corrugated metal remains a popular material in multiple types, gauges, and thicknesses, allowing a match to be easily found in most instances.

3.4 ASBESTOS-CEMENT

Asbestos-cement panels were revolutionary in the twentieth century, as they combined the best characteristics of industrial materials with seemingly no weaknesses. Asbestos-cement panels, both flat and corrugated, were fireproof, corrosion-proof, and highly insulative. The material was strong, durable, and aesthetically pleasing. In addition, it was both easy to use and highly economical (Illustration 23). The benefits to the industrial, commercial, and military construction markets were thought to be ideal. Asbestos-cement panels, a cement product consisting of 10 to 15 percent asbestos fibers, are safe to leave in place until damaged (Asbestos Information Centre website, accessed January 2016). According to the National Emission Standards for Hazardous Air Pollutants (NESHAP), Asbestos Containing Material (ACM) is defined as products or materials

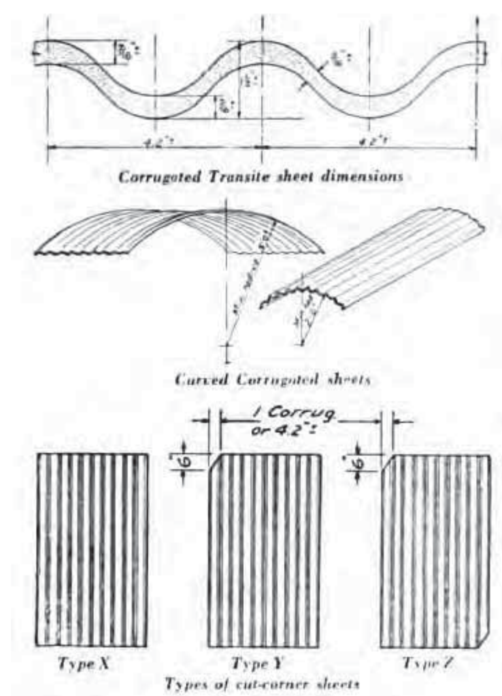


Illustration 23: Details of corrugated asbestos-cement panels (Johns-Manville 1944:9).

containing more than 1 percent asbestos. Common ACM found at DoD installations includes building materials such as insulation, floor tiles, and panels. Friable asbestos products are defined as materials that can be crumbled or pulverized by hand pressure, which can release asbestos into the air. Asbestos-cement is classified as a non-friable material; however, it is specifically noted that a non-friable ACM can become friable due to processes such as weathering. Asbestos fibers can be considered "releasable" after the material has become friable (NAVFAC 2012:4-5). The United States Environmental Protection Agency (EPA) states exposure to asbestos occurs when ACM is disturbed or damaged in some way to release particles and fibers into the air. Exposure can cause lung cancer, mesothelioma, and asbestosis (EPA website 1, accessed April 2016). Asbestos-cement panels are no longer manufactured today in the United States, so in-kind replacement is not an option, and suitable substitutes should be considered.

3.4.1 HISTORY OF ASBESTOS-CEMENT

Asbestos is a mineral made of soft, flexible fibers that occurs naturally all over the world. It has been used since ancient times for candle wicks, ceramics, and textiles. The name itself comes from the Greek word for "inextinguishable." The Greeks and Romans noted a sickness of the lungs in the slaves that wove the mineral into fabric, and even described the attempted use of a respirator for protection (How Products Are Made website, accessed January 2016; Smith 1843:111; University of Montana, accessed April 2016; Shepro 2006:885).

The use of asbestos continued into the nineteenth century for paper, money, bags, and cloth, but it was never a flourishing industry. The Industrial Revolution of the late nineteenth century caused a sharp growth of asbestos mining for industrial applications. Asbestos was resistant to water, chemicals, and electricity, and was an excellent insulator; all important qualities in a range of industries. From 1870 to 1900, asbestos mines all over the world switched from manual to steam-driven machinery, and worldwide asbestos production rose to 30,000 tons annually (Roselli 2014:18-24; Farlex website, accessed April 2016).

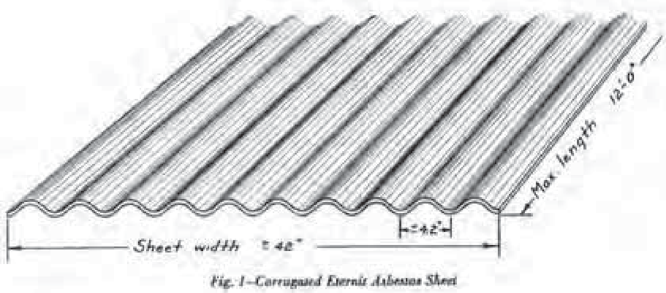
In 1900, Austrian asbestos worker Ludwig Hatschek developed asbestos-cement panels by adding Portland cement to the asbestos fibers. He called the first asbestos-cement panels "Eternit" (Eternit website, accessed February 2016). The benefits of asbestos were adapted into asbestos-cement, a cement product of which 10 to 15 percent was comprised of asbestos fibers to reinforce the cement. Asbestos-cement was used in roofing, cladding, insulation sheeting, fittings, soffits, gutters, pipes, and panels. Not only insulated and fireproof, asbestos-cement could absorb moisture, making it mostly weatherproof (Asbestos Information Centre website, accessed January

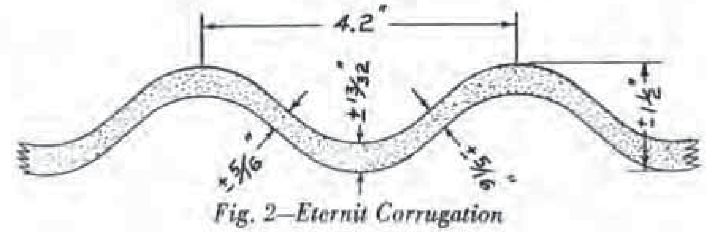
2016). Ludwig Hatschek received a U.S. patent for his product in 1904, in which he referred to the product as "imitation stone plates, slabs, or tiles" (U.S. Patents 1904:769078 A). Ludwig Hatschek's patents were used worldwide in the first quarter of the twentieth century (Keasbey & Mattison Company 1918:28).

A leader of asbestos-cement panel production in the United States was the Johns-Manville Company. Henry Ward Johns formed the H.W. John Manufacturing Company in New York City in 1858, selling a fireproof roofing material made of burlap, asbestos, and tar. He expanded the use of asbestos applications to pipe fittings and created a successful company before he died of "dust phthisis pneumonitis," believed to be asbestosis, in 1898. The H.W. John Manufacturing Company merged with the Manville Covering Company, a producer of heat insulating material, in 1901 to become Johns-Manville (Korris 2005:n.p.; Business History website, accessed April 2016; Gelbert 2007:n.p.). The Johns-Manville Company was involved in the mining, manufacture, and supply of asbestos for industrial applications and became a main supplier of asbestos-cement to the U.S. government (Encyclopedia.com, accessed January 2016). Johns-Manville created asbestos-cement products under the trade name "Transite" in 1929, which has become a generic term for asbestos-cement material (Aarons Asbestos & Demolitions Services, LLC, accessed April 2016). However, there were several other manufacturers of asbestos-cement with their own brand names such as Eternit, CertainTeed, National Gypsum, GAF Corporation, Celotex, and Nicolet (The Environmental Consultancy website, accessed January 2016).

Illustration 24: An example of flat asbestos-cement panels on a cooling tower (Johns-Manville 1944:13).

Asbestos-cement was formed under great pressure into dense, unlaminated, monolithic sheets. Asbestos-cement came in flat or corrugated boards. Flat asbestos-cement was used in smaller buildings such as employee houses, sheds, tool houses, and similar structures (Illustration 24). Flat material would most commonly be used in siding, while the roof would be corrugated. Corrugated asbestos-cement boards were strong, rigid, and durable. Corrugated asbestos-cement was designed for industrial roofing and siding for structural efficiency and the ability to withstand many forms of destruction common in chemical or metallurgical processes (Illustrations 25 and 26). Asbestos-cement was touted for its durability, fire-resistant qualities, ease of application, and minimal upkeep. Asbestos-cement materials were used extensively by railroads, public utilities, maritime, and industrial plants because of a high resistance to fumes, alkaline vapors, atmospheric conditions, and sudden temperature changes (Illustration 27; Johns-Manville 1948:1-2).





Illustrations 25 and 26: Corrugated asbestos-cement panels could be used for roofing or siding and had the strength to accommodate longer spans (Ruberoid Co. 1930:7).

Illustration 27: Asbestos-cement corrugated siding was ideal for large buildings, especially those in harsh environments like this shipyard building in Philadelphia, Pennsylvania (Keasbey & Mattison Company 1918:11).

Although medical implications were known, asbestos products remained popular throughout the mid-twentieth century. In 1973, the EPA prohibited the spraying of ACM on buildings and structures for fireproofing and insulation purposes, and the ban was then expanded to include applications for decorative purposes. The Consumer Product Safety Commission banned other uses in 1977, including its inclusion in patching compound. In 1989, the EPA issued a ban called the "Asbestos Ban and Phase Out Rule" to prohibit the manufacture, import, processing, and distribution of asbestos and most asbestos-containing products by 1997. This was overturned by a United States federal court in 1991. The result is that only products banned before 1989 remained prohibited (flooring felt, rollboard, and specialty paper), and that no new uses of asbestos can be created (Agency for Toxic Substances and Disease Registry (ATSDR) website, accessed March 2016; EPA website 3, accessed April 2016). Asbestos-cement is therefore not illegal, but is no longer commercially produced in the United States.

3.4.2 CONSTRUCTION

Asbestos-cement panels were created by mixing asbestos, water, and hydraulic cement and spreading the mixture into plates, similar to the creation of cardboard. The cardboard-like plates were then pressed under high pressure, which was calibrated based on the desired shape or appearance (Illustration 28). The plate was then cured by the setting of the cement, making it as hard as stone. The addition of asbestos did not affect the hardening of the cement, and no separation took place. An early test showed that even a plate only 4 millimeters thick would not crack when dropped 3 meters from the ground, indicating its durability. The sheets were called frost-proof and condensation-proof, as small amounts of water could be absorbed (U.S. Patents 1904:769078 A). The rigidness of asbestos-cement made it brittle, and asbestos-cement manufacturers experimented with their own designs. In 1943, the Turners Asbestos Cement Company patented reinforced panels with a layer of textile between two layers of asbestos-cement for flexibility (Illustration 29; U.S. Patents 1943:2335208 A).

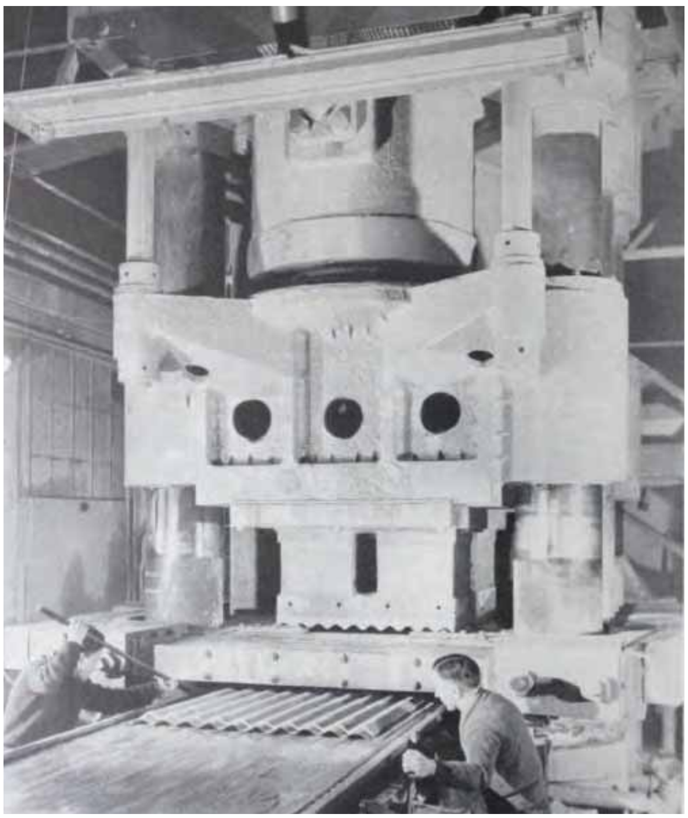


Illustration 28: A photograph of the standard press machinery used in 1944 (Johns-Manville 1944:2).

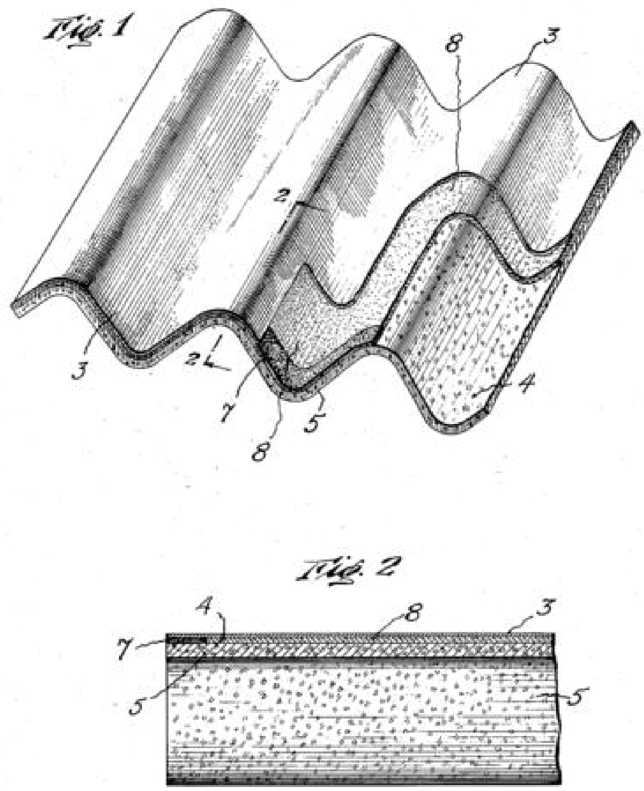


Illustration 29: An example of a reinforced asbestos-cement panel, with a layer of textile between two asbestos-cement boards (U.S. Patents 1943:2335208 A).

Although flat asbestos-cement panels were available, corrugated panels were more popular. Both styles were used for roofing and siding with fairly equal regularity, much in the same method of construction as corrugated metal sheets (Illustrations 30 and 31). Asbestos-cement panels were attached directly to studding, joists, or over existing plaster, and used offset joints to increase leak protection (Illustration 32; Ruberoid 1930:9). Asbestos-cement panel roofs required a ridge-roll, and siding required a corner-roll; both were also made of asbestos-cement (Illustrations 33 and 34; Ruberoid 1930:14-15).

Illustration 30: The application of asbestos-cement corrugated roofing on a steel structure (Keasbey & Mattison Company 1918:28).

Illustration 31: The application of asbestos-cement panels was easy and quick (Johns-Manville 1944:7).

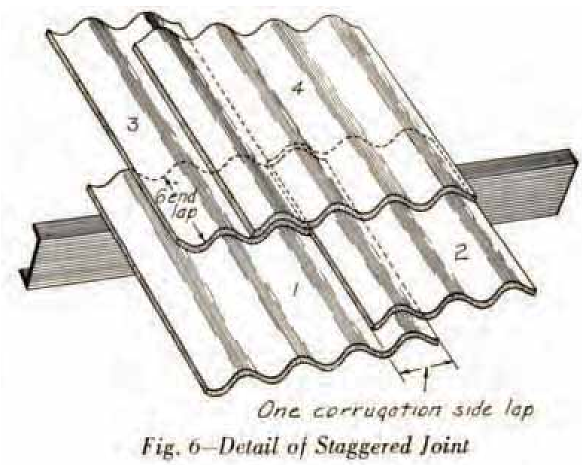
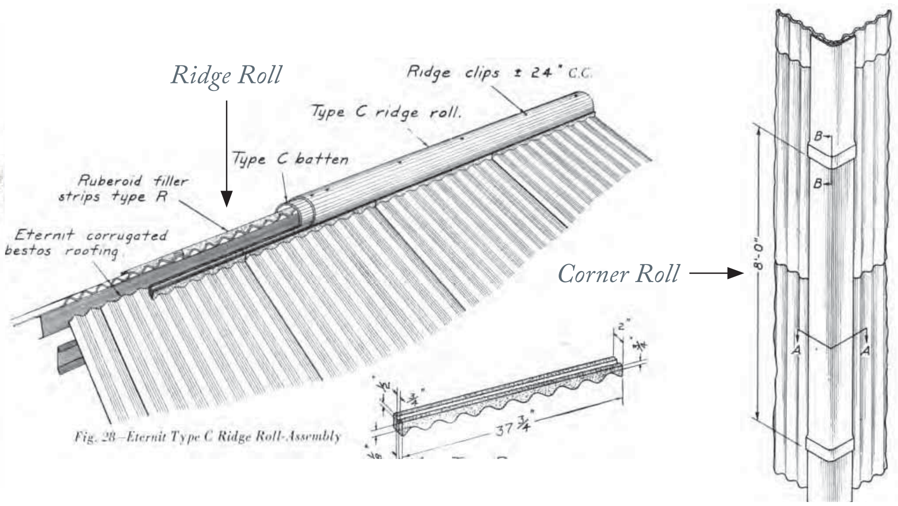


Illustration 32: The joints of corrugated asbestos-cement panels were staggered to prevent leaks (Ruberoid Co. 1930:9)



Illustrations 33 and 34: Asbestos-cement panel roofing required a ridge roll, and corrugated asbestos-cement panel siding required a corner roll; each was made of asbestos-cement ((Ruberoid Co. 1930:14-15).

3.4.3 ARCHITECTURAL IMPACT

Asbestos-cement was advertised as a substitute for stone, slate, wood, and clay. Asbestos was naturally a light cement gray and had a uniform texture, and could be painted. Before paining, asbestos-cement panels were coated in chlorinated rubber enamel or a priming coat of boiled linseed oil. Exterior paint could then be applied in a recommended three coats (Johns-Manville 1944:6, 13-15). Asbestos-cement products could be created in any shape, and also any color by adding pigment to the wet mix or rolling on color during the finishing process. Although advertised as "colorfast" by the 1920s, it was noted that fading was rampant. The pressing process of the asbestos-cement construction allowed the opportunity for different textures to be applied as well (NPS website, accessed January 2016).

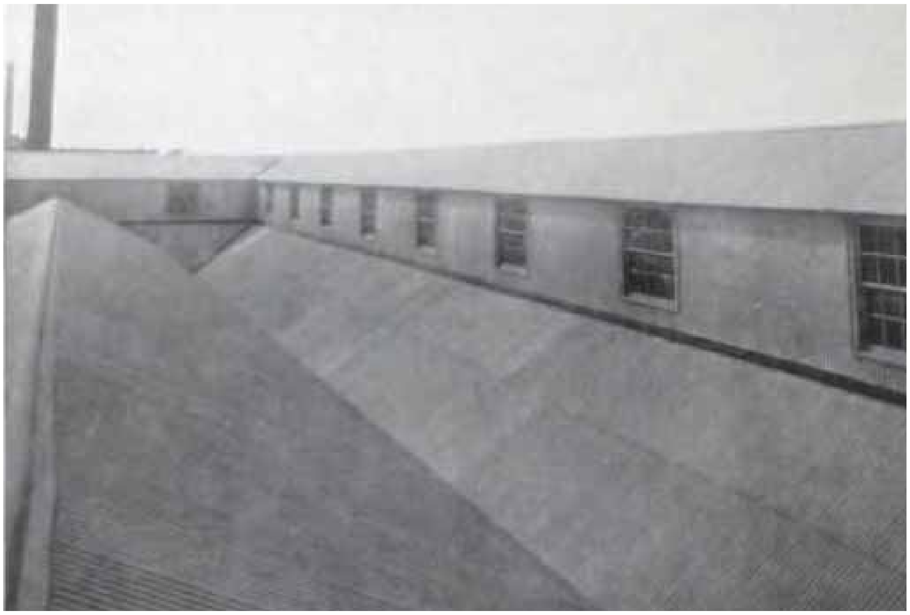


Illustration 35: An example of corrugated asbestos-cement panels on the roof of an industrial plant (Asbestos Manufacturing Company 1909:16).

Illustration 36: An example of corrugated asbestos-cement panels as siding on an industrial plant (Asbestos Manufacturing Company 1909:17).

Asbestos-cement panels were also called "asbestos building lumber," because the large sheets could be installed just like ordinary lumber for floors or partitions (GluedIdeas.com, accessed April 2016). The product was advertised as a substitute for corrugated iron or steel roofing and cladding (Illustrations 35 and 36). Asbestos-cement panels were almost exclusively used for industrial applications (NPS website, accessed January 2016). Flat panels were suggested for ceilings, roofing, and siding in industrial buildings, furnace casings, ductwork, and residential construction. Corrugated asbestos-cement panels were recommended for roofing, siding, and awnings specifically for industrial applications like mills, train sheds, and warehouses (Asbestos Manufacturing Company 1909:10-14; Johns-Manville 1944:13-15). Asbestos-cement could also be made into louvers, benefiting industries requiring ventilation (Illustration 37; Johns-Manville 1944:22).

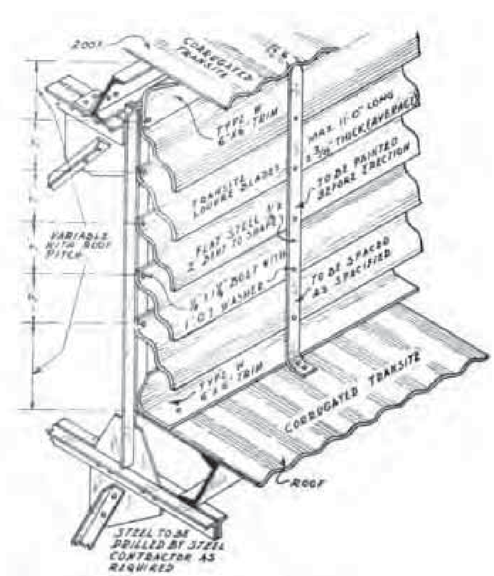


Illustration 37: Asbestos-cement panels were also made into louvers for industrial applications requiring extra ventilation (Johns-Manville 1944:22).

Modernism appeared after World War I, and was classified by the utilization of new technology, rejection of ornamentation, and belief that function should dictate form. The materials to suit theses tenants were primarily glass, steel, and concrete (Bose 2008:n.p.). Asbestos-cement manufacturers recognized the public's embrace of simplified architecture and began to market asbestos-cement as a modern material. Asbestos-cement combined the architectural aesthetics of concrete and corrugated metal, two materials already embraced by Modernist principles. Asbestos-cement was a technologically advanced building material, and was advertised as such. The panels of asbestos-cement could be easily incorporated into a curtain wall system, which was a key feature of Modernist architecture (Illustrations 38 and 39; Johns-Manville 1944:31).

Illustration 38: An example of a curtain wall constructed with flat asbestos-cement panels (Johns-Manville 1944:32).

Illustration 39: An example of a curtain wall constructed with corrugated asbestos-cement panels (Johns-Manville 1944:33).

3.4.4 ASBESTOS-CEMENT AND THE U.S. MILITARY

Asbestos-cement was primarily used on military installations as a functional material on utilitarian buildings. The use of asbestos-cement originated in the military's embrace of the Modernist idea that form follows function. Asbestos-cement had the simplicity favored during the twentieth century. (Hampton 2012:10). Section 3.1 includes a discussion of the military's embrace of the Modernist ideas and how it relates to the study materials. The U.S. military recognized the benefits of asbestos-cement with a wartime focus on efficiency and budget. Utilitarian buildings needed on military installations benefited from the availability of asbestos-cement, a seemingly miracle product when it came to insulation and fire protection.

The Johns-Manville Company was a key supplier of asbestos-cement to the U.S. military during World War II. Asbestos was a common material for building ships and airplanes. The health risks of asbestos were published in a study by the Navy Department and U.S. Maritime Commission in 1943, but the material continued to be frequently used (Encylcopedia.com, accessed January 2016). In 1944, the Johns-Manville Company advertised flat panel asbestos-cement for curtain walls as an effective construction system for rapid emergency construction (Illustration 40). It was also considered to be an "architectural and engineering advancement with wide possibilities for use in post-war building" (Johns-Manville 1944:31).

Asbestos-cement remained a popular choice in military architecture for Research and Development and support buildings for decades, only to cease as knowledge of the medical implications of its use increased.

Illustration 40: Buildings often integrated both flat and corrugated asbestos-cement panels, as seen here (Johns-Manville 1944:28).

3.4.5 QUALITIES AND CHARACTERISTICS OF ASBESTOS-CEMENT

Resistance to Fire

Asbestos-cement was non-combustible. This was considered essential anywhere combustible products were manufactured. Asbestos-cement could confine fire at the source, which was important for industrial complexes with closely clustered buildings. Oil refineries and other flammable production centers were the target uses for asbestos-cement (Johns-Manville 1948:1; Ruberoid Co. 1930:2).

Resistance to Weather and Corrosion

Asbestos-cement was advertised as resistant to climactic conditions of rain, salt corrosion, or acid rain. Asbestos-cement roofing prevented condensation, as dripping water over exposed electrical equipment was an issue. Asbestos-cement was resistant to practically all common acid fumes and gases that occurred near gas plants, coke ovens, smelters, and metallurgical equipment. Other types of roofing and siding usually needed to be replaced frequently, but asbestos-cement required no maintenance or replacement. Asbestos-cement was also smoke and chemical resistant (Johns-Manville 1948:1; Ruberoid Co. 1930:2).

Resistance to Temperatures and Steam

Corrugated asbestos-cement was not compromised by alternate dry and wet conditions or high and low temperatures, which were common conditions of industrial use. It could be used over open vats, in boiler rooms, or wherever steam occurred, without cracking, buckling, or warping. One example featured in Johns-Manville trade catalogs was its use in a "coke-quencher," in which 1,700 degrees Fahrenheit coke was cooled under cold water, creating immense amounts of steam. Asbestos-cement was said to be the only material to withstand the process (Johns-Manville 1948:1).

Durability and Economy

Asbestos-cement was advertised as becoming tougher and stronger with age and stable for years under conditions that would destroy other forms of roofing and siding. Asbestos-cement did not require protective paint covering or other maintenance expenses. It reduced fire risks to a minimum and was noted to have the longest life and lowest per annum cost when compared to other materials (Johns-Manville 1948:1). Both the flat and corrugated asbestos-cement sheets were able to be applied directly to the structural frame and were touted to "outlast the life of any industrial building" (Ruberoid Co. 1930:3). In addition to durable uses, asbestos-cement was easily removed, relocated, and reconstructed with almost no loss of materials (Johns-Manville 1944:31).

Physical and Structural Properties

The great pressure used to combine asbestos fiber and cement, together with the reinforcing action of the asbestos fiber, created a strong sheet. Panels only required widely spaced supporting members. Roofing could be spaced at up to 54-inch intervals and siding up to 60-inch intervals, center to center; reduced to 45-inch intervals in heavy ice or snow areas (Johns-Manville 1948:2).

Appearance

Asbestos-cement was naturally light cement gray in color with a uniform texture. Its light-reflecting properties were of advantage for both interiors and exteriors in reducing the heat of the sun. Asbestos-cement could be painted, although it was not required to preserve or protect the material (Johns-Manville 1948:2). Painting was easily done and provided an optional decorative effect (Johns-Manville 1944:31).

Ease of Application

Asbestos-cement required no special tools for application and could be installed as rapidly as any other corrugated material. Asbestos-cement was drilled with twist drills and fastened with screws or bolts, and could be sawed with a hand saw. The inside and outside radii of the corrugations were the same, assuring perfect nesting as a seal (Johns-Manville 1948:20; Ruberoid Co. 1930:3).

Insulation

Asbestos-cement was also sold for its insulation properties (Ruberoid Co. 1930:3). In 1944, Johns-Manville advertised that a 1-inch thick asbestos-cement board had as much insulating value as a 14-inch masonry wall (Johns-Manville 1944:31).

Health Hazards

The EPA states that exposure to asbestos occurs when ACM is disturbed or damaged in some way to release particles and fibers into the air. Exposure can cause lung cancer, mesothelioma, and asbestosis (EPA website 1, accessed April 2016). Deterioration can cause asbestos-cement to crumble and become friable. Extensive litigation has occurred as a result of health effects. Asbestos removal must be abated by trained professionals (American Society for Testing and Materials [ASTM] International website, accessed April 2016).

3.4.6 CONCLUSION

The asbestos-cement panels, which revolutionized utilitarian architecture, largely remain in place today. The cement construction allows them to remain without risk to health, as long as they are not damaged. The durability of asbestos-cement panels has resulted in very little common damage or preservation issues, and they were even advertised as becoming tougher with age. In actuality, absorbed water, lichen growth, or other damage will cause the panels to begin to degrade. The largest issue is that the product is no longer manufactured, and therefore replacement in-kind is not possible. New asbestos-free options are available, and corrugated metal is commonly used as a replacement.

4.0 Repair Versus Replacement

Exterior materials like roofing or cladding are the most important materials in the preservation of a building. Without a weather-tight envelope, a building becomes highly vulnerable to deterioration, and maintenance and repair tend to be urgent, often resulting in quick, affordable fixes that often do not take into account the harm to historic materials or related features, as it becomes more pressing to preserve the whole. The inadvertent damage caused by quick repairs can cause a loss of material or even create new conservation issues (Sweetser n.d.:1).

The SOI Standards state that exterior materials, including roofs, should be identified and evaluated before pursuing replacement. Before any repair work is performed, the historic value of the materials as roofing or cladding should be understood. The next step should be a complete internal and external investigation and conditions survey to determine all causes of failure. Once the causes have been identified, all repair or replacement alternatives should be considered (Sweetser n.d.:1).

The primary reasons for replacement of historic exterior materials at DoD installations are as follows:

1. The conditions survey determines that the material is too deteriorated for repair; and/or
2. The project team, consisting of design and cultural resource specialists, installation planners, and construction personnel, determine (after consultation with the SHPO) that the existing exterior materials cannot be rehabilitated to meet regulations such as building codes or antiterrorism (AT) requirements.

The potential weakness of the existing material should be considered. The more durable the material, the longer the material can theoretically be maintained. It should also be determined whether the repairs will be effective, as once an issue begins, maintenance costs will continue, and repeated repairs may equate to replacement costs. A one-time cost replacement will mean lower maintenance costs over time (Sweetser n.d.:5).

The four choices when dealing with a material issue are to maintain, repair, replace in-kind, or replace with a suitable substitute. When historic building material is damaged or deteriorated and in need of replacement, the ideal option is to replace in-kind with the same historic material. In certain cases, it is necessary to use substitute materials that should match the appearance and properties of the historic materials. If substitute materials are necessary, great care must be taken to keep the historic exterior building as visually similar as possible. Substitute materials can be cost-effective, accurately mimic characteristics of historic materials, and have a long service life (Park 1986:1).

Four circumstances warrant the use of substitute materials:

1. The unavailability of historic materials;
2. The unavailability of skilled craftsmen;
3. Inherent flaws in the original materials; or
4. Code-required changes (Park 1986:3).

For the materials of concrete and corrugated metal, the material should be replaced in-kind, as the materials remain available. Asbestos-cement, however, falls under the first, third, and fourth circumstances: the unavailability of historic materials; inherent flaws in the material; and code-required changes, which is the reason asbestos-cement is no longer produced, hence the material is unavailable.

5.0 Installations Visited for Case Studies

The installations selected for case studies were determined based on the results of the CRM survey as well as in coordination with NAVFAC MIDLANT. These visits provided a context within which to evaluate the use and feasibility of substitute materials, particularly within a larger historic district, and assist in documenting key factors to consider when assessing project effects with regard to Section 106. On-site research and documentation was carried out at the following DoD Installations: NSA Norfolk Naval Shipyard (Navy; Virginia); NSA Bethesda (Navy; Maryland); NSF Indian Head (Navy; Maryland); Picatinny Arsenal (Army; New Jersey); and NSF Carderock (Navy, Maryland). Each installation CRM, or the individual acting in this capacity, offered case studies for at least one, if not all three, exterior material types. Supporting materials gathered from each installation included copies of ICRMPs; historic structure reports; historic and current photographs of historic twentieth-century buildings; and correspondence and other documentation regarding SHPO consultation for rehabilitation projects.

In order to understand the issues faced at each installation with regard to replacement or upgrades of historic twentieth-century buildings, it is helpful to first understand the historical development and historic properties of each installation.

5.1 NAVAL SUPPORT ACTIVITY NORFOLK NAVAL SHIPYARD AND ST. JULIENS CREEK ANNEX, PORTSMOUTH, VIRGINIA

5.1.1 HISTORICAL SUMMARY

NSA NNSY, including the St. Juliens Creek Annex, is one of six Naval installations located in the Hampton Roads Region of Virginia and controlled by Commander, Navy Region Mid-Atlantic (CNRMA).

Naval presence in the Hampton Roads Region began with the lease of Gosport Yard to the federal government in 1794. Hampton Roads had been the site of past fortifications and was recognized as a key military position. Gosport Yard later became Norfolk Naval Shipyard, and is the oldest Naval installation in the United States. Gosport Yard played key roles in both the War of 1812 and the Civil War (NSA NNSY Regional ICRMP 2013:xii). Gosport Yard saw significant improvements in both the 1880s and early twentieth century as military technology grew. The Hampton Roads Region underwent rapid expansion and construction in the years leading up to World War I. The largest period of growth for the Navy in Hampton Roads was in the years prior to and during World War II when NSA NNSY again expanded and increased training, supply, and construction to prepare for wartime efforts. NSA NNSY ended ship construction in 1953, focusing instead on overhauling and servicing existing ships (NSA NNSY Regional ICRMP 2013:xii, 6.2, 10.3-10.4).

St. Juliens Creek Annex, originally called St. Juliens Magazine, was built in 1897 as an improvement to Gosport Yard. The magazine was designed to accommodate the assembly, storage, and maintenance of Naval ordnance at a safe distance from Gosport Yard, about 1 mile away. In 1917, the magazine was redesignated as the Naval Ammunition Depot, St. Juliens, and played a critical role in the development of the "North Sea Mine Barrage," a new type of Naval mine successfully used in World War I. St. Juliens played an important role in World War II production and testing of ammunition and ordnance, and was expanded in 1943. St. Juliens functioned in the same capacity until 1970, when it was redesignated as an annex of Naval Weapons Station, Yorktown and renamed St. Juliens Creek Annex. St. Juliens Creek Annex was transferred to NSA NNSY in 1977, to Naval Station Norfolk in 1996, and recently back to NSA NNSY (NSA NNSY Regional ICRMP 2013:10.33-10.36).

5.1.2 HISTORIC PROPERTIES

The Norfolk Naval Shipyard Historic District is characterized by a densely developed industrial complex whose component buildings and structures comprise a visually cohesive grouping that documents at a national level the historical development of a major U.S. Navy shore installation from 1827 to 1945, and embodies the themes of Military Planning and Architecture, and Military Engineering and Technology. The historic district includes over 60 contributing resources that are eligible for inclusion in the NRHP under Criteria A and C. The Norfolk Naval Shipyard Historic District can be separated into four precincts, organized by theme: Gosport Yard (1827-1945), Industrial Area (1911-1945), Marine Corps (1890-1916), and Support and Supply Area (1904-1945; Illustration 41; NSA NNSY Regional ICRMP 2013: 10.6, 10.11-10.15).

Illustration 41: A map of NSA Norfolk Naval Shipyard Historic District precincts: Gosport Yard, Industrial Area, Marine Corp, and Support and Supply (NNSY Regional ICRMP 2013:10.9).

A potential St. Juliens Creek Annex Historic District was identified in 1997, but has not yet been nominated for or listed in the NRHP. It was determined as potentially eligible under Criteria A and C as an integrated military-industrial complex associated with the production and storage of Naval munitions during World War I. The period of significance of 1897 to 1919 was proposed to encompass the period of work on the North Sea Mine Barrage (Illustration 42; NSA NNSY Regional ICRMP 2013:10.37-10.38).

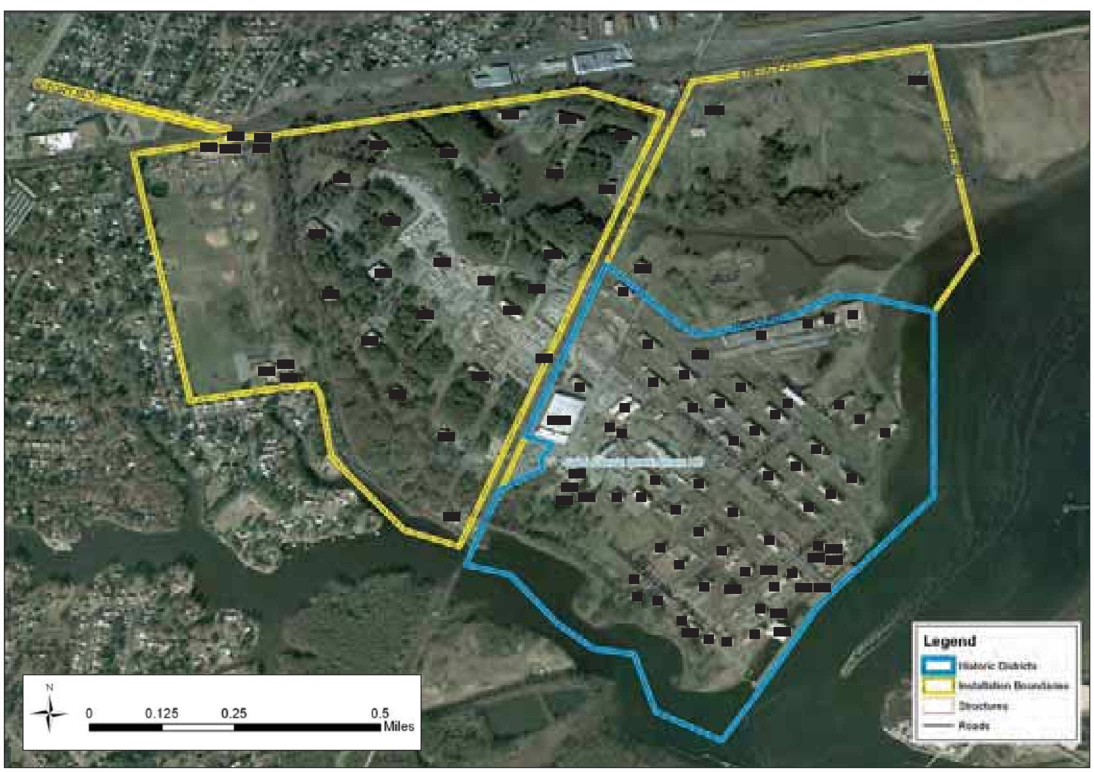


Illustration 42: A map of the potential St. Juliens Creek Annex Historic District (NNSY Regional ICRMP 2013:10.41).

5.2 NAVAL SUPPORT ACTIVITY BETHESDA, MONTGOMERY COUNTY, MARYLAND

5.2.1 HISTORICAL SUMMARY

NSA Bethesda is a Naval installation integrated with, but separate in command from, the Walter Reed National Military Medical Center (WRNMMC), located in Bethesda, Maryland. The mission of NSA Bethesda is to create an environment that enables patients to heal, staff to thrive, and guests to feel at home (NSA Bethesda ICRMP 2015:1-3).

Historically, the installation first developed as the National Naval Medical Center (NNMC) to unite medical care, medical training, research, and a medical library in one location. The site was selected by President Franklin D. Roosevelt and construction began in 1939. When it opened in 1942, the center was designed to hold 1,200 beds, the Navy Medical School, the Naval Dental School, and the Naval Medical Research Institute (NMRI). In 1945, temporary buildings were constructed to accommodate 2,500 returning sailors and marines. The installation gradually grew throughout the 1960s and 1970s to provide the most technologically advanced medical care. The NNMC provided healthcare to Navy personnel, veterans, and military families. In addition, it has served as the primary care facility for government officials and dignitaries (NSA Bethesda ICRMP 2015:1-3).

As part of the 2005 Base Realignment and Closure (BRAC), the DoD recommended the relocation of the Walter Reed Army Medical Center to the National Naval Medical Center, merging the two into the WRNMMC. The merger took place over 2008 to 2011, and included 2.4 million square feet of renovated facilities, including extensive upgrades to existing hospital facilities. NSA Bethesda was created as a separate entity in 2009 through a Memorandum of Agreement between the National Naval Medical Center Commander and the Naval District Washington Commander to create a command structure separate from the medical center (NSA Bethesda ICRMP 2015:1-3).

5.2.2 HISTORIC PROPERTIES

Building 1 was constructed as the National Naval Medical Center in 1941 and was listed in the National Register in 1977 for significance associated with the themes of architecture, education, military, and science. President Franklin D. Roosevelt chose the location of the building as well as sketched the original design for the building (Earle 1975:n.p.). The NNMC Historic District, which includes Building 1, is eligible for the National Register under Criterion A for medical service with state-of-the-art facilities for Naval officers, veterans, and their families; the primary care of the President of the United States; and for the services of the NMRI. The district is also eligible under Criterion B for its association with President Franklin D. Roosevelt. The district is eligible under Criterion C for the Art Deco style architecture designed by architect Philip Cret (Illustration 43; NSA Bethesda ICRMP 2015:4-10).

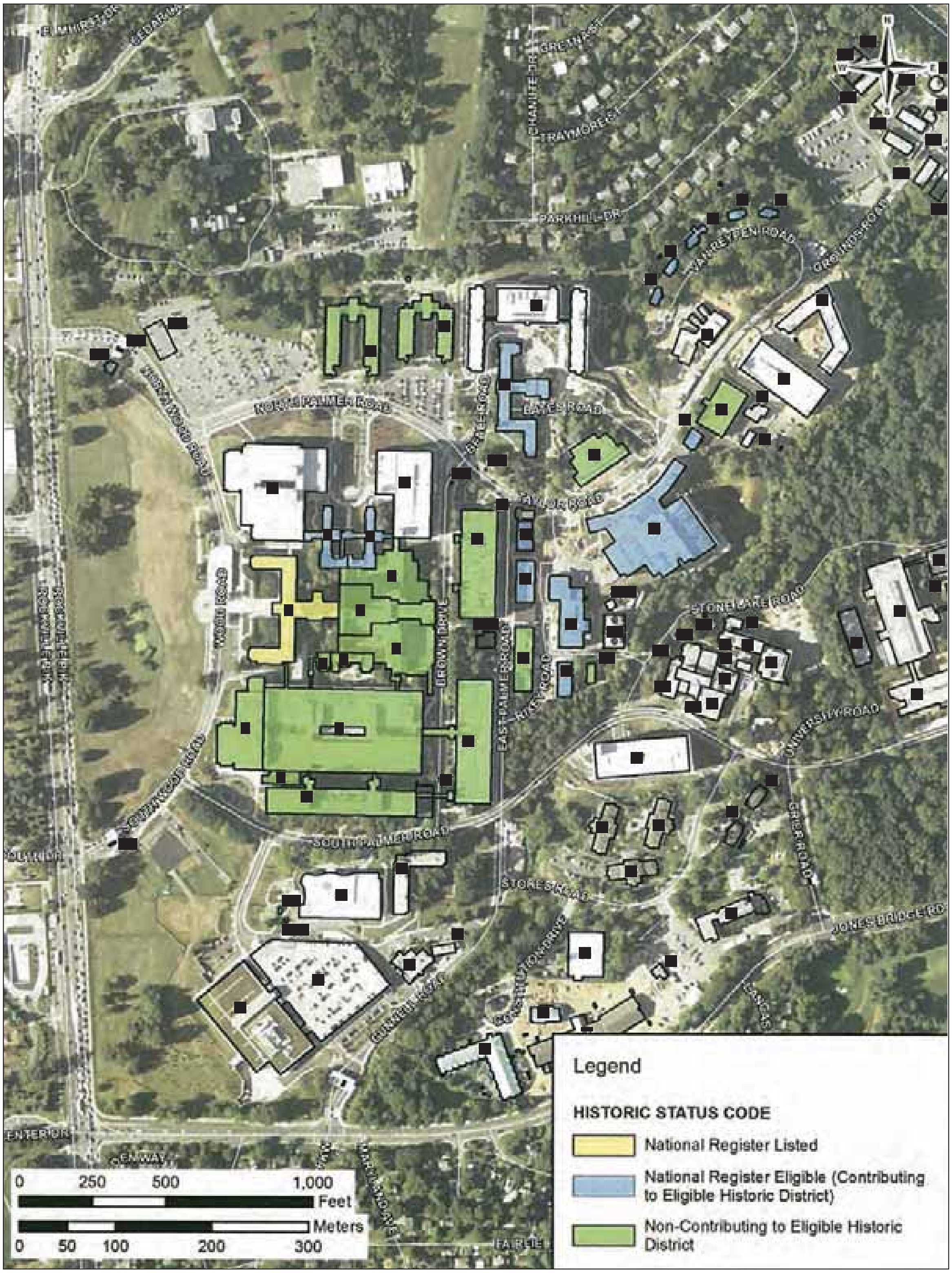


Illustration 43: A map of the NNMC Historic District (NSA Bethesda ICRMP 2015:4-8).

5.3 NAVAL SUPPORT FACILITY INDIAN HEAD, CHARLES COUNTY, MARYLAND

5.3.1 HISTORICAL SUMMARY

NSF Indian Head is a Navy base in Charles County, Maryland. In the nineteenth century, the Naval Gun Factory in Annapolis, Anne Arundel County, Maryland, was the primary location for Naval weapons testing until increased boat traffic in the Chesapeake Bay became problematic. Consequently, the Navy found a new location for a new testing facility in Indian Head, Charles County, purchasing 473 acres along the Potomac River. The location was in a remote area 20 miles south of Washington Navy Yard. It was first established as the Naval Proving Ground at Indian Head in the 1890s, and later became the first major facility for non-agricultural use in Charles County. The Naval Proving Ground was created for testing Naval guns, ammunition, and armor, as part of an expansion into science and engineering (NSF Indian Head ICRMP 2012:3-16).

In 1898, Indian Head developed a powder factory for the production of smokeless powder, and became the first major chemical factory operated by the Navy. The facilities were enlarged throughout the early twentieth century during the administrations of Presidents Theodore Roosevelt and Woodrow Wilson, who both sought to decrease dependence on private suppliers of smokeless powder. World War I caused another expansion in facilities within the installation due to associated military wartime needs (NSF Indian Head ICRMP 2012:2-18).

The Naval Proving Ground became obsolete due to the small range size. Naval ordnance increased in size and range, causing an inability to conduct proving operations and creating safety concerns. As a result the proving ground was relocated down river to Dahlgren (still part of NSF Indian Head) in 1918. The last Naval gun test at NSF Indian Head was on July 21, 1921. However, Indian Head continued to function as a powder factory (NSF Indian Head ICRMP 2012:2-17).

As World War II approached, Indian Head was one of only two Naval stations equipped with facilities for explosives production. The Extrusion Plant facilities were built, expanding the role of powder production into rocket propellant production research and development. Between 1941 and 1942, Indian Head saw an expansion of hundreds of new buildings for research, production, distillation, storage, solvent recovery, and magazines (NSF Indian Head ICRMP 2012:2-19).

During the Cold War, Indian Head changed its production from smokeless powder to rocket and missile propellant. Indian Head made technological advances through the 1950s that resulted in the abandonment of smokeless powder production. In 1956, Indian Head became instrumental in the support of the Polaris program, which was the focused research and design development of nuclear-armed submarine-launched ballistic missiles. The installation's mission evolved through the 1960s to developing, testing, and manufacturing the newest generation of explosives and propellants for use in weapons systems and aboard Navy ships and aircraft. Today, as the principal Energetics Center for DoD, the Naval Surface Warfare Center, Indian Head Explosive Ordnance Disposal Technology Division (NSWC, IHEODTD) provides primary technical capability in energetics (explosives, propellants, and pyrotechnics) through engineering, fleet and operational support, manufacturing technology, limited production, and industrial base support. They also provide research, development, and test and evaluation for energetic materials, ordnance devices, and components, as well as development of ordnance engineering standards for chemicals, propellants, and their propulsion systems, explosives, pyrotechnics, warheads, and simulators (NSF Indian Head ICRMP 2012:2-20; 2-1).

5.3.2 HISTORIC PROPERTIES

NSF Indian Head has four existing NRHP-eligible historic districts, including the Naval Proving Ground Historic District, Naval Powder Factory Historic District, Indian Head Residential Historic District, and the Extrusion Plant Historic District; as well as two pending historic districts: the Polaris Base Grain Historic District and the Explosive Ordnance Disposal (EOD) Historic District. The four existing historic districts encompass a total of 111 buildings on approximately 607 acres. For the purposes of this study, the two historic districts of immediate interest are the Naval Powder Factory Historic District and the Extrusion Plant Historic District.

The Naval Powder Factory Historic District, which is associated with smokeless powder production, includes approximately 22 contributing buildings on 370 acres. The period of significance is 1900 through 1945. The district is significant under Criterion A for its historical association as the first major chemical powder factory operated by the Navy and as an important supplier of smokeless powder in World War I and World War II, and under Criterion C for embodying distinctive characteristics of a type, period, or method of construction for its industrial edifices that were designed to house machinery and processes (Illustration 44; Burden and Giglio 1996b:7-2).

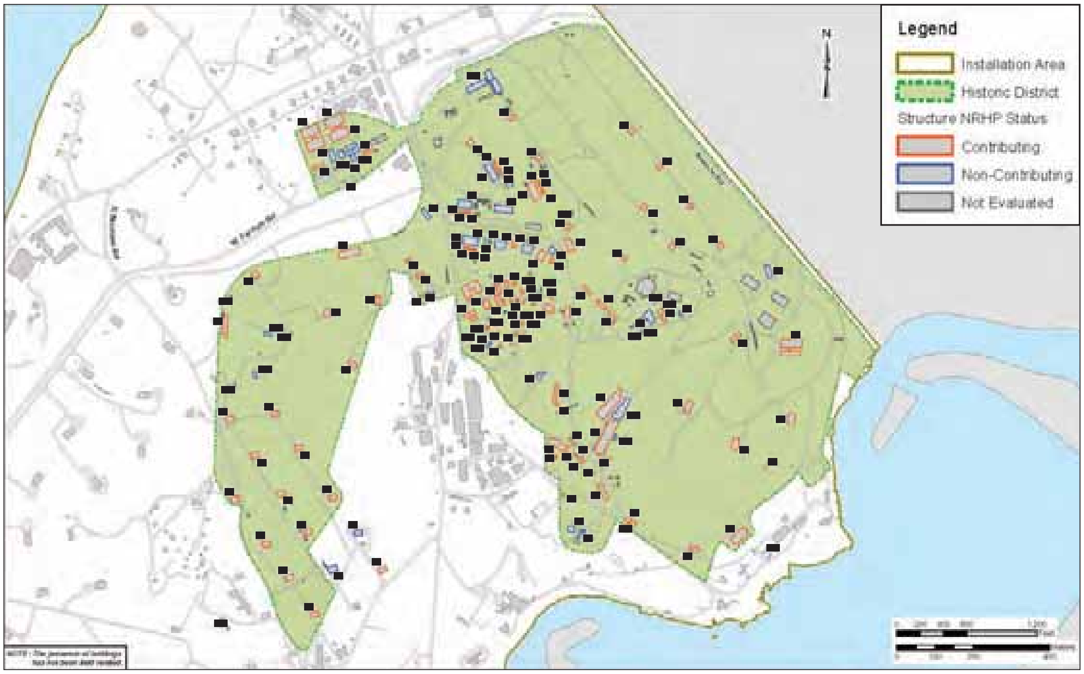


Illustration 44: A map of the Naval Powder Factory Historic District (NSF Indian Head ICRMP 2012:3-27).

The Extrusion Plant Historic District is associated with the extrusion plant and ballistic laboratory established for producing and testing rocket propellant. The historic district includes approximately 64 buildings and 64.5 acres. The district is significant from 1943 to 1946 under Criterion A as the first full-scale rocket propellant production facility operated by and for the Navy, and under Criterion C for its unique design of an industrial process for the Navy and the development of ordnance technology. The contributing buildings reflect major military technological advancement and arrangement dictated by function (Illustration 45; Burden and Giglio 1996a:8-3; NSF Indian Head ICRMP 2012:3-28).

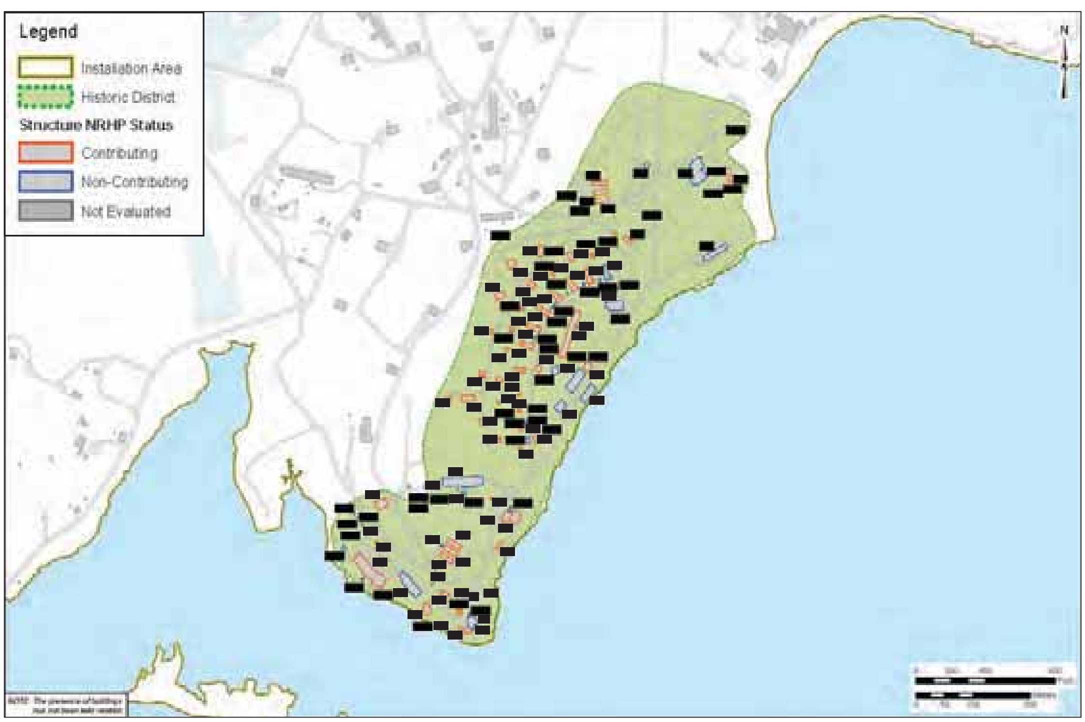


Illustration 45: A map of the Extrusion Plant Historic District (NSF Indian Head ICRMP 2012:3-32).

5.4 PICATINNY ARSENAL, MORRIS COUNTY, NEW JERSEY

5.4.1 HISTORICAL SUMMARY

Picatinny Arsenal is an Army installation in Morris County, New Jersey, known as the Joint Center of Excellence for Armaments and Munitions and the headquarters for the Armament Research, Development, and Engineering Center. Picatinny Arsenal was established in 1880 as the Dover Powder Depot, then later as the Picatinny Powder Depot. Initial construction consisted of mainly storage magazines, officers' quarters, and service buildings. In 1891, the Army turned 315 acres over to the Navy as the Lake Denmark Ammunition Depot. The Picatinny Powder Depot and the Lake Denmark Ammunition Depot were primarily for the manufacture and storage of powerful explosives and ordnance (Picatinny Arsenal ICRMP 2014:iv).

The Picatinny Powder Depot was renamed Picatinny Arsenal in 1907. In 1911, the Arsenal continued munitions production but added a research and development mission. By World War I, Picatinny Arsenal had established testing laboratories and a small plant for the development of artillery ammunition (Picatinny Arsenal, "Picatinny Arsenal Historical Overview," accessed March 2016). In 1926, lightning struck a storage building at the Lake Denmark Ammunition Depot and caused a massive explosion, launching projectiles for miles and causing destruction of the surrounding built environment (Picatinny Arsenal ICRMP 2014:iv). The period after the explosion involved rebuilding impacted areas with the help of the Civilian Works Administration (CWA) in 1933 and Works Progress Administration (WPA) in 1935, allowing the Arsenal to host approximately 1,000 workers per year until 1939 (Picatinny Arsenal, "Administration and Research Area," accessed March 2016).

Between World War I and World War II, Picatinny Arsenal developed more research and development facilities, with work in smokeless powder and the discovery of the explosive haleite. In the years leading up to World War II, the Arsenal expanded. As the United States entered the war, Picatinny Arsenal reverted back to a focus on munitions, as it was one of the few military installations with manufacturing capabilities. The Arsenal developed new production processes for bombs and artillery shells that would have a nationwide impact. After World War II, Picatinny Arsenal returned to the mission of research and development. Rocket testing commenced in 1946, and the Arsenal began development of new weapons into the Korean and Vietnam wars. The Armament Research and Development Command moved their headquarters to Picatinny Arsenal in 1977, where research and development remains the primary mission of the installation (Picatinny Arsenal, "Picatinny Arsenal Historical Overview," accessed March 2016).

5.4.2 HISTORIC PROPERTIES

Picatinny Arsenal has five eligible historic districts including the Administration and Research (100 Area) Historic District, the Ordnance Testing (600 Area) Historic District, the Army Rocket Test (1500 Area) Historic District, the Navy Air Rocket Test Station (3600 Area) Historic District, and the new Former Lake Denmark Naval Ammunition Depot Historic District. For the purposes of this study, the two historic districts of immediate interest are the Administration and Research Historic District and the Army Rocket Test Historic District.

The Administration and Research Historic District includes housing constructed in the late 1800s, as well as buildings which were built as part of the reconstruction efforts following the explosion at the Lake Denmark Ammunition Depot in 1926. The district is significant under Criterion A for the research and development activities resulting in new advances and products leading up to World War II. The district has 21 contributing structures and a period of significance from 1880 to 1945 (Illustration 46; Panamerican 1999:iv).

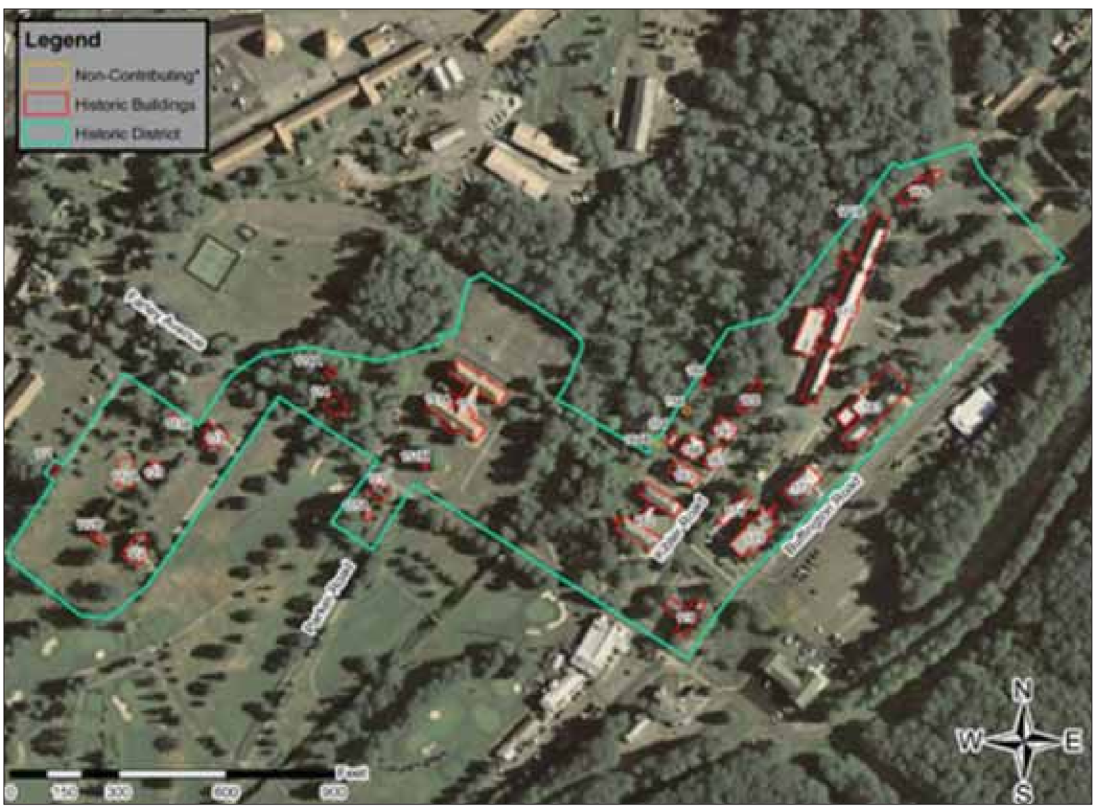


Illustration 46: A map of the Administration and Research Historic District (Picatinny Arsenal, "Administration and Research Area," accessed March 2016).

The Army Rocket Test Area Historic District was built over the late 1940s through the 1960s, during the Cold War. The district is significant under Criterion A for the testing of rockets and missiles for research purposes and the role of Picatinny Arsenal as one of six old-line manufacturing arsenals that participated in major weapons programs after World War II. Picatinny Arsenal was assigned nuclear munitions development in the 1950s, making it an important rocket testing program. The pyrotechnic facilities built at that time were state-of-the-art, but were largely obsolete by the end of the 1970s (Illustration 47; Picatinny Arsenal, "Army Rocket Test Area," accessed March 2016).

Illustration 47: A map of the Army Rocket Test Area Historic District (Picatinny Arsenal, "Army Rocket Test Area," accessed March 2016).

5.5 NAVAL SUPPORT FACILITY CARDEROCK, MONTGOMERY COUNTY, MARYLAND

5.5.1 HISTORICAL SUMMARY

NSF Carderock (NSFC) is a Navy installation in Montgomery County, Maryland, that is historically known as the David Taylor Model Basin. It was established in 1937 as the primary center for research, development, and testing of ship models for the Navy (NSFC 2012:i-i, 2-20)

In the nineteenth century, British Naval architect William Froude developed a method of building ship models while scaling relationships to allow for experimental results. This method was utilized worldwide as countries built towing basins for ship models as testing facilities. In 1898-1899, David W. Taylor became the principal designer and director for a Navy towing basin built at Washington Navy Yard. The original basin was obsolete by the 1930s, and a larger and more capable basin was designed as the David Taylor Model Basin at Carderock, Maryland. The David Taylor Model Basin was the best facility of its type in the world when it was built, and was extended in the late 1940s. The basin was heavily used during World War II to determine new ship designs, modifications, stability, and to conduct testing (Allison 1984:n.p.).

After a decline in federal funding and an increase in private industry contracts through the 1970s and 1980s, the David Taylor Model Basin was merged with the Naval Ship Systems Engineering Station to become NSFC in 1992 (NSFC 2012:2-24).

5.5.2 HISTORIC PROPERTIES

Carderock has one historic district, the David Taylor Model Basin Historic District, which encompasses all 186 acres of the installation (National Capital Planning Commission 2014:n.p.). The district is listed in the NRHP under Criterion A for its impact and association with important events in the U.S. Navy and under Criterion C for its distinctive design and unique scientific facilities. The period of significance is from 1937 to 1945 (Illustration 48; Allison 1984:n.p).

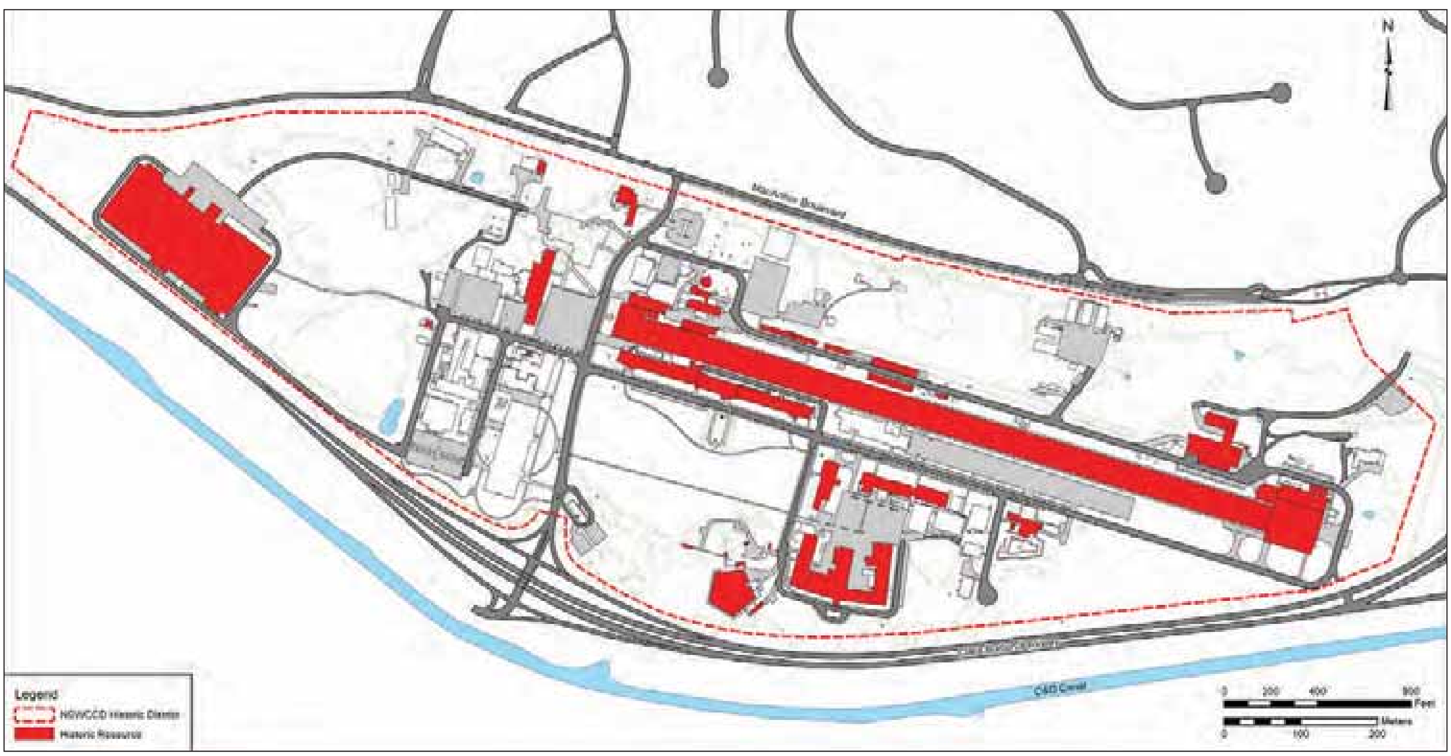


Illustration 48: A map of the David Taylor Model Basin Historic District (NSFC 2012:3-14).

6.0 Case Studies

The exterior materials of concrete, corrugated metal, and asbestos-cement were used for cladding or roofing, which together create the building envelope. As such, each material is highly vulnerable to moisture, which is the top cause of conservation issues for these materials. Each material has its own strengths and weaknesses, but each material has a long service life if properly maintained.

The key issue for each material is maintenance. Though there are certainly exceptions, concrete, corrugated metal, and asbestos-cement are utilitarian materials. They share the qualities of durability, minimal upkeep, and fire protection, which made each material a popular choice on military installations in the twentieth century. The utilitarian natures of the three types of materials means that they are mostly used on secondary and support buildings, which may be vacant, underused, or used for simple storage. Their practical uses often make them last in line for maintenance, and even small problems, when left unrepaired, can lead to a failure of the material.

Every installation is experiencing work on exterior material maintenance, repair, and replacement. The following case studies are not intended to restate regulations or solutions, but rather to address the issues that select installations have encountered with the intent that the problems are applicable elsewhere. Concrete, corrugated metal, and asbestos-cement are extremely common materials that are often overlooked. The utilitarian uses of the buildings constructed of these materials make them less likely to have been modernized, so they often retain their historic fabrics. The intent of this report, including the succeeding case studies, is to provide CRMs with information that will assist them in developing maintenance, repair, and replacement plans that comply with SOI Standards as the materials reach the ends of their service lives. The examples in the following section are intended to provide CRMs with an array of possibilities with regard to repair and replacement projects pertaining to exterior materials in historic buildings.

6.1 ANTITERRORISM (AT) STANDARDS

The intent of the AT standards, as specified in the Unified Facilities Criteria (UFC) 4-010-01, DoD Minimum Antiterrorism Standards for Buildings is to minimize mass casualties in buildings or portions of buildings owned, leased, privatized, or otherwise occupied, managed, or controlled by or for DoD in the event of a terrorist attack.

These standards provide appropriate, implementable, and enforceable measures to establish levels of protection against terrorist attacks for all inhabited DoD buildings where no known threat of terrorist activity currently exists. (UFC 2013:1-3).

The minimum antiterrorism standards for new and existing buildings have many considerations. In addition to exterior materials, the type of framing, windows, occupancy, and use are all analyzed for recommendations. Due to the widely varying uses for buildings that utilize concrete, corrugated metal, and asbestos-cement, this study cannot outline all the considerations or applicable AT standards which may apply. However, as previously noted, many of the buildings constructed with these materials are utilitarian buildings that may be exempted from the requirements of the AT standards because they are classified as low occupancy. Low occupancy buildings are defined as, "Any building or portion of a building routinely occupied by fewer than 11 DoD personnel or with a population density of less than one person per 430 gross square feet (40 gross square meters)" (UFC 2013:44). For those buildings not exempted from the standards, if required standoff distances are met, conventional construction generally may be used for cladding and roofing materials. Table B-2 in the AT Standards lists standoff distance requirements for buildings with metal panel, reinforced concrete, and masonry block exteriors, as well as for buildings with conventional construction roofs. Table 2-3 of the AT Standards defines the parameters of what is considered conventional construction (UFC 2013:28, 52). The 2013 UFC references additional DoD instructions and handbooks that assist in applying AT standards (UFC 2013:1-2, 1-3). In addition, DoD Legacy Project No. 03-176, Antiterrorism Measures for Historic Properties (Webster et al. 2006) provides information regarding the responsibility of the project team, consisting of design and cultural resources personnel, as well as installation planners and construction personnel, to identify solutions that will comply with UFC 4-010-01 and conform to SOI Standards.

6.2 CONCRETE

Concrete is versatile and is used for a wide range of buildings. While concrete is considered "permanent," it still is subject to deterioration (Gaudette and Slaton 2007:1). Concrete also went through a period of technological advancement with admixtures and air entrainment, which are conditions that should be considered in the evaluation of historic concrete. The chemical processes and quality control methods improved through the twentieth century, allowing for an increase in strength and durability (Gaudette and Slaton 2007:4). Concrete deterioration occurs for four main reasons: corrosion of embedded steel reinforcement, degradation of the material, structural problems, or improper construction/application.

Illustration 49: A section of rusted steel reinforcement on NSFC Building 1 has resulted in the spalling of the concrete (Graves 2012).

Illustration 50: The grid of the steel reinforcement is visible on NSFC Building 1, as the rusted steel has caused the delamination and spalling of the surface concrete (Graves 2012).

Steel reinforcement was an important advance in concrete construction, as it gave the material more tensile strength and allowed for wider applications. However, it is often the cause of deterioration in concrete. Steel reinforcement, when installed, is surrounded by an oxide layer that both protects the steel from corrosion and bonds to the concrete. When water, water vapor, or high humidity can reach the steel, corrosion occurs. Most maintenance issues of concrete are a result of water. If concrete is saturated with water and then exposed to freezing temperatures, the water expands and applies force on the concrete. The freeze and thaw cycle results in cracks or delamination. The evidence on the exterior of the concrete is often scaling or micro-cracking. The use of air entrainment provided protection from the freeze and thaw cycle. Another moisture issue is alkalis in cement reacting with certain aggregates to create a crystalline gel, which expands when exposed to moisture and results in cracking. Professional analysis is required to determine whether this type of aggregate exists. Low alkali cements are used in new construction to avoid this issue (Gaudette and Slaton 2007:5). Staining of the concrete may be evidence of this issue.

6.2.1 COMMON CONDITIONS

Corrosion

Corrosion is the rusting of the steel, but the effects can be structural (Illustrations 49 and 50). The rusted steel expands, requiring more space within the concrete. The change in volume causes either cracking or spalling of the concrete. Visible staining of the concrete is evidence of corrosion. Delaminating, or the planar separation of the concrete, is also evidence of interior corrosion (Gaudette and Slaton 2007:5).

Carbonation

Concrete can be compromised by carbonation, which reduces the inherent alkalinity of the concrete. Carbonation is the carbon dioxide in the atmosphere reacting with the calcium hydroxide and water in the concrete. This occurs on the concrete's surface, but can infiltrate to the steel reinforcement over time. The process of carbonation can be accelerated in a few ways. If calcium chloride was an admixture of the original concrete, often used to promote rapid curing, then the concrete is at high risk for carbonation. Similarly, concrete exposed to "deicing salts," which are common in the winter in northern climates, are also at risk. Large amounts of salt from proximity to seawater can also cause carbonation. The result is that water, water vapor, or high humidity can then reach the steel and cause corrosion (Gaudette and Slaton 2007:5).

Honeycombing

Honeycombing is another moisture issue occurring primarily in concrete that dates from before World War I. At that time, aggregate was often comprised of cinder from burned coal or crushed brick, and the concrete mixture was tamped into place. The result is that the concrete can be poorly consolidated. The voids, or honeycombs, trap water, reduce the protection of the reinforcing steel, or even cause localized weakness. Today, vibrations are used to prevent honeycombing (Gaudette and Slaton 2007:5-6).

Erosion

Concrete is subject to erosion or weathering from wind, rain, snow, or salt water. The weathering acts on the cement paste and results in the exposure of the aggregates. This can also be caused by leaking pipes, gutters, etc. High pressure water is often used for cleaning concrete and can also exacerbate the problem (Gaudette and Slaton 2007:6). Too much erosion of the cement paste could cause the aggregates to fall out.

Cracking

Concrete may have active cracks (which continue to spread or widen) or dormant cracks (which stay the same size). Dormant cracks are sometimes caused by shrinkage during curing and do not affect the structural integrity; however, they do allow a channel for moisture, which can lead to further problems. Structural cracks can be caused by overloading, uneven foundations, or design issues. They are considered active if overloading continues or more settling occurs, and dormant if the cause has been stabilized (Illustration 51). Cracking can also be caused by expansion and contraction from thermal changes, often occurring in older structures built without expansion joints (Gaudette and Slaton 2007:7).

Illustration 51: An example of a hairline crack on Building 3 at NSA Bethesda. The concrete is undergoing repairs, and the blue tape is used to mark the location of a crack that will be filled with an epoxy injection (Photographer: Samantha Driscoll 2015).

Illustration 52: An example of a pop-out around a joint on Building 1 at NSFC (Graves 2012).

Pop-Outs

A pop-out is a conical-shaped fragment that breaks out of the surface of concrete and is usually caused by the expansion of porous aggregate particles with a high rate of absorption (Illustration 52). The aggregate absorbs moisture or freezes under moist conditions, and swells to create internal pressure, which in turn ruptures the concrete surface (Basham 2013). The pop-out causes a deeper loss of material than scaling, but is still generally cosmetic and not structural (United Materials website, accessed April 2016).

Spalling, Scaling, and Delaminating

Spalling, scaling, and delaminating are the loss of surface material. These conditions are most often associated with freezing and thawing or the corrosion of reinforcing steel. For the freeze and thaw cycle, moisture is absorbed and expands when frozen, causing cracking and displacement. Similarly, if the reinforcing steel becomes corroded, the steel expands and puts pressure on the surrounding concrete until it cracks and is displaced. Spalling, scaling, and delaminating may also be caused by improper finishes, which detach in thin layers (Illustrations 53, 54, and 55). If the spalling is severe enough, it can affect the load-carrying capacity of the concrete (Gaudette and Slaton 2007:7).

Illustration 53: An example of spalling on Building 3 at NSA Bethesda. The concrete is undergoing repairs, and the blue tape is used to mark the location of a needed repair (Photographer: Samantha Driscoll 2015).

Illustration 54: An example of spalling on Building 3 at NSFC (Graves 2012).

Illustration 55: Corrosion of steel reinforcement, as shown in this example from Building 173 at Picatinny Arsenal, is a common cause of spalling (Photographer: Samantha Driscoll 2015).

Deflection

Deflection is the bending, sagging, or displacement of concrete and often affects the structural integrity of the building. Deflection can be caused by overloading or uneven loading, or by the corrosion of reinforcing steel. A mistake in the design, such as a low-strength concrete or undersized reinforcing bars, can also result in deflection (Gaudette and Slaton 2007:7).

Staining and Efflorescence

Staining can be caused by a number of exterior causes and conditions, such as pollution, dirt, organic growth, etc. While not structural issues, staining and efflorescence can be indicative of moisture infiltration that can cause future issues (Illustration 56). Staining can be evidence of corrosion of the reinforcement, alkali-aggregate reactions, or improper surface treatments. Efflorescence is a type of white staining that is caused by the deposition of soluble salts on the surface of the concrete as a result of water migration (Gaudette and Slaton 2007:7).

Illustration 56: Building 1507 at Picatinny Arsenal has a rather extreme example of efflorescence, cracking, and spalling due to moisture infiltration (Photographer: Samantha Driscoll 2015).

6.2.2 ASSESSMENT

Proper maintenance is the ideal preservation method of historic concrete, as it requires minimal intervention while retaining the historic fabric. However, repair and replacement are necessary when the concrete has experienced severe deterioration; internal problems will lead to ongoing issues; or structural deficiencies have surfaced (Gaudette and Slaton 2007:8). When determining the correct route for repairing or replacing historic concrete, it is important to identify the causes of the deterioration. A conditions survey should be completed to evaluate the extent, types, and patterns of deterioration. These can be non-destructive (such as tapping with a hammer to determine hollow sounds beneath the surface or using a pachometer to detect reinforcement below surface) or destructive (such as core sampling or revealing reinforcement; American Concrete Institute 2007:11-13). Repairing the concrete should be considered if the deterioration is not structural, and include details such as analysis of the concrete; development of multiple mixes to determine appropriate cement and aggregates; and allowance of time or creation of methods for the aging of the new concrete so that it will match the historic concrete (Gaudette and Slaton 2007:7).

An important step in assessment is a visual condition survey which evaluates the extent, types, and patterns of deterioration. Laboratory analysis of the concrete to be repaired is an important part of the investigation. Laboratory analysis involves removing samples to identify original components of the concrete and any evidence of damage. Information from the testing can include the following: chloride content, alkali levels, sulfate content, deleterious aggregates, location of carbonation, and compressive strength (Jester 2014:65, 68). However, CRMs may find themselves without the funding for laboratory analysis. In that case, the CRM should concentrate on the visual inspection of the concrete's deterioration followed by research of the possible causes and/or historic construction information. The results of the investigation should guide appropriate techniques.

6.2.3 MAINTENANCE

Cleaning

Cleaning can be used to improve appearance, either as a maintenance tool or in preparation for repairs. There are three ways to clean concrete: water, abrasive surface treatments, or chemical surface treatments. When using water, low pressure (under 200 pounds per square inch [psi]) or steam cleaning is effective for dirt. However, even the low pressure could harm a deteriorated surface. Power washing can be used on high-strength concrete, but is generally too damaging for most historic buildings. Abrasive treatments can alter texture or reflectivity of the concrete, and can do damage to fragile concrete. Microabrasive surface treatments that use fine particulates at a low pressure (35 to 75 psi) can be less damaging. Chemical surface treatments are detergent cleaners or diluted acid cleaners. Side effects of this method can be bleaching, etching, or other surface alterations. With any cleaning method, a small area should be tested before applying it to the whole building (Gaudette and Slaton 2007:9).

Picatinny Arsenal: Building 173

Building 173 at Picatinny Arsenal is an example of stained concrete that will be cleaned (Illustrations 57 and 58). Building 173 is a contributing resource to the Administration and Research Historic District. Built in 1942, the historic use of the building was as a guard house, telephone building/transformer station, and firehouse (Picatinny Arsenal ICRMP 2014:n.p.). The staining is only an aesthetic issue, with no known structural implications for the historic concrete. The last cleaning was likely 20 to 30 years ago. For Building 173, Picatinny Arsenal will clean the concrete by powerwashing with a mild detergent at a low pressure, a technique approved by the New Jersey Historic Preservation Office (NJHPO) (Huggan 2015). In accordance with Picatinny Arsenal's Programmatic Agreement with the NJHPO, this action does not require a separate Section 106 consultation.

Illustration 57: Building 173 at Picatinny Arsenal showing staining along concrete. The staining will be removed with a low pressure powerwash with mild detergent, a technique approved by the NJHPO (Photographer: Samantha Driscoll 2015).

Illustration 58: Detail of staining on Building 173 at Picatinny Arsenal. The last cleaning of the concrete is estimated to have occurred between 20 and 30 years ago (Photographer: Samantha Driscoll 2015).

Sealant and Paint

The most important aspect of concrete maintenance is monitoring and maintaining/reducing moisture infiltration. The preferred sealant is an elastomeric sealant, which replaced more traditional oil-based caulk. Sealants can be applied to all common points of water infiltration: cracks; joints; window and door perimeters; connections with other materials; and around lamps, signs, and plumbing fixtures. Urethane or polyurethane sealants are common for joints and cracks, and last for up to ten years. High-performance silicone sealants can have a service life of up to 20 years. Sealants for crack repairs can be sandblasted to mimic the texture of the surrounding concrete, making it less visually apparent. The effectiveness of sealants depends on proper application, and should be regularly examined during routine maintenance (Gaudette and Slaton 2007:9-10). Once sealed, the concrete can be painted to match the historic concrete color. Painting can assist in the prevention of moisture infiltration.

NSA Norfolk Naval Shipyard: Buildings 280 and 276

At NSA NNSY, there are two examples of sealed and painted concrete maintenance. Building 280 and Building 276 are two of the seven contributing resources to the Support and Supply Area Precinct of the Naval Shipyard Historic District. Building 280 was built in 1942 for the historic use of flammable storage. Building 276 was built in 1942 as a general storehouse (NSA NNSY Regional ICRMP 2013:10.16). Both buildings were built with cast-in-place concrete (Robbins 2016). The buildings have been in continual use, and the concrete has been maintained through sealant and paint, resulting in no noticeable material issues (Illustrations 59 and 60). With proper maintenance, the service life of the concrete is indefinite.

Illustration 59: Building 280 at NSA NNSY is an example of maintained, sealed, and painted concrete (Photographer: Samantha Driscoll 2016).

Illustration 60: Building 276 at NSA NNSY is an example of maintained, sealed, and painted concrete (Photographer: Samantha Driscoll 2016).

6.2.4 REPAIR

Patching

Patches are the most common concrete repair. However, patching with inadequate materials can affect the future performance of the concrete. If patching was previously done and the concrete continues to deteriorate, corrective work may be needed (Gaudette and Slaton 2007:8). If the cracks are cosmetic, they can be repaired but may become even more obvious due to the patch, potentially requiring a full surface coating (American Concrete Institute 2007:11-13). The most common situations that require patching are for cracks, which can be filled with options such as epoxy injection, routing and sealing, near-surface reinforcing and pinning, drilling and plugging, gravity filling, grouting, drypacking, crack arrest, polymer impregnation, or overlay/surface treatments. Hairline cracks that are not growing can usually be left unrepaired. The width of the crack and growth rate will determine the appropriate patching method (American Concrete Institute 2007:13-18; Gaudette and Slaton 2007:12-13).

An epoxy injection includes sealing the crack and injecting the epoxy under high pressure. While there are some waterproof epoxy options, most epoxy injections cannot be done until the crack has dried out, as moisture will affect the bond. Routing and sealing can be used when there is no structural failure. The method involves making the crack slightly larger at the face, then filling it with a joint sealant. Near-surface reinforcing and pinning is a patch that can add tensile reinforcement perpendicular to the crack. A slot is cut across the crack, filled with an epoxy resin, and deformed steel reinforcing bars are inserted. Drilling and plugging is done by drilling the crack and grouting it, and is only applicable when the cracks are in straight lines and are accessible at one end. Gravity filling is when low-viscosity monomers and resin are used to seal cracks with surface widths of 0.001 to 0.08 inch. Grouting is used for wider cracks, and although waterproof, it will not bond the cracked sections together. The grouting can be done with Portland cement or chemicals. Drypacking is the placement of low water content mortar into the crack, and is typically used for filling narrow slots cut on dormant cracks. Crack arrest is the method of preventing the expansion of active cracks by inserting steel and grouting the crack to redirect tensile stress. Polymer impregnation uses a low-viscosity monomer, which is then polymerized (heated) in place to create a durable plastic bond. Overlay or surface treatments are when a sufficiently reinforced new slab is simply placed on top, obstructing but not fixing the crack (American Concrete Institute 2007:13-18).

NSF Carderock: Buildings 1, 2, and 3

When historic concrete needs patching, it is important to match the color and texture as much as possible. In 2012, Buildings 1, 2, and 3 at NSFC underwent repairs, which included patching. Buildings 1, 2, and 3 make up a single, rectilinear building 960 feet in length, contributing to the David Taylor Model Basin Historic District. Built in 1938, the historic uses of the buildings were experimental, shop, and office facilities (Allison 1984:n.p.). The precast concrete panels of the buildings' exteriors had experienced cracks, corroded reinforcement, and spalling, so many patches were needed.

For a previous project in 2006, materials testing and analysis had been performed by John Milner Associates, Inc., to examine the composition and color of the historic concrete (Graves 2012). The task of the materials testing was to identify the mineral aggregate, find a source for the aggregate, and create a stucco-like finish to mimic the historic concrete. The aggregate was identified as a milky-white quartz, and a supplier was found in Wisconsin (Illustration 61). The aggregate was tested with different mortars to mimic the cement of the historic concrete, as Portland cement was decided to be too unforgiving for the small patches. After curing, washing, and creating a mock-up, a mix was chosen (John Milner Associates, Inc. 2006:1-9). Those results were used to ensure that the 2012 patches matched the historic elevations. Samples and mock-ups were again provided before the patch work began (Illustration 62; Graves 2012). The Maryland Historical Trust (MHT) was consulted, and the preservation officer reviewed and approved the sample patches for Building 1, 2, and 3, noting the samples were impressive and that the project did meet the SOI Standards (Apple 2012).

Illustration 61: The historic concrete (bottom) was analyzed for the aggregate type. In this case, it was quartz (John Milner Inc. 2006).

Illustration 62: A mock-up was created (right) and compared to the historic example (left) to determine patch compatibility (John Milner Inc. 2006).

6.2.5 REPLACEMENT IN-KIND

Concrete can deteriorate, so replacement is an important option, although all other possibilities should be explored first. Concrete is widely produced and can be customized to match historic concrete as closely as possible. The process of choosing a matching replacement concrete material involves evaluation of the performance, characteristics, and limitations of both the original and replacement concrete. The replacement material must match the composition, design, and quality of workmanship of the original. Prepackaged concrete mixes are usually not appropriate for historic concrete replacement.

A mix design should include materials used in the historic concrete when possible, as well as an appropriate selection of aggregate and cement and a proper ratio of water. It is important to note admixtures meant to make the concrete more durable can have an effect on the appearance of the mix. To match the various characteristics, trial mixes should be evaluated for cement color; type, size, and color of aggregates; variations; and finishing techniques and coatings. The samples and mock-ups should be created and assessed against the historic fabric only after curing. Aside from aesthetics, the concrete mix must also be considered for durability, workability, and compressive strength. The concrete should also be installed by skilled workmanship to ensure proper mixing, placement, consolidation, and curing (Gaudette and Slaton 2007:10-12).

NSA Bethesda Buildings 1, 3, and 5

Building 1 was built in 1941, and Buildings 3, and 5 were built in 1943 at NSA Bethesda; all three are contributing buildings to the National Register-eligible NNMC Historic District. All three buildings are in the midst of substantial concrete repairs and in-kind replacement (NSA Bethesda ICRMP 2015:4-11). The first phase was Building 1, which underwent repair work from 2009 to 2010. Building 1 had crack repairs and patches. Though not a true full replacement in-kind, the process for choosing the appropriate composition and color of the concrete was the same for the repairs and patches as it would be for in-kind replacement (Reckley 2015). The historic concrete was first tested in a lab for material composition. Based on the analysis, the engineer specified aggregate size and mortar color. The company Cathedral Stone Products, Inc., was contracted to create the concrete to specifications. Several mock-ups were created for review by the engineer. The selection process was intensive, as the samples varied in multiple ways. There were issues in finding geographic locations of quarries which could produce the appropriate aggregate, and multiple mortar mixes were needed. After a composition was selected, the MHT was consulted and reviewed a mock-up, providing conditional concurrence on the stipulation that they review the project results (Updegraff 2015; Reckley 2015).

As of December 2015, Building 3 repair work was underway and Building 5 had not yet been started (Illustrations 63 and 64). Similar to Building 1, the work on Building 3 was targeted to cracks and patching. The same method

Illustration 63: Building 3 at NSA Bethesda during repair work to correct cracking, spalling, and exposed reinforcement (Photographer: Samantha Driscoll 2015).

Illustration 64: Detail of the corroded and exposed steel reinforcement on Building 3, which caused the de-lamination and spalling of the surface concrete. Wire mesh and stainless steel bars will be inserted in these areas prior to patching for stability (Photographer: Samantha Driscoll 2015).

of concrete mock-ups was used based on the Building 1 sampling (Illustration 65). MHT received a consultation package on Building 3 but did not request a mock-up due to their approval on Building 1 (Reckley 2015; Updegraff 2015).

Illustration 65: The concrete mock-ups for the patching to Building 3. Each sample varies slightly in color and/or aggregate type (Photographer: Samantha Driscoll 2015).

The engineer and contractors began the process by using blue tape to identify all conditions that needed to be addressed. Building 3 had almost 200 cracks. The intention is to fill smaller cracks with an epoxy injection. The larger cracks and spalling will need patch repair. In sections of Building 3 where the steel reinforcement has corroded and caused the spalling of the surface concrete, wire mesh and stainless steel bars will be inserted prior to patching for stability (Updegraff 2015).

6.2.6 SUITABLE SUBSTITUTES

The material strengths and weaknesses of concrete are well documented. If proper maintenance occurs, concrete can last indefinitely. Even the most common material issues (i.e., cracking and spalling) can be addressed with injections and patches with in-kind replacement material, which can remain almost invisible if done correctly. In most instances, small surface repairs do not hinder the stability of the concrete as a whole. The malleability of concrete allows for a flexible repair and in-kind replacement that is available, affordable, and sturdy. In the two highlighted case studies of Buildings 1, 2, and 3 at NSFC and Building 3 at NSA Bethesda, the concrete in question was on prominent buildings at the installations. For this reason, much attention was given to matching concrete composition to result in the ideal repair plan. While maintenance and repair projects on more common support and secondary buildings may not be afforded this level of detailed study, with relatively limited effort, work can still be accomplished in a manner that preserves the building's historic character. In the rare instances of full historic concrete replacement, concrete does not require an assessment of suitable substitute materials, as concrete remains widely available and customizable.

All concrete repairs or replacements require some basic steps to meet the SOI Standards. First, a qualified contractor should be identified, as that is often a specification for SHPO concurrence. A qualified contractor has a demonstrated experience in the treatment of historic concrete, particularly for more significant buildings. Refer to NPS Preservation Brief 15: Preservation of Historic Concrete for further information (Appendix B; Gaudette and Slaton 2007). The next step should be a conditions assessment to determine the cause of the problem (e.g., moisture, erosion, etc.). A repair or replacement procedure should then be determined based on the cause (e.g., grouting, epoxy injection, drypacking, partial replacement, etc.). Once a procedure has been selected, a trial must be done: for replacements, this is a mock-up; for repairs, this should be a test on a low visibility section of the historic concrete. Once set, the trial areas should be evaluated on color, texture, and durability. If modifications are necessary, the trial phase should be repeated. Final repair or replacement should only begin when the trial phase has resulted in a satisfactory match (Gaudette and Slaton 2007:10-11). SHPO consultation should occur during the planning and trial phases for approval.

A qualified contractor should ideally have demonstrated experience in historic material. The CRM can contact other DoD installations for recommendations on contractors by material. Additionally, SHPOs or state-level Departments of Transportation often have assembled lists of qualified contractors from previous projects due to their extensive experience in historic and modern concrete for roads, bridges, and infrastructure. However, CRMs may find themselves without qualified contractors available in their area. Additionally, it is quite common that the DoD and individual installations have either in-house teams or approved vendor lists to do the repairs or replacements. In those cases when a CRM knows the contractors working on the historic building do not have previous experience in the treatment of historic material, the CRM should educate the contractors to the best of their abilities before the work begins. Available information about known concrete conditions and causes, such as the information presented in this report, can be formatted into a fact sheet or slideshow to show less experienced contractors what to expect and what the CRM's concern are (color matching, appropriate cleaning techniques, compatible patch material, etc.).

6.3 CORRUGATED METAL

Corrugated metal roofing was commonly iron or steel, and both were sometimes galvanized by coating them in zinc, which offers protection against corrosion. Corrugated metal cladding and roofing can be iron, steel, aluminum, copper, tin, zinc, or lead-coated copper (Illustrations 66 and 67). It is important to identify the metals used, as it will determine the maintenance and repair techniques (About Home website, accessed March 2016).

Illustration 66: Building 224 at NSF Indian Head, built in 1915, is an example of steel corrugated metal. Note the amount of corrosion below the peeling paint (Photographer: Samantha Driscoll 2015).

Illustration 67: Building 1504 at Picatinny Arsenal, built in 1956, is an example of aluminum corrugated metal. Note there is no evidence of corrosion (Photographer: Samantha Driscoll 2015).

The metals identified in the following case studies were steel and aluminum. Corrugated metal sheets started as iron and were replaced by steel in the late nineteenth century. Although both have similar conservation issues, only steel examples were used for the purposes of this report. The primary material issue of corrugated metal sheeting as either cladding or a roofing material is corrosion. Proper maintenance and preventative measures must occur to prevent moisture infiltration, as corrosion spreads quickly (InspectAPedia website, accessed March 2016).

6.3.1 COMMON CONDITIONS

Corrosion

Steel rusts unless painted or plated. Galvanizing helps, but is only durable if the coating remains intact. Any lack of maintenance of a steel roof will result in corrosion due to moisture. Galvanic action is another type of corrosion and occurs when dissimilar metals are used in direct contact. The same can occur even if not in direct contact, as intervening rainwater can cause a reaction between the two (e.g., when a metal roof is decorated with cresting or flashing of a different metal type, or when steel nails are used in aluminum sheets (Sweetser n.d.:4).

Picatinny Arsenal Building 1504A

Building 1504A is a contributing resource to the Rocket Test Area Historic District. Built in 1948, the historic use of the building was as test stand #3; storage bottle stand and manifold; general purpose warehouse ordinance facility; and conditioning building (Picatinny Arsenal 2014:n.p.). The uses of the building warranted utilitarian, sturdy, fireproof construction, which corrugated steel cladding and roofing supplied. However, as a support building, Building 1504A has not received proper maintenance. The corrugated metal cladding was painted, but over time the paint has peeled and left the steel susceptible to moisture, resulting in corrosion (Illustrations 68, 69, and 70).

Illustration 68: Building 1504A at Picatinny Arsenal has suffered a lack of maintenance, resulting in corrosion (Photographer: Samantha Driscoll 2015).

Illustration 69: Detail of corrosion on Building 1504A. Painting is the primary maintenace of corrugated steel, as it protects the steel from moisture (Photographer: Samantha Driscoll 2015).

Illustration 70: Corrosion is not just an aesthetic issue, it can make the material unstable. As seen here, the corrosion has caused a hole in the corrugated steel (Photographer: Samantha Driscoll 2015).

Pitting or Streaking

Pitting or streaking is the deterioration of the metal from a chemical action. Possible causes are airborne pollutants, acid rain, lichen or moss, alkalis found in lime mortar or Portland cement, and tannic acid from wood (Sweetser n.d.:4). There were no instances of this condition noted at any installation.

Fatigue

Fatigue of metal sheeting is the wear and tear that can occur at joints or other connections as a result of thermal changes (Sweetser n.d.:4). Fatigue can also occur from wind or physical damage. The result can be cracking or tearing, which leads to moisture infiltration and corrosion. There were no instances of this condition noted at any installation.

Distortion

If the corrugated metal has been overlapped and secured with a simple nail-over-panel installation, which is the recommended construction, it can be subject to wind damage (InspectAPedia website, accessed March 2016). The wind can distort the panels in varying degrees of severity. Distortion from wind damage may also occur if fasteners have failed. Physical damage may also cause distortion.

NSF Indian Head Building 179

Building 179 is a contributing resource to the Naval Powder Factory Historic District. Built in 1904, the historic use of the building was as storage as Dryhouse #7 (NSF Indian Head ICRMP 2012:3-24). Building 179 has galvanized corrugated steel cladding and non-galvanized steel roofing (Illustration 71). The cladding was once painted but has not been properly maintained, and the paint is peeling off. However, the exposed corrugated steel is not corroding, indicating that it was galvanized. In contrast, the roof appears to have been treated or painted, but the protective layer has failed. The result is obvious corrosion. Though the cladding is not corroded, it appears to have suffered distortion (Illustration 72). The corrugated metal lapped installation may have been

Illustration 71: Building 179 at NSF Indian Head shows the galvanized corrugated steel cladding, though not maintained, is not experiencing corrosion. The corrugated steel roof appears to have had a treatment, though it failed and corrosion has occurred (Photographer: Samantha Driscoll 2015).

Illustration 72: Building 179 also has distortion of its corrugated steel cladding, which may have occurred from weather or physical damage (Photographer: Samantha Driscoll 2015).

compromised due to wind, or this may be a result of physical damage. Regardless, the distortion shows the flexibility of corrugated metal, which may be an issue in harsh weather patterns when the material can bend and fail.

6.3.2 ASSESSMENT

Corrugated metal roofing and cladding was chosen as an economical, durable, and fire-resistant choice, both historically and presently. Corrugated metal, most commonly steel, has one major conditions issue: corrosion. However, corrugated metal can be almost entirely rusted yet still be structurally sound (InspectAPedia website, accessed March 2016). Metal sheeting, as either roofing or cladding, has a life expectancy of 40 to 70 years, depending on the metal type. Corrugated metal can handle extreme weather conditions and requires very little maintenance (Build Direct website, accessed March 2016). When contemplating repair versus replacement, it should also be determined whether the repairs will be effective. Once an issue begins, maintenance costs will continue, and repeated repairs may equate to replacement costs. A one-time cost replacement will mean lower maintenance costs over time (Sweetser n.d.:5).

6.3.3 MAINTENANCE

Cleaning

Metal roofing, while very durable, does need to be maintained through cleaning. Dirt, pollen, leaves, and debris can accumulate on surfaces or in gutters, causing a problem with drainage or pooling water. Metal can be cleaned with water, biodegradable cleaner, or chemical cleaner using a low pressure spray (Kline 2014:n.p.).

Painting and Sealing

Paint is the most important line of defense against corrosion, especially if the metal has not been galvanized. Severe weather or debris can scratch paint off, allowing moisture infiltration to cause corrosion. If paint becomes scratched or peeled, the area must be sealed and repainted as soon as possible (Kline 2014:n.p.). The paint used should be specific to metal and should be applied with a roller or brush, as spray can be uneven. Two coats are recommended, and regular touch-ups should occur (Build Direct website, accessed March 2016). If the corrugated metal has any sign of rust, a rust inhibitor should be used prior to any coating or painting to reduce the spread of rust (About Home website, accessed March 2016). Sealants are required at the perimeter of the metal sheet, as well as at all penetrations (Facilitiesnet website, accessed March 2016). The sealants will require regular touch-ups. There are also waterproof coatings that can be applied to the corrugated metal to protect the metal from corrosion.

Fasteners

Corrugated metal sheets need their fasteners maintained, inspected, and replaced at the ends of their service lives (Facilitiesnet website, accessed March 2016). Loose fasteners lead to corrosion or rust because water will begin to build up in any gaps. Fasteners and screws can become loose after years of enduring all sorts of weathering, which is why annual maintenance checks are best. A compatible metal type must be chosen for replacing fasteners or else further corrosion will occur (Build Direct website, accessed March 2016).

6.3.4 REPAIR

Patching

Repairs to metal roofing and cladding can prove difficult. If the patch has even slightly different composition, thermal expansion and contraction can cause the patch to fail. Metal sheeting can be patched with metal, but the repair metal must be a compatible type, and ideally the same type. If incompatible metals come in contact, the result is corrosion, which causes cracking, splitting, and failure of the patch (Kline 2014:n.p.). To create a patch, the area must first be cleaned. Then the sheet metal, of the same type of metal as the surrounding historic material, should be cut to a size at least 2 inches larger than the damaged area on all sides. The patch corners should then be rounded, as to not catch debris later. A sealant should be applied to the damaged area before the patch is placed. Screws should then be placed every 3 to 4 inches around the perimeter to provide uniform pressure. The patch can be painted to match the corrugated metal (About Home website, accessed March 2016).

Picatinny Arsenal Building 1506

Building 1506 is a contributing resource to the Rocket Test Area Historic District. Moved to its present location ca. 1946, it is clad in corrugated aluminum (Illustration 73). A patch was applied over a former opening with

Illustration 73: Building 1506 at Picatinny Arsenal is clad in corrugated aluminum. In the center of the front elevation is a patch of in-kind material fitted with incompatible fasteners (Photographer: Samantha Driscoll 2015).

in-kind material. The patch fit securely to the material by aligning the corrugations. The visibility of the patch is an example of using incompatible metal fasteners. The steel nails used to apply the patch have corroded, causing staining on the historic corrugated aluminum (Illustration 74).

Illustration 74: Detail of the in-kind material patch on Building 1506. Note the alignments of the corrugations make the patch almost undetectable, but the corroded steel fasteners have caused staining (Photographer: Samantha Driscoll 2015).

6.3.5 REPLACEMENT IN-KIND

In the case of corrugated metal, in-kind replacement is available, customizable, and affordable. Exterior materials must withstand moisture, ultraviolet (UV) degradation, and thermal expansion-contraction cycles; therefore, any time a replacement is made, even seemingly in-kind, consideration should be made to install the materials correctly and assess the impact on the surrounding historic material. New, high-tech materials may have differences in vapor permeability that could cause further deterioration (Park 1986:6). Therefore, in-kind materials should always be considered first as replacements for corrugated metal. Although the earliest examples are iron, steel replaced iron in the late nineteenth century, and aluminum became popular after World War II. Corrugated steel is still widely produced and can be customized to match the historic gauges. The replacement corrugated metal should try to match corrugation width in order to maintain the visual rhythm of the historic material. Corrugated aluminum and other metals are also available.

Norfolk Naval Shipyard Building 268

Building 268 is one of 12 contributing buildings to the Industrial Area Precinct within the Naval Shipyard Historic District. Built in 1942, the historic use of the building was as a machine shop (NSA NNSY Regional ICRMP 2013:10.14). The corrugated metal on Building 268 was replaced in-kind, but the date is not known. Original drawings could not be found, so the type of original metal was unknown (Robbins 2016). Though no original elevations could be found for Building 268, the replacement corrugated metal may have been chosen to match the historic corrugation width, in order to maintain the visual rhythm of the historic material (Illustration 75). Since Building 268's corrugated metal was historically painted, the replacement corrugated metal is painted as well; though again, the original paint color is unknown.

Illustration 75: Building 268 at NNSY has replacement corrugated metal cladding, which has been painted. As long as the rhythm of corrugation can be retained, in-kind replacement should be considered for any type of corrugated metal (Photographer: Samantha Driscoll 2016).

6.3.6 SUITABLE SUBSTITUTES

The options for suitable substitutes are other metals. Painting or coating a different metal can result in a similar aesthetic to the historic material. Special attention should be given to the structural properties as well to ensure the appropriate selection. A common substitute for corrugated steel is corrugated aluminum, which, if anodized or painted, is resistant to corrosion. Aluminum is lighter weight but has a high coefficient of expansion, meaning attachment systems must accommodate more movement. The lighter-weight material can also experience more damage in bending, pitting, or denting. Corrugated copper was historically used, though less common, and remains available but expensive. Copper-plated-corrugated steel is also available, as well as galvanized steel. Stainless steel is available, and is generally rust resistant but is more expensive. A terne (a zinc and tin alloy) coating can be used for corrosion resistance, but trace amounts of lead also present an environmental concern (InspectAPedia website, accessed March 2016).

6.4 ASBESTOS-CEMENT

Asbestos-cement was designed as a durable building material ideal for utilitarian and industrial uses. However, it is not indestructible. Asbestos-cement contains asbestos fibers that are locked into the cement. Asbestos-cement panels, a cement product consisting of 10 to 15 percent asbestos fibers, are safe to leave in place until damaged (Asbestos Information Centre website, accessed January 2016). According to NESHAP, ACM is defined as products or materials containing more than 1 percent asbestos. Common ACM found at DoD installations includes building materials such as insulation, floor tiles, and panels. Friable asbestos products are defined as materials that can be crumbled or pulverized by hand pressure, which can release asbestos into the air. Asbestos-cement is classified as a non-friable material; however, it is specifically noted that a non-friable ACM can become friable due to processes such as weathering. Asbestos fibers can be considered "releasable" after the material has become friable (NAVFAC 2012:4-5). The EPA states exposure to asbestos occurs when ACM is disturbed or damaged in some way to release particles and fibers into the air. Exposure can cause lung cancer, mesothelioma, and asbestosis (EPA website 1, accessed April 2016). As many utilitarian buildings utilized asbestos-cement for its durable, insulating, and fireproof qualities, the buildings' functional uses may have caused physical damage to the material. This is not rare and is most often revealed by cracking and crumbling around pipes, doors, windows, or joints.

According to the EPA and NESHAP, the evaluation of asbestos must be in concurrence with the Clean Air Act (CAA), which requires the EPA to develop and enforce regulations to protect the public from exposure to airborne contaminants that are known to be hazardous to human health. The CAA specified safe work practices for ACM to be followed during demolition and renovations of structures, installations, and buildings. The first step is a thorough inspection. The following rules apply to all buildings except those which have less than 260 linear feet, 160 square feet, or 35 cubic feet of ACM to be disturbed. If the disturbed areas are more than those threshold levels, the following steps apply. If ACM is identified, the installation must notify the appropriate delegated entity, which may be within the DoD or the state environmental agency. The delegated entity will identify the appropriate work practices. Work practices for demolition or removal of the ACM will involve careful removal, adequately wetting the ACM, sealing the ACM in leak-tight containers, and disposing the ACM in accordance with federal and state guidance. In the case of renovation, if ACM is being removed or disturbed, similar work practices should be used, as well as ensuring areas remaining in use in the building are not contaminated during or after the renovation. To help ensure that the work practice standards of NESHAP, EPA, and CAA are followed during a demolition or renovation operation, at least one on-site representative trained in the regulatory provisions and the means of compliance is required. The trained individual is periodically trained in the applicability of the rules; material identification; control procedures for removal; adequate wetting; local exhaust ventilation; negative pressure enclosures; glove-bag procedures; High Efficiency Particulate Air (HEPA) filters; waste disposal work practices; reporting and recordkeeping; and asbestos hazards and worker protection (EPA website 2, accessed April 2016).

6.4.1 COMMON CONDITIONS

Degradation

Asbestos-cement is subject to staining, erosion, discoloration, and lichen growths. The material is not waterproof and absorbs some moisture, which leads to degradation. The resulting staining, discoloration, or growth does not affect the stability of the material at first. However, degradation and erosion of the material may occur over time, causing asbestos fibers to protrude, or even be released, from the surface (Illustration 76).

Illustration 76: Building 466 at NSF Indian Head has a corrugated asbestos-cement roof with degradation. The material has begun to break down and looks rough, which may release asbestos fibers (Photographer: Samantha Driscoll 2015).

Crumbling and Cracking

Asbestos-cement was designed as a very durable material, but it has always been brittle. As it ages, the asbestos-cement becomes friable, easily crumbling when subjected to pressure. Asbestos-cement is classified as a non-friable material; however, it is specifically noted that a non-friable ACM can become friable due to processes such as weathering. Asbestos fibers can be considered "releasable" after the material has become friable (NAVFAC 2012:4-5). The release of fibers can be harmful (EPA website 1, accessed April 2016). If asbestos-cement is cracked, broken, or eroded, this is an indication the asbestos-cement is, or will soon become, friable.

Picatinny Arsenal Building 1507

Building 1507 is a contributing resource to the Rocket Test Area Historic District. Built in 1946, the historic use of the building was as a general purpose magazine (Picatinny Arsenal ICRMP 2014:n.p.). Due to its requirement for fireproof characteristics, the former magazine was clad in flat panel asbestos-cement. The asbestos-cement has not been maintained and is heavily stained (Illustration 77). The staining may be caused by moisture, environmental factors, erosion, or biological growth. According to NESHAP, asbestos-cement can become friable due to processes such as weathering (NAVFAC 2012:4-5). There are also cracks and areas where the asbestos-cement has crumbled (Illustrations 78 and 79). One example surrounds a corroded metal pipe, indicating a leak as the culprit. The asbestos-cement material on Building 1507 should not be repaired; it should be replaced with a suitable substitute.

Illustration 77: Building 1507 at Picatinny Arsenal is clad in flat panel asbestos-cement that is heavily stained, indicating degradation (Photographer: Samantha Driscoll 2015).

Illustration 78: Detail of a crumbled section of asbestos-cement on Building 1507 at Picatinny Arsenal (Photographer: Samantha Driscoll 2015).

Illustration 79: Detail of a crumbled section of asbestos-cement located around a corroded pipe on Building 1507 at Picatinny Arsenal, indicating moisture as the cause (Photographer: Samantha Driscoll 2015).

NSF Indian Head Building 448

Building 448 is a contributing resource to the Naval Powder Factory Historic District. Built in 1941, the historic use of the building was for inert storage (NSF Indian Head ICRMP 2012:3-25). Building 448 has corrugated asbestos-cement cladding and roofing (Illustration 80). Asbestos-cement was ideal for the support building, as it was fireproof and required almost no maintenance. However, Building 448 has condition issues. There are several hairline cracks, which indicate material degradation (Illustration 81). The more obvious condition is the dark staining, which is degradation by erosion that caused cracking and crumbling along the foundation line (Illustration 82). According to NESHAP, asbestos-cement can become friable due to processes such as weathering (NAVFAC 2012:4-5). Degradation, cracks, and crumbling are all indications the material is or may become friable. Utilitarian buildings like Building 448 are unlikely to receive the maintenance they need, so the asbestos-cement needs replacement.

Illustration 80: Building 448 at NSF Indian Head is clad in corrugated asbestos-cement. Note the dark degradation areas along the foundation line (Photographer: Samantha Driscoll 2015).

Illustration 81: Detail of the hairline cracks visible in the corrugated asbestos-cement on Building 448 (Photographer: Samantha Driscoll 2015).

Illustration 82: Detail of the staining, erosion, discoloration, and lichen growths on Building 448, indicative of degradation (Photographer: Samantha Driscoll 2015).

NSF Indian Head Building 508

Building 508 is a contributing resource to the Naval Powder Factory Historic District. Built in 1942, the historic use of the building was as Dryhouse #62 (NSF Indian Head ICRMP 2012:3-25). The corrugated asbestos-

Illustration 83: The corrugated asbestos-cement cladding has severe stains, indicating lichen growth (Photographer: Samantha Driscoll 2015).

Illustration 84: Detail of the corrugated asbestos-cement wall where the material has crumbled off. Note the thinness of the asbestos-cement panels, as well as the exposed insulation layer (Photographer: Samantha Driscoll 2015).

cement cladding is heavily stained, indicating what may be lichen growths (Illustration 83). According to NESHAP, asbestos-cement can become friable due to processes such as weathering (NAVFAC 2012:4-5). The absorption of water has caused degradation and erosion, indicating the material is or may become friable. Other areas of Building 508 have cracking and crumbling of the asbestos-cement, which also release asbestos fibers (Illustration 84).

6.4.2 ASSESSMENT

Asbestos-cement is unique in that repair is often not a feasible or advisable solution. Asbestos-cement was created to combine the insulation and fire-resistance of asbestos fibers combined with the strength of cement. Asbestos is a dangerous material, yet only if disturbed. The typical life expectancy for asbestos-cement was 30 years, but examples over 50 years of age remain in good condition (InspectAPedia website, accessed March 2016). If the asbestos-cement remains in good condition, regular non-evasive maintenance is all that is needed. As soon as the material becomes deteriorated or damaged, the hazardous asbestos fibers can be released. Therefore, repair is not recommended, and the material should be removed, handled, and disposed of in accordance with EPA regulations, and replaced with a suitable substitute.

6.4.3 MAINTENANCE

Well-maintained asbestos-cement is not a risk to human health unless it is physically disturbed (Department of Justice and Attorney-General website, accessed March

2016). Maintenance procedures like regular visual inspections and regular cleaning of the material can decelerate deterioration. Adding a bumper material along the bottom of siding can reduce cracking and chipping (Woods 2000:7). Asbestos-cement is classified as a non-friable material; however, it is specifically noted that a non-friable ACM can become friable due to processes such as weathering. Asbestos fibers can be considered "releasable" after the material has become friable (NAVFAC 2012:4-5). The EPA and NESHAP guidelines should be followed regarding any renovation or demolition of the asbestos-cement (EPA website 2, accessed April 2016). If the material is not damaged, it may remain in place. Any removal or maintenance should be overseen by an on-site representative trained in the regulatory provisions and the means of compliance, as defined by NESHAP and the EPA (EPA website 2, accessed April 2016).

Paint and Encapsulation

One of the most common ways of maintaining asbestos-cement is applying paint and encapsulation sealants as protective coatings. Although removing asbestos-cement may be desirable, the removal must be abated professionally (as it may become friable during the removal process), and there are instances where the asbestos-cement is in good condition and can remain in place (Asbestos in Victoria website, accessed March 2016). Chemical consolidants and/or breathable sealers (most commonly silane) can be applied, which can help strengthen the material and add water protection (Woods 2007:9). However, two risks can occur from this process. The first is the surface preparation before painting. Sanding, scraping, or cleaning the asbestos-cement may release asbestos fibers, which are harmful. Secondly, the paint or encapsulation may chip over time, and the paint chips will pull asbestos fibers from the panel, again releasing harmful asbestos into the environment (The Environmental Consultancy website, accessed March 2016). Asbestos-cement panels can be maintained only as long as they stay in good shape; at the first sign of degradation, asbestos-cement presents a hazard risk.

NSF Indian Head Building 544D

Building 544D is a contributing resource to the Extrusion Plant Historic District. Built in 1944, the historic use of the building was as an electronic physical laboratory (NSF Indian Head ICRMP 2012:C-22). This provides an example of flat panel asbestos-cement that has been maintained (Illustration 85). The panels had begun to form hairline cracks, and the installation

Illustration 85: Building 544D has flat panel asbestos-cement, which was set to be replaced, but instead was maintained through sealing and painting (Photographer: Samantha Driscoll 2015).

initiated a replacement plan. The installation initially planned to use Hardie Board, a fiber cement siding material, and submitted a letter to the MHT, which concurred with the replacement as a suitable substitute. However, the installation opted to remove the lead paint on the panels and seal and repaint them instead. The result solved the cracking, and the panels were able to be left in place. The approved suitable substitute was not used (Wright 2015).

Cleaning

Asbestos-cement should not be cleaned with high-power water, as it can cause erosion resulting in asbestos fibers being released into the air and contaminating the surroundings (Department of Justice and Attorney-General website, accessed March 2016). If cleaning is necessary, safety precautions must be taken, and the work should be completed by a trained professional. Remote cleaning is the use of enclosed rotary heads using high pressure jets, with the operator at a distance. Remote cleaning can harm the surroundings due to runoff, and can be expensive. Surface biocides can be used for plant growth; they should be applied in a low pressure spray or as a wash. However, the plants removed may have roots that could loosen the asbestos fibers (Health and Safety Authority 2005:23-25). No case studies were found illustrating the cleaning of asbestos-cement.

6.4.4 REPAIR

When asbestos-cement is subject to crumbling, cracking, weathering, or any form of degradation, the material can potentially release asbestos fibers into the surrounding environment (Illustration 86). Even average repair techniques have the potential to release asbestos (Asbestos in Victoria website, accessed March 2016). Any repair should include an investigation and the process should be tailored to each situation. Even the gentlest means of repair can affect the brittle material. A clear epoxy can be used for hairline cracks, and a mix of Portland cement and water can be used as grout for larger cracks; however, the repair must be kept damp for one week to prevent shrinkage. Fasteners can be replaced, but care should be taken to not drill larger

Illustration 86: Detail of Building 1508 at Picatinny Arsenal where large sections of flat panel asbestos-cement have been broken. Note the thin, brittle nature of asbestos-cement (Photographer: Samantha Driscoll 2015).

holes (Woods 2000:8). Once degradation has begun, asbestos-cement is a material that is not recommended for repair, and replacement with a suitable substitute material should be considered. The Consumer Product Safety Commission banned other uses, including patching compounds, by the 1990s (ATSDR website, accessed March 2016). To help ensure that the work practice standards of NESHAP, EPA, and CAA are followed during a demolition or renovation operation, at least one on-site representative trained in the regulatory provisions and the means of compliance is required (EPA website 2, accessed April 2016).

6.4.5 REPLACEMENT IN-KIND

Asbestos-cement is a medium for which historic materials are unavailable, and in-kind replacement is hard to find (Park 1986:4). Asbestos-cement is not illegal, but is no longer produced in the United States (ATSDR website, accessed March 2016; EPA website 3, accessed April 2016). Asbestos-cement is classified as a non-friable material, but it can become friable due to processes such as weathering. The weathering releases asbestos fibers that can be hazardous (NAVFAC 2012:4-5; EPA website 1, accessed April 2016). It is recommended that historic asbestos-cement be replaced only with suitable substitutes for health and environmental reasons, and therefore replacement in-kind is not an option.

6.4.6 SUITABLE SUBSTITUTES

Although asbestos-cement is not illegal, production is rare, if not obsolete. A review of possible resources did not reveal any asbestos-cement for purchase, but there are non-asbestos cement board products available. Other asbestos replacement products use carbon fiber, cellulose fiber, steel fiber, glass fiber, talc, fiberboard with asphalt, and silica. A highly available option is corrugated fiber-cement. The material is similar to asbestos-cement in performance, but it contains no asbestos. Fiberglass is often used as the fiber in place of the asbestos (InspectAPedia website, accessed March 2016; Woods 2000:10). Fiber cement that is currently made does not quite match the texture of the historic material, but is considered a suitable substitute and should result in no adverse effect (Craren 2016). In the case of NSF Indian Head Building 544D mentioned above, MHT approved the replacement material Hardie Board, which is a fiber cement siding material (Wright 2015). Some companies that manufacture replacement products are: Supradur Manufacturing Company; Cement Board Fabricators; U.S. Architectural Products, Inc.; Re-Con Building Products; and GAF Materials Corp. (Woods 2000:11).

The other suitable substitute for corrugated asbestos-cement is corrugated metal. Corrugated metal is widely produced, economical, and already on many of the same utilitarian types of buildings that used asbestos-cement.

Illustration 87: Building 508 at NSF Indian Head replaced two formed corrugated asbestos-cement panels with corrugated metal panels. Attention was paid to the width of the corrugations, and the rhythm was maintained. The material should be painted to match the historic material surrounding it and camouflage the replacement material (Photographer: Samantha Driscoll 2015).

Corrugated metal also retains the shape of corrugated asbestos-cement, and maintains the visual rhythm of a building. Furthermore, the construction processes for both materials are similar, making them compatible without major structural changes. Corrugated asbestos-cement was invented to be used in conjunction with, or instead of, corrugated metal in the twentieth century. Their entwined histories, uses, and aesthetics make corrugated metal a suitable substitute for replacement (Illustration 87). Corrugated metal and corrugated asbestos-cement are visually different textures at closer inspection, age differently, and have differing conservation concerns (Craren 2016). The SHPO concurrence on whether corrugated metal will have no adverse effect relates back to the character-defining features of an historic building or district. If only the look of asbestos-cement is needed, then corrugated metal can be a suitable substitute. Treatments can dull the shiny nature of the metal or a matte paint will give the effect most similar to the original product (Diehl 2016; Craren 2016). In the case of either fiber cement or corrugated metal as a suitable substitute, the SHPO should be provided with detailed paint and color information, cut sheets for the cladding, and potentially a sample of the proposed replacement product (Craren 2016).

Norfolk Naval Shipyard , St. Juliens Creek Annex Building 74

Building 74 is a contributing resource to the potential St. Juliens Creek Annex Historic District, and was built ca. 1917 as a World War I magazine (NSA NNSY Regional ICRMP 2013:10.379). The roof was corrugated asbestos-cement (Illustration 88). Various repairs to the roof were patched with corrugated metal panels as needed. The installation attempted to match corrugation widths, and was more successful in some patches than others; however, the difference in material is obvious, and it is apparent that the patches are corrugated aluminum. Corrugated aluminum will not age to blend with the asbestos-cement. If corrugated metal is to be used, the metal should be painted or treated to blend with the historic fabric.

Illustration 88: Building 74 at NNSY, St. Juliens Creek Annex has several corrugated metal patches on the corrugated asbestos-cement roof. While the replacement patches have similar corrugation widths, the difference in materials in obvious. If the corrugated metal was painted, the patches would blend more with the historic fabric (Photographer: Samantha Driscoll 2016).

NSF Indian Head Building 160

Building 160 is a contributing resource to the Naval Powder Factory Historic District. Built in 1900, the historic use of the building was as a Cartridge-Activated Device (CAD) assembly building (NSF Indian Head ICRMP 2012:3-23). Building 160 originally had a corrugated asbestos-cement roof that experienced condition issues. As this was an occupied building, Building 160 was a maintenance priority. The roof was entirely replaced with corrugated metal in 2010 (Illustration 89). Attention was paid to match the corrugation widths to maintain the historic rhythm, so it was considered a suitable material. The installation is currently in the process of developing a Programmatic Agreement with the MHT, which would allow them to do general maintenance work without individual submissions. Corrugated metal as a replacement for asbestos-cement is included under general maintenance, indicating its acceptance as a suitable substitute (Wright 2015).

Illustration 89: Building 160 at NSF Indian Head is an example of a suitable substitute replacement roof. The corrugated asbestos-cement roof was replaced with a corrugated metal roof in 2010 (Photographer: Samantha Driscoll 2015).

7.0 Strategies for Section 106 Compliance

The DoD supports and facilitates the reuse of historic properties. Early consideration of preservation concerns in project planning and full consultation with interested parties, including respective SHPOs, is key to effective compliance with Section 106 of the National Historic Preservation Act. The following describes a plan of action and process for projects that include exterior material repair or replacement on historic twentieth-century buildings. The proposed plan of action and process detailed below is based on information obtained through the lessons learned by installation CRMs as well as through consultation with various SHPOs.

For those projects involving the rehabilitation of historic buildings, successful consultation with SHPOs and other interested parties early in the design review process can ensure preservation concerns are balanced with sustainability and regulatory needs. The development of project plans and designs should take into account those features that qualify a building for listing in the NRHP (whether it be individually or as part of a larger historic district), with the goal of compliance with the SOI Standards and a Section 106 finding of no adverse effect if at all feasible.

Before any repair work is performed, the historic value of the exterior materials should be understood. The next step should be a complete internal and external investigation to determine all causes of failure. Once the causes haven been identified, various repair or replacement alternatives should be considered.

All projects involving exterior materials that are character-defining features of historic buildings must consider the following factors at the project onset:

1. Preservation of historic materials;
2. Preservation of historic design and appearance;
3. Potential weaknesses or inherent flaws in historic material;
4. Potential effectiveness of repairs; and
5. AT requirements, to be determined by installation.

When replacement of historic exterior materials is warranted, the following text identifies steps that can assist in successful Section 106 compliance and SHPO consultation. NPS Preservation Brief No. 16: *The Use of Substitute Materials on Historic Building Exteriors*; NPS Preservation Brief No. 4: *Roofing for Historic Buildings*; and NPS Preservation Brief No 15: *Preservation of Historic Concrete*, all of which are included in Appendix B of this report, should also be consulted (Park 1986; Sweetser n.d.; Gaudette and Slaton 2007).

7.1 IDENTIFICATION OF CHARACTER-DEFINING FEATURES

Exterior materials, such as concrete, corrugated metal, and asbestos-cement, may be character-defining features. This is especially true in utilitarian buildings that may have very little architectural detail otherwise.

In order to consider the effects of a removal or replacement project on a historic property, it is imperative to understand the significance of the property. As part of this understanding, the first step is to identify those features that qualify the building for eligibility for or listing in the NRHP, whether individually or (as often is the case for DoD installations) as a contributing resource to a larger historic district. Documentation of the history, development, and character-defining features should be prepared by qualified CRMs or qualified consultants. Sources of information for determining character-defining features include NRHP nominations and state-level survey forms, ICRMPs, and historic construction drawings and blueprints. This information can be compiled into a character-defining feature memorandum that explains the following: 1) why the property is NRHP listed or eligible (or why it contributes to a historic district); 2) changes to the building over time; and, 3) those character-defining features that are critical to the building's ability to convey its significance. The document should be illustrated with recent photographs of the building that will identify for the architects and project planners those features that need to be preserved, as well as those features that can be removed or modified without adversely affecting the historic integrity of the building. Where replacement is required, the historic documentary evidence of the original feature will allow replacement in-kind or in a manner that is sensitive to the historic integrity of the property. This memorandum will assist not only project planners but can be provided to the SHPO as part of the Section 106 consultation package in order to expedite reviews.

7.2 ADDRESSING AT ISSUES

As previously noted, due to the widely varying uses for buildings that utilize concrete, corrugated metal, and asbestos-cement, this study cannot outline all the considerations or applicable AT standards that may apply. However, many of the buildings constructed with these materials, particularly corrugated metal and asbestos-cement, are utilitarian buildings that may be exempted from the requirements of the AT standards because they are classified as low occupancy. For those buildings not exempted from the standards, if required standoff distances are met, conventional construction generally may be used for exterior cladding and roofing materials. The applicable AT requirements for projects involving historic buildings need to be determined at an early stage.

As noted in the report on DoD Legacy Project No. 03-176, Antiterrorism Measures for Historic Properties (Webster et al. 2006), it is critical that the project team, consisting of design and cultural resource personnel, installation planners, and construction personnel, identify solutions that will comply with UFC 4-010-01, DoD Minimum Antiterrorism Standards for Buildings (2013) and conform to SOI Standards. Based upon discussions with various DoD CRMs and AT specialists, there are many challenges associated with applying the UFC 4-010-01 to existing buildings and, more specifically, historic buildings. The UFC is a living document that is subject to change based on additional research and new guidance with the application of the standards. Additionally, the interpretation of the standards is based on several factors, such as the risk assessment of the installation and/or building and building occupancy; therefore, interpretation can vary from installation to installation and from project to project. The general consensus among DoD CRMs and AT specialists is a recommendation of two strategies: 1) engagement with the CRM and AT specialist as early as possible when a project involves a historic building and AT standards must be applied; and 2) familiarity with the AT policies, the UFC 4-010-01, and the previous Legacy reports regarding AT.

When replacement of character-defining features of historic buildings is proposed to comply with UFC 4-010-01, the CRM and AT specialist should discuss possible options involving repair or in-kind replacement, and should ensure these options are given adequate consideration. This collaborative process should begin at the project planning stage. Input from other CRMs and AT specialists who have dealt with similar issues should also be sought to ensure all feasible alternatives are considered. This analysis should be well documented and included as part of the Section 106 consultation package so the SHPO and other consulting parties are aware of alternatives that were considered and why they are considered not feasible.

7.3 IDENTIFYING ALTERNATIVES

In order to comply with SOI Standards, repair is always the preferred alternative, if feasible. In the case of concrete, repair should be considered the preferred method. For unique reasons, repair may not always be the best option for corrugated metal, so replacement must be explored as necessary. Asbestos-cement should either be maintained or replaced with a substitute material.

Concrete

If proper maintenance occurs, concrete can last indefinitely. Even the most common material issues, cracking and spalling, can be addressed with injections and patches; if these repairs are done correctly, they can remain almost invisible. Small surface repairs do not hinder the stability of the concrete as a whole in most instances. The malleability of concrete allows for a flexible repair and in-kind replacement that is readily available, affordable, and sturdy. In the rare instances of full historic concrete replacement, concrete does not require an assessment of suitable substitute materials. Concrete should only be replaced in-kind, as concrete remains widely available and customizable in color, aggregate type, and composition, and repairs should only be performed by qualified contractors. A "qualified contractor" has demonstrated experience in treatment of historic concrete, particularly for more significant buildings (Craren 2016). If a CRM must use a contractor without demonstrated experience in historic materials, the CRM should educate the contractors to the best of their abilities before the work begins. Available information about known concrete conditions and causes, such as the information presented in this report, can be formatted into a fact sheet or slideshow to show less experienced contractors what to expect, appropriate methods, and specific concerns. To meet the SOI Standards, all concrete repair or replacements require a conditions assessment; determination of a repair or replacement procedure based on the cause (grouting, epoxy injection, drypacking, partial replacement, etc.); repair trials and replacement mock-ups; assessment of the trials; and then final repair or replacement application (Gaudette and Slaton 2007:10-11).

Corrugated Metal

If the corrugated metal has been maintained, the durability will allow for a long service life. Corrugated metal repairs tend to be difficult. While traditional repairs like patching can be done to corrugated metal, the corrosion that may have occurred could affect the integrity of the material. Replacement may be preferable to repair since in-kind replacement is readily available, customizable, and affordable. The options for suitable substitutes are numerous, including different metals or different treatments. While painting or coating a different metal may result in a similar aesthetic to the historic material, special attention should be given to the structural properties like thermal expansion rates to ensure the appropriate selection.

Asbestos-Cement

Asbestos-cement is unique, in that the hazardous properties of the material make repair unfeasible. This is an instance of potential weaknesses or inherent flaws in historic material that make repair dangerous and ineffective. It is recommended that historic asbestos-cement be replaced not with in-kind materials, but instead with suitable substitutes for health and environmental reasons. One recommended suitable substitute is fiber-cement, which is similar to asbestos-cement but contains no asbestos. Fiberglass is often used as the fiber in place of the asbestos. Fiber-cement does not quite match the texture of the historic material, but is a suitable substitute. The other suitable substitute for asbestos-cement is corrugated metal. Though not an exact match, corrugated metal is successful in the preservation of historic design and appearance. A matte paint will give the effect most similar to the original product and should be reviewed prior to selection. The SHPO should be consulted with the detailed paint and color information, cut sheets for the cladding, and potentially a sample of the proposed replacement product for either fiber-cement or corrugated metal replacement (Craren 2016).

Any proposed replacements should be discussed with the appropriate SHPO at an early stage so design details can be incorporated that will avoid or minimize adverse effects. It is critical that any design features specified during the consultation process be clearly documented in the final project plans and specifications so that the "agreed to" materials are actually installed.

7.4 SHPO AND CONSULTING PARTY REVIEW PACKAGE

To assist in SHPO and consulting party review for a project that includes replacement of historic materials, a SHPO/consulting party consultation package should be assembled that includes a brief report supported by historic drawings, proposed project plans, and other pertinent materials, including historic and current photographs that convey changes over time, condition survey results, and an alternatives analysis report. The included narrative should provide the following points of information: 1) general building description; 2) NRHP status; 3) architectural history, including the application of replacement materials; 4) concise description of the project, including overall purpose and need; 5) a discussion of those character-defining features that will be impacted as part of the proposed project; and 6) an analysis of alternatives and why they were not selected.

For those projects involving in-kind replacement or replacement with a material believed to be a suitable substitute, the consultation package should also include appropriate design specifications and drawings. For those projects involving replacement with materials not considered to be suitable substitutes, the consultation package should also include information on efforts to minimize effects and possible mitigation actions. Direct correlation to compliance with the SOI Standards should be noted. Supporting materials should include historic photographs; current photographs, particularly illustrating those features that are proposed for replacement; as-built drawings; the conditions survey; an alternatives analysis, with specifications regarding replacement materials; and proposed project plans and sheets.

7.5 PRESERVATION GROUP INVOLVEMENT

The Advisory Council on Historic Preservation's regulations implementing Section 106 of the NHPA (36 CFR Part 800) require federal agencies to involve appropriate interested parties in the consultation process. Depending on the uniqueness and significance of the resource, these groups may include local, regional, state, and/or national preservation groups who are concerned about the effects of the project on the property. If the property in question is a National Historic Landmark (NHL) or contributes to an NHL District, in addition to the interested preservation groups, the consulting parties would include the NPS. It is critical that potentially interested preservation groups be identified early in the consultation process, their input sought, and their concerns properly addressed. As with the SHPO, the preservation groups' preference is to retain original material when feasible, so any proposal to replace historic materials could potentially be an area of concern. To address these concerns, the groups should be provided information that 1) defines the purpose and need of the action; 2) details why repair or in-kind replacement is not feasible; and 3) describes actions taken to avoid or minimize adverse effects. When the proposed action will result in an adverse effect, the preservation groups' input should be sought regarding the proposed mitigation actions. The key to avoiding potential confrontation with the preservation groups is early involvement and providing information that demonstrates a clear need for the action, as well as serious consideration of reasonable alternatives.

8.0 Summary

The aim of this report is to serve as a useful tool that will assist DoD CRMs, facility planners, architects, and engineers responsible for the maintenance and repair of historic twentieth-century buildings in complying with Section 106 of the NHPA. This report focuses specifically on twentieth-century exterior materials that are common on historic twentieth-century buildings on U.S. military installations nationwide: concrete, corrugated metal, and asbestos-cement. The conclusions of this report are supported by archival research, documentary research, and data analysis, as well as through case studies of select DoD installations throughout the Mid-Atlantic region.

The three material types were primarily used for utilitarian purposes. Concrete is a material with a long history that became widely used in the twentieth century, but its roots in U.S. architecture were industrial. Corrugated metal took an already strong substance and used technology to improve its form, creating an even stronger material with more possible applications. Asbestos-cement was created to combine the best features of two extremely popular materials into a fireproof, high insulation, affordable super material. All three materials were revolutionary in the twentieth-century architectural landscape.

Each material was advertised as "low-maintenance," but each material required basic maintenance over its life cycle. The use of all three materials on support or secondary buildings meant that more often than not, maintenance was not a priority. Concrete can crack or spall, allowing moisture to corrode steel reinforcement or generally reduce the stability of the material. Corrugated steel needed paint or sealants to keep moisture out, but without regular upkeep, moisture caused corrosion. Asbestos-cement can remain in place indefinitely, as long as there is no breakdown of the material. Water, erosion, physical damage, and cracking can cause degradation that results not only in a failure of the material, but also in physical and environmental hazards. DoD installations responsible for historic twentieth-century buildings are challenged with balancing preservation needs, future sustainability, shrinking maintenance budgets, and federal regulations.

While the ideal scenario is to keep historic materials in place, the feasibility varies between materials. In the case of concrete, repair should be considered first, and if repair is not feasible, replacement in-kind should be pursued. The replacement concrete should be chosen to match the color, aggregate, and composition of the historic concrete to every extent possible. Corrugated metal should be evaluated for the extent of damage and assessed as to whether a repair would help or hinder the strength of the material, and/or offer a long-term solution. If the repair will not fix the issue, in-kind replacement should be chosen. If corrosion is the issue, a suitable substitute like aluminum could be chosen but should maintain the historic design and appearance through color and corrugation rhythm. Asbestos-cement, once damaged, is hazardous, and repair should not be attempted once degradation occurs. Replacement in-kind is not feasible due to the lack of availability and inherent flaws of the historic material. Corrugated or flat fiber cement board is the preferred replacement, but corrugated metal can be a suitable substitute with the aim of preserving the historic design and appearance through color and corrugation rhythm.

When adverse effects cannot be avoided and replacement is the only viable option, mitigation and minimization efforts should be considered. Section 3.0 of this report presents the history of the three particular material types, identifying their unique characteristics and special circumstances that led to their developments and the key manufacturers that historically produced them. This history can be used toward the preparation of mitigation documentation, such as HABS/HAER and public history reports.

Illustration 90:

DETERMINING THE USE OF SUBSTITUTE MATERIALS FOR EXTERIOR MATERIALS

HISTORIC DESIGNATION OF BUILDING
Is building historic (either individually and/or as contributing to a larger historic district)?

→ *Not Historic* → *Notification to SHPO/consulting parties on no historic properties affected finding.*

↓ *Building is Historic*

ASSESS SIGNIFICANCE
Are exterior materials character-defining features?

→ *Not Character-Defining* → *Notification to SHPO/consulting parties of no adverse effect finding including description of proposed replacement material's compatibility with the building's existing appearance.*

↓ *Character-Defining Feature*

REPAIR VS. REPLACEMENT
Perform Conditions Study

Determine percentage of original material that can be retained.

Identify materials in need of replacement and document reason.

→ *Repair* → *Notification to SHPO/consulting parties of no adverse effect finding including description of proposed repairs.*

↓ *Replacement Warranted*

IN-KIND REPLACEMENT VS. SUBSTITUTE MATERIALS
Determine feasibility of in-kind replacement based on:

- Availability of historic materials
- Inherent flaws in material type
- Cost
- Code compliance (AT, energy)

→ *In-Kind Replacement* → *Notification to SHPO/consulting parties of no adverse effect finding including description of proposed in-kind exterior material replacement.*

↓ *In-Kind Replacement Not Feasible*

DETERMINE IF REPLACEMENT MATERIAL COMPLIES WITH SOI STANDARDS

→ *Compliant* → *Notification to SHPO/consulting parties of no adverse effect finding including description of proposed in-kind exterior material replacement.*

↓ *Non-Compliant*

ADVERSE EFFECT CONSULTATION
Submit Project Review Package to SHPO/ Consulting Parties including:

1. Brief report describing the building, NRHP status, architectural history, concise description of project, discussion of character-defining features that will be impacted; analysis of alternatives that would avoid adverse effect and discussion on why they are not considered feasible (i.e., non-compliance with Antiterrorism/Force Protection [ATFP], excessive cost, availability); efforts to minimize effects; possible mitigation actions (if applicable)Historic and current photographs
2. As-built drawings
3. Conditions survey
4. Proposed project plans and sheets

→ ***Execute Memorandum of Agreement***

Illustration 91: Historic Twentieth-Century Exterior Material Types

Historic Exterior Material Type	In-Kind Replacement Feasible	Common Replacements - Material	Common Replacements - Achieves No Adverse Effect
Concrete	Yes – it is still produced and available in the United States.	No replacement materials identified.	Any replacement material would be adverse effect.
Corrugated Metal	Yes - it is still produced and available in the United States.	Corrugated metal (different type).	Yes - If the replacement metal replicates the original metal as closely as possible in corrugation width, rhythm, thermal expansion properties, color, and reflectivity, then the material will retain a similar aesthetic of the original metal.
Asbestos-Cement	No - it is no longer produced in the United States.	Fiber-cement. Corrugated metal.	Yes - though the substitute does not quite match the texture of the historic material, the replacement material can match the color and corrugation of original asbestos-cement, without containing asbestos. Fiberglass is often used as the fiber in place of the asbestos. Yes - the most common replacement, corrugated metal, can match the width and rhythm of the corrugated asbestos-cement. A matte paint will give the effect most similar to the original product and should be reviewed with SHPO prior to selection.

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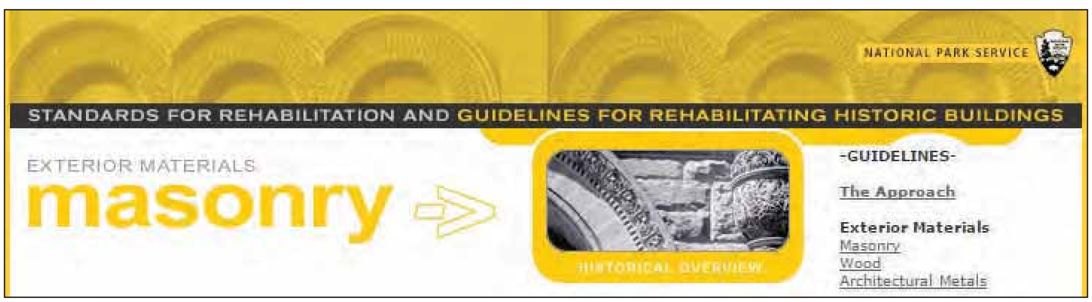
Appendix A

SECRETARY OF THE INTERIOR'S STANDARDS FOR REHABILITATION

To access the Secretary of the Interior's standards for rehabilitations, please visit:

http://www.nps.gov/tps/standards/four-treatments/standguide/rehab/rehab_standards.htm

http://www.nps.gov/tps/standards/four-treatments/standguide/rehab/rehab_approach.htm



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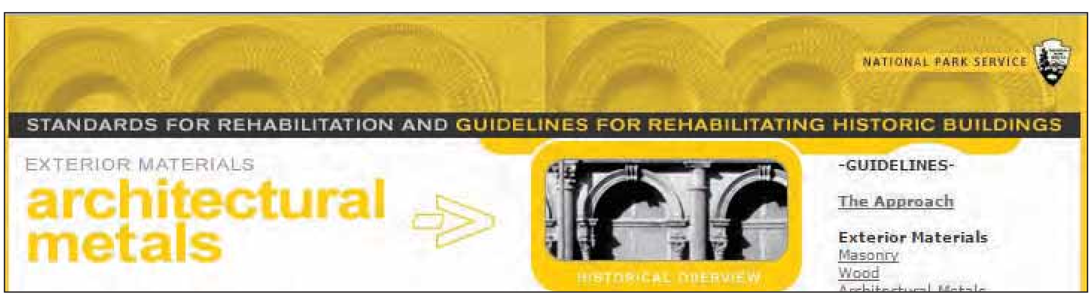
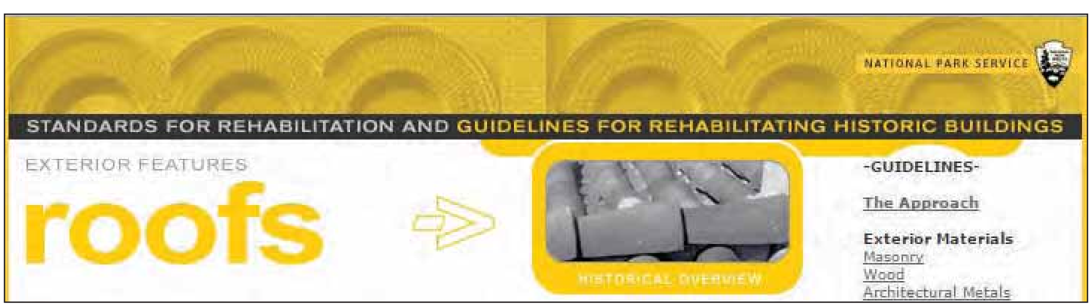


http://www.nps.gov/tps/standards/four-treatments/standguide/rehab/rehab_metals.htm

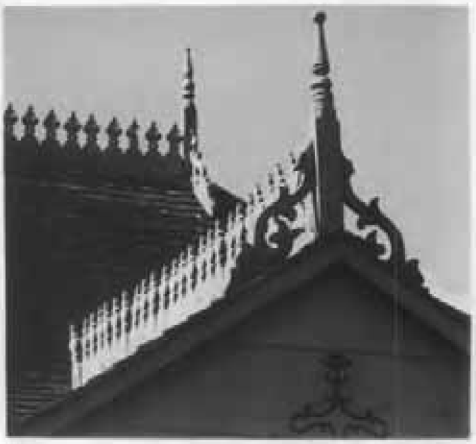


http://www.nps.gov/tps/standards/four-treatments/standguide/rehab/rehab_roofs.htm

Appendix B

NATIONAL PARK SERVICE PRESERVATION BRIEFS AND TECHNICAL NOTES

4 PRESERVATION BRIEFS



HABS

Roofing for Historic Buildings

Sarah M. Sweetser

U.S. Department of the Interior
National Park Service
Cultural Resources
Heritage Preservation Services

Significance of the Roof

A weather-tight roof is basic in the preservation of a structure, regardless of its age, size, or design. In the system that allows a building to work as a shelter, the roof sheds the rain, shades from the sun, and buffers the weather.

During some periods in the history of architecture, the roof imparts much of the architectural character. It defines the style and contributes to the building's aesthetics. The hipped roofs of Georgian architecture, the turrets of Queen Anne, the Mansard roofs, and the graceful slopes of the Shingle Style and Bungalow designs are examples of the use of roofing as a major design feature.

But no matter how decorative the patterning or how compelling the form, the roof is a highly vulnerable element of a shelter that will inevitable fail. A poor roof will permit the accelerated deterioration of historic building materials—masonry, wood, plaster, paint—and will cause general disintegration of the basic structure. Furthermore, there is an urgency involved in repairing a leaky roof since such repair costs will quickly become prohibitive. Although such action is desirable as soon as a failure is discovered, temporary patching methods should be carefully chosen to prevent inadvertent damage to sound or historic roofing materials and related features. Before any repair work is performed, the historic value of the materials used on the roof should be understood. Then a complete internal and external inspection of the roof should be planned to determine all the causes of failure and to identify the alternatives for repair or replacement of the roofing.

Historic Roofing Materials in America

Clay Tile: European settlers used clay tile for roofing as early as the mid-17th century; many pantiles (S-curved tiles), as well as flat roofing tiles, were used in Jamestown, Virginia. In some cities such as New York and Boston, clay was popularly used as a precaution against such fire as those that engulfed London in 1666 and scorched Boston in 1679.

Tiles roofs found in the mid-18th century Moravian settlements in Pennsylvania closely resembled those found in Germany. Typically, the tiles were 14–15" long, 6–7" wide with a curved butt. A lug on the back allowed the tiles to hang on the lathing without nails or pegs. The tile surface was usually scored with finger marks to promote drainage. In the Southwest, the tile roofs of the Spanish missionaries (mission tiles) were first manufactured (ca. 1780) at the Mission San Antonio de Padua in California. These semicircular tiles were made by molding clay over sections of logs, and they were generally 22" long and tapered in width.

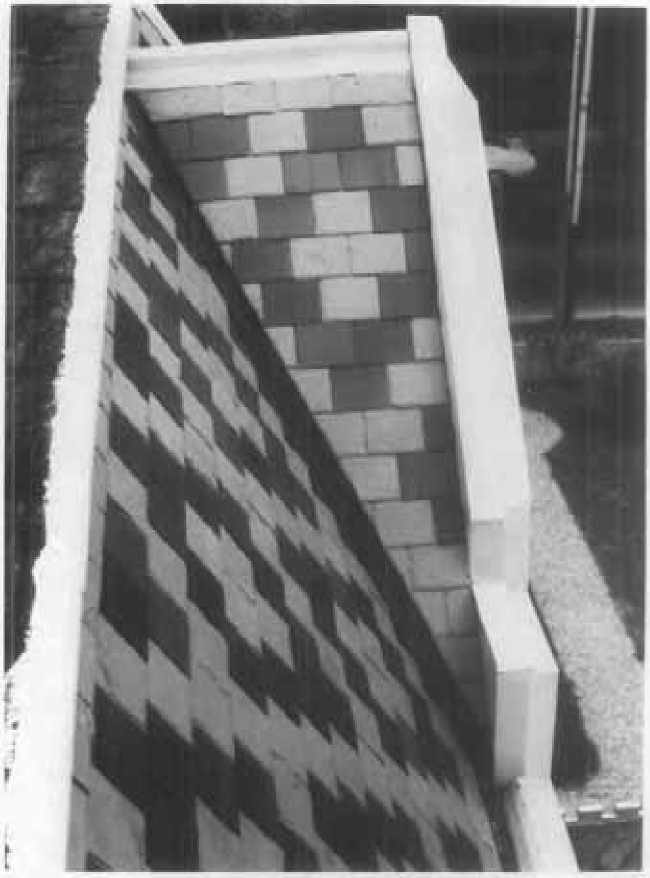
Repairs on this pantile roof were made with new tiles held in place with metal hangers. (Main Building, Ellis Island, New York)

The plain or flat rectangular tiles most commonly used from the 17th through the beginning of the 19th century measured about 10" by 6" by ½", and had two holes at one end for a nail or peg fastener. Sometimes mortar was applied between the courses to secure the tiles in a heavy wind.

In the mid-19th century, tile roofs were often replaced by sheet-metal roofs, which were lighter and easier to install and maintain. However, by the turn of the century, the Romanesque Revival and Mission style buildings created a new demand and popularity for this picturesque roofing material.

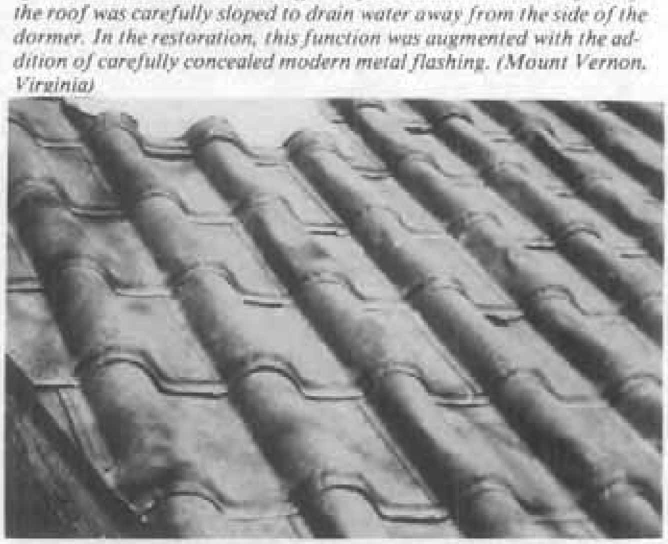
Slate: Another practice settlers brought to the New World was slate roofing. Evidence of roofing slates have been found also among the ruins of mid-17th-century Jamestown. But because of the cost and the time required to obtain the material, which was mostly imported from Wales, the use of slate was initially limited. Even in Philadelphia (the second largest city in the English-speaking world at the time of the Revolution) slates were so rare that "The Slate Roof House" distinctly referred to William Penn's home built late in the 1600s. Sources of native slate were known to exist along the eastern seaboard from Maine to Virginia, but difficulties in inland transportation limited its availability to the cities, and contributed to its expense. Welsh slate continued to be imported until the development of canals and railroads in the mid-19th century made American slate more accessible and economical.

Slate was popular for its durability, fireproof qualities, and



The Victorians loved to used different colored slates to create decorative patterns on their roofs, an effect which cannot be easily duplicated by substitute materials. Before any repair work on a roof such as this, the slate sizes, colors, and position of the patterning should be carefully recorded to assure proper replacement. (Ebenezer Maxwell Mansion, Philadelphia, Pennsylvania, photo courtesy of William D. Hershey)

Replacement of particular historic details is important to the individual historic character of a roof, such as the treatment at the eaves of this rounded butt wood shingle roof. Also note that the surface of the roof was carefully sloped to drain water away from the side of the dormer. In the restoration, this function was augmented with the addition of carefully concealed modern metal flashing. (Mount Vernon, Virginia)



Galvanized sheet-metal shingles imitating the appearance of pantiles remained popular from the second half of the 19th century into the 20th century. (Episcopal Church, now the Jerome Historical Society Building, Jerome, Arizona, 1927)

aesthetic potential. Because slate was available in different colors (red, green, purple, and blue-gray), it was an effective material for decorative patterns on many 19th-century roofs (Gothic and Mansard styles). Slate continued to be used well into the 20th century, notably on many Tudor revival style buildings of the 1920s.

Shingles: Wood shingles were popular throughout the country in all periods of building history. The size and shape of the shingles as well as the detailing of the shingle roof differed according to regional craft practices. People within particular regions developed preferences for the local species of wood that most suited their purposes. In New England and the Delaware Valley, white pine was frequently used: in the South, cypress and oak; in the far west, red cedar or redwood. Sometimes a protective coating was applied to increase the durability of the shingle such as a mixture of brick dust and fish oil, or a paint made of red iron oxide and linseed oil.

Commonly in urban areas, wooden roofs were replaced with more fire resistant materials, but in rural areas this was not a major concern. On many Victorian country houses, the practice of wood shingling survived the technological advances of metal roofing in the 19th century, and near the turn of the century enjoyed a full revival in its namesake, the Shingle Style. Colonial revival and the Bungalow styles in the 20th century assured wood shingles a place as one of the most fashionable, domestic roofing materials.

Metal: Metal roofing in America is principally a 19th-century phenomenon. Before then the only metals commonly used were lead and copper. For example, a lead roof covered "Rosewell," one of the grandest mansions in 18th-century Virginia. But more often, lead was used for protective flashing. Lead, as well as copper, covered roof surfaces where wood, tile, or slate shingles were inappropriate because of the roof's pitch or shape.

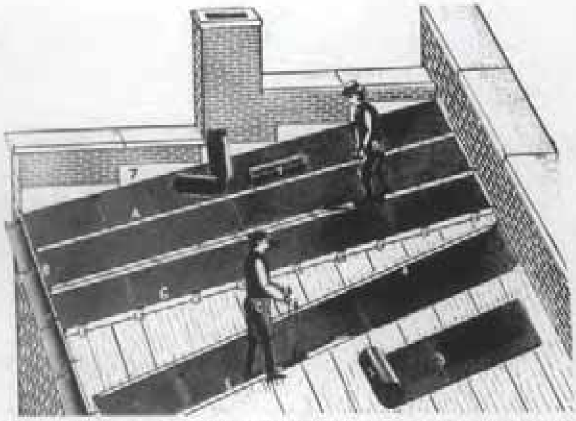
Copper with standing seams covered some of the more notable early American roofs including that of Christ Church (1727–1744) in Philadelphia. Flat-seamed copper was used on many domes and cupolas. The copper sheets were imported from England until the end of the 18th century when facilities for rolling sheet metal were developed in America.

Sheet iron was first known to have been manufactured here by the Revolutionary War financier, Robert Morris, who had a rolling mill near Trenton, New Jersey. At his mill Morris produced the roof of his own Philadelphia mansion, which he started in 1794. The architect Benjamin H. Latrobe used sheet iron to replace the roof on Princeton's "Nassau Hall," which had been gutted by fire in 1802.

The method for corrugating iron was originally patented in England in 1829. Corrugating stiffened the sheets, and allowed greater span over a lighter framework, as well as reduced installation time and labor. In 1834 the American architect William Strickland proposed corrugated iron to cover his design for the market place in Philadelphia.

Galvanizing with zinc to protect the base metal from rust was developed in France in 1837. By the 1850s the material was used on post offices and customhouses, as well as on train sheds and factories. In 1857 one of the first metal roofs in the

Repeated repair with asphalt, which cracks as it hardens, has created a blistered surface on this sheet-metal roof and built-in gutter, which will retain water. Repairs could be made by carefully heating and scraping the surface clean, repairing the holes in the metal with a flexible mastic compound or a metal patch, and coating the surface with a fibre paint. (Roane County Courthouse, Kingston, Tennessee, photo courtesy of Building Conservation Technology, Inc.)



A Chicago firm's catalog dated 1896 illustrates a method of unrolling, turning the edges, and finishing the standing seam on a metal roof.

Tin shingles, commonly embossed to imitate wood or tile, or with a decorative design, were popular as an inexpensive, textured roofing material. These shingles $8\frac{3}{8}$ inch by $12\frac{1}{2}$ inch on the exposed surface) were designed with interlocking edges, but they have been repaired by surface nailing, which may cause future leakage. (Ballard House, Yorktown, Virgina, photo by Gordie Whittington, National Park Service)

South was installed on the U.S. Mint in New Orleans. The Mint was thereby "fireproofed" with a 20-gauge galvanized, corrugated iron roof on iron trusses.

Tin-plate iron, commonly called "tin roofing," was used extensively in Canada in the 18th century, but it was not as common in the United States until later. Thomas Jefferson was an early advocate of tin roofing, and he installed a standing-seam tin roof on "Monticello" (ca. 1770–1802). The Arch Street Meetinghouse (1804) in Philadelphia had tin shingles laid in a herringbone pattern on a "piazza" roof.

However, once rolling mills were established in this country, the low cost, light weight, and low maintenance of tin plate made it the most common roofing material. Embossed tin shingles, whose surfaces created interesting patterns, were popular throughout the country in the late 19th century. Tin roofs were kept well-painted, usually red; or, as the architect A. J. Davis suggested, in a color to imitate the green patina of copper.

Terne plate differed from tin plate in that the iron was dipped in an alloy of lead and tin, giving it a duller finish. Historic, as well as modern, documentation often confuses the two, so much that it is difficult to determine how often actual "terne" was used.

Zinc came into use in the 1820s, at the same time tin plate was becoming popular. Although a less expensive substitute for lead, its advantages were controversial, and it was never widely used in this country.

Other Materials: Asphalt shingles and roll roofing were used in the 1890s. Many roofs of asbestos, aluminum, stainless steel, galvinized steel, and lead-coated copper may soon have historic values as well. Awareness of these and other traditions of roofing materials and their detailing will contribute to more sensitive preservation treatments.

Locating the Problem

Failures of Surface Materials

When trouble occurs, it is important to contact a professional, either an architect, a reputable roofing contractor, or a craftsman familiar with the inherent characteristics of the particular historic roofing system involved. These professionals may be able to advise on immediate patching procedures and help plan more permanent repairs. A thorough examination of the roof should start with an appraisal of the existing condition and quality of the roofing material itself. Particular attention should be given to any southern slope because year-round exposure to direct sun may cause it to break down first.

Wood: Some historic roofing materials have limited life expectancies because of normal organic decay and "wear." For example, the flat surfaces of wood shingles erode from exposure to rain and ultraviolet rays. Some species are more hardy than others, and heartwood, for example, is stronger and more durable than sapwood.

Ideally, shingles are split with the grain perpendicular to the surface. This is because if shingles are sawn across the grain, moisture may enter the grain and cause the wood to deteriorate. Prolonged moisture on or in the wood allows moss or fungi to grow, which will further hold the moisture and cause rot.

Metal: Of the inorganic roofing materials used on historic buildings, the most common are perhaps the sheet metals: lead, copper, zinc, tin plate, terne plate, and galvanized iron. In varying degrees each of these sheet metals are likely to deteriorate from chemical action by pitting or streaking. This can be caused by airborn pollutants; acid rainwater; acids from lichen or moss; alkalis found in lime mortars or portland cement, which might be on adjoining features and washes down on the roof surface; or tannic acids from adjacent wood sheathings or shingles made of red cedar or oak.

Corrosion from "galvanic action" occurs when dissimilar metals, such as copper and iron, are used in direct contact. Corrosion may also occur even though the metals are physically separated; one of the metals will react chemically against the other in the presence of an electrolyte such as rainwater. In roofing, this situation might occur when either a copper roof is decorated with iron cresting, or when steel nails are used in copper sheets. In some instances the corrosion can be prevented by inserting a plastic insulator between the dissimilar materials. Ideally, the fasteners should be a metal sympathetic to those involved.

Iron rusts unless it is well-painted or plated. Historically this problem was avoided by use of tin plating or galvinizing. But this method is durable only as long as the coating remains intact. Once the plating is worn or damaged, the exposed iron will rust. Therefore, any iron-based roofing material needs to be undercoated, and its surface needs to be kept well-painted to prevent corrosion.

One cause of sheet metal deterioration is fatigue. Depending upon the size and the gauge of the metal sheets, wear and metal failure can occur at the joints or at any protrusions in the sheathing as a result from the metal's alternating movement to thermal changes. Lead will tear because of "creep," or the gravitational stress that causes the material to move down the roof slope.

Slate: Perhaps the most durable roofing materials are slate and tile. Seemingly indestructable, both vary in quality. Some slates are hard and tough without being brittle. Soft slates are more subject to erosion and to attack by airborne and rainwater chemicals, which cause the slates to wear at nail holes, to delaminate, or to break. In winter, slate is very susceptible to breakage by ice, or ice dams.

Tile: Tiles will weather well, but tend to crack or break if hit, as by tree branches, or if they are walked on improperly. Like slates, tiles cannot support much weight. Low quality tiles that have been insufficiently fired during manufacture, will craze and spall under the effects of freeze and thaw cycles on their porous surfaces.

Failures of Support Systems

Once the condition of the roofing material has been determined, the related features and support systems should be examined on the exterior and on the interior of the roof. The gutters and downspouts need periodic cleaning and maintenance since a variety of debris fill them, causing water to back up and seep under roofing units. Water will eventually cause fasteners, sheathing, and roofing structure to deteriorate. During winter, the daily freeze-thaw cycles can cause ice floes to develop under the roof surface. The pressure from these ice floes will dislodge the roofing material, especially slates, shingles, or tiles. Moreover, the buildup of ice dams above the gutters can trap enough moisture to rot the sheathing or the structural members.

Many large public buildings have built-in gutters set within the perimeter of the roof. The downspouts for these gutters may run within the walls of the building, or drainage may be through the roof surface or through a parapet to exterior downspouts. These systems can be effective if properly maintained; however, if the roof slope is inadequate for good runoff, or if the traps are allowed to clog, rainwater will form pools on the roof surface. Interior downspouts can collect debris and thus back up, perhaps leaking water into the surrounding walls. Exterior downspouts may fill with water, which in cold weather may freeze and crack the pipes. Conduits from the built-in gutter to the exterior downspout may also leak water into the surrounding roof structure or walls.

Failure of the flashing system is usually a major cause of roof deterioration. Flashing should be carefully inspected for failure caused by either poor workmanship, thermal stress, or metal deterioration (both of flashing material itself and of the fasteners). With many roofing materials, the replacement of flashing on an existing roof is a major operation, which may require taking up large sections of the roof surface. Therefore, the installation of top quality flashing material on

This detail shows slate delamination caused by a combination of weathering and pollution. In addition, the slates have eroded around the repair nails, incorrectly placed in the exposed surface of the slates. (Lower Pontalba Building, New Orleans, photo courtesy of Building Conservation Technology, Inc.)

Temporary stabilization or "mothballing" with materials such as plywood and building paper can protect the roof of a project until it can be properly repaired or replaced. (Narbonne House, Salem, Massachusetts)

These two views of the same house demonstrate how the use of a substitute material can drastically affect the overall character of a structure. The textural interest of the original tile roof was lost with the use of asphalt shingles. Recent preservation efforts are replacing the tile roof. (Frank House, Kearney, Nebraska, photo courtesy of the Nebraska State Historical Society, Lincoln, Nebraska)

a new or replaced roof should be a primary consideration. *Remember, some roofing and flashing materials are not compatible.*

Roof fasteners and clips should also be made of a material compatible with all other materials used, or coated to prevent rust. For example, the tannic acid in oak will corrode iron nails. Some roofs such as slate and sheet metals may fail if nailed too rigidly.

If the roof structure appears sound and nothing indicates recent movement, the area to be examined most closely is the roof substrate—the sheathing or the battens. The danger spots would be near the roof plates, under any exterior patches, at the intersections of the roof planes, or at vertical surfaces such as dormers. Water penetration, indicating a breach in the roofing surface or flashing, should be readily apparent, usually as a damp spot or stain. Probing with a small pen knife may reveal any rot which may indicate previously undetected damage to the roofing membrane. Insect infestation evident by small exit holes and frass (a sawdust-like debris) should also be noted. Condensation on the underside of the roofing is undesirable and indicates improper ventilation. Moisture will have an adverse effect on any roofing material; a good roof stays dry inside and out.

Repair or Replace

Understanding potential weaknesses of roofing material also requires knowledge of repair difficulties. Individual slates can be replaced normally without major disruption to the rest of the roof, but replacing flashing on a slate roof can require substantial removal of surrounding slates. If it is the substrate or a support material that has deteriorated, many surface materials such as slate or tile can be reused if handled carefully during the repair. Such problems should be evaluated at the outset of any project to determine if the roof can be effectively patched, or if it should be completely replaced.

Will the repairs be effective? Maintenance costs tend to multiply once trouble starts. As the cost of labor escalates, repeated repairs could soon equal the cost of a new roof.

The more durable the surface is initially, the easier it will be to maintain. Some roofing materials such as slate are expensive to install, but if top quality slate and flashing are used, it will last 40–60 years with minimal maintenance. Although the installation cost of the roof will be high, low maintenance needs will make the lifetime cost of the roof less expensive.

Historical Research

In a restoration project, research of documents and physical investigation of the building usually will establish the roof's history. Documentary research should include any original plans or building specifications, early insurance surveys, newspaper descriptions, or the personal papers and files of people who owned or were involved in the history of the building. Old photographs of the building might provide evidence of missing details.

Along with a thorough understanding of any written history of the building, a physical investigation of the roofing and its structure may reveal information about the roof's construction history. Starting with an overall impression of the structure, are there any changes in the roof slope, its configuration, or roofing materials? Perhaps there are obvious patches or changes in patterning of exterior brickwork where a gable roof was changed to a gambrel, or where a whole upper story was added. Perhaps there are obvious stylistic changes in the roof line, dormers, or ornamentation. These observations could help one understand any important alteration, and could help establish the direction of further investigation.

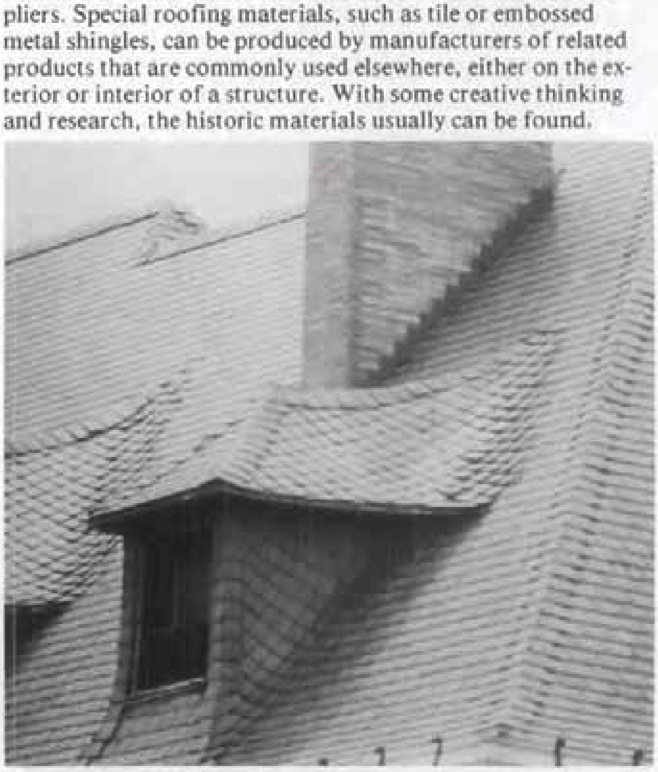
Because most roofs are physically out of the range of careful scrutiny, the "principle of least effort" has probably limited the extent and quality of previous patching or replacing, and usually considerable evidence of an earlier roof surface remains. Sometimes the older roof will be found as an underlayment of the current exposed roof. Original roofing may still be intact in awkward places under later features on a roof. Often if there is any unfinished attic space, remnants of roofing may have been dropped and left when the roof was being built or repaired. If the configuration of the roof has been changed, some of the original material might still be in place under the existing roof. Sometimes whole sections of the roof and roof framing will have been left intact under the higher roof. The profile and/or flashing of the earlier roof may be apparent on the interior of the walls at the level of the alteration. If the sheathing or lathing appears to have survived changes in the roofing surface, they may contain evidence of the roofing systems. These may appear either as dirt marks, which provide "shadows" of a roofing material, or as nails broken or driven down into the wood, rather than pulled out during previous alterations or repairs. Wooden headers in the roof framing may indicate that earlier chimneys or skylights have been removed. Any metal ornamentation that might have existed may be indicated by anchors or unusual markings along the ridge or at other edges of the roof. This primary evidence is essential for a full understanding of the roof's history.

Caution should be taken in dating early "fabric" on the evidence of a single item, as recycling of materials is not a mid-20th-century innovation. Carpenters have been reusing materials, sheathing, and framing members in the interest of economy for centuries. Therefore, any analysis of the materials found, such as nails or sawmarks on the wood, requires an accurate knowledge of the history of local building practices before any final conclusion can be accurately reached. It is helpful to establish a sequence of construction history for the roof and roofing materials; any historic fabric or pertinent evidence in the roof should be photographed, measured, and recorded for future reference.

During the repair work, useful evidence might unexpectedly appear. It is essential that records be kept of any type of work on a historic building, before, during, and after the project. Photographs are generally the easiest and fastest method, and should include overall views and details at the gutters, flashing, dormers, chimneys, valleys, ridges, and eaves. All photographs should be immediately labeled to insure accurate identification at a later date. Any patterning or design on the roofing deserves particular attention. For example, slate roofs are often decorative and have subtle changes in size, color, and texture, such as a gradually decreasing coursing length from the eave to the peak. If not carefully noted before a project begins, there may be problems in replacing the surface. The standard reference for this phase of the work is *Recording Historic Buildings,* compiled by Harley J. McKee for the Historic American Buildings Survey, National Park Service, Washington, D.C., 1970.

Replacing the Historic Roofing Material

Professional advice will be needed to assess the various aspects of replacing a historic roof. With some exceptions, most historic roofing materials are available today. If not, an architect or preservation group who has previously worked with the same type material may be able to recommend suppliers. Special roofing materials, such as tile or embossed metal shingles, can be produced by manufacturers of related products that are commonly used elsewhere, either on the exterior or interior of a structure. With some creative thinking and research, the historic materials usually can be found.



Because of the roof's visibility, the slate detailing around the dormers is important to the character of this structure. Note how the slates swirl from a horizontal pattern on the main roof to a diamond pattern on the dormer roofs and side walls. (18th and Que Streets, NW, Washington, D.C.)

Craft Practices: Determining the craft practices used in the installation of a historic roof is another major concern in roof restoration. Early builders took great pride in their work, and experience has shown that the "rustic" or irregular designs commercially labled "Early American" are a 20th-century invention. For example, historically, wood shingles underwent several distinct operations in their manufacture including splitting by hand, and smoothing the surface with a draw knife. In modern nomenclature, the same item would be a "tapersplit" shingle which has been dressed. Unfortunately, the rustic appearance of today's commercially available "handsplit" and re-sawn shingle bears no resemblance to the hand-made roofing materials used on early American buildings.

Good design and quality materials for the roof surface, fastenings, and flashing minimize roofing failures. This is essential on roofs such as on the National Cathedral where a thorough maintenance inspection and minor repairs cannot be done easily without special scaffolding. However, the success of the roof on any structure depends on frequent cleaning and repair of the gutter system. (Washington, D.C., photo courtesy of John Burns, A.I.A.)

Early craftsmen worked with a great deal of common sense; they understood their materials. For example they knew that wood shingles should be relatively narrow; shingles much wider than about 6" would split when walked on, or they may curl or crack from varying temperature and moisture. It is important to understand these aspects of craftsmanship, remembering that people wanted their roofs to be weather-tight and to last a long time. The recent use of "mother-goose" shingles on historic structures is a gross underestimation of the early craftsman's skills.

Supervision: Finding a modern craftsman to reproduce historic details may take some effort. It may even involve some special instruction to raise his understanding of certain historic craft practices. At the same time, it may be pointless (and expensive) to follow historic craft practices in any construction that will not be visible on the finished product. But if the roofing details are readily visible, their appearance should be based on architectural evidence or on historic prototypes. For instance, the spacing of the seams on a standing-seam metal roof will affect the building's overall scale and should therefore match the original dimensions of the seams.

Many older roofing practices are no longer performed because of modern improvements. Research and review of specific detailing in the roof with the contractor before beginning the project is highly recommended. For example, one early craft practice was to finish the ridge of a wood shingle roof with a roof "comb"—that is, the top course of one slope of the roof was extended uniformly beyond the peak to shield the ridge, and to provide some weather protection for the raw horizontal edges of the shingles on the other slope. If the "comb" is known to have been the correct detail, it should be used. Though this method leaves the top course vulnerable to the weather, a disguised strip of flashing will strengthen this weak point.

Detail drawings or a sample mock-up will help ensure that the contractor or craftsman understands the scope and special requirements of the project. It should never be assumed that the modern carpenter, slater, sheet metal worker, or roofer will know all the historic details. Supervision is as important as any other stage of the process.

Special problems inherent in the design of an elaborate historic roof can be controlled through the use of good materials and regular maintenance. The shape and detailing are essential elements of the building's historic character, and should not be modified, despite the use of alternative surface materials. (Gamwell House, Bellingham, Washington)

Alternative Materials

The use of the historic roofing material on a structure may be restricted by building codes or by the availability of the materials, in which case an appropriate alternative will have to be found.

Some municipal building codes allow variances for roofing materials in historic districts. In other instances, individual variances may be obtained. Most modern heating and cooking is fueled by gas, electricity, or oil—none of which emit the hot embers that historically have been the cause of roof fires. Where wood burning fireplaces or stoves are used, spark arrestor screens at the top of the chimneys help to prevent flaming material from escaping, thus reducing the number of fires that start at the roof. In most states, insurance rates have been equalized to reflect revised considerations for the risks involved with various roofing materials.

In a rehabilitation project, there may be valid reasons for replacing the roof with a material other than the original. The historic roofing may no longer be available, or the cost of obtaining specially fabricated materials may be prohibitive. But the decision to use an alternative material should be weighed carefully against the primary concern to keep the historic character of the building. If the roof is flat and is not visible from any elevation of the building, and if there are advantages to substituting a modern built-up composition roof for what might have been a flat metal roof, then it may make better economic and construction sense to use a modern roofing method. But if the roof is readily visible, the alternative material should match as closely as possible the scale, texture, and coloration of the historic roofing material.

Asphalt shingles or ceramic tiles are common substitute materials intended to duplicate the appearance of wood shingles, slates, or tiles. Fire-retardant, treated wood shingles are currently available. The treated wood tends, however, to be brittle, and may require extra care (and expense) to install. In some instances, shingles laid with an interlay of fire-retardent building paper may be an acceptable alternative.

Lead-coated copper, terne-coated steel, and aluminum/zinc-coated steel can successfully replace tin, terne plate, zinc, or lead. Copper-coated steel is a less expensive (and less durable) substitute for sheet copper.

The search for alternative roofing materials is not new. As early as the 18th century, fear of fire cause many wood shingle or board roofs to be replaced by sheet metal or clay tile. Some historic roofs were failures from the start, based on overambitious and naive use of materials as they were first developed. Research on a structure may reveal that an inadequately designed or a highly combustible roof was replaced early in its history, and therefore restoration of a later roof material would have a valid precedent. In some cities, the substitution of sheet metal on early row houses occurred as soon as the rolled material became available.

Cost and ease of maintenance may dictate the substitution of a material wholly different in appearance from the original. The practical problems (wind, weather, and roof pitch) should be weighed against the historical consideration of scale, texture, and color. Sometimes the effect of the alternative material will be minimal. But on roofs with a high degree of visibility and patterning or texture, the substitution may seriously alter the architectural character of the building.

Temporary Stabilization

It may be necessary to carry out an immediate and temporary stabilization to prevent further deterioration until research can determine how the roof should be restored or rehabilitated, or until funding can be provided to do a proper job. A simple covering of exterior plywood or roll roofing might provide adequate protection, but any temporary covering should be applied with caution. One should be careful not to overload the roof structure, or to damage or destroy historic evidence or fabric that might be incorporated into a new roof at a later date. In this sense, repairs with caulking or bituminous patching compounds should be recognized as potentially harmful, since they are difficult to remove, and at their best, are very temporary.

Precautions

The architect or contractor should warn the owner of any precautions to be taken against the specific hazards in installing the roofing material. Soldering of sheet metals, for instance, can be a fire hazard, either from the open flame or from overheating and undected smoldering of the wooden substrate materials.

Thought should be given to the design and placement of any modern roof appurtenances such as plumbing stacks, air vents, or TV antennas. Consideration should begin with the placement of modern plumbing on the interior of the building, otherwise a series of vent stacks may pierce the roof membrane at various spots creating maintenance problems as well as aesthetic ones. Air handling units placed in the attic space will require vents which, in turn, require sensitive design. Incorporating these in unused chimneys has been very successful in the past.

Whenever gutters and downspouts are needed that were not on the building historically, the additions should be made as unobtrusively as possible, perhaps by painting them out with a color compatible with the nearby wall or trim.

Maintenance

Although a new roof can be an object of beauty, it will not be protective for long without proper maintenance. At least twice a year, the roof should be inspected against a checklist. All changes should be recorded and reported. Guidelines should be established for any foot traffic that may be required for the maintenance of the roof. Many roofing materials should not be walked on at all. For some—slate, asbestos, and clay tile—a self-supporting ladder might be hung over the ridge of the roof, or planks might be spanned across the roof surface. Such items should be specifically designed and kept in a storage space accessible to the roof. If exterior work ever requires hanging scaffolding, use caution to insure that the anchors do not penetrate, break, or wear the roofing surface, gutters, or flashing.

Any roofing system should be recognized as a membrane that is designed to be self-sustaining, but that can be easily damaged by intrusions such as pedestrian traffic or fallen tree branches. Certain items should be checked at specific times. For example, gutters tend to accumulate leaves and debris during the spring and fall and after heavy rain. Hidden gutter screening both at downspouts and over the full length of the gutter could help keep them clean. The surface material would require checking after a storm as well. Periodic checking of the underside of the roof from the attic after a storm or winter freezing may give early warning of any leaks. Generally, damage from water or ice is less likely on a roof that has good flashing on the outside and is well ventilated and insulated on the inside. Specific instructions for the maintenance of the different roof materials should be available from the architect or contractor.

Summary

The essential ingredients for replacing and maintaining a historic roof are:

- Understanding the historic character of the building and being sympathetic to it.
- Careful examination and recording of the existing roof and any evidence of earlier roofs.
- Consideration of the historic craftsmanship and detailing and implementing them in the renewal wherever visible.
- Supervision of the roofers or maintenance personnel to assure preservation of historic fabric and proper understanding of the scope and detailing of the project.
- Consideration of alternative materials where the original cannot be used.
- Cyclical maintenance program to assure that the staff understands how to take care of the roof and of the particular trouble spots to safeguard.

With these points in mind, it will be possible to preserve the architectural character and maintain the physical integrity of the roofing on a historic building.

This Preservation Brief was written by Sarah M. Sweetser, Architectural Historian, Technical Preservation Services Division. Much of the technical information was based upon an unpublished report prepared under contract for this office by John G. and Dianá S. Waite. Some of the historical information was from Charles E. Peterson, FAIA, "American Notes," *Journal of the Society of Architectural Historians.*

The illustrations for this brief not specifically credited are from the files of the Technical Preservation Services Division.

This publication was prepared pursuant to Executive Order 11593, "Protection and Enhancement of the Cultural Environment," which directs the Secretary of the Interior to "develop and make available to Federal agencies and State and local governments information concerning professional methods and techniques for preserving, improving, restoring and maintaining historic properties." The Brief has been developed under the technical editorship of Lee H. Nelson, AIA, Chief, Preservation Assistance Division, National Park Service, U.S. Department of the Interior, Washington, D.C. 20240. Comments on the usefulness of this information are welcome and can be sent to Mr. Nelson at the above address. **February 1978.**

Decorative features such as cupolas require extra maintenance. The flashing is carefully detailed to promote run-off, and the wooden ribbing must be kept well-painted. This roof surface, which was originally tin plate, has been replaced with lead-coated copper for maintenance purposes. (Lyndhurst, Tarrytown, New York, photo courtesy of the National Trust for Historic Preservation)

Additional readings on the subject of roofing are listed below.

Boaz, Joseph N., ed. *Architectural Graphic Standards.* New York: John Wiley and Sons, Inc., 1970. (Modern roofing types and detailing)

Briggs, Martin S. *A Short History of the Building Crafts.* London: Oxford University Press, 1925. (Descriptions of historic roofing materials)

Bulletin of the Association for Preservation Technology. Vol. 2 (nos. 1-2) 1970. (Entirely on roofing)

Holstrom, Ingmar; and Sandstrom, Christina. *Maintenance of Old Buildings: Preservation from the Technical and Antiquarian Standpoint.* Stockholm: National Swedish Building Research, 1972. (Contains a section on roof maintenance problems)

Insall, Donald. *The Care of Old Buildings Today.* London: The Architectural Press, 1972. (Excellent guide to some problems and solutions for historic roofs)

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Lefer, Henry. "A Birds-eye View." *Progressive Architecture.* (Mar. 1977), pp. 88–92. (Article on contemporary sheet metal)

National Slate Association. *Slate Roofs.* Reprint of 1926 edition, now available from the Vermont Structural Slate Co., Inc., Fairhaven, VT 05743. (An excellent reference for the many designs and details of slate roofs)

Peterson, Charles E. "Iron in Early American Roofs." *The Smithsonian Journal of History* 3 (no. 3). Edited by Peter C. Welsh. Washington, D.C.: Smithsonian Institution, 1968, pp. 41–76.

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16 PRESERVATION BRIEFS

The Use of Substitute Materials on Historic Building Exteriors

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U.S. Department of the Interior
National Park Service
Cultural Resources
Heritage Preservation Services

The Secretary of the Interior's *Standards for Rehabilitation* require that "deteriorated architectural features be repaired rather than replaced, wherever possible. In the event that replacement is necessary, the new material should match the material being replaced in composition, design, color, texture, and other visual properties." Substitute materials should be used only on a limited basis and only when they will match the appearance and general properties of the historic material and will not damage the historic resource.

Introduction

When deteriorated, damaged, or lost features of a historic building need repair or replacement, it is almost always best to use historic materials. In limited circumstances substitute materials that imitate historic materials may be used if the appearance and properties of the historic materials can be matched closely and no damage to the remaining historic fabric will result.

Great care must be taken if substitute materials are used on the exteriors of historic buildings. Ultra-violet light, moisture penetration behind joints, and stresses caused by changing temperatures can greatly impair the performance of substitute materials over time. Only after consideration of all options, in consultation with qualified professionals, experienced fabricators and contractors, and development of carefully written specifications should this work be undertaken.

The practice of using substitute materials in architecture is not new, yet it continues to pose practical problems and to raise philosophical questions. On the practical level the inappropriate choice or improper installation of substitute materials can cause a radical change in a building's appearance and can cause extensive physical damage over time. On the more philosophical level, the wholesale use of substitute materials can raise questions concerning the integrity of historic buildings largely comprised of new materials. In both cases the integrity of the historic resource can be destroyed.

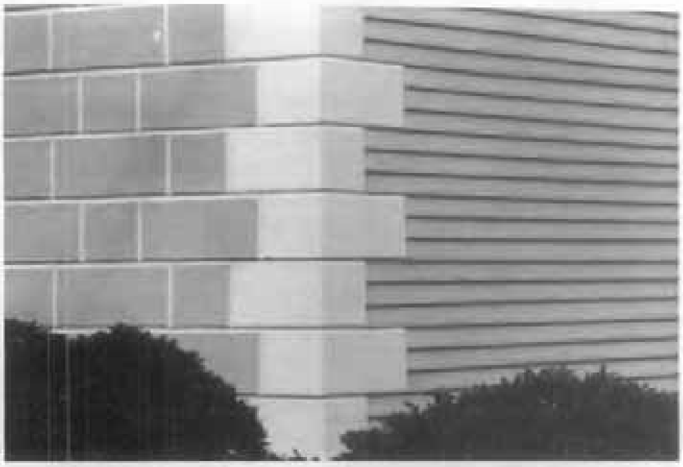
Some preservationists advocate that substitute materials should be avoided in all but the most limited cases. The fact is, however, that substitute materials are being used more frequently than ever in preservation projects, and in many cases with positive results. They can be cost-effective, can permit the accurate visual duplication of historic materials, and last a reasonable time. Growing evidence indicates that with proper planning, careful specifications and supervision, substitute materials can be used successfully in the process of restoring the visual appearance of historic resources.

This Brief provides general guidance on the use of substitute materials on the exteriors of historic buildings. While substitute materials are frequently used on interiors, these applications are not subject to weathering and moisture penetration, and will not be discussed in this Brief. Given the general nature of this publication, specifications for substitute materials are not provided. The guidance provided should not be used in place of consultations with qualified professionals. This Brief includes a discussion of when to use substitute materials, cautions regarding their expected performance, and descriptions of several substitute materials, their advantages and disadvantages. This review of materials is by no means comprehensive, and attitudes and findings will change as technology develops.

Historical Use of Substitute Materials

The tradition of using cheaper and more common materials in imitation of more expensive and less available materials is a long one. George Washington, for example, used wood painted with sand-impregnated paint at Mount Vernon to imitate cut ashlar stone. This technique along with scoring stucco into block patterns was fairly common in colonial America to imitate stone (see illus. 1, 2).

Molded or cast masonry substitutes, such as dry-tamp cast stone and poured concrete, became popular in place of quarried stone during the 19th century. These masonry units were fabricated locally, avoiding



Illus. 1. An early 18th-century technique for imitating carved or quarried stone was the use of sand-impregnated paint applied to wood. The facade stones and quoins are of wood. The Lindens (1754), Washington, D.C. Photo: Sharon C. Park, AIA.

Illus. 2. Stucco has for many centuries represented a number of building materials. Seen here is the ground floor of a Beaux Arts mansion, circa 1900, which represents a finely laid stone foundation wall executed in scored stucco. Photo: Sharon C. Park, AIA.

Illus. 3. Casting concrete to represent quarried stone was a popular late 19th-century technique seen in this circa 1910 mail-order house. While most components were delivered by rail, the foundations and exterior masonry were completed by local craftsmen. Photo: Sharon C. Park, AIA.

Illus. 4. The 19th-century also produced a variety of metal products used in imitation of other materials. In this case, the entire exterior of the Long Island Safety Deposit Company is cast-iron representing stone. Photo: Becket Logan, Friends of Cast Iron Architecture.

expensive quarrying and shipping costs, and were versatile in representing either ornately carved blocks, plain wall stones or rough cut textured surfaces. The end result depended on the type of patterned or textured mold used and was particularly popular in conjunction with mail order houses (see illus. 3). Later, panels of cementitious perma-stone or formstone and less expensive asphalt and sheet metal panels were used to imitate brick or stone.

Metal (cast, stamped, or brake-formed) was used for storefronts, canopies, railings, and other features, such as galvanized metal cornices substituting for wood or stone, stamped metal panels for Spanish clay roofing tiles, and cast-iron column capitals and even entire building fronts in imitation of building stone (see illus. no. 4).

Terra cotta, a molded fired clay product, was itself a substitute material and was very popular in the late 19th and early 20th centuries. It simulated the appearance of intricately carved stonework, which was expensive and time-consuming to produce. Terra cotta could be glazed to imitate a variety of natural stones, from brownstones to limestones, or could be colored for a polychrome effect.

Nineteenth century technology made a variety of materials readily available that not only were able to imitate more expensive materials but were also cheaper to fabricate and easier to use. Throughout the century, imitative materials continued to evolve. For example, ornamental window hoods were originally made of wood or carved stone. In an effort to find a cheaper substitute for carved stone and to speed fabrication time, cast stone, an early form of concrete, or cast-iron hoods often replaced stone. Toward the end of the century, even less expensive sheet metal hoods, imitating stone, also came into widespread use. All of these materials, stone, cast stone, cast-iron, and various pressed metals were in

Illus. 5. The four historic examples of various window hoods shown are: (a) stone; (b) cast stone; (c) cast-iron; and (d) sheet metal. The criteria for selecting substitute materials today (availability, quality, delivery dates, cost) are not much different from the past. Photo: Sharon C. Park, AIA.

production at the same time and were selected on the basis of the availability of materials and local craftsmanship, as well as durability and cost (see illus. 5). The criteria for selection today are not much different.

Many of the materials used historically to imitate other materials are still available. These are often referred to as the traditional materials: wood, cast stone, concrete, terra cotta and cast metals. In the last few decades, however, and partly as a result of the historic preservation movement, new families of synthetic materials, such as fiberglass, acrylic polymers, and epoxy resins, have been developed and are being used as substitute materials in construction. In some respects these newer products (often referred to as high tech materials) show great promise; in others, they are less satisfactory, since they are often difficult to integrate physically with the porous historic materials and may be too new to have established solid performance records.

When to Consider Using Substitute Materials in Preservation Projects

Because the overzealous use of substitute materials can greatly impair the historic character of a historic structure, all preservation options should be explored thoroughly before substitute materials are used. It is important to remember that the purpose of repairing damaged features and of replacing lost and irreparably damaged ones is both to match visually what was there and to cause no further deterioration. For these reasons it is not appropriate to cover up historic materials with synthetic materials that will alter the appearance, proportions and details of a historic building and that will conceal future deterioration (see illus. 6).

Some materials have been used successfully for the repair of damaged features such as epoxies for wood infilling, cementitious patching for sandstone repairs, or plastic stone for masonry repairs. Repairs are preferable to replacement whether or not the repairs are in kind or with a synthetic substitute material (see illus. 7).

In general, four circumstances warrant the consideration of substitute materials: 1) the unavailability of historic materials; 2) the unavailability of skilled craftsmen; 3) inherent flaws in the original materials; and 4) code-required changes (which in many cases can be extremely destructive of historic resources).

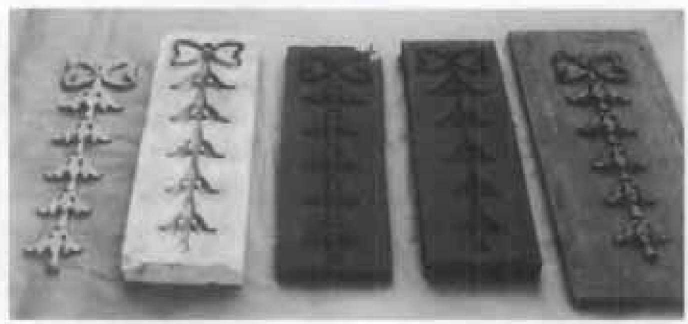
Cost may or may not be a determining factor in considering the use of substitute materials. Depending on the area of the country, the amount of material needed, and the projected life of less durable substitute materials, it may be cheaper in the long run to use the original material, even though it may be harder to find. Due to many early failures of substitute materials, some preservationist are looking abroad to find materials (especially stone) that match the historic materials in an effort to restore historic

Illus. 6. Substitute materials should never be considered as a cosmetic cover-up for they can cause great physical damage and can alter the appearance of historic buildings. For example, a fiberglass coating was used at Ranchos de Taos, NM, in place of the historic adobe coating which had deteriorated. The waterproof coating sealed moisture in the walls and caused the spalling shown. It was subsequently removed and the walls were properly repaired with adobe. Photo: Lee H. Nelson, FAIA.

Illus. 7. Whenever possible, historic materials should be repaired rather than replaced. Epoxy, a synthetic resin, has been used to repair the wood window frame and sill at the Auditors Building (1878) Washington, DC. The cured resin is white in this photo and will be primed and painted. Photo: Lee H. Nelson, FAIA.

Illus. 8. Even when materials are not locally available, it may be possible and cost effective to find sources elsewhere. For example, the local sandstone was no longer available for the restoration of the New York Shakespeare Festival Public Theater. The deteriorated sandstone window hoods, were replaced with stone from Germany that closely matched the color and texture of the historic sandstone. Photo: John G. Waite.

Illus. 9. Simple solutions should not be overlooked when materials are no longer available. In the case of the Morse-Libby Mansion (1859), Portland, ME, the deteriorated brownstone porch beam was replaced with a carved wooden beam painted with sand impregnated paint. Photo: Stephen Sewall.



Illus. 10. The use of substitute materials is not necessarily cheaper or easier than using the original materials. The complex process of fabricating the polyester bronze reproduction pieces of the gilded wood molding for the clockcase at Independence Hall required talented artisans and substantial mold-making time. From left to right is the final molded polyester bronze detail; the plaster casting mold; the positive and negative interim neoprene rubber molds; and the expertly carved wooden master. Photo: Courtesy of Independence National Historical Park.

buildings accurately and to avoid many of the uncertainties that come with the use of substitute materials.

1. The unavailability of the historic material. The most common reason for considering substitute materials is the difficulty in finding a good match for the historic material (particularly a problem for masonry materials where the color and texture are derived from the material itself). This may be due to the actual unavailability of the material or to protracted delivery dates. For example, the local quarry that supplied the sandstone for a building may no longer be in operation. All efforts should be made to locate another quarry that could supply a satisfactory match (see illus. 8). If this approach fails, substitute materials such as dry-tamp cast stone or textured precast concrete may be a suitable substitute if care is taken to ensure that the detail, color and texture of the original stone are matched. In some cases, it may be possible to use a sand-impregnated paint on wood as a replacement section, achieved using readily available traditional materials, conventional tools and work skills. (see illus. 9). Simple solutions should not be overlooked.

2. The unavailability of historic craft techniques and lack of skilled artisans. These two reasons complicate any preservation or rehabilitation project. This is particularly true for intricate ornamental work, such as carved wood, carved stone, wrought iron, cast iron, or molded terra cotta. However, a number of stone and wood cutters now employ sophisticated carving machines, some even computerized. It is also possible to cast substitute replacement pieces using

Illus. 11. The unavailability of historic craft techniques is another reason to consider substitute materials. The original first floor cast iron front of the Grand Opera House, Wilmington, DE, was missing; the expeditious reproduction in cast aluminum was possible because artisans working in this medium were available. Photo: John G. Waite.

aluminum, cast stone, fiberglass, polymer concretes, glass fiber reinforced concretes and terra cotta. Mold making and casting takes skill and craftsmen who can undertake this work are available. (see illus. 10, 11). Efforts should always be made, prior to replacement, to seek out artisans who might be able to repair ornamental elements and thereby save the historic features in place.

3. Poor original building materials. Some historic building materials were of inherently poor quality or their modern counterparts are inferior. In addition, some materials were naturally incompatible with other materials on the building, causing staining or galvanic corrosion. Examples of poor quality materials were the very soft sandstones which eroded quickly. An example of poor quality modern replacement material is the tin coated steel roofing which is much less durable than the historic tin or terne iron which is no longer available. In some cases, more durable natural stones or precast concrete might be available as substitutes for the soft stones and modern terne-coated stainless steel or lead-coated copper might produce a more durable yet visually compatible replacement roofing (see illus. 12).

4. Code-related changes. Sometimes referred to as life and safety codes, building codes often require changes to historic buildings. Many cities in earthquake zones, for example, have laws requiring that overhanging masonry parapets and cornices, or freestanding urns or finials be securely reanchored to new structural frames or be removed completely. In some cases, it may be acceptable to replace these heavy historic elements with light replicas (see illus. 13). In other cases, the extent of historic fabric removed may be so great as to diminish the integrity of the resource. This could affect the significance of the structure and jeopardize National Register status. In addition, removal of repairable historic materials could result in loss of Federal tax credits for rehabilitation. Department of the Interior regulations make

Illus. 12. Substitute materials may be considered when the original materials have not performed well. For example, early sheet metals used for roofing, such as tinplate, were reasonably durable, but the modern equivalent, terne-coated steel, is subject to corrosion once the thin tin plating is damaged. Terne-coated stainless steel or lead-coated copper (shown here) are now used as substitutes. Photo: John G. Waite.

Illus. 13. Code-related changes are of concern in historic preservation projects because the integrity of the historic resource may be irretrievably affected. In the case of the Old San Francisco Mint, the fiberglass cornice was used to bring the building into seismic conformance. The original cornice was deteriorated, and the replacement (1982) was limited to the projecting pediment. The historic stone fascia was retained as were the stone columns. The limited replacement of deteriorated material did not jeopardize the integrity of the building. Photo: Walter M. Sontheimer.

clear that the Secretary of the Interior's Standards for Rehabilitation take precedence over other regulations and codes in determining whether a project is consistent with the historic character of the building undergoing rehabilitation.

Two secondary reasons for considering the use of substitute materials are their lighter weight and for some materials, a reduced need of maintenance. These reasons can become important if there is a need to keep dead loads to a minimum or if the feature being replaced is relatively inaccessible for routine maintenance.

Cautions and Concerns

In dealing with exterior features and materials, it must be remembered that moisture penetration, ultraviolet degradation, and differing thermal expansion and contraction rates of dissimilar materials make any repair or replacement problematic. To ensure that a repair or replacement will perform well over time, it is critical to understand fully the properties of both the original and the substitute materials, to install replacement materials correctly, to assess their impact on adjacent historic materials, and to have reasonable expectations of future performance.

Many high tech materials are too new to have been tested thoroughly. The differences in vapor permeability between some synthetic materials and the historic materials have in some cases caused unexpected further deterioration. It is therefore difficult to recommend substitute materials if the historic materials are still available. As previously mentioned, consideration should always be given first to using traditional materials and methods of repair or replacement before accepting unproven techniques, materials or applications.

Substitute materials must meet three basic criteria before being considered: they must be compatible with the historic materials in appearance; their physical properties must be similar to those of the historic materials, or be installed in a manner that tolerates differences; and they must meet certain basic performance expectations over an extended period of time.

Matching the Appearance of the Historic Materials

In order to provide an appearance that is compatible with the historic material, the new material should match the details and craftsmanship of the original as well as the color, surface texture, surface reflectivity and finish of the original material (see illus. 14). The closer an element is to the viewer, the more closely the material and craftsmanship must match the original.

Matching the color and surface texture of the historic material with a substitute material is normally difficult. To enhance the chances of a good match, it is advisable to clean a portion of the building where new materials are to be used. If pigments are to be added to the substitute material, a specialist should determine the formulation of the mix, the natural aggregates and the types of pigments to be used. As all exposed material is subject to ultra-violet degradation, if possible, samples of the new materials made during the early planning phases should be tested or allowed to weather over several seasons to test for color stability.

Fabricators should supply a sufficient number of samples to permit on-site comparison of color, texture, detailing, and other critical qualities (see illus. 15, 16). In situations where there are subtle variations in color and texture within the original materials, the

Illus. 14. The visual qualities of the historic feature must be matched when using substitute materials. In this illustration, the lighter weight mineral fiber cement shingles used to replace the deteriorated historic slate roof were detailed to match the color, size, shape and pattern of the original roofing and the historic snow birds were reattached. Photo: Sharon C. Park, AIA.

Illus. 15. Poor quality workmanship can be avoided. In this example, the crudely cast concrete entrance pier (shown) did not match the visual qualities of the remaining historic sandstone (not shown). The aggregate is too large and exposed; the casting is not crisp; the banded tooling edges are not articulated; and the color is too pale. Photo: Sharon C. Park, AIA.

Illus. 16. The good quality substitute materials shown here do match the historic sandstone in color, texture, tooling and surface details. Dry-tamp cast stone was used to match the red sandstone that was no longer available. The reconstructed first floor incorporated both historic and substitute materials. Sufficient molds were made to avoid the problem of detecting the substitutes by their uniformity. Photo: Sharon C. Park, AIA.

Illus. 18. Substitute materials must be properly installed to allow for expansion, contraction, and structural security. The new balustrade (a polymer concrete modified with glass fibers) at Carnegie Hall, New York City, was installed with steel structural supports to allow window-washing equipment to be suspended securely. In addition, the formulation of this predominantly epoxy material allowed for the natural expansion and contraction within the predesigned joints. Photo: Courtesy of MJM Studios.

Illus. 17. Care must be taken to ensure that the replacement materials will work within a predesigned system. At the Norris Museum, Yellowstone National Park, the 12-inch diameter log rafters, part of an intricate truss system, had rotted at the inner core from the exposed ends back to a depth of 48 inches. The exterior wooden shells remained intact. Fiberglass rods (left photo) and specially formulated structural epoxy were used to fill the cleaned out cores and a cast epoxy wafer end with all the detail of the original wood graining was laminated onto the log end (right photo). This treatment preserved the original feature with a combination of repair and replacement using substitute materials as part of a well thought out system. Photos: Courtesy of Harrison Goodall.

substitute materials should be similarly varied so that they are not conspicuous by their uniformity.

Substitute materials, notably the masonry ones, may be more water-absorbent than the historic material. If this is visually distracting, it may be appropriate to apply a protective vapor-permeable coating on the substitute material. However, these clear coatings tend to alter the reflectivity of the material, must be reapplied periodically, and may trap salts and moisture, which can in turn produce spalling. For these reasons, they are *not* recommended for use on historic materials.

Matching the Physical Properties

While substitute materials can closely match the appearance of historic ones, their physical properties may differ greatly. The chemical composition of the material (i.e., presence of acids, alkalines, salts, or metals) should be evaluated to ensure that the replacement materials will be compatible with the historic resource. Special care must therefore be taken to integrate and to anchor the new materials properly (see illus. 17). The thermal expansion and contraction coefficients of each adjacent material must be within tolerable limits. The function of joints must be understood and detailed either to eliminate moisture penetration or to allow vapor permeability. Materials that will cause galvanic corrosion or other chemical reactions must be isolated from one another.

To ensure proper attachment, surface preparation is critical. Deteriorated underlying material must be cleaned out. Non-corrosive anchoring devices or fasteners that are designed to carry the new material and to withstand wind, snow and other destructive elements should be used (see illus. 18). Properly chosen fasteners allow attached materials to expand and contract at their own rates. Caulking, flexible sealants or expansion joints between the historic material and the substitute material can absorb slight differences of movement. Since physical failures often result from poor anchorage or improper installation techniques, a structural engineer should be a member of any team undertaking major repairs.

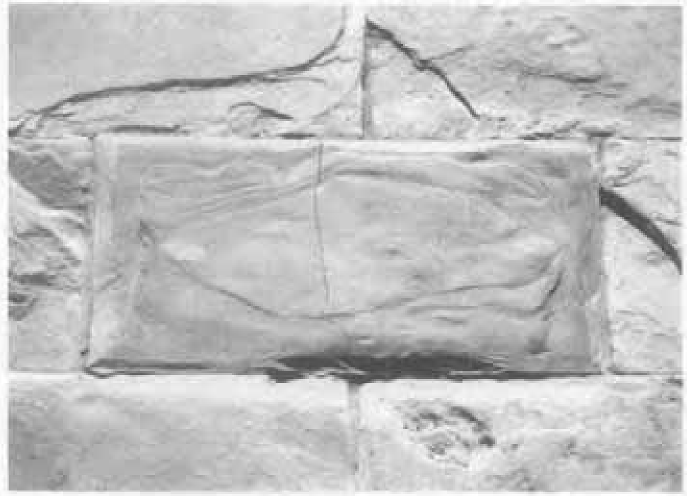
Some of the new high tech materials such as epoxies and polymers are much stronger than historic materials and generally impermeable to moisture. These differences can cause serious problems unless the new materials are modified to match the expansion and contraction properties of adjacent historic materials more closely, or unless the new materials are isolated from the historic ones altogether. When stronger or vapor impermeable new materials are used alongside historic ones, stresses from trapped moisture or differing expansion and contraction rates generally hasten deterioration of the weaker historic material. For this reason, a conservative approach to repair or replacement is recommended, one that uses more pliant materials rather than high-strength ones (see illus. 19). Since it is almost impossible for substitute materials to match the properties of historic materials perfectly, the new system incorporating new and historic materials should be designed so that if material failures occur, they occur within the new material rather than the historic material.

Performance Expectations

While a substitute material may appear to be acceptable at the time of installation, both its appearance and its performance may deteriorate rapidly. Some materials are so new that industry standards are not available, thus making it difficult to specify quality control in fabrication, or to predict maintenance requirements and long term performance. Where possible, projects involving substitute materials in similar circumstances should be examined. Material specifications outlining stability of color and texture; compressive or tensile strengths if appropriate; the acceptable range of thermal coefficients, and the durability of coatings and finishes should be included in the contract documents. Without these written documents, the owner may be left with little recourse if failure occurs (see illus. 20, 21).

The tight controls necessary to ensure long-term performance extend beyond having written performance standards and selecting materials that have a successful track record. It is important to select qualified fabricators and installers who know what they are doing and who can follow up if repairs are necessary. Installers and contractors unfamiliar with specific substitute materials and how they function in your local environmental conditions should be avoided.

The surfaces of substitute materials may need special care once installed. For example, chemical residues or mold release agents should be removed completely prior to installation, since they attract pollutants and cause the replacement materials to appear dirtier than the adjacent historic materials. Furthermore, substitute materials may require more frequent cleaning, special cleaning products and protection from impact by hanging window-cleaning scaffolding. Finally, it is critical that the substitute materials be identified as part of the historical record of the building so that proper care and maintenance of all the building materials continue to ensure the life of the historic resource.



Illus. 19. When the physical properties are not matched, particularly thermal expansion and contraction properties, great damage can occur. In this case, an extremely rigid epoxy replacement unit was installed in a historic masonry wall. Because the epoxy was not modified with fillers, it did not expand or contract systematically with the natural stones in the wall surrounding it. Pressure built up resulting in a vertical crack at the center of the unit, and spalled edges to every historic stone that was adjacent to the rigid unit. Photo: Walter M. Sontheimer.

Illus. 20. Long-term performance can be affected by where the substitute material is located. In this case, fiberglass was used as part of a storefront at street level. Due to the brittle nature of the material and the frequency of impact likely to occur at this location, an unsightly chip has resulted. Photo: Sharon C. Park, AIA.

Illus. 21. Change of color over time is one of the greatest problems of synthetic substitute materials used outdoors. Ultra-violet light can cause materials to change color over time; some will lighten and others will darken. In this photograph, the synthetic patching material to the sandstone banding to the left of the window has aged to a darker color. Photos: Sharon C. Park, AIA.

Illus. 22. A fiber reinforced polymer (fiberglass) cornice and precast concrete elements replaced deteriorated features on the 19th-century exterior. Photo: Sharon C. Park, AIA.

Choosing an Appropriate Substitute Material

Once all reasonable options for repair or replacement in kind have been exhausted, the choice among a wide variety of substitute materials currently on the market must be made (see illus. 22). The charts at the end of this Brief describe a number of such materials, many of them in the family of modified concretes which are gaining greater use. The charts do not include wood, stamped metal, mineral fiber cement shingles and some other traditional imitative materials, since their properties and performance are better known. Nor do the charts include vinyls or molded urethanes which are sometimes used as cosmetic claddings or as substitutes for wooden millwork. Because millwork is still readily available, it should be replaced in kind.

The charts describe the properties and uses of several materials finding greater use in historic preservation projects, and outline advantages and disadvantages of each. It should not be read as an endorsement of any of these materials, but serves as a reminder that numerous materials must be studied carefully before selecting the appropriate treatment. Included are three predominantly masonry materials (cast stone, precast concrete, and glass fiber reinforced concrete); two predominantly resinous materials (epoxy and glass fiber reinforced polymers also known as fiberglass), and cast aluminum which has been used as a substitute for various metals and woods.

Summary

Substitute materials—those products used to imitate historic materials—should be used only after all other options for repair and replacement in kind have been ruled out. Because there are so many unknowns regarding the long-term performance of substitute materials, their use should not be considered without a thorough investigation into the proposed materials, the fabricator, the installer, the availability of specifications, and the use of that material in a similar situation in a similar environment.

Substitute materials are normally used when the historic materials or craftsmanship are no longer available, if the original materials are of a poor quality or are causing damage to adjacent materials, or if there are specific code requirements that preclude the use of historic materials. Use of these materials should be limited, since replacement of historic materials on a large scale may jeopardize the integrity of a historic resource. Every means of repairing deteriorating historic materials or replacing them with identical materials should be examined *before* turning to substitute materials.

The importance of matching the appearance and physical properties of historic materials and, thus, of finding a successful long-term solution cannot be overstated. The successful solutions illustrated in this Brief were from historic preservation projects involving professional teams of architects, engineers, fabricators, and other specialists. Cost was not necessarily a factor, and all agreed that whenever possible, the historic materials should be used. When substitute materials were selected, the solutions were often expensive and were reached only after careful consideration of all options, and with the assistance of expert professionals.

FOLLOWING ARE DESCRIPTIONS OF VARIOUS SUBSTITUTE MATERIALS

PROs and CONs of VARIOUS SUBSTITUTE MATERIALS

Cast Aluminum

Material: Cast aluminum is a molten aluminum alloy cast in permanent (metal) molds or one-time sand molds which must be adjusted for shrinkage during the curing process. Color is from paint applied to primed aluminum or from a factory finished coating. Small sections can be bolted together to achieve intricate or sculptural details. Unit castings are also available for items such as column plinth blocks.

Application: Cast aluminum can be a substitute for cast-iron or other decorative elements. This would include grillwork, roof crestings, cornices, ornamental spandrels, storefront elements, columns, capitals, and column bases and plinth blocks. If not self-supporting, elements are generally screwed or bolted to a structural frame. As a result of galvanic corrosion problems with dissimilar metals, joint details are very important.

Close-up detail showing the crisp casting in aluminum of this 19th-century replica column and capital for a storefront. Photo: Sharon C. Park, AIA.

Advantages:
- light weight (1/2 of cast-iron)
- corrosion-resistant, non-combustible
- intricate castings possible
- easily assembled, good delivery time
- can be prepared for a variety of colors
- long life, durable, less brittle than cast iron

Disadvantages:
- lower structural strength than cast-iron
- difficult to prevent galvanic corrosion with other metals
- greater expansion and contraction than cast-iron; requires gaskets or caulked joints
- difficult to keep paint on aluminum

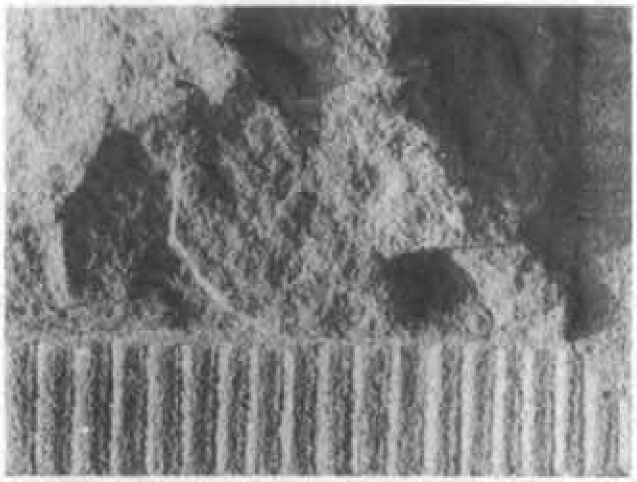
Checklist:
- Can existing be repaired or replaced in-kind?
- How is cast aluminum to be attached?
- Have full-size details been developed for each piece to be cast?
- How are expansion joints detailed?
- Will there be a galvanic corrosion problem?
- Have factory finishes been protected during installation?
- Are fabricators/installers experienced?

The new cast aluminum storefront replaced the lost 19th-century cast-iron original. Photo: Sharon C. Park, AIA.

Cast Stone *(dry-tamped)*:

Material: Cast stone is an almost-dry cement, lime and aggregate mixture which is dry-tamped into a mold to produce a dense stone-like unit. Confusion arises in the building industry as many refer to high quality precast concrete as cast stone. In fact, while it is a form of precast concrete, the dry-tamp fabrication method produces an outer surface ressembling a stone surface. The inner core can be either dry-tamped or poured full of concrete. Reinforcing bars and anchorage devices can be installed during fabrication.

Application: Cast stone is often the most visually similar material as a replacement for unveined deteriorated stone, such as brownstone or sandstone, or terra cotta in imitation of stone. It is used both for surface wall stones and for ornamental features such as window and door surrounds, voussoirs, brackets and hoods. Rubber-like molds can be taken of good stones on site or made up at the factory from shop drawings.



Dry-tamped cast stone can reproduce the sandy texture of some natural stones. Photo: Sharon C. Park, AIA.

Advantages:
- replicates stone texture with good molds (which can come from extant stone) and fabrication
- expansion/contraction similar to stone
- minimal shrinkage of material
- anchors and reinforcing bars can be built in
- material is fire-rated
- range of color available
- vapor permeable

Disadvantages:
- heavy units may require additional anchorage
- color can fade in sunlight
- may be more absorbent than natural stone
- replacement stones are obvious if too few models and molds are made

Checklist:
- Are the original or similar materials available?
- How are units to be installed and anchored?
- Have performance standards been developed to ensure color stability?
- Have large samples been delivered to site for color, finish and absorption testing?
- Has mortar been matched to adjacent historic mortar to achieve a good color/tooling match?
- Are fabricators/installers experienced?

Glass Fiber Reinforced Concretes (GFRC)

Material: Glass fiber reinforced concretes are lightweight concrete compounds modified with additives and reinforced with glass fibers. They are generally fabricated as thin shelled panels and applied to a separate structural frame or anchorage system. The GFRC is most commonly sprayed into forms although it can be poured. The glass must be alkaline resistant to avoid deteriorating effects caused by the cement mix. The color is derived from the natural aggregates and if necessary a small percentage of added pigments.

Application: Glass fiber reinforced concretes are used in place of features originally made of stone, terra cotta, metal or wood, such as cornices, projecting window and door trims, brackets, finials, or wall murals. As a molded product it can be produced in long sections of repetitive designs or as sculptural elements. Because of its low shrinkage, it can be produced from molds taken directly from the building. It is installed with a separate non-corrosive anchorage system. As a predominantly cementitious material, it is vapor permeable.

This glass fiber reinforced concrete sculptural wall panel will replace the seriously damaged resin and plaster original. A finely textured surface was achieved by spraying the GFRC mix into molds that were created from the historic panel and resculpted based on historic photographs. Photo: Courtesy of MJM Studios.

Advantages:
- lightweight, easily installed
- good molding ability, crisp detail possible
- weather resistant
- can be left uncoated or else painted
- little shrinkage during fabrication
- molds made directly from historic features
- cements generally breathable
- material is fire-rated

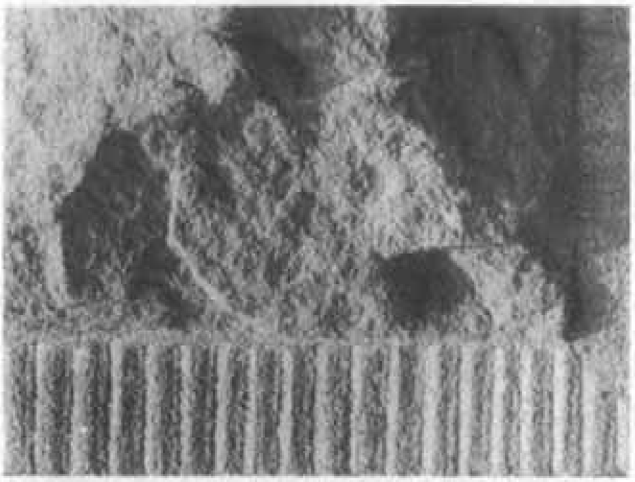
Disadvantages:
- non-loadbearing use only
- generally requires separate anchorage system
- large panels must be reinforced
- color additives may fade with sunlight
- joints must be properly detailed
- may have different absorption rate than adjacent historic material

Checklist:
- Are the original materials and craftsmanship still available?
- Have samples been inspected on the site to ensure detail/texture match?
- Has anchorage system been properly designed?
- Have performance standards been developed?
- Are fabricators/installers experienced?

Cast Stone *(dry-tamped)*:

Material: Cast stone is an almost-dry cement, lime and aggregate mixture which is dry-tamped into a mold to produce a dense stone-like unit. Confusion arises in the building industry as many refer to high quality precast concrete as cast stone. In fact, while it is a form of precast concrete, the dry-tamp fabrication method produces an outer surface ressembling a stone surface. The inner core can be either dry-tamped or poured full of concrete. Reinforcing bars and anchorage devices can be installed during fabrication.

Application: Cast stone is often the most visually similar material as a replacement for unveined deteriorated stone, such as brownstone or sandstone, or terra cotta in imitation of stone. It is used both for surface wall stones and for ornamental features such as window and door surrounds, voussoirs, brackets and hoods. Rubber-like molds can be taken of good stones on site or made up at the factory from shop drawings.



Dry-tamped cast stone can reproduce the sandy texture of some natural stones. Photo: Sharon C. Park, AIA.

Advantages:
- replicates stone texture with good molds (which can come from extant stone) and fabrication
- expansion/contraction similar to stone
- minimal shrinkage of material
- anchors and reinforcing bars can be built in
- material is fire-rated
- range of color available
- vapor permeable

Disadvantages:
- heavy units may require additional anchorage
- color can fade in sunlight
- may be more absorbent than natural stone
- replacement stones are obvious if too few models and molds are made

Checklist:
- Are the original or similar materials available?
- How are units to be installed and anchored?
- Have performance standards been developed to ensure color stability?
- Have large samples been delivered to site for color, finish and absorption testing?
- Has mortar been matched to adjacent historic mortar to achieve a good color/tooling match?
- Are fabricators/installers experienced?

Glass Fiber Reinforced Concretes (GFRC)

Material: Glass fiber reinforced concretes are lightweight concrete compounds modified with additives and reinforced with glass fibers. They are generally fabricated as thin shelled panels and applied to a separate structural frame or anchorage system. The GFRC is most commonly sprayed into forms although it can be poured. The glass must be alkaline resistant to avoid deteriorating effects caused by the cement mix. The color is derived from the natural aggregates and if necessary a small percentage of added pigments.

Application: Glass fiber reinforced concretes are used in place of features originally made of stone, terra cotta, metal or wood, such as cornices, projecting window and door trims, brackets, finials, or wall murals. As a molded product it can be produced in long sections of repetitive designs or as sculptural elements. Because of its low shrinkage, it can be produced from molds taken directly from the building. It is installed with a separate non-corrosive anchorage system. As a predominantly cementitious material, it is vapor permeable.

This glass fiber reinforced concrete sculptural wall panel will replace the seriously damaged resin and plaster original. A finely textured surface was achieved by spraying the GFRC mix into molds that were created from the historic panel and resculpted based on historic photographs. Photo: Courtesy of MJM Studios.

Advantages:
- lightweight, easily installed
- good molding ability, crisp detail possible
- weather resistant
- can be left uncoated or else painted
- little shrinkage during fabrication
- molds made directly from historic features
- cements generally breathable
- material is fire-rated

Disadvantages:
- non-loadbearing use only
- generally requires separate anchorage system
- large panels must be reinforced
- color additives may fade with sunlight
- joints must be properly detailed
- may have different absorption rate than adjacent historic material

Checklist:
- Are the original materials and craftsmanship still available?
- Have samples been inspected on the site to ensure detail/texture match?
- Has anchorage system been properly designed?
- Have performance standards been developed?
- Are fabricators/installers experienced?

Epoxies *(Epoxy Concretes, Polymer Concretes)*:

Material: Epoxy is a resinous two-part thermo-setting material used as a consolidant, an adhesive, a patching compound, and as a molding resin. It can repair damaged material or recreate lost features. The resins which are poured into molds are usually mixed with fillers such as sand, or glass spheres, to lighten the mix and modify their expansion/contraction properties. When mixed with aggregates, such as sand or stone chips, they are often called epoxy concrete or polymer concrete, which is a misnomer as there are no cementitious materials contained within the mix. Epoxies are vapor impermeable, which makes detailing of the new elements extremely important so as to avoid trapping moisture behind the replacement material. It can be used with wood, stone, terra cotta, and various metals.

Application: Epoxy is one of the most versatile of the new materials. It can be used to bind together broken fragments of terra cotta; to build up or infill missing sections of ornamental metal; or to cast missing elements of wooden ornaments. Small cast elements can be attached to existing materials or entire new features can be cast. The resins are poured into molds and due to the rapid setting of the material and the need to avoid cracking, the molded units are generally small or hollow inside. Multiple molds can be combined for larger elements. With special rods, the epoxies can be structurally reinforced. Examples of epoxy replacement pieces include: finials, sculptural details, small column capitals, and medallions.

This replica column capital was made using epoxy resins poured into a mold taken from the building. The historic wooden column shaft was repaired during the restoration. Photo: Courtesy Dell Corporation.

Advantages:
- can be used for repair/replacement
- lightweight, easily installed
- good casting ability; molds can be taken from building
- material can be sanded and carved.
- color and ultra-violet screening can be added; takes paint well
- durable, rot and fungus resistant

Disadvantages:
- materials are flammable and generate heat as they cure and may be toxic when burned
- toxic materials require special protection for operator and adequate ventilation while curing
- material may be subject to ultra-violet deterioration unless coated or filters added
- rigidity of material often must be modified with fillers to match expansion coefficients
- vapor impermeable

Checklist:
- Are historic materials available for molds, or for splicing-in as a repair option?
- Has the epoxy resin been formulated within the expansion/contraction coefficients of adjacent materials?
- Have samples been matched for color/finish?
- Are fabricators/installers experienced?
- Is there a sound sub-strate of material to avoid deterioration behind new material?
- Are there performance standards?

Columns were repaired and a capital was replaced in epoxy on this 19th-century 2-story porch. Photo: Dell Corporation

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15 PRESERVATION BRIEFS

Preservation of Historic Concrete

Paul Gaudette and Deborah Slaton

National Park Service
U.S. Department of the Interior

Heritage Preservation Services

Introduction to Historic Concrete

Concrete is an extraordinarily versatile building material used for utilitarian, ornamental, and monumental structures since ancient times. Composed of a mixture of sand, gravel, crushed stone, or other coarse material, bound together with lime or cement, concrete undergoes a chemical reaction and hardens when water is added. Inserting reinforcement adds tensile strength to structural concrete elements. The use of reinforcement contributes significantly to the range and size of building and structure types that can be constructed with concrete.

While early twentieth century proponents of modern concrete often considered it to be permanent, it is, like all materials, subject to deterioration. This Brief provides an overview of the history of concrete and its popularization in the United States, surveys the principal causes and modes of concrete deterioration, and outlines approaches to repair and protection that are appropriate to historic concrete. In the context of this Brief, historic concrete is considered to be concrete used in construction of structures of historical, architectural, or engineering interest, whether those structures are old or relatively new.

Brief History of Use and Manufacture

The ancient Romans found that a mixture of lime putty and pozzolana, a fine volcanic ash, would harden under water. The resulting hydraulic cement became a major feature of Roman building practice, and was used in many buildings and engineering projects such as bridges and aqueducts. Concrete technology was kept alive during the Middle Ages in Spain and Africa. The Spanish introduced a form of concrete to the New World in the first decades of the sixteenth century, referred to as "tapia" or "tabby." This material, a mixture of lime, sand, and shell or stone aggregate mixed with water, was placed between wooden forms, tamped, and allowed to dry in successive layers. Tabby was later used by the English settlers in the coastal southeastern United States.

The early history of concrete was fragmented, with developments in materials and construction techniques occurring on different continents and in various countries. In the United States, concrete was slow in achieving widespread acceptance in building construction and did not begin to gain popularity until the late nineteenth century. It was more readily accepted for use in transportation and infrastructure systems.

The Erie Canal in New York is an example of the early use of concrete in transportation in the United States. The natural hydraulic cement used in the canal construction was processed from a deposit of limestone found in 1818 near Chittenango, southeast of Syracuse. The use of concrete in residential construction was

Figure 1. The Sebastopol House in Seguin, Texas, is an 1856 Greek Revival-style house constructed of lime concrete. Lime concrete or "limecrete" was a popular construction material, as it could be made inexpensively from local materials. By 1900, the town had approximately ninety limecrete structures, twenty of which remain. Photo: Texas Parks and Wildlife Department.

Figure 2. Chatterton House was the home of the post trader at Fort Fred Steel in Wyoming, one of several forts established in the 1860s to protect the Union Pacific Railroad. The walls of the post trader's house were built using stone aggregate and lime, without cement. The use of this material presents special preservation challenges.

publicized in the second edition of Orson S. Fowler's *A Home for All* (1853) which described the advantages of "gravel wall" construction to a wide audience. The town of Seguin, Texas, thirty-five miles east of San Antonio, already had a number of concrete buildings by the 1850s and came to be called "The Mother of Concrete Cities," with approximately ninety concrete buildings made from local "lime water" and gravel (Fig. 1).

Impressed by the economic advantages of poured gravel wall or "lime-grout" construction, the Quartermaster General's Office of the War Department embarked on a campaign to improve the quality of building for frontier military posts. As a result, lime-grout structures were constructed at several western posts soon after the Civil War, including Fort Fred Steele and Fort Laramie, both in Wyoming (Fig. 2). By the 1880s, sufficient experience had been gained with unreinforced concrete to permit construction of much larger buildings. A notable example from this period is the Ponce de Leon Hotel in St. Augustine, Florida.

Extensive construction in concrete also occurred through the system of coastal fortifications commissioned by the federal government in the 1890s for the Atlantic, Pacific, and Gulf coasts. Unlike most concrete construction to that time, the special requirements of coastal fortifications called for concrete walls as much as 20 feet thick, often at sites that were difficult to access. Major structures in the coastal defenses of the 1890s were built of mass concrete with no internal reinforcing, a practice that was replaced by the use of reinforcing bars in fortifications constructed after about 1905.

The use of reinforced concrete in the United States dates from 1860, when S.T. Fowler obtained a patent for a reinforced concrete wall. In the early 1870s, William E. Ward built his own house in Port Chester, New York, using concrete reinforced with iron rods for all structural elements. Despite these developments, such construction remained a novelty until after 1880, when innovations introduced by Ernest L. Ransome made the use of reinforced concrete more practicable. Ransome made many contributions to the development of concrete construction technology, including the use of twisted reinforcing bars to improve bond between the concrete and the steel, which he patented in 1884. Two years later, Ransome introduced the rotary kiln to United States cement production. The new kiln had greater capacity and burned more thoroughly and uniformly, allowing development of a less expensive, more uniform, and more reliable manufactured cement. Improvements in concrete production initiated by Ransom led to a much greater acceptance of concrete after 1900.

The Lincoln Highway Association, incorporated in 1913, promoted the use of concrete in construction of a coast-to-coast roadway system. The goal of the Lincoln Highway Association and highway advocate Henry B. Joy was to educate the country in the need for good roads made of concrete, with an improved Lincoln

Figure 3. The Lincoln Highway Association promoted construction of a high quality continuous hard surface roadway across the country. The Boys Scouts of America installed concrete road markers along the Lincoln Highway in 1928.

Figure 4. The highly ornamental concrete panels on the exterior facade of the Baha'i House of Worship in Wilmette, Illinois, illustrate the work of fabricator John J. Earley, known as "the man who made concrete beautiful."

Figure 5. Following World War II, architects and engineers took advantage of improvements in concrete production, quality control, and advances in precast concrete to design structures such as the Police Headquarters building in Philadelphia, Pennsylvania, constructed in 1961. Photo: Courtesy of the Philadelphia Police Department.

Figure 6. The Bailey Magnet School in Jackson, Mississippi, was designed as the Jackson Junior High School by the firm of N.W. Overstreet & Town in 1936. The streamlined building exemplifies the applicability of concrete to creating a modern architectural aesthetic. Photo: Bill Burris, Burris/Wagnon Architects, P.A.

Figure 7. Detailed bas reliefs as well as sculptures, such as this lion at the Bailey Magnet School, could be used as ornamentation on concrete buildings. Sculptural concrete elements were typically cast in molds.

Highway as an example. Concrete "seedling miles" were constructed in remote areas to emphasize the superiority of concrete over unimproved dirt. The Association believed that as people learned about concrete, they would press the government to construct good roads throughout their states. Americans' enthusiasm for good roads led to the involvement of the federal government in road-building and the creation of numbered U.S. routes in the 1920s (Fig. 3).

During the early twentieth century, Ernest Ransome in Beverly, Massachusetts, Albert Kahn in Detroit, and Richard E. Schmidt in Chicago, promoted concrete for use in "Factory Style" utilitarian buildings with an exposed concrete frame infilled with expanses of glass. Thomas Edison's cast-in-place reinforced concrete homes in Union Township, New Jersey (1908), proclaimed a similarly functional emphasis in residential construction. From the 1920s onward, concrete began to be used with spectacular design results: examples include John J. Earley's Meridian Hill Park in Washington, D.C.; Louis Bourgeois' exuberant, graceful Baha'i Temple in Wilmette, Illinois (1920–1953), for which Earley fabricated the concrete (Fig. 4); and Frank Lloyd Wright's Fallingwater near Bear Run, Pennsylvania (1934). Continuing improvements in quality control and development of innovative fabrication processes, such as the Shockbeton method for precast concrete, provided increasing opportunities for architects and engineers. Wright's Guggenheim Museum in New York City (1959); Geddes Brecher Qualls & Cunningham's Police Headquarters building in Philadelphia, Pennsylvania (1961); and Eero Saarinen's soaring terminal building at Dulles International Airport outside Washington, D.C., and the TWA terminal at Kennedy Airport in New York (1962), exemplify the masterful use of concrete achieved in the modern era (Fig. 5).

Throughout the twentieth century, a wide range of architectural and engineering structures were built using concrete as a practical and cost-effective choice—and concrete also became valued for its aesthetic qualities. Cast in place and precast concrete were readily adapted to the Streamlined Moderne style, as exemplified by the Bailey Magnet School in Jackson, Mississippi, designed as the Jackson Junior High School by N.W. Overstreet & Town in 1936 (Figs. 6 and 7). The school is one of many concrete buildings designed and constructed under the auspices of the Public Works Administration. Recreational structures and landscape features also utilized the structural range and unique character of exposed concrete to advantage, as seen in Chicago's Lincoln Park Chess Pavilion, designed by Morris Webster in 1956 (Fig. 8), and the Ira C. Keller Fountain in Portland Oregon, designed by Lawrence Halprin in 1969 (Fig. 9). Concrete was also popular for building interiors, with ornamental features and exposed structural elements recognized as part of the design aesthetic (See Figs. 10 and 11 in sidebar).

Historic Interiors

The expanded use of concrete provided new opportunities to create dramatic spaces and ornate architectural detail on the interiors of buildings, at a significant cost savings over traditional construction practices. The architectural design of the Berkeley City Club in Berkeley, California, expressed Moorish and Gothic elements in concrete on the interior of the building (Fig. 10). Used as a woman's social club, the building was designed by noted California architect Julia Morgan and constructed in 1929. The vaulted ceilings, columns, and ornamental capitals of the lobby and the ornamental arches and beamed ceiling of the "plunge" are all constructed of concrete.

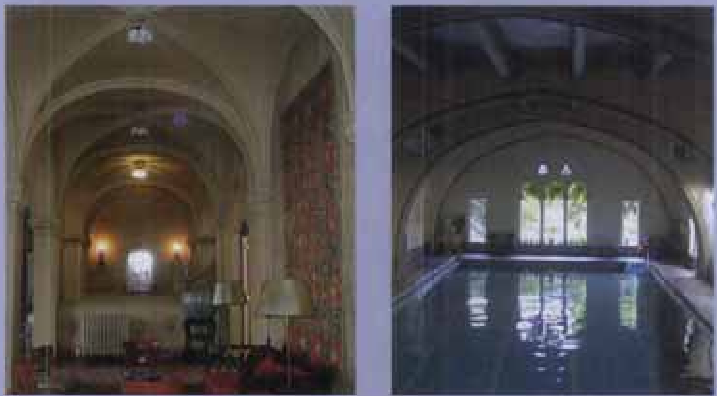

Figure 10. The Berkeley City Club has significant interior spaces and features of concrete construction, including the lobby and pool. Photos: Una Gilmartin (left) and Brian Kehoe (right), Wiss, Janney, Elstner Associates, Inc.

The historic character of a building's interior can also be conveyed in a more utilitarian manner in terms of concrete features and finishes (Fig. 11). The exposed concrete structure—columns, capitals, and drop panels—is an integral part of the character of this old commercial building in Minneapolis. In concrete warehouse and factory buildings of the early twentieth century, exposed concrete columns and formboard finish concrete slab ceilings are common features as seen in this warehouse, now converted for use as a parking garage and shops.

Figure 11. Whether in a circa 1925 office (left) or in a parking garage and retail facility (right), exposed concrete structures help characterize these building interiors. Photo: Minnesota Historical Society (left).

Concrete Characteristics

Concrete is composed of fine (sand) and coarse (crushed stone or gravel) aggregates and paste made of portland cement and water. The predominant material in terms of bulk is the aggregate. Portland cement is the binder most commonly used in modern concrete. It is commercially manufactured by blending limestone or chalk with clays that contain alumina, silica, lime, iron oxide and magnesia, and heating the compounds together to high temperatures. The hydration process that occurs between the portland cement and water results in formation of an alkali paste that surrounds and binds the aggregate together as a solid mass.

The quality of the concrete is dependent on the ratio of water to the binder; binder content; sound, durable, and well-graded aggregates; compaction during placement; and proper curing. The amount of water used in the mix affects the concrete permeability and strength. The use of excess water beyond that required in the hydration process results in more permeable concrete, which is more susceptible to weathering and deterioration. Admixtures are commonly added to concrete to adjust concrete properties such as setting or hardening time, requirements for water, workability, and other characteristics. For example, the advent of air entraining agents in the 1930s provided enhanced durability for concrete.

During the twentieth century, there was a steady rise in the strength of ordinary concrete as chemical processes became better understood and quality control measures improved. In addition, the need to protect embedded reinforcement against corrosion was acknowledged. Requirements for concrete cover over reinforcing steel, increased cement content, decreased water-cement ratio, and air entrainment all contributed to greater concrete strength and improved durability.

Mechanisms and Modes of Deterioration

Causes of Deterioration

Concrete deterioration occurs primarily because of corrosion of the embedded steel, degradation of the concrete itself, use of improper techniques or materials in construction, or structural problems. The causes of concrete deterioration must be understood in order to select an appropriate repair and protection system.

While reinforcing steel has played a pivotal role in expanding the applications of concrete in twentieth century architecture, corrosion of this steel has also caused deterioration in many historic structures. Reinforcing steel embedded in the concrete is normally surrounded by a passivating oxide layer that, when present, protects the steel from corrosion and aids in bonding the steel and concrete. When the concrete's normal alkaline environment (above a pH of 10) is compromised and the steel is exposed to water, water vapor, or high relative humidity, corrosion of the steel reinforcing takes place. A reduction in alkalinity results from carbonation, a process that occurs when the carbon dioxide in the atmosphere reacts with calcium hydroxide and moisture in the concrete. Carbonation starts at the concrete's exposed surface but may extend to the reinforcing steel over time. When carbonation reaches the metal reinforcement, the concrete no longer protects the steel from corrosion.

Corrosion of embedded reinforcing steel may be initiated and accelerated if calcium chloride was added to the concrete as a set accelerator during original construction to promote more rapid curing. It may also take place if the concrete is later exposed to deicing salts, as may occur during the winter in northern climates. Seawater or other marine environments can also provide large amounts of chloride, either from inadequately washed original aggregate or from exposure of the concrete to seawater.

Figure 8. The Chess Pavilion in Chicago's Lincoln Park was designed by architect Morris Webster and constructed in 1956. The pavilion is a distinctive landscape feature, with its reinforced concrete cantilevered slab that provides cover for chess players.

Figure 9. The Ira C. Keller Fountain in Portland, Oregon, was designed by Lawrence Halprin and constructed in 1969. The fountain is constructed primarily of concrete pillars with formboard textures and surrounding elements, patterned with geometric lines, which facilitate the path of water. Photo: Anita Washko, Wiss, Janney, Elstner Associates, Inc.

Corrosion-related damage to reinforced concrete is the result of rust, a product of the corrosion process of steel, which expands and thus requires more space in the concrete than the steel did at the time of installation. This change in volume of the steel results in expansive forces, which cause cracking and spalling of the adjacent concrete (Fig. 12). Other signs of corrosion of embedded steel include delamination of the concrete (planar separations parallel to the surface) and rust staining (often a precursor to spalling) on the concrete near the steel.

Lack of proper maintenance of building elements such as roofs and drainage systems can contribute to water-related deterioration of the adjacent concrete, particularly when concrete is saturated with water and then exposed to freezing temperatures. As water within the concrete freezes, it expands and exerts forces on the adjacent concrete. Repeated freezing and thawing can result in the concrete cracking and delaminating. Such damage appears as surface degradation, including severe scaling and micro-cracking that extends into the concrete. The condition is most often observed near the surface of the concrete but can also eventually occur deep within the concrete. This type of deterioration is usually most severe at joints, architectural details, and other areas with more surface exposure to weather. In the second half of the twentieth century, concrete has utilized entrained air (the incorporation of microscopic air bubbles) to provide enhanced protection against damage due to cyclic freezing of saturated concrete.

The use of certain aggregates can also result in deterioration of the concrete. Alkali-aggregate reactions—in some cases alkali-silica reaction (ASR)—occur when alkalis normally present in cement react with certain aggregates, leading to the development of an expansive crystalline gel. When this gel is exposed to moisture, it expands and causes cracking of the aggregate and concrete matrix. Deleterious aggregates are typically found only in certain areas of the country and can be detected through analysis by an experienced petrographer. Low-alkali cements as well as fly ash are used today in new construction to prevent such reactions where this problem may occur.

Problems Specifically Encountered with Historic Concrete

Materials and workmanship used in the construction of historic concrete structures, particularly those built before the First World War, sometimes present potential sources of problems. For example, where the aggregate consisted of cinder from burned coal or crushed brick,

Figure 12. The concrete lighthouse at the Kilauea Point Light Station, Kilauea, Kauai, Hawaii, was constructed circa 1913. The concrete, which was a good quality, high strength mix for its day, is in good condition after almost one hundred years in service. Deterioration in the form of spalling related to corrosion of embedded reinforcing steel has occurred primarily in areas of higher ornamentation such as projecting bands and brackets (see close-up photo).

the concrete tends to be weak and porous because these aggregates absorb water. Some of these aggregates can be extremely susceptible to deterioration when exposed to moisture and cyclic freezing and thawing. Concrete was sometimes compromised by inclusion of seawater or beach sand that was not thoroughly washed with fresh water, a condition more common with coastal fortifications built prior to 1900. The sodium chloride present in seawater and beach sand accelerates the rate of corrosion of the reinforced concrete.

Another problem encountered with historic concrete is related to poor consolidation of the concrete during its placement in forms, or in molds in the case of precasting. This problem is especially prevalent in highly ornamental units. Early twentieth century concrete was often tamped or rodded into place, similar to techniques used in forming cast stone. Poorly consolidated concrete often contains voids ("bugholes" or "honeycombs"), which can reduce the protective concrete cover over the embedded reinforcing bars, entrap water, and, if sufficiently large and strategically numerous, reduce localized concrete strength. Vibration technology has improved over time and flowability agents are also used today to address this problem.

A common type of deterioration observed in concrete is the effect of weathering from exposure to wind, rain, snow, and salt water or spray. Weathering appears as erosion of the cement paste, a condition more prevalent in northern regions where precipitation can be highly acidic. This results in the exposure of the aggregate particles on the exposed concrete surface. Variations may occur in the aggregate exposure due to differential erosion or dissolution of exposed cement paste. Erosion can also be caused by the mechanical action of water channeled over concrete, such as by the lack of drip grooves in belt courses and sills, and by inadequate drainage. In addition, high-pressure water when used for cleaning can also erode the concrete surface.

In concrete structures built prior to the First World War, concrete was often placed into forms in relatively short vertical lifts due to limitations in lifting and pouring techniques available at the time. Joints between different concrete placements (often termed cold joints or lift lines) may sometimes be considered an important part of the character of a concrete element (Fig. 13). However, wide joints may permit water to infiltrate the concrete, resulting in more rapid paste erosion or freeze-thaw deterioration of adjacent concrete in cold climates.

In the early twentieth century, concrete was sometimes placed in several layers parallel to the exterior surface. A base concrete was first created with formwork and then a more cement rich mortar layer was applied to the exposed vertical face of the

Figure 13. Fort Casey on Admiralty Head, Fort Casey, Washington, was constructed in 1898. The lift lines from placement of concrete are clearly visible on the exterior walls and characterize the finished appearance.

base concrete. The higher cement content in the facing concrete provided a more water-resistant outer layer and finished surface. The application of a cement-rich top layer, referred to in some early concrete publications as "waterproofing," was also used on top surfaces of concrete walls, or as the top layer in sidewalks. With this type of concrete construction, deterioration can occur over time as a result of debonding between layers, and can proceed very rapidly once the protective cement-rich layer begins to break down.

It is common for historic concrete to have a highly variable appearance, including color and finish texture. Different levels of aggregate exposure due to paste erosion are often found in exposed aggregate concrete. This variability in the appearance of historic concrete increases the level of difficulty in assessing and repairing weathered concrete.

Signs of Distress and Deterioration

Characteristic signs of failure in concrete include cracking, spalling, staining, and deflection. Cracking occurs in most concrete but will vary in depth, width, direction, pattern, and location, and can be either active or dormant (inactive). Active cracks can widen, deepen, or migrate through the concrete, while dormant cracks remain relatively unchanged in size. Some dormant cracks, such as those caused by early age shrinkage of the concrete during curing, are not a structural concern but when left unrepaired, can provide convenient channels for moisture penetration and subsequent damage. Random surface cracks, also called map cracks due to their resemblance to lines on a map, are usually related to early-age shrinkage but may also indicate other types of deterioration such as alkali-silica reaction.

Structural cracks can be caused by temporary or continued overloads, uneven foundation settling, seismic forces, or original design inadequacies. Structural cracks are active if excessive loads are applied to a structure, if the overload is continuing, or if settlement is ongoing. These cracks are dormant if the temporary overloads have been removed or if differential settlement has stabilized. Thermally-induced cracks result from stresses produced by the expansion and contraction of the concrete during temperature changes. These cracks frequently occur at the ends or re-entrant corners of older concrete structures that were built without expansion joints to relieve such stress.

Spalling (the loss of surface material) is often associated with freezing and thawing as well as cracking and delamination of the concrete cover over embedded reinforcing steel. Spalling occurs when reinforcing bars corrode and the corrosion by-products expand, creating high stresses on the adjacent concrete, which cracks and is displaced. Spalling can also occur when water absorbed by the concrete freezes and thaws (Fig. 14). In addition, surface spalling or scaling may result from the improper finishing, forming, or other surface phenomena when water-rich cement paste (laitance) rises to the surface. The resulting weak material is vulnerable to spalling of thin layers, or scaling. In some cases, spalling of the concrete can diminish the load-carrying capacity of the structure.

Figures 14. Layers of architectural concrete that have debonded (spalled) from the surface were removed from a historic water tank during the investigation performed to assess existing conditions. Photos: Anita Washko, Wiss, Janney, Elstner Associates, Inc.

Deflection is the bending or sagging of structural beams, joists, or slabs, and can be an indication of deficiencies in the strength and structural soundness of concrete. This condition can be produced by overloading, corrosion of embedded reinforcing, or inadequate design or construction, such as use of low-strength concrete or undersized reinforcing bars.

Staining of the concrete surface can be related to soiling from atmospheric pollutants or other contaminants, dirt accumulation, and the presence of organic growth. However, stains can also indicate more serious underlying problems, such as corrosion of embedded reinforcing steel, improper previous surface treatments, alkali-aggregate reaction, or efflorescence, the deposition of soluble salts on the surface of the concrete as a result of water migration (Fig. 15).

Planning for Concrete Preservation

The significance of a historic concrete building or structure—including whether it is important for its architectural or engineering design, for its materials and construction techniques, or both—guides decision making about repair and, if needed, replacement methods. Determining the causes of deterioration is also central to the development of a conservation and repair plan. With historic concrete buildings, one of the more difficult challenges is allowing for sufficient time during the planning phase to analyze the concrete, develop mixes, and provide time for adequate aging of mock-ups for matching to the original concrete.

An understanding of the original construction techniques (cement characteristics, mix design, original intent of assembly, type of placement, precast versus cast in place, etc.) and previous repair work performed on the concrete is important in determining causes of existing deterioration and the susceptibility of the structure to potential other types of deterioration. For example, concrete placed in short lifts (individual concrete placements) or constructed in precast segments will have numerous joints that can provide entry points for water infiltration. Inappropriate prior repairs, such as installation of patches using an incompatible material, can affect the future performance of the concrete. Such prior repairs may require corrective work.

As with other preservation projects, three primary approaches are usually considered for historic concrete structures: ***maintenance, repair,*** or ***replacement***. Maintenance and repair best achieve the preservation goal of minimal intervention and the greatest retention of existing historic fabric. However, where elements of the building are severely deteriorated or where inherent problems with the material lead to ongoing failures, replacement may be necessary.

During planning, information is gathered through research, visual survey, inspection openings, and laboratory studies. The material should then be reviewed by professionals experienced in concrete deterioration to help evaluate the nature and causes of the concrete problems, to assess both the short-term and long-term effects of the deterioration, and to formulate proper repair approaches.

Condition Assessment

A condition assessment of a concrete building or structure should begin with a review of all available documents related to original construction and prior repairs. While plans and specifications for older concrete buildings are not always available, they can be an invaluable resource and every attempt should be made to find them. They may provide information on the composition of the concrete mix or on the type and location of reinforcing bars. If available, documents related to past repairs should also be reviewed to

Figure 15. Evidence of moisture movement through concrete is apparent in the form of mineral deposits on the concrete surface. Cyclic freezing and thawing of entrapped moisture, and corrosion of embedded reinforcement, have also contributed to deterioration of the concrete column on this fence at Crocker Field in Fitchburg, Massachusetts, designed by the Olmsted Brothers.

understand how the repairs were made and to help evaluate their anticipated performance and service life. Archival photographs can also provide a valuable source of information about original construction.

A visual condition survey will help identify and evaluate the extent, types, and patterns of distress and deterioration. The American Concrete Institute offers several useful guides on how to perform a visual condition survey of concrete. Generally, the condition assessment begins with an overall visual survey, followed by a close-up investigation of representative areas to obtain more detailed information about modes of deterioration.

A number of nondestructive testing methods can be used in the field to evaluate concealed conditions. Basic techniques include sounding with a hand-held hammer (or for horizontal surfaces, a chain) to help identify areas of delamination. More sophisticated techniques include impact-echo testing (Fig. 16), ground penetrating radar, pulse velocity, and other methods that characterize concrete thickness and locate voids or delaminations. Magnetic detection instruments are used to locate embedded reinforcing steel and can be calibrated to identify the size and depth of reinforcement. Corrosion measurements can be taken using copper-copper sulfate half-cell tests or linear polarization techniques to determine the probability or rate of active corrosion of the reinforcing steel.

To further evaluate the condition of the concrete, samples may be removed for laboratory study to determine material components and composition, and causes of deterioration. Samples need to be representative of existing conditions but should be taken from unobtrusive locations. Laboratory studies of the concrete may include petrographic evaluation following ASTM C856, *Practice for Petrographic Examination of Hardened Concrete*. Petrographic examination, consisting of microscopical studies performed by a geologist specializing in the evaluation of construction materials, is performed to determine air content, water-cement ratio, cement content, and general aggregate characteristics. Laboratory studies can also include chemical analyses to determine chloride content, sulfate content, and alkali levels of the concrete; identification of deleterious aggregates; and determination of depth of carbonation. Compressive strength studies can be conducted to evaluate the strength of the existing concrete and provide information for repair work. The laboratory studies provide a general identification of the original concrete's components and aggregates, and evidence of damage due to various mechanisms including cyclic freezing and thawing, alkali-aggregate reactivity, or sulfate attack. Information gathered through laboratory studies can also be used to help develop a mix design for the repair concrete.

Cleaning

As with other historic structures, concrete structures are cleaned for several reasons: to improve the appearance of the concrete, as a cyclical maintenance measure, or in preparation for repairs. Consideration should first be given to whether the historic concrete structure needs to be cleaned at all. If cleaning is required, then the gentlest system that will be effective should be selected.

Three primary methods are used for cleaning concrete: water methods, abrasive surface treatments, and chemical surface treatments. Low-pressure water (less than 200 psi) or steam cleaning can effectively remove surface soiling from sound concrete; however, care is required on fragile or deteriorated surfaces. In addition, water and steam methods are typically not effective in removing staining or severe soiling. Power washing with high-pressure water is sometimes used to clean or remove coatings from sound, high-strength concrete, but high-pressure water washing is generally damaging to and not appropriate for concrete on historic structures.

When used with proper controls and at very low pressures (typically 35 to 75 psi), microabrasive surface treatments using very fine particulates, such as dolomitic limestone powder, can sometimes clean effectively. However, microabrasive cleaning may alter the texture and surface reflectivity of concrete. Some concrete can be damaged even by fine particulates applied at very low pressures.

Figure 16. Impact echo testing is performed on a concrete structural slab to help determine depth of deterioration. In this method, a short pulse of energy is introduced into the structure and a transducer mounted on the impacted surface of the structure receives the reflected input waves or echoes. These waves are analyzed to help identify flaws and deterioration within the concrete.

Chemical surface treatments can clean effectively but may also alter the appearance of the concrete by bleaching the concrete, removing the paste, etching the aggregate, or otherwise altering the surface. Detergent cleaners or mild, diluted acid cleaners may be appropriate for removal of staining or severe soiling. Cleaning products that contain strong acids such as hydrochloric (muriatic) or hydrofluoric acid, which will damage concrete and are harmful to persons, animals, site features, and the environment, should not be used.

For any cleaning process, trial samples should be performed prior to full-scale implementation. The intent of the cleaning program should not be to return the structure to a like new appearance. Concrete can age gracefully, and as long as soiling is not severe or deleterious, many structures can still be appreciated without extensive cleaning.

Methods of Maintenance and Repair

The maintenance of historic concrete often is thought of in terms of appropriate cleaning to remove unattractive dirt or soiling materials. However, the implementation of an overall maintenance plan for a historic structure is the most effective way to help protect historic concrete. For examples, the lack of maintenance to roofs and drainage systems can promote water related damage to adjacent concrete features. The repeated use of deicing salts in winter climates can pit the surface of old concrete and also may promote decay in embedded steel reinforcements. Inadequate protection of concrete walls adjacent to driveways and parking areas can result in the need for repair work later on.

The maintenance of historic concrete involves the regular inspection of concrete to establish baseline conditions and identify needed repairs. Inspection tasks involve monitoring protection systems, including sealant joints, expansion joints, and protective coatings; reviewing existing conditions for development of distress such as cracking and delaminations; documenting conditions observed; and developing and implementing a cyclical repair program.

Sealants are an important part of maintenance of historic concrete structures. Elastomeric sealants, which have replaced traditional oil-resin based caulks for many applications, are used to seal cracks and joints to keep out moisture and reduce air infiltration. Sealants are commonly used at windows and door perimeters, at interfaces between concrete and other materials, and at attachments to or through walls or roofs, such as with lamps, signs, or exterior plumbing fixtures.

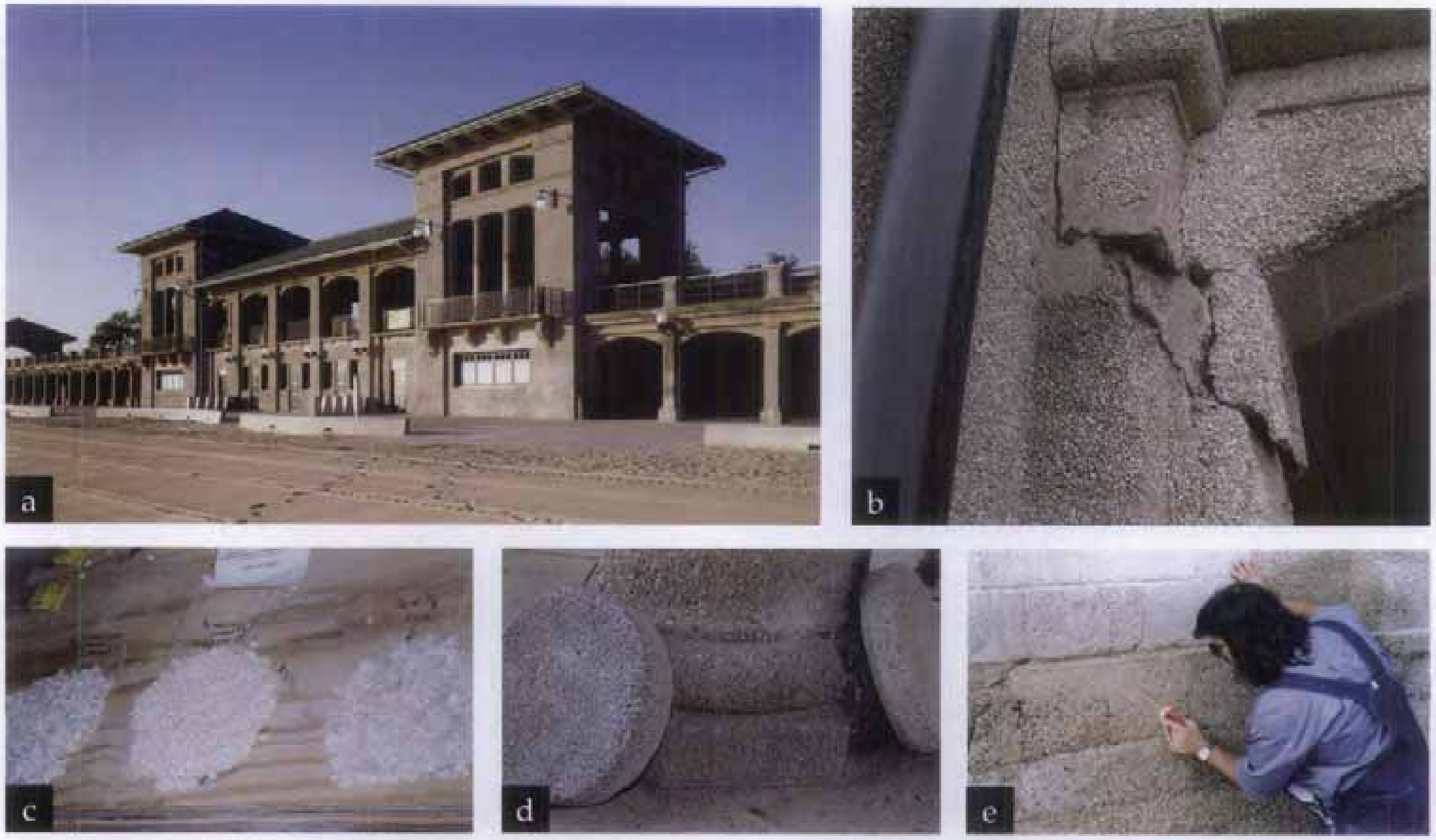

Figure 17. (a) The 63rd Street Beach House was constructed on the shoreline of Chicago in 1919. The highly exposed aggregate concrete of the exterior walls of the beach house was used for many buildings in the Chicago parks as an alternative to more expensive stone construction. Photo: Leslie Schwartz Photography. (b) Concrete deterioration included cracking, spalling, and delamination caused by corrosion of embedded reinforcing steel and concrete damage due to cyclic freezing and thawing. (c) Various sizes and types of aggregates were reviewed for matching to the original concrete materials. (d) Mock-ups of the concrete repair mix were prepared for comparison to the original concrete. Considerations included aggregate type and size, cement color, proportions, aggregate exposure, and surface finish. (e) The craftsman finished the surface to replicate the original appearance in a mock-up on the structure. Here, he used a nylon bristle brush to remove loose paste and expose the aggregate, creating a variable surface to match the adjacent original concrete.

Where used for crack repairs on historic facades, the finished appearance of the sealant application must be considered, as it may be visually intrusive. In some cases, sand can be broadcast onto the surface of the sealant to help conceal the repair.

Urethane and polyurethane sealants are often used to seal joints and cracks in concrete structures, paving, and walkways; these sealants provide a service life of up to ten years. High-performance silicone sealants also are often used with concrete, as they provide a range of movement capabilities and a service life of twenty years or more. Some silicone sealants may stain adjacent materials, which may be a problem with more porous concrete, and may also tend to accumulate dust and dirt. The effectiveness of sealants for sealing joints and cracks depends on numerous factors including proper surface preparation and application. Sealants should be examined as part of routine maintenance inspections, as these materials deteriorate faster than their substrates and must be replaced periodically as a part of cyclical maintenance.

Repair of historic concrete may be required to address deterioration because the original design and construction did not provide for long-term durability, or to facilitate a change in use of the structure. Examples include increasing concrete cover to protect reinforcing steel and reducing water infiltration into the structure by repair of joints. Any such improvements must be thoroughly evaluated for compatibility with the original design and appearance. Care is required in all aspects of historic concrete repair, including surface preparation; installation of formwork; development of the concrete mix design; and concrete placement, consolidation, and curing.

An appropriate repair program addresses existing distress and reduces the rate of future deterioration, which in many cases involves moisture-related issues. The repair program should incorporate materials and methods that are sympathetic to the existing materials in character and appearance, and which provide good long-term performance. In addition, repair materials should age and weather similarly to the original materials. In order to best achieve these goals, concrete repair projects should be divided into three phases: development of trial repair procedures, trial repairs and evaluation, and production repair work.

For any concrete repair project, the process of investigation, laboratory analysis, trial samples, mock-ups, and full-scale repairs allows ongoing refinement of the repair work as well as implementation of quality-control measures. The trial repair process provides an opportunity for the owner, architect, engineer, and contractor to evaluate the concrete mix design and the installation and finishing techniques for the repairs from both technical and aesthetic standpoints. The final repair materials and procedures should match the original concrete in appearance while meeting the established criteria for durability. Information gathered through trial repairs and mock-ups is invaluable in refining the construction documents prior to the start of the overall repair project (Fig. 17).

Surface Preparation

In undertaking surface preparation for historic concrete repair, care must be taken to limit removal of existing material while still providing an appropriate substrate for repairs. This is particularly important where ornamentation and fine details are involved. Preparation for localized repairs usually begins with removal of the loose concrete to determine the general extent of the repair, followed by saw-cutting the perimeter of the repair area. The repair area should extend beyond the area of concrete deterioration to a sufficient extent to provide a sound substrate. When repairing concrete with an exposed aggregate or other special surface texture, a sawcut edge may be too visually evident. To hide the repair edge, techniques such as lightly hand-chipping the edge of the patch may be used to conceal the joint between the original concrete and the new repair material. The depth to which the concrete needs to be removed may be difficult to determine without invasive probing in the repair area. Removal of concrete should typically extend beyond the level of the reinforcing steel, if present, so that the patch encapsulates the reinforcing steel, which provides mechanical attachment for the repair.

If the concrete was originally of lower strength and quality, the assessment of present soundness is more difficult. Deteriorated and unsound concrete is typically removed using pneumatic chipping hammers. Removal of concrete in historic structures is better controlled by using smaller chipping hammers or hand tools. The area of the concrete to be repaired and the exposed reinforcing steel are then cleaned, usually by careful sandblast and air blast procedures applied only within the repair area. Adjacent original concrete surfaces should be protected during this work. In some cases, project constraints such as dust control may limit the ability to thoroughly clean the concrete and steel. For example, it may be necessary to use needle scaling (a small pneumatic impact device) and wire brushing instead of sandblasting.

Supplemental steel may be needed when existing reinforcing steel is severely deteriorated, or if reinforcing steel is not present in repair areas. Exposed existing reinforcing and other embedded steel elements can be cleaned, primed, and painted with a corrosion-inhibiting coating. The patching material should be reinforced and mechanically attached to the existing concrete. Reinforcement materials used in repairs most often include mild steel, epoxy-coated steel, or stainless steel, depending on existing conditions.

Formwork and Molds

Special formwork is needed to recreate ornamental concrete features—which may be complex, in high relief, or architecturally detailed—and to provide special surface finishes such as wood form board textures. Construction of the formwork itself requires particular skill and craftsmanship. Reusable forms can be used for concrete ornamentation that is repeated across a building facade, or precast concrete elements may be used to replace missing or unrepairable architectural features. Formwork for ornamental concrete is often created using a four-step process: a casting of the original concrete is taken; a plaster replica of the unit is prepared; a mold or form is made from the plaster replica; and a new concrete unit is cast. Custom formwork and molds are often the work of specialty companies, such as precasters and cast stone fabricators.

The process of forming architectural features or special surface textures is particularly challenging if early age stripping (removal of formwork early in the concrete curing process) is needed to perform surface treatment on the concrete. Timing for formwork removal is related to strength gain, which in turn is partly dependent on temperature and weather conditions. Early age removal of formwork in highly detailed concrete can lead to damage of the new concrete that has not yet gained sufficient strength through curing.

Selection of Repair Materials and Mix Design

Selection and design of proper repair materials is a critical component of the repair project. This process requires evaluation of the performance, characteristics, and limitations of the repair materials, and may involve laboratory testing of proposed materials and trial repairs. The materials should be selected to address the specific type of repair required and to be compatible with special characteristics of the original concrete. Some modern repair materials are designed to have a high compressive strength and to be impermeable. Even though inherently durable, these newer materials may not be appropriate for use in repairing a low strength historic concrete.

The concrete's durability, or resistance to deterioration, and the materials and methods selected for repair depend on its composition, design, and quality of workmanship. In most cases, a mix design for durable replacement concrete should use materials similar to those of the original concrete mix. Prepackaged materials are often not appropriate for repair of historic concrete. The concrete patching material can be air entrained or polymer-modified if subject to exterior exposure, and should incorporate an appropriate selection of aggregate and cement type, and proper water content and water

Figure 18. (a) Exposed aggregate precast concrete is sounded with a hammer to detect areas of deterioration. Corrosion of the exposed reinforcing steel bar has led to spalling of the adjacent concrete. (b) Samples of aggregate considered for use in repair concrete are compared to the original concrete materials in terms of size, color, texture, and reflectance. (c) Various sample panels are made using the selected concrete repair mix design for comparison to the original concrete on the building, and the mix design is adjusted based on review of the samples. (d) After removal of the spall, the concrete surface is prepared for installation of a formed patch. (e) Prior to placement of the concrete, a retarding agent is brush-applied to the inside face of the formwork to slow curing at the surface. After the concrete is partially cured, the forms are removed and the surface of the concrete is rubbed to remove some of the paste and expose the aggregate to match the original concrete.

to cement ratio. Some admixtures, including polymer modifiers, may change the appearance of the concrete mix. Design of the concrete patching material should address characteristics required for durability, workability, strength gain, compressive strength, and other performance attributes. During installation of the repair, skilled workmanship is required to ensure proper mixing procedures, placement, consolidation, and curing.

Matching and Repair Techniques for Historic Concrete

Repair measures should be selected that retain as much of the original material as possible, while providing for removal of an adequate amount of deteriorated concrete to provide a sound substrate for a durable repair. The installed repair must visually match the existing concrete as closely as possible and should be similar in other aspects such as compressive strength, permeability, and other characteristics important in the mix design of the concrete (Fig. 18).

Understanding the original construction techniques often provides opportunities in the design of repairs. For example, joints between the new and old concrete can be hidden in changes in surface profile and cold joints. The required patching mix for the concrete to be used in the repair will likely need to be specially designed to replicate the appearance of the adjacent historic concrete. A high level of craftsmanship is required for finishing of historic concrete, in particular to create the sometimes inconsistent finish and variation in the original concrete in contrast to the more even appearance required for most non-historic repairs.

To match the various characteristics of the original concrete, trial mixes should be developed. These mixes need to take into account the types and colors of aggregates and paste present in the original concrete. Different mixes may be needed because of variations in the appearance and composition of the historic concrete. The trials should utilize different forming and finishing techniques to achieve the best possible match to the original concrete. Initial trials should first take place on site but off the structure. The mix designs providing the best match are then installed as trial repairs on the structure, and assessed after they have cured.

Achieving compatibility between repair work and original concrete may be difficult, especially given the variability often present in historic concrete materials and finishes. Formed rather than trowel-applied patch repairs are recommended for durability, as forming permits better ranges of mix ingredients (such as coarse aggregates) and improved consolidation as compared to trowel-applied repairs. Parge coatings usually are not recommended as they do not provide as durable repair as formed concrete. However, in some cases parge coatings may be appropriate to match an original parged surface treatment. Proper placement and finishing of the repair are important to obtain a match with the original concrete. To minimize problems associated with rapid curing of concrete, such as surface cracking, it is important to use proper curing methods and to allow for sufficient time.

Hairline cracks that show no sign of increasing in size may often be left unrepaired. The width of the crack and the amount of movement usually limits the selection of crack repair techniques that are available. Although it is difficult to determine whether cracks are moving or non-moving, and therefore most cracks should be assumed to be moving, it is possible to repair non-moving cracks by installation of a cementitious repair mortar matching the adjacent concrete. It is generally desirable not to widen cracks prior to the mortar application. Repair mortar containing sand in the mix may be used for wider cracks; unsanded repair mortar may be used for narrower cracks.

When it is desirable to re-establish the structural integrity of a concrete structure involving dormant cracks, epoxy injection repair has proven to be an effective procedure. Such a repair is made by first sealing the crack on both sides of a wall or structural member with epoxy, polyester, wax, tape, or cement slurry, and then injecting epoxy through small holes or ports drilled in the concrete. Once the epoxy in the crack has hardened, the surface sealing material may be removed; however, this type of repair is usually quite apparent. Although it may be possible to inject epoxy without leaving noticeable residue, this process is difficult and, in general, the use of epoxy repairs in visible areas of concrete on historic structures is not recommended.

Active structural cracks (which move as loads are added or removed) and thermal cracks (which move as temperatures fluctuate) must be repaired in a manner that will accommodate the anticipated movement. In some more extreme cases, expansion joints may have to be introduced before crack repairs are undertaken. Active cracks may be filled with sealants that will adhere to the sides of the cracks and will compress or expand during crack movement. The design, detailing, and execution of sealant repairs require considerable attention, or they will detract from the appearance of the historic building. The routing and cleaning of a crack, and installation of an elastomeric sealant to prevent water penetration, is used to address cracks where movement is anticipated. However, unless located in a concealed area of the concrete, this technique is often not acceptable for historic structures because the repair will be visually intrusive (Fig. 19). Other approaches, such as installation of a cementitious crack repair, may need to be considered even though this type of repair may be less effective or have a shorter service life than a sealant repair.

Replacement

If specific components of historic concrete structures are beyond repair, replacement components can be cast to match historic ones. Replacement of original concrete should be carefully considered and viewed as a method of last resort. In some cases, such as for repeated ornamental units, it may be more cost-effective to fabricate precast concrete units to replace missing elements. The forms created for precast or cast-in-place units can then be used again during future repair projects.

Careful mix formulation, placement, and finishing are required to ensure that replacement concrete units will match the historic concrete. There is often a tendency to make replacement concrete more consistent in appearance than the original concrete. The consistency can be in stark contrast with the variability of the original concrete

Figure 19. A high-speed grinder ia used to widen a crack in preparation for installation of a sealant. This process is called "routing." After the crack is prepared, the sealant is installed to prevent moisture infiltration through the crack. Although sealant repairs can provide a durable, watertight repair for moving cracks, they tend to be very visible.

due to original construction techniques, architectural design, or differential exposure to weather. Trial repairs and mock-ups are used to evaluate the proposed replacement concrete work and to refine construction techniques (Fig 20).

Protection Systems

Coatings and Penetrating Sealers. Protection systems such as a penetrating sealers or film forming coating are often used with non-historic structures to protect the concrete and increase the length of the service life of concrete repairs. However, film-forming coatings are often inappropriate for use on a historic structure, unless the structure was coated historically. Film-forming coatings will often change the color and appearance of a surface, and higher build coatings can also mask architectural finishes and ornamental details. For example, the application of a coating on concrete having a formboard finish may hide the wood texture of the surface. Pigmented film-forming coatings are also typically not appropriate for use over exposed aggregate concrete, where the uncoated exposed surface contributes significantly to the historic character of

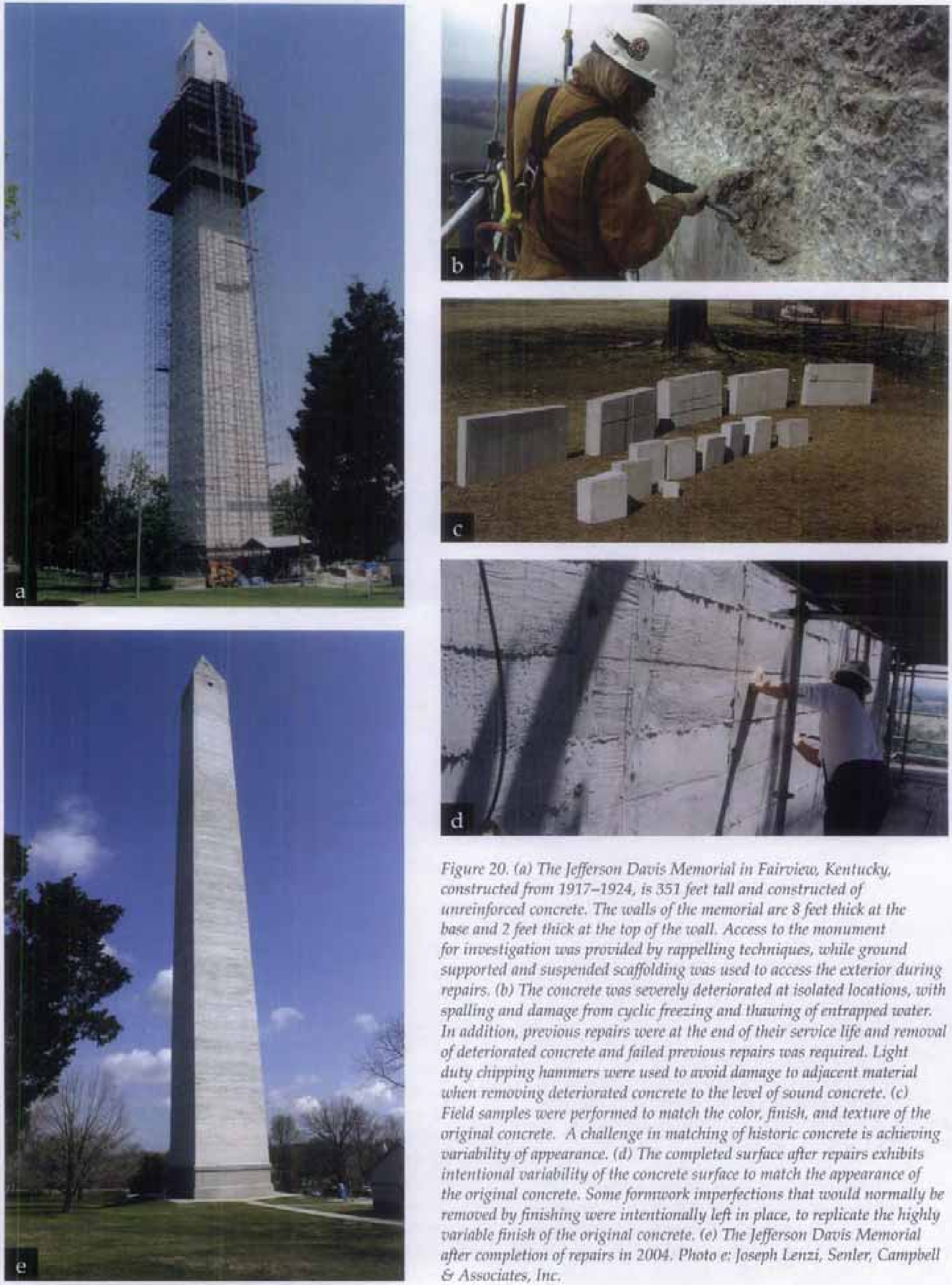

Figure 20. (a) The Jefferson Davis Memorial in Fairview, Kentucky, constructed from 1917–1924, is 351 feet tall and constructed of unreinforced concrete. The walls of the memorial are 8 feet thick at the base and 2 feet thick at the top of the wall. Access to the monument for investigation was provided by rappelling techniques, while ground supported and suspended scaffolding was used to access the exterior during repairs. (b) The concrete was severely deteriorated at isolated locations, with spalling and damage from cyclic freezing and thawing of entrapped water. In addition, previous repairs were at the end of their service life and removal of deteriorated concrete and failed previous repairs was required. Light duty chipping hammers were used to avoid damage to adjacent material when removing deteriorated concrete to the level of sound concrete. (c) Field samples were performed to match the color, finish, and texture of the original concrete. A challenge in matching of historic concrete is achieving variability of appearance. (d) The completed surface after repairs exhibits intentional variability of the concrete surface to match the appearance of the original concrete. Some formwork imperfections that would normally be removed by finishing were intentionally left in place, to replicate the highly variable finish of the original concrete. (e) The Jefferson Davis Memorial after completion of repairs in 2004. Photo e: Joseph Lenzi, Senler, Campbell & Associates, Inc.

concrete. In cases where the color of a substrate needs to be changed, such as to modify the appearance of existing repairs, an alternative to pigmented film-forming coatings is the use of pigmented stains.

Many proprietary clear, penetrating sealers are currently available to protect concrete substrates. These products render fine cracks and pores within the concrete hydrophobic; however, they do not bridge or fill cracks. Clear sealers may change the appearance of the concrete in that treated areas become more visible after rain in contrast to the more absorptive areas of original concrete. Once applied, penetrating sealers cannot be effectively removed and are therefore considered irreversible. They should not be used on historic concrete without thorough prior consideration. However, clear penetrating sealers provide an important means of protection for historic concrete that is not of good quality and can help to avoid more extensive future repairs or replacement. Thus they are sometimes appropriate for use on historic concrete. Once applied, these sealers will require periodic re-application.

Waterproofing membranes are systems used to protect concrete surfaces such as roofs, terraces, plazas, or balconies, as well as surfaces below grade. Systems range from coal tar pitch membranes used on older buildings, to asphalt or urethane-based systems. On historic buildings, membrane systems are typically used only on surfaces that were originally protected by a similar system and surfaces that are not visible from grade. Waterproofing membranes may be covered by roofing, paving, or other architectural finishes.

Laboratory and field testing is recommended prior to application of a protection system or treatment on any concrete structure; testing is even more critical for historic structures because many such treatments are not reversible. As with other repairs, trial samples are important to evaluate the effectiveness of the treatment and to determine whether it will harm the concrete or affect its appearance.

Cathodic Protection. Corrosion is an electrochemical process in which electrons flow between cathodic (positively charged) and anodic (negatively charged) areas on a metal surface; corrosion occurs at the anodes. Cathodic protection is a technique used to control the corrosion of metal by making the whole metal surface the cathode of an electrochemical cell. This technique is used to protect metal structures from corrosion and is also sometimes used to protect steel reinforcement embedded in concrete. For reinforced concrete, cathodic protection is typically accomplished by connecting an auxiliary anode to the reinforcing so that the entire reinforcing bar becomes a cathode. In sacrificial anode (passive) systems, current flows naturally by galvanic action between the less noble anode (such as zinc) and the cathode. In impressed-current (active) systems, current is impressed between an inert anode (such as titanium) and the cathode. Cathodic protection is intended to reduce the rate of corrosion of embedded steel in concrete, which in turn reduces overall deterioration. Protecting embedded steel from corrosion helps to prevent concrete cracking and spalling.

Impressed-current cathodic protection is the most effective means of mitigating steel corrosion and has been used in practical structural applications since the 1970s. However, impressed-current cathodic protection systems are typically the most costly to install and require substantial ongoing monitoring, adjustment, and maintenance to ensure a proper voltage output (protection current) over time. Sacrificial anode cathodic protection dates back to the 1800s, when the hulls of ships were protected using this technology. Today many industries utilize the concept of sacrificial anode cathodic protection for the protection of steel exposed to corrosive environments. It is less costly than an impressed-current system, but is somewhat less effective and requires reapplication of the anode when it becomes depleted.

Re-alkalization. Another technique currently available to protect concrete is realkalization, which is a process to restore the alkalinity of carbonated concrete. The treatment involves soaking the concrete with an alkaline solution, in some cases forcing it into the concrete to the level of the reinforcing steel by passage of direct current. These actions increase the alkalinity of the concrete around the reinforcement, thus restoring the protective alkaline environment for the reinforcement. Like impressed-current cathodic protection methods, it is costly. Other corrosion methods are also available but have a somewhat shorter history of use.

Careful evaluation of existing conditions, the causes and nature of distress, and environmental factors is essential before a protection method is selected and implemented. Not every protection system will be effective on each structure. In addition, the level of intrusion caused by the protection system must be carefully evaluated before it is used on a historic concrete structure.

Summary

In the United States, concrete has been a popular construction material since the late nineteenth century and recently has gained greater recognition as a historic material. Preservation of historic concrete requires a thorough understanding of the causes and types of deterioration, as well as of repair and replacement materials and methods. It is important that adequate time is allotted during the planning phase of a project to provide for trial repairs and mock-ups in order to evaluate the effectiveness and aesthetics of the repairs. Careful design is essential and, as with other preservation efforts, the skill of those performing the work is critical to the success of the repairs. The successful repair of many historic concrete structures in recent years demonstrates that the techniques and materials now available can extend the life of such structures and help ensure their preservation.

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Acknowledgements

Paul Gaudette is an engineer with Wiss, Janney, Elstner Associates, Inc., in Chicago, Illinois. Deborah Slaton is an architectural conservator with Wiss, Janney, Elstner Associates, Inc., in Northbrook, Illinois. All photographs by Paul Gaudette unless otherwise stated. Front cover image: Kyle Normandin, Wiss, Janney, Elstner Associates, Inc.

The authors wish to thank William Bing Coney, author of the first edition of this preservation brief, who served as a peer reviewer for the current edition. In addition, the authors gratefully acknowledge the assistance of the following individuals as peer reviewers of this brief: Arne Johnson and Una Gilmartin, Wiss, Janney, Elstner Associates, Inc.; Robert Joyce, Quality Restorations, Inc.; Susan Macdonald, New South Wales Heritage Office; Miles T. Murray, Restruction Corporation; and Jack Pyburn, OJP/Architect, Inc. Anne E. Grimmer, Chad Randl, and former staff Sharon C. Park, FAIA, of the Technical Preservation Services, National Park Service, offered valuable comments during development of the brief. Charles E. Fisher of the National Park Service was the technical editor for this publication project.

This publication has been prepared pursuant to the National Historic Preservation Act of 1966, as amended, which directs the Secretary of the Interior to develop and make available information concerning historic properties. Comments about this publication should be addressed to: Charles E. Fisher, Technical Preservation Publications Program Manager, Technical Preservation Services—2255, National Park Service, 1849 C Street, NW, Washington, DC 20240. This publication is not copyrighted and can be reproduced without penalty. Normal procedures for credit to the authors and the National Park Service should be provided. The photographs used in this publication may not be used to illustrate other publications without permission of the owners. For more information about the programs of the National Park Service's Technical Preservation Services see our website at http://www.nps.gov/history/hps/tps.htm

ISBN: 978-0-16-078946-5
U.S. Government Printing Office Stock Number: 024-005-01253-2

2007

Appendix C

CULTURAL RESOURCES MANAGERS QUESTIONNAIRE AND RESULTS SUMMARY

FY13 DOD Cultural Resources Legacy Project
20th Century Historic Building Materials and Suitable Substitutes

DOD CULTURAL RESOURCES MANAGERS QUESTIONNAIRE

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PLEASE RESPOND TO THE REMAINING QUESTIONS AS THEY RELATE TO YOUR HISTORIC 20TH CENTURY BUILDINGS

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Thank you for completing this questionnaire. Your response will provide valuable input in helping us focus our research on materials of concern to DOD installations.

Please email the completed form to Pam Anderson with A.D. Marble & Company at

panderson@admarble.com

FY 13 DoD Cultural Resources Legacy Project
20th Century Historic Building Materials and Suitable Substitutes
CRM Questionnaire Results Summary (January 28, 2014)

NAVFAC MIDLANT submitted the CRM Questionnaire, developed by A.D. Marble & Company, to the Cultural Resources Managers at DoD installations in November 2013. Emails were sent to 29 Cultural Resources Managers (including regional and installation level personnel) in the Northeast and Mid-Atlantic regions from Virginia to Maine. The following 18 responses covering 27 DoD installations were received:

NAVY (9 responses covering 18 installations)

- NSA Washington (Washington Navy Yard, Naval Observatory, NSF Arlington, NSF Suitland, NSA Carderock)
- MIDLANT Navy Hampton Rds VA Installations (NAVSTA Norfolk, NSA HR, NSA NNSY, NWS Yorktown, NAS Oceana, JEB LC-Ft. Story)
- NSA Bethesda, MD
- NSF Indian Head, MD
- NWS Earle, NJ
- Portsmouth Naval Shipyard, Kittery, ME
- NCTAMSLANT Detachment ,Cutler, ME
- USNA Annapolis, MD
- NAVSTA Newport, RI

ARMY (6 responses)
- Carlisle Barracks, PA
- Ft. Belvoir, VA
- Ft. Drum, NY
- JB Langley-Ft. Eustis, VA
- USMA West Point, NY
- Picatinny Arsenal, NJ

AIR FORCE (1 response)
- Wright Patterson AFB, OH

MARINE CORPS (2 responses)
- Marine Barracks Washington DC
- MCB Quantico, VA

Based on the results of the survey, the scope of the study was refined to focus on window types- steel windows (including industrial ribbon windows), corrugated wire glass, wire glass, and glass block. The focus on windows was necessitated by the extent of problems identified, the need to have sufficient time to properly document specific issues and examples of successful replacement projects, and prepare a brief history on the development of the various window types, as well as document information on manufacturers of replacement materials. The results of the study as well as the other problematic materials noted will be fully documented in the report methodology.

The following provides a summary of the responses received.

- 18 responses received covering 27 DoD installations:
    1. 1 installation responded as having no 20th century historic buildings (JB Langley-Fort Eustis, VA)
    2. 2 installations responded as having 1-10 historic 20th century buildings but did not meet requirements/needs of study (Fort Drum, NY; Marine Barracks Washington, DC)
    3. 1 installation responded as having no issues relating to replacement of 20th century building materials (US Army Carlisle Barracks, PA)

- Of the remaining 14 responses, the number of historic buildings were as follows:
    1. 1 – 10: NSA Bethesda (MD), NCTS Cutler (ME)
    2. 11-50: Portsmouth Naval Shipyard (ME), NS Newport (RI), US Naval Academy (MD)
    3. 51-100: None
    4. 101-200: Picatinny Arsenal (NJ)
    5. More than 200: USAG West Point (NY), NS Norfolk/NSA Hampton Roads (VA), Wright-Patterson AFB (OH), NWS Earle (NJ), NSA South Potomac/Indian Head (MD), Fort Belvoir (VA), Marine Corps Quantico (VA), NSA Washington/Arlington/NSF Suitland/Carderock (DC/MD/VA)

- The following materials were marked as the greatest challenges (Question 7):
    1. Steel Windows (10 responses; 6 of which marked as greatest challenge)
    2. Precast Concrete (4 responses; 2 of which marked as greatest challenge)
    3. Transite Roofs (4 responses; 1 of which marked as greatest challenge)
    4. Corrugated Metal Siding (4 responses)
    5. Cast-in-Place Concrete (3 responses)
    6. Corrugated Wire Glass (2 responses; 1 of which marked as greatest challenge)
    7. Wire Glass (1 response)
    8. Glass Block (1 response)
    9. Other (4 responses—included windows in general, mortar, brick/masonry, stone bases, light fixtures)

- The following issues were noted as the most problematic in regards to the materials identified above (Question 8):
    1. Acceptable substitutes not found because of unique appearance of original material (8 responses)
    2. Suitable substitute materials available, but exceed project budget (11 responses)
    3. Poor workmanship during installation of replacement materials (6 responses)
    4. Poor quality of replacement materials (3 responses)

5. Suitable substitute does not comply with ATFP Standards (7 responses)
6. Suitable substitute does not meet energy requirement (7 responses)
7. Other: (2 responses that did not fit into categories above)
    - Suitable substitute materials available but the time to acquire materials extends beyond the completion schedule for the job

Appendix D:

LIST OF MATERIAL MANUFACTURERS

Appendix D: List of Material Manufacturers

Limited Selection of Historic Concrete Services

**Note: This list is not inclusive, and concrete contractors will be found locally in most areas. To identify a qualified firm, a general process should be to determine the firm's specializations; ask the contractor for past clients/projects or a portfolio; and discuss possible repair techniques. A "qualified contractor" should have a demonstrated experience in treatment of historic concrete. Please refer to* NPS Preservation Brief 15: Preservation of Historic Concrete *for further information (Appendix B; Gaudette and Slaton 2007).*

C.A. Lindman, Inc.
10401 Guilford Road
Jessup, MD 20794
301-470-4700
http://www.calindman.com/htmlfiles/services4.html

Valente-Lindman LLC
4 Cliff Drive
Englewood, NJ 07631
201-816-0606
http://www.calindman.com/htmlfiles/services4.html

Cathedral Stone Products, Inc.
7266 Park Circle Drive
Hanover, MD 21076
410-782-9150
http://www.cathedralstone.com/

Commonwealth Heritage Group, Inc.
(formerly John Milner Associates, Inc.)
535 N. Church Street
West Chester, PA 19380
610-436-9000
or
5250 Cherokee Avenue, Suite 300
Alexandria, VA 22312
703-354-9737
or
410 Great Road, B-14
Littleton, MA 01460
978-793-2579
http://commonwealthheritagegroup.com/

U.S. Heritage Group, Inc.
3516 N. Kostner Avenue
Chicago, IL 60641
773-286-2100
http://usheritage.com/

The Witmer Group
1003 Cornerstone Drive
Mount Joy, PA 17552
717-653-1428

WA Associates
990 A Street, Suite K
San Rafael, CA 94901
415-485-9797

John G. Waite Associates PLLC
64 Fulton Street
New York, NY 10038
212-619-4881

J.J. Morley Enterprises
7560 Industrial Court
Alpharetta, GA 30004
770-569-1100

Architexas
1907 Marilla Street
Dallas, TX 75201
214-748-4561

Spectra Company
2510 Supply Street
Pomona, CA 91767
800-375-1771

GL Capasso, Inc.
34 Lloyd Street
New Haven, CT 06513
203-469-2810

Limited Selection of Customizable Corrugated Metal Manufacturers

Corrugated Metals, Inc.
6550 Revlon Drive
Belvidere, IL 61008
1-800-621-5617
http://www.corrugated-metals.com/

Triad Corrugated Metal
208 Luck Road
Asheboro, NC 27205
336-625-9727
http://www.triadmetalroof.com/

Custom Corrugated
2727 W. Park
Gray, LA 70359
985-876-2555
http://www.customcorrugated.net/

Creative Building Supply Co.
501 Prospect Street
Lakewood Township, NJ 08701
732-276-1021
https://www.cbssheetmetal.com/

Custom-Bilt Metals
1333 Corporate Drive, Suite 103

Irving, TX 75038
800-826-7813
www.custombiltmetals.com

American Building Components
6168 State Route 233
Rome, NY 13440
315-334-8611
http://www.abcmetalroofing.com/

Mechanical Metals
1778 North Dove Road
Yardley, PA 19067
215-860-3600
www.mechanicalmetals.com

James River Steel, Inc.
P.O. Box 11498
Richmond, VA 23230
1-800-825-0717
http://www.jamesriversteel.com/

Holland Roofing Group, LLC
7450 Industrial Road
Florence, KY 41042
1-877-455-7663
http://www.hollandroofing.com/

Ridgeline Metal
1305 SW Lake Road
Redmond, OR 97756
541-548-7044
http://ridgelinemetal.com/

Limited Selection of Fiber-Cement or Cement Board Asbestos-Cement Substitutes

James Hardie
231 S. LaSalle Street, Suite 2000
Chicago, IL 60604
or 26300 La Alameda, Suite 400
Mission Viejo, California 92691
1-888 J-HARDIE (1-888-542-7343)
www.JamesHardie.com

Nichiha Fiber Cement
6465 E Johns Crossing, Suite 250
Johns Creek, GA 30097
1-770-805-9466
http://www.nichiha.com/

Supradur Manufacturing Company
134 Broadway
Bangor, PA 18013
610-435-0970

Foundry Service & Supplies, Inc.
2029 South Parco Avenue
Ontario, CA 91761
909-284-5000
http://www.foundryservice.com

American Fiber Cement Corporation
6901 S. Pierce St., Ste. 260
Littleton, CO 80128
1-800-688-8677 x102
http://www.americanfibercement.com/

Nudo
1500 Taylor Avenue,
Springfield, IL 62703
800-358-8018
http://www.hsipanels.com/

Cement Board Fabricators, Inc.
2148 S. 41st Street
Louisville, KY 40211
502-774-5757
https://cementboardfabricators.com

BNZ Materials, Inc.
400 Iron Horse Park
North Billerica, MA 01862
978-663-3401
http://www.bnzmaterials.com/

Allura
15055 Woodham Drive
Houston, TX 77073
844-425-5872
http://www.allurausa.com/

U.S. Architectural Products, Inc.
103 Carnegie Center, Suite 300
Princeton, NJ 08540
1-800-243-6677
https://www.architecturalproducts.com

GAF WeatherSide
440 Katherine Road
Wind Gap, PA 18091
610-863-4101, x229
http://www.gaf.com

A.D. MARBLE
environmental·cultural·engineering

2200 Renaissance Boulevard, Suite 260
King of Prussia, PA 19406

NAVFAC
Naval Facilities Engineering Command

Naval Facilities Engineering Command Mid-Atlantic
9742 Maryland Avenue
Norfolk, VA 23511

DoD Legacy Resource Management Program
3400 Defense Pentagon
Room 5C646
Washington, D.C. 20301