2013

A Program for the Conservation, Interpretation, and Reuse of Downdraft Kilns at the Western Clay Manufacturing Company of Helena, Montana

Brett Cameron Phelps Sturm

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A Program for the Conservation, Interpretation, and Reuse of Downdraft Kilns at the Western Clay Manufacturing Company of Helena, Montana

Abstract
This is the second thesis generated by a collaborative effort between the Montana Preservation Alliance, the Archie Bray Foundation for the Ceramic Arts, and the University of Pennsylvania's Master’s Program in Historic Preservation to research, document, and conserve architectural components of the former Western Clay Manufacturing Company of Helena, Montana. This project’s focus is the complex of five downdraft brick kilns and sheds (built between 1905 and 1922), which drove production at Western Clay until at least 1957 and now constitutes an iconic backdrop for the Archie Bray Foundation, one of the country’s foremost centers for contemporary ceramic art. The goal of the project was to provide the Bray with a series of recommendations for how the kilns might be stabilized, interpreted to the public, and put to new use. Three chapters—a contextual history of brick kilns; a diagnostic, materials-based analysis of the Western Clay prototypes; and a discussion of industrial heritage conservation and relevant, clay-related case studies—culminate in the delivery of the said recommendations as a final, concluding chapter—the conservation program. Oral histories, publications in industrial archaeology, and period trade literature pertaining to brick-firing form the bulk of the thesis’ resource base. A symptomatic conditions survey of a kiln exterior and a series of laboratory tests run on kiln brick and soil samples inform the materials-based portions of the study. Ultimately, the stabilization and limited reuse of the kilns as exhibition and performance spaces are encouraged, as is the formation of partnerships with organizations striving, like the Bray, to institute craft-and art-making at sites traditionally employed in the manufacture of goods using similar media.

Keywords
brick, conditions survey, industrial sites, industrial heritage conservation, montana

Disciplines
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A PROGRAM FOR THE
CONSERVATION, INTERPRETATION, AND REUSE OF DOWNDRAFT KILNS
AT THE WESTERN CLAY MANUFACTURING COMPANY OF
HELENA, MONTANA

Brett Cameron Phelps Sturm

A THESIS
in
Historic Preservation
Presented to the Faculties of the University of Pennsylvania in
Partial Fulfillment of the Requirements of the Degree of

MASTER OF SCIENCE IN HISTORIC PRESERVATION
2013

Advisor and Acting Program Chair
Frank G. Matero
Professor of Architecture
Craft, almost eliminated from the practical world and a seeming anachronism, has become a precious remnant. In it, we can sense the potential for full development of the person, for the restoration of wholeness.

The artist and the craftsman, laboring outside of society’s system of production—money-consumption, keep alive a different way of working and living. They work for the joy of working and they seek and find their identity in the work of their own hands…

-Daniel Rhodes, *Pottery Form* (1976)

This thesis is dedicated to brickmakers, potters, and all those devoted to good work in clay.
Acknowledgements

This project surely would not have come together without the help, input, and encouragement of several dear friends and colleagues.

I would first of all like to thank Frank Matero for granting me the privilege of working on the Western Clay project through a summer internship at the Architectural Conservation Lab. Exposure to this fascinating site and a wonderful team of collaborators has changed my way of thinking about architecture, art, industry, and, especially, brick. Thanks to Frank for his confidence, and for his comments on multiple drafts of this work.

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Special thanks are due to Steve Lee, the artists, and staff of the Archie Bray Foundation for the Ceramic Arts in Helena, Montana, for without their presence on Country Club Avenue, now in its sixty-second year, there would be no brickyard to conserve. Thanks to the long- and short-term residents of 2012, who patiently and graciously shared their space with us during our protracted tinkering at the kilns in June and July of that year. The work done at the Bray is an inspiration—may the organization continue to thrive for another half-century, at least.

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in Medicine Hat, Alberta. Working and spending time with him both in Montana and Wyoming, meanwhile, was a true highlight of 2012.

Of all the great partners in Montana, this project is arguably most indebted to Chip Clawson, who, for years, maintained elements of the kiln complex to the best of his ability. Without his knowledge, skills, and openness, our investigation of the site would not have been possible. Thanks, Chip, for your insights on the Bray, on ceramics, and on life. I’ll see you at the Blackfoot.

I would like to thank both Meredith Keller and Joe Torres of the ACL. They have been great colleagues, teachers, and friends to me during my time at Penn. (As trite as it sounds, I don’t know what I would have done without them!) Thanks to Joe and Meredith for their help, company, and constant laughs.

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Table of Contents

List of Figures vii
List of Tables x

1. Introduction 1

2. Contextual History of the Downdraft Kiln 4

2.1 Downdraft Kiln Technology 6
   2.1.1 Operational Principle and Kiln Components 6
   2.1.2 The Refinement of Heavy Clay Kilns Over Time 17

2.2 The Downdraft Kilns of the WCMC 30
   2.2.1 The Site 30
   2.2.2 The Firing Process 33
   2.2.3 Design and Construction: the Case of Kiln No. 7 35

2.3 The Significance of Historic Kilns for the 21st-Century Bray 45

3. Diagnostic Analysis of Conditions On-Site at the WCMC Kiln Complex 52

3.1 Basic Material and Structural Observations 52
   3.1.1 The Sheds 53
   3.1.2 The Kilns (incl. Kiln No. 7 Conditions Survey) 56
   3.1.3 Notes on the Documentation Process 62

3.2 Supplemental Material Analysis 78
   3.2.1 Methodology 79
   3.2.2 Testing 92
   3.2.3 Discussion of Results 96

3.3 The Effects of the Environment and Prior Use on Material State 98

3.4 Hypothesis Formulation and Treatment Recommendations 103

3.5 Suggestions for Further Monitoring and Analysis 105

4. Lessons in the Conservation of Industrial Heritage 108
## List of Figures

### Chapter Two

2.1 A round downdraft kiln in section 164
2.2 The firebox and bag wall 164
2.3 A Kiln bottom 165
2.4 Proper springing of the crown 165
2.5 The clamp 166
2.6 Scoving a modern-day kiln in Madagascar 166
2.7 Nineteenth-century scove kiln in Pennsylvania 167
2.8 Roman updraft brick and tile kiln 167
2.9 Nineteenth-century Scotch kiln 168
2.10 Seventeenth-century Scotch kiln excavated at Jamestown 168
2.11 Minton’s downdraft porcelain kiln 169
2.12 The Minter System on the cover of *Brick and Clay Record* 170
2.13 The Hoffmann *Ringofen* 171
2.14 Path of the fire in a Hoffmann-style continuous kiln 171
2.15 Schmidt & Firestone, Hoffmann kiln-builders of Helena, Montana 172
2.16 The kilns of the Western Clay Manufacturing Co. circa 1908 172
2.17 Sanborn map of the Western Clay Manufacturing Co. circa 1922 173
2.18 Early image of Kiln Nos. 1, 2, or 3 173
2.19 Mid-1950s aerial view of the Western Clay Manufacturing Co. 174
2.20 Inside a partial masonry collapse in Tier 1, Kiln No. 7 174
2.21 Dry-laid model section of Tier 3, Kiln No. 7 175
2.22 Archie Bray, Sr., salts Kiln No. 7 175
Chapter Three

3.1 Border between the two sheds of the WCMC kiln complex 176
3.2 Punky sheathing 176
3.3 Lack of fixity among several wooden shed members 177
3.4 Masonry collapse at Kiln No. 5 177
3.5 Kiln No. 5 mortar joint reverted to powder salt 178
3.6 Masonry collapse at Kiln No. 4 178
3.7 Extent of invasive vegetation growth at Kiln No. 4 179
3.8 Tier 1 bulging and buckstays on Kiln No. 8 179
3.9 Kiln No. 7 before and after cleaning 180
3.10 Oven-dried soil samples from Kiln No. 7 wall interior 180
3.11 Soil samples sieved and organized by color 181
3.12 Non-plastic soil prepared in Casagrande device 181
3.13 Testing ceramic properties via water immersion 182
3.14 Identification of effloresced salts using EM Quant strips 182
3.15 Initial rate of absorption test carried out on historic brick 183
3.16 Ceramic dust accumulation in a Tier 1 masonry void 183

Chapter Four

4.1 The Doric portico at Euston Station, London 184
4.2 Pemberton Mill in Lawrence, Massachusetts, as photographed for the New England Textile Mills Survey in 1967 184
4.3 The Old Furnace at Coalbrookdale 185
4.4 Pratt Street Power Plant in Baltimore, Maryland 185
4.5 Interior of Kiln No. 4 186
| 4.6 | The WCMC kiln complex with surrounding natural landscape | 186 |
| 4.7 | Art in the kiln complex | 187 |
| 4.8 | Brick assembled on the former brick-loading ramp | 187 |
| 4.9 | Aerial view of Medicine Hat’s Alberta Clay Products | 188 |
| 4.10 | Downdraft pottery kiln and the Schlachter Collection | 188 |
| 4.11 | Medalta’s “Working Pottery” | 189 |
| 4.12 | Medalta exhibit in the former pottery drying room | 189 |
| 4.13 | Flue excavations and gift shop at Medalta | 190 |
| 4.14 | Contemporary art on display in a repurposed downdraft kiln | 190 |
| 4.15 | “Tempo der Gründerjahre” by Friedrich Kaiser | 191 |
| 4.16 | Brick floating into Berlin on the river Spree | 191 |
| 4.17 | Aerial view of the Stackebrandt Ziegelei in Zehdenick circa 1945 | 192 |
| 4.18 | Modern-day aerial view of the Ziegeleipark Mildenberg | 192 |
| 4.19 | Inside a Hoffmann kiln | 193 |
| 4.20 | Brick cart chairs in a picnic area at Mildenberg | 193 |
| 4.21 | School-aged girls enjoy the *Handwerkertage* at the Ziegeleipark Mildenberg | 194 |
List of Tables

Table 2.1 – Chronology for the development of the kiln complex at the former WCMC 31
Table 3.1 – Possible cause-and-effect scenarios driving deterioration of Kiln No. 7 80
Table 3.2 – Results obtained for initial rate of absorption among Kiln No. 7 brick 95
Table 3.3 – Identification of salts present in Kiln No. 7 efflorescence and encrustation 96
1. Introduction

This is the second thesis generated in as many years by a collaborative effort between the Montana Preservation Alliance, the Archie Bray Foundation for the Ceramic Arts, and the University of Pennsylvania’s Master’s Program in Historic Preservation to research, document, and conserve architectural components of the former Western Clay Manufacturing Company in Helena, Montana.¹ First exposed to the site during a field course in June 2012, the author was fortunate to continue his investigations at the Bray, which shares its grounds with the derelict brickyard, in July 2012 under the auspice of Penn’s Architectural Conservation Laboratory (ACL). Returning to Philadelphia that fall, the author set about writing this study, the aim of which was to provide the Bray with a series of recommendations—a so-called conservation program—for what might be done with the complex of five downdraft brick kilns (and sheds) that drove production at Western Clay in the first half of the twentieth century and have since become an iconic backdrop for the renowned arts center. How the kilns functioned in the past, what material issues threaten them in the present, and what they might become in the future—these questions constituted his initial modes of inquiry.

As is typical with projects of this magnitude, however, the author’s interests evolved over the long course of research, testing, and writing. Somewhat selfishly, the author followed those interests, and the results of his journey unfold over the next one hundred forty-odd pages. This thesis might thus be perceived in one of two ways: either as a reference tool for people interested in anything from heavy clay manufacturing to load-bearing brick masonry, from conditions surveying to the conservation of industrial heritage sites; or, as the protracted musings of a preservation dilettante. In the hopes fostering the former perception over the latter, the author

¹ For expediency’s sake, the Archie Bray Foundation for Ceramic Arts is referred to, throughout, as “the Bray,” while Western Clay Manufacturing Company appears both as “WCMC,” and “Western Clay.”
will elaborate on the thesis’ structure here, and direct the reader to the Table of Contents and Index should additional orientation prove necessary.

Recommending a proper course of action in the conservation of historic brick kilns requires three essential elements: an understanding of the kilns’ history and past function, an understanding of the modes and mechanics of deterioration jeopardizing their future survival, and an awareness of the conservation profession’s approach (if any) toward interpreting and reusing similar sites of industry. The second chapter begins with the first item on the list, providing a “contextual history” of brick-firing technology. Anyone curious as to the operation and development of heavy clay kilns over time will want to consult this portion of the thesis. And insofar that the chapter contains passages detailing the construction and maintenance of Western Clay’s kilns, as well as their modern-day significance for the Bray, writing here bears a direct influence on both subsequent chapters and the conservation program issued at the thesis’ end.

The third chapter of the thesis concerns itself with kiln deterioration, and builds upon the technical information put forth in the second chapter with an in-depth analysis of masonry and wood conditions within the complex. Included here are qualitative observations from the field, a graphics-based conditions survey of Kiln No. 7’s exterior, procedures for additional laboratory testing, and finally, notes on the impact of the environment and past industrial use on the kilns’ current material state. This chapter ultimately arrives at a diagnosis of the complex’s most pressing physical maladies, outlining their causes, consequences, and potential strategies for repair. Those concerned with conditions recording, brick and wood pathology, and the effects of use (or disuse) on the material health of industrial grade kilns should refer to this middle portion of the study.

The fourth chapter, finally, is the portion of the thesis in which the author pursues his intellectual curiosities most wantonly. Here the history of industrial heritage conservation—a relatively young movement within the greater realm of architectural preservation—is recounted.
Suggestions are made as to how conservators might frame their interpretation of the kiln complex, and what material facets of the site might be preserved and emphasized over others. Then, two case studies from the world of clay-related industrial heritage conservation are presented, with aspects of each case recommended for consideration in future work at the Bray. Readers who wish to know how, why, and where preservationists have successfully salvaged remnants of the industrial past should refer to this chapter, as should readers who seek assurance that, indeed, clay-related sites on the scale of Western Clay can be—and have been—stabilized, reused, and artfully interpreted for the public good.

The thesis concludes with the original impetus for this project, a program recommending guidelines and critical next steps for the conservation of the Bray’s historic kiln complex. The program is, in many ways, a distillation of the rest of the thesis, so those with limited time or insatiable interest should refer directly to its roughly twelve pages for a synopsis of the author’s most important conclusions. Otherwise, the author encourages readers to dissect this work—which is a year’s worth of investigation into clay, fire, brick, and industrial heritage—in whatever way proves most convenient. If nothing else, the thesis demonstrates that the kiln complex of Western Clay is a significant industrial and historical artifact; that its material condition is grave but not terminal; and that there are multiple, inspiring precedents for the conservation of similar sites.

Over the course of this project, the author has grown to realize that the Western Clay site is and should be subordinate to the Bray’s larger mission of excellence in contemporary ceramic arts. Indeed, some things in life are more important than old, fascinating buildings. Nonetheless, the author hopes that this work will in some way encourage the Bray to seriously explore options for conserving the industrial artifacts which populate and add value to their property—if not to preserve Montana’s brickmaking heritage, then to preserve Archie Bray’s original vision of “A fine place to work…”
2. Contextual History of the Downdraft Kiln

“Of all man’s arts, ceramics deals most directly with earth, water, air and fire—those elements which the ancients considered the essentials of our world. Fire is the key. By its action the soft and formless clay is given hardness and permanence, and a range of color related to the colors of the primordial igneous landscape.”

Across millennia, as humans have toiled toward the perfection of the ceramic craft, the kiln has been a device of foremost importance. It is the arena in which earth meets fire—the vessel from which amorphous clay emerges complete: a permanent reflection of human skill and imagination. Even by 1968, however, the year in which ceramicist Daniel Rhodes penned the passage above, the kiln was an instrument not fully understood. Unlike the woodworker and his plane, for example, or the mason and his chisel, the potter, Rhodes asserts, regards his kiln with an air of suspicion, if not superstition. He looks upon the kiln as “a place of holocaust, a potential enemy and destroyer as well as collaborator.”

One can only imagine, then, that alongside potters, brickmakers—those who utilize clay for the construction of habitable space—have gazed upon their own kilns with the same wary deference. If today’s fully-mechanized, digitally-controlled tunnel kilns have finally dispensed with the uncertainty inherent in brick-firing, it is striking to note that brickmakers like Western Clay’s Archie Bray, Jr., were, as late as 1957, staking—and, in Bray’s case, losing—their entire livelihoods on the caprice of their kilns.

The opportunity to conserve century-old downdraft kilns at the site of the former WCMC is an exciting chance to reconnect with this now remote world of trial-and-error, craft brickmaking. The sensitive reuse and interpretation of Western Clay’s largely-intact kiln

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3 Ibid., x.
complex will enable its beholders to envision a time when the ubiquitous red building brick was not merely the product of a computer-powered production sequence, but rather the fruit of a brick toser’s sweat and a fireman’s intuition. A study which focused exclusively on the kilns’ material state or potential redesign could indeed rescue the kilns from utter demise. But such work would do little to illuminate their meaning as machines—skillfully built and skillfully operated to produce valuable things in the past. This thesis begins, therefore, with the centuries-long trajectory of brick-firing technology, because the ideal conservation of Western Clay’s kiln complex—an intervention forging meaningful connections between now and then—will proceed only from a sound knowledge of the position the kilns occupy along this path.

This chapter is labeled a “contextual history” and exists in three parts. The first section, “Downdraft Kiln Technology,” expounds on the nuts and bolts of downdraft kilns—what purpose they were meant to fulfill and the parts of the machine that enabled them to fulfill it. This section will enable both the conservator and the bystander to understand the larger principles underlying kiln function (e.g., the conveyance of heat via draft), as well as the machine’s more specialized, even unseen, components (e.g., main and auxiliary flues). Comments here on the refinement of heavy clay kilns over time will assist readers in situating the Helena kilns within the larger sweep of industrial brickmaking technology.

The second section, entitled “The Downdraft Kilns of Western Clay,” then turns its full attention to the kilns on-site at today’s Archie Bray Foundation, offering specific details on their use, construction, and maintenance. Though this section will also help visitors understand what they see when they enter the kiln complex, it will prove to be a particularly useful reference tool for would-be conservators of the site, as the author suspects there are substantial links between the kilns’ past era of operation and the material degradation threatening them in the present.

Finally, a section entitled “The Significance of Historic Kilns for the 21st-Century Bray” explains why the preservation of obsolete, inoperable, industrial grade brick kilns is a worthwhile
pursuit for a non-profit residency center devoted to excellence in the ceramic arts. This section will revive the above notion of establishing evocative connections to the past, including additional commentary on the kilns’ historical meaning, rarity, and contribution to the Bray’s intangible sense of place—an aura known among artists and guests alike. If successful, this chapter will provide the historical, technological, and even theoretical support needed to proceed with the remaining chapters of the study and the conservation program itself.

2.1 Downdraft Kiln Technology

“We must be prepared to acknowledge that various forms of furnaces and kilns have a much longer history that we are generally prepared to admit.” 5 An insight on mankind’s prolonged infatuation with heat and heating, this statement, made by Dutch chemist and historian of science R. J. Forbes, is enough to humble any novice kiln researcher. Newcomers to the world of kilns may nonetheless take solace in the fact that, while civilizations have built with fired clay for several millennia, the kilns themselves changed relatively little until the industrialization of Europe in the eighteenth century. In fact, one could even argue that the most fundamental physical principles underlying kilns and kiln operation never deviated at all, remaining unchanged up to the present day. It makes sense to begin this technical history of the brick kiln with a review of these immutable kiln principles, followed by a review of the disparate components which, as a whole, enable the system to function.

2.1.1 Operational Principle and Kiln Components

In his 1958 book Personal Knowledge, Hungarian chemist and philosopher Michael Polanyi discusses scientific progress and achievement in a manner which is nicely analogous to heavy clay manufacturing. Any scientific patent, Polanyi argues, inevitably seeks to define an invention’s operational principle—“How its characteristic parts fulfill their special function in

combination to an overall operation which achieves the purpose.” If one applies Polanyi’s notion of the operational principle to a device like the brick kiln, one would ultimately arrive at the following “special functions,” which, in concert, fulfill a kiln’s sole purpose of firing clay: heat generation, heat containment, heat transfer to the ware, and the preservation of a stable environment for the ware. Defined by its operational principle, then, a brick kiln is any structure, permanent or impermanent, that achieves brick production via heat generation, heat containment, heat transfer, and the preservation of a stable setting.

The one “special function” to have changed most dramatically over the ages is the third from the list above: heat transfer to the ware. To accomplish their task, kilns have always utilized nature’s relentless pursuit of thermal equilibrium—the flow of heat, as dictated by the second law of thermodynamics, from regions of high temperature to regions of low temperature. Only the method by which kilns have harnessed that flow has evolved. The most primitive brick-firing would have been akin to the mere placement of unfired, or green, brick in a campfire. Exploiting the natural, upward convection of hot air from the smoldering coals to the cooler air above, early brickmakers founded what is now known as the updraft kiln. Categorized variously as clamp, scove, or “Scotch,” updraft kilns are, in essence, carefully arranged masses of green brick fired from below. Eventually, clayworkers in the nineteenth century found that if they could reverse the flow of heat—from the top of the setting of green brick downward and out its bottom—the effects of firing would be achieved more evenly and efficiently than ever before. Though the finer details of kiln evolution are elaborated upon below, it suffices here to know that such “top-down” kilns are labeled, quite logically, downdraft kilns. Downdraft kilns are distinguished by their barrel- or dome-like, “beehive” appearance, and were the firing machines most trusted by

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brickmakers at the turn of the twentieth century. That Charles Bray supervised the construction of at least six such kilns at Western Clay between 1897 and 1916 is a testament to this fact.7

“To all appearances the down-draft kiln is a simple affair,” writes A. F. Greaves-Walker in his 1919 manual Clay Plant Construction and Operation. “Yet it is with wonder and not a little awe that one goes about this continent and observes what a difficult and intricate proposition the average clayworker has made of it.”8 Ostensibly, the downdraft kiln is indeed a simple affair. The space, either round or rectangular, is set with ware. Fires are ignited and stoked, surrounding the ware at grade. The products of combustion first pass up and over the ware, and are then drawn through the setting by the improbable, earthward draft—a heat flow engendered by the connection of the kiln’s firing chamber to a network of underground flues via perforations in the floor. These flues ultimately lead to a chimney stack, where the kiln’s waste heat is exhausted into the lower temperature, lower pressure outdoor air beyond (Fig. 2.1).

While the likes of Alfred B. Searle, a prolific English writer in ceramic engineering, proclaimed downdraft kilns “among the best single chamber kilns known,” the device faced its share of skepticism and criticism, beginning in the mid-nineteenth century.9 “[Downdraft kilns] are as good and in some respects better than the up draft [sic] furnace kilns,” wrote Morrison in his 1890 Brickmakers’ Manual. “They are, however, in proportion to their capacity, much more expensive... Another objection is that the kilns are not so easily filled and emptied, the arch being in the way.”10 Indeed, poor accessibility, low firing capacity, heat loss (via the indirect exposure of the brick to the fuel), and the high cost and complexity of construction all provoked controversy surrounding the use of downdraft kilns in nineteenth-century brickmaking. Many seasoned veterans of the brickyard, like the grizzled John Crary, for example, dismissed the

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9 Alfred B. Searle, Modern Brickmaking (London: Scott, Greenwood & Son, 1911), 244.
downdraft kiln and its complications, voicing confidence instead in time-tested iterations of the updraft kiln: “The main thing involved in the question of kilns is economy in labor and fuel… A perfect brick can be burned in an old-fashioned ‘cased up’ kiln.”

In the undeniable uniformity and cleanliness of its burn, however, as well as its ability to achieve higher temperatures higher up in the kiln (thus lowering the risk of over-firing and distortion in ware set at grade), the downdraft kiln was, for many others, an appealing instrument. “The down-draft kiln, whether circular or rectangular, is the most efficient and satisfactory of all single kilns, yielding the most perfect colour and the lowest fuel consumption of any intermittent kiln,” wrote Searle. The downdraft kiln “turns out more high-grade ware than any other kiln,” praised Lovejoy in his pragmatic 1913 manual Economies in Brickyard Construction and Operation. And for brickmakers aiming to produce more than just common brick, downdraft kilns offered not only an enhanced ability to control the firing process, but also greater flexibility in the types of ware one could fire. For Charles Bray and his son Archie, the downdraft kiln provided an open-plan firing chamber the updraft “Scotch” kiln did not. In all likelihood, the downdraft kiln enabled them to diversify their production to include everything from salt-glazed sewer pipe and face brick to earthenware flower pots—specialty clay wares which were, unlike common brick, impossible to fire in rectilinear updraft kilns.

With the basic principles of the downdraft kiln in hand, it is appropriate to turn now to the machine’s constituent parts. An overview of kiln anatomy is useful both in examining the

11 J. W. Crary, Sixty Years A Brickmaker: A Practical Treatise on Brickmaking and Burning (Indianapolis: T. A. Randall & Co., 1890), 18. Crary is likely referring here to the permanent scove type of updraft kiln, which is described below.
12 Searle, Modern Brickmaking, 248. Searle’s reference to the downdraft kiln as a “single” or “intermittent” kiln distinguishes the machine from “chamber” and “continuous” kilns—kilns that are, respectively, composed of multiple chambers and fired in rotation on a continuous basis. This dichotomy is further explored below.
14 This statement is admittedly conjectural. Quivik cites the arrival of sewer pipe and flower pot machinery as part of an early push by Charles Bray to upgrade Charles Thurston’s Helena brickyard after its purchasing by Nicholas Kessler in 1885. The first three downdraft kilns first appear on an inventory taken thirteen years later, in 1898. In all of his research, the author did not find an explanation of how glazed or cylindrical clay units might be fired in rectilinear clamp, scove, or Scotch kilns. Thus, if Bray and Kessler indeed produced such wares prior to their investment in round downdraft kilns, the author is relatively certain that such an upgrade in firing technology would have greatly boosted their production capabilities. See Quivik, Western Clay Manufacturing Company: An Historical Analysis, 9-10.
Bray’s prototypes, and in understanding the debate, excerpted above, which swirled around the device and its merits at the time of its arrival in Helena. The following paragraphs tackle the make-up of a typical round downdraft kiln in segments, progressing much like the heat generated in such a device, from the ground up and then back down again.\textsuperscript{15}

**The Firebox**

A firebox is the permanent, arched opening in a kiln wall that houses the fuel and powers the firing process. Downdraft kilns usually sport ten to twelve fireboxes, whereas some updraft kilns accommodate as many as twenty.\textsuperscript{16} At the minimum, coal-powered fireboxes contain a door for charging the fire, a grate for the ignited fuel, an ashpit for burnt debris, and some means for the air circulation required in combustion. From the firebox, heat and combustion gases enter the kiln via the bag wall.

**The Bag Wall (Fig. 2.2)**

Bag walls are constructed inside a kiln’s firing chamber to act as a barrier between each individual firebox and the setting of brick. In deflecting the products of combustion upward and along the curvature of the kiln roof, bag walls protect the ware from direct, potentially damaging exposure to heat. Bag walls may be square, rectangular, or even semi-circular in plan, and are sometimes substituted by a flash wall—one unbroken barrier extending along the entire circumference of the kiln.\textsuperscript{17} The throat is the opening at the top of the bag or flash wall through which heat and combustion gases travel on their path toward the top of the kiln.

\textsuperscript{15} In this and the following sections on kiln components, performance, and history, the author has, for the sake of simplicity, elected to conjugate verbs in the present tense. Readers should nonetheless take note that in modern, industrial brickmaking, many of the kilns described here are virtually obsolete. For more information on the few American downdraft kilns to have survived into this century, please see Appendix A.


\textsuperscript{17} *Ibid.*, 248-9.
The Crown

The crown is the dome of a downdraft kiln. The contour of the crown allows space for combustion, while also funneling heat toward the center of the chamber, where it is drawn down through the brick setting to exhaust flues beyond. Good crowns are relatively shallow (e.g., a six-foot rise over at least a thirty-foot span) and are built with key and wedge-shaped refractory brick. Crown brick are never laid in mortar, but are instead dipped in clay slurry and pounded with mallets into place. Peep holes exist in the crown both to ventilate the kiln during cooling and to enable workers to monitor the ware during firing. Most crowns are roughly nine inches thick (i.e., the length of a standard refractory brick wedge), although it is customary to insulate a crown with an additional, exterior layer of burnt ash and lagging—a single wythe of brick coated with lime-cement mortar.

The Kiln Walls

A kiln’s walls constitute a highly complex system of independent, mobile assemblies: the interior wall or lining, the exterior wall, and iron banding. The lining is built with refractory brick dipped in clay slurry and laid typically to a thickness of one or two wythes (i.e., four and a half or nine inches, respectively). The exterior wall is usually composed of common brick laid to a thickness of twenty-seven inches or more. While the outer wythe of this wall is mortared with lime-cement, the remainder of the wall is laid up in clay to allow for thermal movement during firing. Because different localities in the kiln are exposed to varying levels of heat, the thermal

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19 Greaves-Walker, Clay Plant Construction and Operation, 100.
20 Ibid., 101. In industry literature, the author has seen “lagging” referred to alternatively as “plating.” See Lyon, “Kiln Construction,” 200-1.
21 Ibid., 94. Greaves-Walker recommends the use of especially porous common brick in constructing the portions of the kiln wall abutting the interior lining, as porous brick act as better insulators of heat. By mixing sawdust with shale or clay, he writes, such high porosity brick may be produced in-house, specifically for the purpose of kiln construction.
22 Ibid., 95. “A 3 to 1 [aggregate to binder] cement mortar with 10% lime putty added is practically unequalled for this purpose,” writes Greaves-Walker. Lyon, meanwhile, advocates the use of a fireclay mortar consisting of 50% ground
expansion and contraction of the walls is differential. The interior lining, for example, expands more than the outer wall to which it is sometimes not even tied. Damage and the risk of damage to kiln walls are compounded with age and use, as masonry voids left from prior firings become increasingly filled with hardened brick fragments, sand, and other debris. In the lack of diligent maintenance and oversight, these materials accumulate and exert, in turn, ever increasing amounts of force on the kiln walls during subsequent expansion. While nearly all downdraft kilns are braced with iron bands to help control expansion, some kilns are completely encased in iron, a method endorsed by Carl Harrop in his 1915 paper on kiln expansion and bracing.

**The Bottom (Fig. 2.3)**

The term “bottom” encompasses both the kiln’s floor and its network of exhaust flues below grade. Kiln bottoms may be classified as solid or open. In solid-bottom kilns, there are no floor openings except for one or two perforations directly over the main flue of the kiln, often at the center of the firing chamber. In open-bottom kilns, the floor is composed of evenly-spaced brick or ceramic tile, allowing the flow of heat across the entire surface area. Solid bottoms are also known as “dead” bottoms. Open bottoms appear in trade literature as “riddled” or “checkered bottoms,” as well. Beneath a kiln’s bottom, one will find a cross formed by perpendicular main and auxiliary flues, with secondary flues sloping down to join the two axes. The various flues are separated by thin partitions known as feather walls. In order to avoid amplified expansion stresses stemming from the undue accumulation of debris, the entire flue

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brick and 50% raw clay, ground fine, for the non-exterior wythes of kiln masonry. See Lyon, “Kiln Construction,” 199.


system must be periodically cleaned. Most flues are therefore high and wide enough to accommodate the unlucky workman (with wheelbarrow) assigned to the task.27

**Stack / Dampers**

The stack and associated dampers represent the “end of the line” for a kiln’s draft, and their performance can dramatically influence the quality of a firing. In round kiln construction, one stack often serves flues from two or four kilns.28 The stack generates the pressure differential, or draft, that pulls heated air through and out of a kiln. Dampers may be opened and shut at various points along the system—including at the base of the stack itself—to further manipulate convection. Natural draft becomes mechanical draft when a third, mechanical party augments the flow.29 Mechanical drafts may be generated by a massive fan attached to the flue network, or by a series of heating coils wound up the stack.

“The writer does not think it would be far wrong to say that more than half the kilns built are practically wrecked within the first five years thru [sic] poor workmanship.”30 Greaves-Walker’s grim assessment of downdraft kiln-building in America at the dawn of the 1920s is reason enough to examine more closely the traits shared among well-built, well-functioning brick kilns. Brief commentary on the consequences of poor kiln construction and maintenance follows.

**Kiln Foundations and Moisture Control**

Where a kiln’s positioning renders natural drainage impossible, a sump should be installed and pumped regularly. Footings should be carried slightly below the deepest flue, and a full setting of brick should always be included in design-phase load calculations.31 Some provision should be made for the collection and diversion of rainwater off of the kiln roof and

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28 Ibid., 86.
31 Ibid., 81-3.
away from the foundations—not only for the sake of the kiln’s masonry, but for the sake of its productivity. The infiltration of moisture into the kiln during firing may adversely affect the thermal efficiency of the kiln, perhaps even triggering the deformation or explosion of wetted ware.

**The Fireboxes – Grate, Bag Walls, and Throat**

The grate area is the surface area within the firebox allotted for the combustion of fuel, and is determined with respect to the total floor area of the kiln. A ratio of 1 to 7.5, respectively, is ideal. Flat grates protect workers from heat during the charging of coal better than inclined grates. (This was an important feature during the coal-burning era, as workers were ultimately responsible for stoking the fires and preserving the draft necessary for effective burning.) Excessively high bag walls and overly-narrow throats may slow firing, or—in the case that they become clogged with broken material—block the process entirely. Altogether, the firebox, associated openings, grates, and bags must be able to induce both oxidizing and reducing atmospheres—kiln conditions familiar to potters and brickmakers alike.

**Walls, Banding, and Expansion Joints**

According to Harrop, iron banding should not be used without considering the utility of expansion joints in the kiln's masonry. Provided that vertical (or header) joints are laid at a thickness of one-eighth inch, half-inch clay expansion joints staggered in sixteen-foot increments lengthwise across a kiln’s exterior elevation may compress to accommodate up to fifty-eight percent of lateral kiln expansion at 1200°C, or 2192°F. When too thin, such joints obviously cannot accommodate the extreme thermal expansion engendered by the firing process. When too

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34 Harrop, “Kiln Expansion and Bracing,” 60. 1200°C. corresponds roughly to cone six and is a typical soaking temperature for brick, though Western Clay face brick was reportedly fired to cone four, approximately 1180°C. Harrop reports that sixteen lineal feet of kiln wall may expand nearly one and a quarter inches when heated to 1200°C. In a circular plan, the vector for such expansion would obviously manifest itself in an outward, radial direction.
thick, however, they are liable to fail during the differential cooling of the kiln. Harrop notes that banding used to support the crown is often redundant, adding undue weight to the top of the kiln. Solid construction and persistent up-keep should limit the unwanted accumulation of debris in locations prone to expansion.

The Crown

The crown should always rest on the kiln’s exterior wall—never on the thinner, more mobile, inner lining of refractory brick. To ensure a proper height, a straight line drawn from the springing of the crown to its pinnacle should approximate one-fourth the length of the kiln’s overall diameter. Crowns should never be built with rectilinear brick—only with keys and wedges—and an arch of small radius is preferable to a standard skewback for springing the crown off the wall. In section, the crown thus resembles more of a low-slung Tudor arch than a normal segmented arch springing off a skewback or impost (Fig. 2.4).

Ventilation System – Bottom, Flues, Stack(s), and the Setting of Brick

Open bottoms are almost always more effective than closed, both in distributing heat evenly throughout the kiln and in maintaining a steady draft. Any infill of the kiln bottom should consist of water-impervious materials such as clinker brick or bats, as water driven from the ware as vapor during firing must pass through the bottom on its way toward the stack. Kiln bottoms inevitably suffer damage, so constructing secondary flues at 45° slopes enables debris to collect in the main and auxiliary flues for easier and less frequent cleaning. A round kiln thirty feet in diameter typically requires a forty-foot stack to generate sufficient draft. Stacks should include a refractory brick lining capable of movement during periods of thermal expansion and contraction, and each kiln in operation should command its own independent flue within the

35 Ibid., 80.
36 Greaves-Walker, Clay Plant Construction and Operation, 98.
37 Ibid., 98-9.
38 Ibid., 87.
stack. Finally, green brick should be battered back from the bag walls, or even shimmed to tilt toward the center of the kiln, so as to prevent dreaded “kiln tumbling”—the clogging of fireboxes with brick that have expanded in the heat such that they fall from their perch in the setting.39

What Can, and Often Did, Go Wrong

The myriad frustrations possible in the operation of a downdraft brick kiln may be loosely categorized into two groups: problems affecting the kiln’s draft (and therefore firing efficiency) and problems affecting the kiln’s structural health (and therefore service life). If the draft is suspect, the firing difficulties to potentially arise may include: thermal lag (i.e., the inability to achieve and maintain soaking temperature at an acceptable pace); the localized over- or under-firing of brick set in various spots within the kiln; the appearance of condensation and resultant distortion in the bottom courses of a setting (a phenomenon known as “wet bottom” or “water settling”); and an overall impetuousness or unpredictability on the part of the kiln.

Potential causes of such draft-related problems include, but are not limited to: improper setting technique, blockage in the kiln bottom, blockage in the firebox throats or bag walls, poor drainage (i.e., wet foundation), back-draft from a cold stack, excessive heat loss through the walls or crown, improper crown height, improper stack height, improper flue depth, et cetera.

A compromised kiln structure may be manifested in a variety of troubling symptoms: excessive bulging, or even collapse, of the kiln walls; abnormally short firebox service life; cracked or out-of-plumb chimney stacks; and a cracked, distorted, or partially collapsed crown. Potential causes underlying such structural issues include, but also are not limited to: the lack of expansion joints (both within single assemblies or at the interface of multiple assemblies), poor drainage (i.e., wet foundation), poor masonry work, lack of proper maintenance, excessive loading at the top of the kiln (i.e., redundant banding), improper use of building materials, lack of

39 Ibid., 71-3.
insulation on crown or within the stack and fireboxes, et cetera. Perhaps the downdraft kiln is not such a simple affair after all!

2.1.2 The Refinement of Heavy Clay Kilns Over Time

With a grasp of what downdraft kilns are, how they functioned, and how they sometimes failed to function, one might now wonder what circumstances gave rise to the machine which, quite literally, upended the brick-firing paradigm of its updraft predecessors. Similarly, one might wonder what breed of super kiln must have come about to render the once-revered downdraft obsolete. The following paragraphs address these questions, examining in greater detail the fine-tuning of brick kiln technology over time.

The Fundamental Clamp and Scove Kilns

The earliest and most basic type of brick kiln—that which would have been widely used in pre-Roman times—is the clamp kiln. A clamp is an informal, impermanent setting of green brick that is interspersed with combustible fuel, ignited as a whole, and left to burn. In fact, the comparison above likening the first updraft firing to the placement of brick in a campfire was an allusion to this rudimentary device. A clamp is built as follows. Atop a foundation of burnt brick, a primary bed of fuel (e.g., loose cinders, coke, wood brush, or garbage) is scattered to a thickness of about six inches. As many as thirty courses of green brick are then set strategically in and over the fuel, allowing for several openings—called “flues,” “eyes,” or “live holes”—near

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41 Some period manuals, like Dobson’s *Rudimentary Treatise*, distinguish clamps from kilns entirely, likely on the basis of their impermanence and monolithic construction. Dobson, for example, limits kilns specifically to those “chamber[s] in which the green bricks are loosely stacked.” Pursuant to the earlier definition of the kiln based on its operational principle, the author has consciously included the clamp here as a valid kiln type. See Edward Dobson, *A Rudimentary Treatise on the Manufacture of Bricks and Tiles* (London: John Weale, 1850), 38-42.
the base of the setting. These passages enable the airflow necessary for combustion. To combat instability resulting from shrinkage during firing, clamps are often constructed with a prominent, inward slope (Fig. 2.5). They may even be enclosed by four sides and a top of burnt brick—an insulation layer known as bestowing. Though brick in the bestowing may be arranged in various ways to stimulate or damper the upward draft, human control over the intensity, distribution, and duration of a clamp firing is relatively minimal. The fire is allowed to run its course, usually rendering about four-fifths of the total yield well-fired and suitable for construction. After cooling, the pile is simply taken down, with the over- and under-fired bricks being used in the foundations or bestowing of the next clamp.

According to English archaeologist Seton Lloyd, the first kiln-fired brick began to appear in “protoliterate” Mesopotamia—principally, the ancient Sumerian cities of Uruk and Eridu in modern day Iraq—around 2800 BC. Norman Davey adds that by the end of the 2000 BC, fired-brick construction was being carried out in Sumerian Lagash and Ur (also modern-day Iraq), and in the cities of Harappa and Mohenjo-Daro (modern-day Pakistan). Clay was abundant in the Tigris, Euphrates, and Indus River valleys, and though its silt content was high, the material could be mixed with chopped straw and reeds before firing for added cohesive strength. However, because only straw, animal dung, or, at best, brushweed would have been available as fuel in such arid climes, the use of fired brick was limited to important monuments such as temples, palaces, and burial shrines.

Although the impermanent nature of clamp kilns has precluded extensive archaeological documentation of their use, it is likely that clamp-burning would have been the first and only

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44 *Small Scale Brickmaking*, Chapter VII.III: Kiln Design.
brick-firing technique available to ancient Mesopotamian and Indus River valley cultures. Clamps could be assembled anywhere and at most any size. They could also achieve surprising efficiency—a product of both the structure’s great thermal mass and the close proximity of the ware to the fire. Thus, for areas lacking plentiful or steady reserves of solid fuel, clamp-burning was and remained an ideal method for brick production. That Edward Dobson carefully describes clamp construction in his 1850 treatise chapter “Brickmaking in the Vicinity of London” is proof of the technology’s resilience over time. It also corroborates the notion that refinement in brick-firing—and in industrial manufacturing, at large—was never a clear-cut maturation from one technology to the next. Indeed, as seen on the grounds of Western Clay, brickmakers often employed old technologies adjacent to, and even in concert with, the new.

Archaeologist F. R. Matson suggests that by the mid-fifth century BC, the Babylonians were probably firing brick in scove kilns using clay excavated for the construction of municipal moats—a claim he bases on a colorful passage from the Histories of Herodotus. Scove kilns resemble clamps insofar that they are impermanent. They are built in arches of carefully-arranged green brick, however, which form fire tunnels in the setting and enable the use and replenishment of bulkier forms of fuel such as timber. Also, unlike the occasional bestowing layer seen on clamps, the outer portions of a scove kiln are often daubed with clay for added insulation (Fig. 2.6). This messy exterior skin is called, appropriately, scoving.

The Babylonians might have been the first to employ scove kilns in ancient Mesopotamia, but the device persisted in both Europe and North America deep into the

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47 Edward Dobson, A Rudimentary Treatise. The chapter mentioned above falls under “Rudiments of the Art of Making Bricks and Tiles,” the second part in the treatise’s rather inscrutable organization. Those pages detailing clamp-firing in nineteenth-century London may be found on pages 27-38 of this second part.
48 F. R. Matson, “The Brickmakers of Babylon,” in Ceramics and Civilization, Volume I: Ancient Technology to Modern Science, ed. W. D. Kingery (Columbus, OH: The American Ceramic Society, 1985), 70-1. Describing the great walled city of Babylon, Herodotus writes: “And here I may not omit to tell the use to which the mould dug out of the great moat was turned, nor the manner wherein the wall was wrought. As fast as they dug the moat the soil which they got from the cutting was made into bricks, and when a sufficient number were completed they baked the bricks in kilns...” See The History of Herodotus, Vol. I, tr. George Rawlinson (New York: The Tandy-Thomas Company, 1909), Book I (Clio), Paragraph 178, 174-5.
49 Clews, Heavy Clay Technology, 236.
nineteenth century, often under pseudonyms like “field kiln” or “cased-up kiln.” The scove kiln’s simple construction, its relatively high fuel efficiency (again due to the close proximity of the ware to the fuel), and the relative ease with which it could be set and unloaded, or drawn, perhaps contributed to its longevity. Of course, many later scove kilns were fired with coal or gas, and featured permanent side walls, firebox openings, and retractable wood-plank roofs to protect the workers, fuel, and draft from wind and rain (Fig. 2.7).\(^5\) Thus, the line between permanent scove kilns and the “Scotch” kilns described below is somewhat blurred.

Much like the clamps of the ancient Sumerians before, the physical traces of early Babylonian scove kilns have disappeared entirely. Luckily, because such kilns are still employed to fire brick in developing nations around the world, a paucity of archaeological evidence may not impede today’s intrepid kiln enthusiast from seeking out and experiencing scenes similar to those Herodotus so vividly describes from his travels in Mesopotamia.\(^5\) That this single method of manufacture has survived 2500 years (and counting) is further proof that in brickmaking, trusted technologies—no matter how arcane—die slowly.

**Roman Refinements**

In antiquity, the firing of brick in large quantities could have only taken place in regions boasting a reliable supply of fuel. In Egypt, for example, timber was simply too scarce to be employed in firing brick.\(^5\) In ancient Greece, the transition to fired architectural clay products was also slow, and likely began with more specialized forms such as the terra cotta roof tile. Kiln-fired brick followed in the Hellenistic period, from around 320 BC onward. In Italy, the earliest fired-brick constructions were probably the Etruscan walls at Arezzo, dating to roughly

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\(5\) Ibid.

\(5\) A simple internet search for scove kilns will produce images of contemporary scoves used anywhere from Madagascar and Mexico to India and Uganda.

300 BC.\textsuperscript{53} And although kiln-fired brick was used in Rome in the Sullan period (138-78 BC), it did not become common until about the time of Julius Caesar. Again, the use of fired terra cotta roofing tile was initially more prevalent than that of fired brick.\textsuperscript{54} While updraft kiln types of course continued to predominate under the Romans, the tradition of firing clay repeatedly in more permanent structures gradually took hold.

Updraft kiln types excavated and documented in Roman Sicily feature sophisticated details not seen on the early clamp and scove kilns of the Near East. As firing chambers linked to sub-grade flue networks, the Sicilian kilns employed an indirect method of heat transfer, thereby shielding ware from unwanted damage or distortion. Roman Sicilians also built kilns into hillsides, utilizing natural wind patterns to augment the upward draft.\textsuperscript{55} While Roman techniques of draft manipulation and flue construction presaged changes to occur with the rise of downdraft kiln technology much later, the Roman updraft kilns were not the very first of their type. A similar kiln dating to 2000 BC was excavated at Khafaje near present-day Baghdad and is cited by Norman Davey.\textsuperscript{56} Nonetheless, the Romans did succeed in standardizing more advanced updraft technology, and broadcasted it, as they did so many facets of their culture, across the European continent.

For example, Roman-era updraft kilns in England could achieve temperatures approaching 1000°C, or 1832°F, a temperature approaching the vitrification range for most brick and tile clays. A prototype excavated by Davey near St. Albans in Hertfordshire was built from ceramic fragments set in clay and positioned partially below grade for added stability and insulation. Its floor was set at ground level for easy access despite the structure’s somewhat precarious position on the windward slope of a hill. An elongated firing tunnel increased draft

\textsuperscript{53} Ibid., 69.
\textsuperscript{54} Ibid.
\textsuperscript{55} Ninina Cuomi di Caprio, “Pottery- and Tile-Kilns in South Italy and Sicily,” in Roman Brick and Tile: Studies in Manufacture, Distribution and Use in the Western Empire, ed. Alan McWhirr (Oxford: British Archaeological Reports, 1979), 73-96.
\textsuperscript{56} Davey, History of Building Materials, 66.
while an open-bottomed oven floor enabled the passage of combustion gases through the setting and out the top of the ware (Fig. 2.8).\(^{57}\) In such adroitly conceived and constructed kilns, the firing of clay building materials arguably reached its early technological zenith.

**Firing Brick in the Middle Ages and After**

“With the collapse of the Western Roman Empire brickmaking virtually ceased in Europe and Britain,” writes Davey.\(^{58}\) The manufacture of brick was a long, laborious process, possible therefore only under the most stable social and political circumstances. The need to erect buildings of a permanent character was another precondition for brickmaking that, throughout much of the Middle Ages, rarely arose. In spite of such unrest, however, it is improbable that brickmaking “know-how” was ever entirely lost. The earliest written description of brickmaking is thought to be contained in a letter dated 1683, in which a fellow named J. Houghton recounts the firing process to the sheriff of Bristol, England: “When we begin a new brick ground, for want of burnt brick we are for’st to build a kiln with raw brick, which the heat of the fire by degrees burns… Afterwards we make it with burnt brick and we choose for it a dry ground… At the bottom [of the kiln] we make two arches three foot high.”\(^{59}\) What Houghton seems to be describing is the slow transition from a clamp or scove kiln—“a kiln with raw brick”—to a permanent kiln of fired brick, a device known now as the “Scotch” kiln.

Like scove kilns, Scotch kilns are open-topped, rectangular structures, operated on the updraft principle. And like later scove kilns, Scotch kilns feature permanent side walls, wickets (i.e., doors), and fireboxes for repeated use. Medieval Scotch kilns would have operated on wood burnt in open fireboxes, while later models—again, like later scove kilns—sported grates or burners for the use of coal or gas, respectively. All told, the main and perhaps only characteristic

\(^{58}\) *Ibid.*, 78.
distinguishing Scotch kilns from their scove counterparts is the fact that the entire base of the kiln, including the tunnels running beneath the setting, is permanently built using fired brick (Fig. 2.9). As described above, the base and fire tunnels in scove kilns are laid up with green brick, constructed and disassembled with the kiln itself.

By the seventeenth century, Scotch kiln technology had crossed the Atlantic Ocean, first taking form in the New World at the Jamestown colony of Virginia. Not surprisingly, the Jamestown brick kiln is similar to the model described by Houghton and commonly employed in England at the time. Permanent fire tunnels run across the width of the permanent foundation, indicating where the timber fuel would have been burnt and replenished during firing (Fig. 2.10). Approximately twelve to fifteen vertical feet of green brick—as many as 50,000 units—would have rest upon these tunnels, the solidity of which is illustrated by their long survival: built and fired as early as the mid-seventeenth century, this particular kiln was unearthed by National Park Service archaeologists between 1935 and 1941. The kiln's permanent foundation and walls would have hindered the transport of moisture into the vulnerable, green setting, and cleverly, so as to avoid damage during periods of extreme heat and thermal movement, the kiln’s permanent bricks were laid in loam as opposed to lime mortar.

If Mr. Houghton knew of the export of his humble Scotch kiln to America, he certainly would not have envisioned the design persisting up until the 1960s, as it did both in Britain and the United States. The Scotch kiln is a type which should be well known among Helena natives, as two of Charles Bray’s buttressed Scotch kilns survive in part on the grounds of the Bray as the Summer Kiln Pad and Warehouse No. 3. These structures account presumably for two of the

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60 Small Scale Brickmaking, Chapter VII.III: Kiln Design.
62 Ibid., 27.
63 Reid, (In)Forming and Pressing Matters, 95-6.
four Scotch kilns present at the WCMC in 1916. Last fired in 1924, they were outfitted with gable roofs and converted for storage in 1935.64

**Downdraft Kilns – Old and New**

The exact origin of the downdraft brick kiln is somewhat unclear. Eric Rowden, a British ceramic scientist, asserts that well-designed, round downdraft kilns, or “beehive ovens,” were in use before 1870.65 Hammond, meanwhile, cites Thomas Minton’s 1873 patent for a porcelain kiln to be the design from which most downdraft brick kilns were, at least in England, subsequently derived.66 An illustration of Minton’s kiln may be found in an 1878, Parliament-sponsored report on effluvium nuisances in heavy industry, and the device clearly does exhibit the downdraft principles seen in later beehive brick kilns (Fig. 2.11). Hammond’s claim is undercut, however, by the Parliamentary report’s author, who, at a time when Minton’s kiln is a mere five years old, notes and even illustrates the use of downdraft kilns in the firing of blue Staffordshire brick.67 The possibility that Staffordshire potters like Minton devised kiln designs which were so quickly adopted and modified by local blue-brick manufacturers seems remote. Nonetheless, perhaps the potteries and brickyards of Staffordshire merit further investigation. Perhaps there, where the exchange of material, labor, and knowledge between the fine and heavy clay industries must have been intense, the downdraft kiln fired brick for the first time.68

68 Given the immense competitive pressure among European potters in the seventeenth- and eighteenth centuries to innovate and devise ever more sophisticated clay bodies and glazes, it is certainly likely that downdraft firing caught on first among producers of fine ceramics, spreading later to brickmaking and the heavy ceramics industries.
Their provenance aside, the earliest downdraft kilns would have exhibited the basic principles of draft and heat transfer described in the previous section. They would have likely had but one flue, however, connected to either an external stack or an internal stack that projected through the crown. Early downdraft kilns also would have been smaller than twentieth-century examples. The 1880 kiln at the Loscoe Brickworks in Derbyshire, England, was twenty-two feet in interior diameter with a capacity of 25,000 brick. Diameters of thirty to thirty-six feet were preferred later, especially in North America, as evidenced by the larger dimensions of the downdraft kilns at Western Clay. Such kilns could likely accommodate upwards of 50,000 brick.

Myriad improvements to downdraft kiln designs were patented between the 1870s and 1890s, with the bulk of alterations aimed at achieving more efficient draft management and insulation. To address problems in heat distribution and water settling, an array of flues were developed, including parallel flues, radial flues, ring flues, and combinations thereof. As early downdrafts began to age and deteriorate, the use of diatomaceous earth as insulation in either brick form or as powdered cement became prevalent in quick repairs and retrofits made to kiln linings and crowns. Then, in an effort to cut labor costs, some designs even incorporated mechanical firing via coal stokers. This final improvement, however, was often made to poor effect.

In the initial decades of the twentieth century, an increased desire on the part of plant owners to recover waste heat and boost efficiency resulted in the development of methods linking multiple downdraft kilns via underground flues. Thus, multiple intermittent kilns—that is, kilns that needed to be set, fired, and cooled on an independent, periodic basis—could be fired in nonstop rotation, with, for example, the waste heat of one cooling kiln helping to initiate its

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70 Rowden, “Firing in the Heavy Clay and Refractories Industries,” 785. Diatomaceous earth (also known as diatomite or kieselguhr) is a soft, siliceous sedimentary rock, consisting largely of the fossilized remains of diatoms, a type of hard-shelled algae. Aside from its use as a thermal insulator, diatomite was discovered by Alfred Nobel to be the ideal stabilizing component for nitroglycerin in the appropriately-named explosive dynamite.
71 Ibid., 788.
neighbor’s burn. In 1918, the Minter System proposed the operation of nine downdraft kilns in concert so that fuel would be used only for the highest-temperature stages of firing (Fig. 2.12). Drying and preheating were accomplished using, respectively, hot air from cooling kilns and waste gases from firing kilns. This elegant method enabled plant owners to fire continuously, without having to invest in the wholesale replacement of pre-existing downdraft kilns.72

Nevertheless, for all the attempts at its enhancement in the first half of the twentieth century, the downdraft kiln was not destined to enjoy the long reign known by its updraft predecessors. An increasingly-competitive, increasingly-mobile brick industry demanded higher standards in efficiency, output, versatility, and durability. Thus, the paradigm in brick-firing technology began to shift yet again—away from intermittent devices such as scove, Scotch, and beehive kilns, and toward the ever more appealing notion of a fully-functional, affordable, and freestanding continuous kiln. A practice once grounded in century-old craft traditions, brickmaking seems to have grown rather fickle in its industrial adolescence.

The World of Continuous Kilns

In actuality, the rise of the downdraft kiln coincided with the slower but inexorable ascent of the continuous kiln. “Continuous kilns have increased steadily in popularity during recent years,” wrote Searle in 1911, “and though still misunderstood and mismanaged by many brickmakers, the prejudice which existed against them at one time is slowly dying out.”73 While Chinese potters had supposedly developed by 2000 BC a strategy for recycling waste heat from their high-fire porcelain kilns, the first commercially successful and widely used continuous kiln for brick was a chamber kiln patented by Prussians Hoffmann and Licht in 1858.

72 Ibid., 788-90.
73 Searle, Modern Brickmaking, 263.
First built near present-day Szczecin, Poland, the Hoffmann kiln began as a circular structure, limited by its shape to twelve distinct firing chambers (Fig. 2.13). In the center of the structure stood a tall exhaust stack, which was fed by twelve underground flues radiating from the inside wall of each individual chamber. The chambers themselves were barrel-vaulted and operated on the downdraft principal. Set and drawn via doors on their exterior elevation, the chambers were stoked from above by coal, which would fall and burn at the foot of the brick setting. Essentially, two of the twelve chambers fired at all times, while the opening or closing of dampers in the flue network enabled the other chambers to either cool, discharging excess heat, or warm-up, pulling in excess heat emitted from the cooling chambers. By 1870, Hoffmann had altered the shape of his Ringofen to that of a large oval or ellipse—a form which would accommodate more brick. A schematic drawing depicting the simultaneous firing, cooling, and warming of such a kiln underlines the fundamental principle behind early continuous firing: the kiln and brick remain stationary; the fire does not (Fig. 2.14).

Provided they were continuously built upon with new green brick, clamp and scove kilns could be operated on a continuous basis, as well, with the fire line slowly marching across the setting. The Hoffmann kiln and its descendants were superior, however, for their high fuel efficiency. “This type of kiln,” write Searle, “is characterized by a remarkably low fuel consumption...” Construction costs are high, he continues, “…though not so high in proportion as many brickmakers are apt to suppose.” Dominant in Germany, the Hoffmann kiln was modified in Britain, growing to tremendous size as the Manchester and “super” Staffordshire models. By 1950, more than ninety percent of common and face brick in Britain were fired in these brands of transverse-arch, continuous chamber kiln. Prussian kiln innovation even

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75 Rowden, “Firing in the Heavy Clay and Refractories Industries,” 772.
77 Rowden, “Firing in the Heavy Clay and Refractories Industries,” 817. In 1935 a continuous kiln was built with 80 chambers, each 85 feet long with a capacity of 74,000 brick!
reached as far as the American West. In 1907, the Butte Sewer Pipe and Tile Company constructed a Hoffmann continuous kiln—the first of its kind in Montana.\(^78\) Robert Schmidt and George Firestone, meanwhile, offered to design and draft construction plans for Hoffmann continuous kilns via mail correspondence from their offices in, of all places, Helena (Fig. 2.15). 

Of course, the device to ultimately eclipse all others was the tunnel kiln—the kiln used today in most modern brick plants. As its name suggests, a tunnel kiln reverses the Hoffmann paradigm, holding the fire stationary while putting into motion the brick itself. According to Rowden, a tunnel kiln had been built as early as 1751 in Vincennes, France, for firing glaze on porcelain. The tunnel kiln for brick, however, was first patented in England by E. Peters in 1858.\(^79\) Many early prototypes failed due to difficulties in controlling the overheating of car components and rails. As a result, plant owners attempted to substitute rails with ball bearings, chains, and even water. While Otto Bock developed a more effective sand-seal method for insulating rail in 1877, it was still another thirty-plus years before Dressler’s muffle kiln became, in 1910, the first tunnel kiln to enjoy reasonable market success.\(^80\) Between 1919 and 1930, then, Carl Harrop developed a direct-fire tunnel kiln, a direct antecedent to most modern tunnel types. Indeed, the two tunnel kilns installed at Western Clay in 1957 under the command of Archie Bray, Jr., were Harrop kilns.\(^81\)

In reviewing the myriad changes to occur in brick-firing technology between 1850 and 1950, it is important to consider what factors might have prompted such a swift pace of innovation. British ceramic scientist Noble notes that, “…up to 1860 the industry had relied mainly on traditional methods. Up to 1900 it had very little technical background.” Prior to the 1890s, he continues, “…there were no trade publications to foster its interests and there was only

\(^{78}\) J. P. Rowe, “The Butte Sewer-Pipe & Tile Co., Butte, Mont.,” Brick 26, no. 6 (1907): 291-2.
\(^{79}\) Rowden, “Firing in the Heavy Clay and Refractories Industries,” 775.
\(^{80}\) Ibid., 777.
\(^{81}\) Quivik, Western Clay Manufacturing Company: An Historical Analysis, 22.
very limited collaboration within the industry.”

Reading Noble, one begins to sense the importance that early efforts to organize and disseminate new research in heavy ceramics must have had on the industry. Between 1884 and 1896, no fewer than six different journals appeared in the United States devoted to brick production, brick-laying, or architectural design in brick. The list includes the *Clay-Worker* (1884, Indianapolis); *Brickbuilder* (1892, Boston); *Clay Record* (1892, Chicago); and *Brick* (1894, Chicago). Professional organizations in heavy ceramics began to appear, as well, including the National Brick Manufacturers’ Association (1886, Cincinnati) and the American Ceramic Society (1899, Westerville, Ohio).

Perhaps of most significance for American brickmaking, however, was the founding of the nation’s first ceramics engineering department at the Ohio State University in 1894. The New York State School of Clay-Working and Ceramics followed in 1900.

Lobbying for the creation of a university program in ceramic engineering, Edward Orton, Jr., founder of the Ohio State program, wrote: “Ceramics, or more plainly speaking, the science of clay working, is a complex study which requires in its explanation the aid of nearly every branch of engineering science. No college course or degree covers exactly the range of work needed to successfully prosecute this study...” Orton’s determination to establish clayworking as a science alongside more aged, revered disciplines embodies the tenacity and innovative spirit that drove the remarkable development of kiln technology during his lifetime. The trailblazing achieved by Orton and his brethren—his faculty at Ohio State included, for example, Carl Harrop—would leave a lasting mark on American brickmakers like Archie Bray, Sr., who himself graduated from Ohio State’s ceramic engineering program in 1911, two years prior to becoming foreman at the WCMC.

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83 The New York State School of Clay-Working and Ceramics is now known as the New York State College of Ceramics, a statutory college operated by Alfred University.
2.2 The Downdraft Kilns of the WCMC

Having examined the downdraft kiln broadly, with an eye for its technical specifications and historical development, the study now turns to the subjects of conservation—the downdraft prototypes which survive on the grounds of the Bray. The following section includes information regarding the historical evolution of the WCMC kiln complex, as well as the firing process which unfolded there up until approximately fifty-six years ago.\textsuperscript{86} Finally, the design, construction, and maintenance details of the Bray’s kilns will be explored in depth through the lens of Kiln No. 7—a kiln which, on the basis of its good condition, has been the subject of intensive investigation, documentation, and even trial conservation since the University of Pennsylvania’s first arrival on the site in the summer of 2011.\textsuperscript{87} Aside from providing context for the understanding of the complex’s development and past industrial use, the information offered here will be referenced in the following chapter on material degradation, as the author unravels the story of where, how, and why the Bray’s kilns have yielded to decay in the decades since their last firing.

2.2.1 The Site

What this study refers to collectively as the WCMC kiln complex was at least partially complete and functioning by 1916, at which time an inventory of the Helena brickyard attributed six downdraft kilns to the business.\textsuperscript{88} Knowing which kilns this inventory included, however, and which of those kilns counted still exist today, requires some additional sleuthing.

It is generally accepted that the kilns were numbered according to the chronological order in which they were built. It is unclear, however, exactly when some of the kilns appeared and

\textsuperscript{86} Reid, \textit{(In)Forming and Pressing Matters}, 31. Citing an article from the \textit{Great Falls Tribune}, Reid asserts that the beehive kilns of the WCMC were fired for the last time on July 1, 1957.
\textsuperscript{87} Though the kiln complex is obviously composed of more than just the kiln structures themselves, the following analysis is admittedly kiln-centric. For more details regarding the wooden sheds which surround the complex, delineating it from the remainder of the industrial site, readers may refer to Section 3.1.1, a summation of the sheds’ material condition.
\textsuperscript{88} Quivik, \textit{Western Clay Manufacturing Company: An Historical Analysis}, 21.
when others, in turn, vanished. The table below traces what the author believes is the most accurate timeline for the completion and demolition of downdraft kilns at Western Clay.

<table>
<thead>
<tr>
<th>Approximate Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1897</td>
<td>Kiln Nos. 1, 2, and 3 constructed</td>
</tr>
<tr>
<td>1905 – 1908</td>
<td>Kiln No. 4 constructed</td>
</tr>
<tr>
<td></td>
<td>Kiln Nos. 5 and 6 likely constructed</td>
</tr>
<tr>
<td>1908</td>
<td>J. P. Rowe photograph depicts Kiln Nos. 3, 4, and potentially 1 or 2</td>
</tr>
<tr>
<td>1908 – 1916</td>
<td>Kiln Nos. 7 and 8 constructed</td>
</tr>
<tr>
<td>1916</td>
<td>Kiln Nos. 1 and 2 demolished</td>
</tr>
<tr>
<td>1916 – 1922</td>
<td>Plant inventory lists six kilns in operation</td>
</tr>
<tr>
<td>1922</td>
<td>Kiln Nos. 7 and 8 constructed</td>
</tr>
<tr>
<td>1922</td>
<td>Kiln Nos. 1 and 2 demolished</td>
</tr>
<tr>
<td>1935</td>
<td>Sanborn map depicts Kiln Nos. 3-8</td>
</tr>
<tr>
<td>1935 or shortly thereafter</td>
<td>Kiln No. 3 demolished</td>
</tr>
</tbody>
</table>

Table 2.1 – Chronology for the development of the kiln complex at the former WCMC. Highlighted areas represent events whose exact dates elude confirmation.

Citing plant inventories from the late nineteenth century, industrial historian Fred Quivik dates the construction of the site’s first three downdraft kilns to the year 1897. Nos. 4, 5, and 6, Quivik asserts, likely followed in or after 1905, when the WCMC was incorporated under the general management of Charles Bray.89 A photograph of the kiln complex taken by J. P. Rowe and printed in the University of Montana Bulletin in 1908 focuses on Kiln No. 4 (Fig. 2.16). Absent from the frame are Nos. 5 and 6. One may reasonably assume that these two kilns were built in conjunction with No. 4, however, just as Nos. 1, 2, and 3 were built in a single campaign in 1897.

Meanwhile, the kiln whose shed fills the southern, left margin of Rowe’s image is likely No. 3, which occupied a space roughly thirty yards to the southeast of where Kiln No. 7 sits today. Archie Bray, Jr., who was born in 1919, remembers seeing this kiln as a small child. According to Bray, the kiln was smaller than its successors, and lacked the bag walls and open bottom typical of downdraft machines. Bray never saw the kiln fired, and indeed, was at a loss to explain how it could have functioned without these crucial components. Instead, he remembers

89 Ibid., 10.
the kiln being used to store oil and kerosene, and dates its demolition to the years after the earthquakes of 1935. Whether or not the earthquakes were the sole cause of its demise is uncertain—Bray simply recalled it being taken down and its brick crushed for reuse as grog.90

Kiln No. 3 appears, along with its forty-five foot stack, in a Sanborn fire insurance map last updated in 1922 (Fig. 2.17). Kiln Nos. 7 and 8, which are absent in Rowe’s photograph, are built and indicated on the map along the northern flank of the tile shop. Gone, by this point, are Kiln Nos. 1 and 2 (Fig. 2.18). It is possible that the kiln shed pictured in the northern, right foreground of Rowe’s photograph could correspond to either of these early machines. And indeed, the great distance depicted on the 1922 map between Kiln No. 3 and its associated stack suggests that one or two additional kilns might once have occupied the area directly east of present-day Kiln No. 7. Bray, unfortunately, has no recollection of these kilns. Assuming they were taken down at the latest possible date (i.e., just prior to the final Sanborn update in 1922), he would have been just three years old at the time.

So, given the available evidence, two chronologies are possible for the development of the site. Either the 1916 inventory encompassed Kiln Nos. 1-6, with Nos. 1 and 2 demolished and Nos. 7 and 8 erected by 1922; or, the inventory counted Kiln Nos. 3-8, with Nos. 1 and 2 demolished and Nos. 7 and 8 erected sometime between 1908 (the date of Rowe’s photograph) and 1916 (the date of the inventory). Entertaining though it is, such conjecture is only so productive. Barring the recovery of additional archaeological evidence, photographs, maps, or primary accounts, doubts over which kilns appeared when are unlikely to subside. What is clear, however, is the manner in which the various kilns—that is, the extant Kiln Nos. 4-8—were used. This information, culled largely from Archie Bray, Jr., himself, is presented next.

90 Archie Bray, Jr., telephone interview by author, March, 21, 2012. See Appendix B for a transcript of this conversation. 1935 was no doubt a traumatic year for Western Clay, as earthquakes registering 6.2 and 6.0 on the surface wave magnitude scale shook Helena on October 18th and 31st, respectively, that year. Extensive damage occurred to the city’s stock of heavy masonry buildings. For more information, visit the University of Utah’s Seismograph Station website at: http://www.seis.utah.edu/ltqthreat/nehrp_hmt/1935he1/1935he1.shtml.
2.2.2 The Firing Process

At Western Clay, each downdraft kiln performed a specific role. Kiln No. 6, for example, fired common brick exclusively. According to Bray, No. 6 was just a “straightforward, plain kiln.” It fired evenly, “but just plain hot.” Kiln Nos. 7 and 8, on the other hand, churned out Western Clay’s distinctive, salt- and zinc-glazed face brick. The salt gave a luster to the brick surface, while the zinc turned it dark green—a shade preserved in the layers of glaze coating the interiors of these two companion kilns. As Bray remembers (and not without a subtle note of pride in his voice), Western Clay’s face brick “was a fancy thing.” “Nobody else in the area made green, glazed brick,” he says. Kiln Nos. 4 and 5, meanwhile, were not used to fire brick at all. Instead, these kilns fired “more open things” like hollow structural clay tile, flue lining, and flower pots. Salt-glazed sewer pipe seems to be the one non-brick exception fired in Kiln Nos. 7 and 8, and this fact comes not from Bray himself, but rather from the half-setting of sewer pipe which remains in Kiln No. 8—a vestige of the kiln’s last firing.

According to Bray, firing a downdraft kiln at Western Clay was a time-consuming, arduous process that, from start to finish, took as long as a month. First, the kiln needed to be set with dried ware. In the case of Nos. 7 or 8, as many as five days were needed to set an entire kiln’s worth of dried brick. With the setting complete, the kiln doors were bricked up solid and plastered over to prevent the loss of heat. Then, the fires were lit and stoked slowly—first with hand-shoveled coal and later via gas burners. The “watersmoking” period followed, during which the kiln steamed with the evaporation of the brick’s retained physical and chemical moisture. Richardson charts the end of the watersmoking period at about 500°F, and Bray’s

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91 Archie Bray, Jr., telephone interview by author, March, 21, 2012. For this and the following quotes, please refer to Appendix B.
memory is right on point. He recalls Kiln No. 7 finishing its steaming somewhere between four and five hundred degrees: “Not quite five because when you look[ed] in, it [wasn’t] quite red.”

With watersmoking complete, workers built up the fires and brought the kiln to the soaking temperature suitable for glazing. Archie recalls the glaze kilns being fired to Cone 4, which corresponds roughly to 1180°F, or “whitish hot.” At this point, chips of raw zinc and rock salt were heaved into the fireboxes. Rock salt was delivered in fifty- to one-hundred-pound sacks, Bray recalls, and stored in the annex to the tile shop where today the tile extrusion machine and flower pot press sit exposed to the elements. Back during operation, says Bray, this room’s solid roof and close proximity to the kilns—it is located just south of Kiln No. 5—made it ideal for salt and zinc storage. When tossed into the inferno, the zinc and sodium would be volatilized and conveyed, as vapor, in the draft toward the top of the kiln. There it would settle on and flux the clay surface of the brick, later cooling to a green, shiny glaze. Often, Bray says, the glaze did not reach the lowest courses of the setting—those units closest to the kiln bottom. These brick, which were often slightly under-fired, as well, were sold as common brick alongside ware fired in Kiln No. 6.

Once glazed to an acceptable extent, the kiln was allowed to cool. The fires were extinguished, and after approximately six hours, the doors were slowly and carefully taken down. According to Bray, it took several days for a kiln to cool, despite the large mechanical fans—those fans still present on the drying floor of the tile shop—employed to quicken the procedure. Another week to unload the kiln of its brick, and firing was officially complete. Due to the length and labor intensity of the process, there was no set schedule for kiln operation at Western Clay. The kilns were fired at all times of the year, but generally, only at a rate sufficient to meet demand. As Bray says, “If you knew you were gonna want face brick in a month, then you started loading the kiln today.”

92 Richardson, Burning Brick in Down-Draft Kilns, 25.
2.2.3 Design and Construction: the Case of Kiln No. 7

In the summer of 2011, a team of researchers from the University of Pennsylvania’s Architectural Conservation Lab (ACL) traveled to Helena to systematically document the WCMC kiln complex.\(^9^3\) Faced with five beehives and a limited schedule, the team selected one kiln which, on account of its relatively stable condition, could serve as a representative for the five surviving prototypes on site. Kiln No. 7 thus emerged as the complex’s focal point, and approximately eleven months later, in June 2012, the author of this study ventured to the Bray to continue dissecting, recording, and even repairing parts of the machine. Among the fruits of these two summers of investigation were to-scale drawings and a complete architectural description of Kiln No. 7. This description is incorporated into the following paragraphs, but has been amended to include notes on Kiln Nos. 4, 5, and 8, as well as what limited information is known about the maintenance of the machines during their hard years of service.\(^9^4\)

Situation and Scale

Located approximately ninety yards southwest of the Bray’s original pottery building, Kiln No. 7 is a domed structure of load-bearing brick masonry. It is flanked to the west by Kiln No. 8 and to the south by Kiln Nos. 4 and 5. Kiln No. 6 rests, in turn, on the western side of Kiln No. 8. Greenware dried by steam on the second floor of the tile shop reached the kiln complex by means of a long ramp, which descends along the building’s north elevation to meet Kiln Nos. 7 and 8 below (Fig. 3.1). From the ground floor of the tile shop, dried ware was likely carted through a doorway on the east elevation of the building toward Kiln Nos. 4 and 5, immediately beyond. As an aerial view of the plant taken in the mid-1950s confirms, the brick drying tunnel, 

\(^9^3\) This team consisted of Joseph Torres, Ting Ting Weng, and Sharon Reid. Reid proceeded to complete her master’s thesis on the history of the Western Clay Manufacturing Company, an extensive work which has aided in the drafting of this study.

\(^9^4\) Readers will notice that Kiln No. 6—the kiln positioned closest to the modern-day David and Ann Shaner Resident Studio Building—largely eludes detailed documentation, a decision made on account of the kiln’s especially ruinous condition. Indeed, further examination of Kiln No. 6 should, in the author’s opinion, be undertaken as conservation planning proceeds at the Bray.
which was razed in the late 1990s, emptied directly into Kiln No. 6, proving that the circulation of greenware from drying floor to kiln was well planned at the WCMC (Fig. 2.19). Close examination of this photograph also reveals the expediency with which finished products were transported away from the plant and on to markets beyond. A train is pulled directly up the kiln shed, mere feet from the northern edge of Kiln Nos. 7 and 8. The ramp which workers ascended while loading tall railroad cars with brick, tile, and pipe survives still in the small space separating those kilns (Fig. 4.8).

Linking Kiln No. 7 with its neighbors and, indeed, to the tile works roughly fifteen yards away, is a system of trunk and branch pipelines, installed in 1931 when Archie Bray, Sr., upgraded firing operations from coal to natural gas.95 The wooden and corrugated metal kiln sheds—erected presumably to protect the kiln foundations, clay wares, workers, fuel, and glazing materials from weather—are another highly distinctive element linking the kilns to one another and the tile shop. Such sheds, which effectively demarcate the borders of the kiln complex itself, are rare features on American brickyards dating to the nineteenth and early twentieth centuries. In fact, because kiln sheds are mentioned almost exclusively in British manuals and brick treatises, their appearance at the WCMC has led to some speculation over their existence as a manifestation of Charles Bray’s English birth and training.96

Like all of the downdraft kilns of the WCMC, Kiln No. 7 sits atop a circular plan. Including the width of its exterior wall, the structure measures approximately 36’6” in diameter at its base. From its bottom up, however, the exterior wall is irregular in thickness, and recedes inward in a series of four tiers until culminating in a parapet approximately 11’3” above grade. From the parapet, which averages 34” (roughly eight wythes) in width, the kiln’s distinctive crown appears to spring upward. At this juncture, the total diameter of the kiln measures

96 Reid, *(In)Forming and Pressing Matters*, 25.
approximately 35’. The addition of the crown brings the total height of the structure to approximately 20’.

When viewed in plan, the kiln may be bisected along its north-south axis by a straight line spanning from door to door. Through these northern and southern doors, brick were once set and unloaded. Between them, ten fireboxes perforate the cylindrical kiln elevation at grade, at regular intervals. Enveloping the fireboxes and extending up to the parapet are seven iron bands, associated turnbuckles, and compression springs, which would have stabilized the kiln during the periods of intense thermal movement. Although Kiln No. 7’s exterior wall exhibits myriad irregularities—the product of frequent repair and the sheer abuse of repetitive firing—there are consistencies which merit examining each of its four tiers independently and in detail.

**Tier 1**

Along the majority of the kiln’s exterior, Tier 1 is thirteen brick courses high, beginning at grade. Header courses in the fifth, eleventh, and thirteenth courses tie the outermost wythe of brick masonry into inner wythes. The first iron band—which averages 2’5” above grade and 6” wide—obscures courses eleven through thirteen. The thirteenth course, which features headers of common brick, cedes to paver brick headers that close the course immediately before and after the fireboxes. These large paver bricks measure 10.75” x 5.5” x 2.25” and often bear repressed, ornamental designs on their undersides. They are designated Type E1 in a brick typology compiled in the field. Otherwise, where later reconstructions have not taken place, Tier 1 is composed primarily of machine-pressed common brick laid in lime-cement mortar. These bricks measure 8.5” x 3.75” x 2.5” and are designated Types B6 and B7.

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97 The author has chosen to number the fireboxes of Kiln No. 7 in ascending order, beginning with the firebox immediately west (or left) of the southern door and proceeding clockwise.
98 Due to undulations in the slope of grade at the base of the kiln, some sections of the kiln—especially those to the west and southwest—exhibit twelve courses of exposed brick. In such cases, the positioning of header courses stays the same. On account of there being one fewer stretcher course at grade, however, the numbering of these courses must change: from the fifth, eleventh, and thirteenth courses to the fourth, tenth, and twelfth courses, respectively.
99 See Appendix C for the brick typology assembled at the WCMC kiln complex in July 2012.
Sporadic headers in the tenth course are corbelled out to support the banding, but indeed, around most of the kiln’s circumference, the first band is either disengaged or missing entirely. Other failures in Tier 1 reveal interesting details about the kiln masonry’s construction and subsequent deformation. An explosion between Firebox Nos. 3 and 4 in the kiln’s northwest quadrant enabled the author to access brick up to six wythes deep—a full twenty-one inches into the exterior masonry wall. A photograph of this portion of the wall in section reveals header brick in courses four through seven (Fig. 2.20). Once serving to bind the wall together, many of these headers have failed in tension. Also notable is the paucity of tie-in brick between the second and third wythes. Meanwhile, a convergence of deformation modes has resulted in a bulge on the kiln’s southeastern elevation, the mechanics of which are analyzed later. The use of extruded, nail-combed brick and distinctive “double” brick (Types D5 and C5, respectively) in repairs to this bulging zone could help potentially date interventions. C5 brick, for example, was used extensively in the construction of the stack exhaust fan between Kiln Nos. 7 and 8, an improvement made by Archie Bray, Jr., around 1953. The possibility therefore exists that repairs made with double brick on the southeastern portions of Kiln No. 7 could be among the final alterations made to the downdraft kilns before their last firing in 1957.

**Tier 2**

Tier 2 is eight courses high along most sections of the kiln. The fifth and eighth courses are header courses. The second band, also 6” wide, obscures courses seven and eight wherever it survives. Occasional headers, some of them paver bricks, are corbelled out in the sixth course to support the metal banding. With the exception of the kiln’s southeastern sections, where, again, the majority of the exterior wall has been rebuilt with D5 extruded brick, Tier 2 is composed of B6 and B7 brick, as seen throughout Tier 1.

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100 Fredric L. Quivik, “Montana Historical and Architecture Inventory: Site #16, Kiln #8,” prepared as part of the site’s nomination to the National Register of Historic Places in January 1985, 30.
Tier 3

Tier 3 is the smallest independent brick tier built into Kiln No. 7. It features four courses, the first and fourth courses exhibiting headers exclusively. The tier is unobstructed by banding, and excluding sections in the northwest and southeast where the kiln has been rebuilt with nail-combed extruded brick (Type C4), the brick type most often employed in this tier is B6—the machine-pressed brick built into the kiln throughout. This brick may be distinguished by the slight, vertical grooves spanning its stretcher face.

Like in Tier 1, failures in Tier 3 enabled the author to investigate otherwise-unseen portions of the kiln wall in section. In the case of Tier 3, bonding pattern, brick alignment, and wall thickness could be extrapolated from collapses in the kiln’s southwestern quadrant—in the interior kiln lining between Firebox Nos. 2 and 3, and along the exterior elevation above Firebox No. 3. The author was thus able to model a section of the wall in-situ and to scale, using dry-laid brick (Fig. 2.21). Finding that the kiln lining consists of a mere single wythe of refractory brick with sporadic tie-ins was perhaps the most illuminating conclusion to result from this exercise.

Tier 4

Tier 4 exhibits the lowest degree of irregularity and repair, despite the fact that it is the tier spanning the greatest vertical distance. It is twenty-five courses high, with header courses in its first, sixth, tenth, twentieth, and twenty-fifth courses. Five compression bands, ranging from 6” to 8” in width, obscure courses one through three; seven through nine; thirteen through fifteen; seventeen through nineteen; and twenty-three through twenty-five. Corbelled headers support banding in courses six, twelve, sixteen, and twenty. Perhaps due in part to the high degree of lateral stability afforded by the banding, replacement bricks are rare in this tier. A great many Type C4 and D2 brick in the kiln’s northwest section are the one notable exception. Otherwise,
brick employed in this top tier are, as elsewhere along the kiln’s exterior, Type B6 and B7 common brick.

The Fireboxes

The ten fireboxes interrupt the above-described tiers and brick bonding patterns in Tiers 1 and 2 only. Averaging approximately 4’9” high and 3’5” wide, the firebox chambers extend at an average depth of 36” through the masonry construction and into the kiln’s interior. Each firebox is built as a rounded arch—the inner archivolt of refractory brick wedges bound together by clay slurry; the outer archivolt often rebuilt with rectilinear, common brick laid in clay. Only four of the ten fireboxes retain a second, outer archivolt of refractory brick wedges. The retrofitted gas-firing system survives in the lower portion of all ten openings, and consists of a burner apparatus and a ceramic pipe, or throat, fit within a hollow, cubic, terra cotta block measuring 9” by 9”. Bordering this block on both sides are stacked refractory bricks—some laid in fire clay, others laid dry. Meanwhile, the semicircle formed by the firebox arches above marks the opening through which workers would have shoveled salt and zinc during glazing. Terra cotta shields covered these openings during the remainder of the firing process, as can been seen in a photograph of Archie Bray, Sr., tending the kiln (Fig. 2.22). One such shield was replaced on a portion of the kiln during pilot conservation work in July 2012.

The burners themselves are high-pressure, Venturi-style burners, which would have ignited high-pressure gas within a constricted, bottle-shaped unit, channeling the resultant flame into the firebox’s ceramic throat. In the case of all ten fireboxes, the burner’s metal casting wheel remains attached via a series of elbow pipe fittings to a gas shut-off valve. From there, vertical branch pipelines measuring 4.25” in diameter lead to the main, ring-shaped supply pipeline,

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101 For a visual comparison of Kiln No. 7’s ten fireboxes, see Appendix D.
which encircles the kiln approximately 7’2” from grade. This ring measures 7.5” in diameter and is supported by brackets welded to the second and third iron bands in Tier 4.

**The Doors**

In contrast to the fireboxes, the northern and southern doors penetrate all four tiers of brick masonry along the kiln’s exterior elevation. The southern door, which is today the structure’s only unobstructed entry point, is approximately 4’6” wide and 8’ high, topped by a three-archivolt rounded arch. This arch’s inner two archivolts are composed of refractory brick wedges laid in clay slurry; the third and outermost archivolt is composed of what appear to be rectilinear, common brick laid in mortar. The northern door—which is similar to its counterpart in width but shorter in height, measuring only 7’8” to the top of its arch—has been sealed with multicolored bricks laid in mortar as both stretchers and soldiers. The door’s rounded arch is formed by two archivolts, both of which are composed of refractory brick wedges laid in clay slurry. Wooden arched forms found in the vicinity of Kiln Nos. 7 and 8 are most likely remnants of the formwork used to construct and periodically reconstruct these arched openings.

**Interior and Crown**

Roughly 30’ in diameter, the interior of Kiln No. 7 is marked by the ten, rectangular bag walls that correspond to each firebox chamber. Each bag wall abuts the interior wall of the kiln, forming a fence-like partition approximately 4’ wide and 5’ high, extending roughly 3’6” toward the center of the structure. Constructed of refractory brick (Type A1) laid in a clay slurry, the bag walls of Kiln No. 7 are all approximately 9.5” thick.

Behind and to each side of the bag walls, the kiln’s interior lining bears the scars of multiple collapses and persistent repair. Though it is difficult to ascertain a consistent bonding pattern across the entire wall, courses six, nineteen, and twenty-six appear to be header courses.
The brick employed is Type A1 refractory stock, yet beyond the twenty-sixth course, layers of salt- and zinc-glazing render the orientation and condition of these bricks impossible to discern.

Originally, the kiln’s bottom would have been open, consisting of tiles laid in a perforated, checker pattern to enable the downward passage of heat into sub-grade exhaust flues. Approximately eight feet above this surface, which has since been filled in with rock crusher fines to facilitate public access, Kiln No. 7’s “beehive” crown springs upward, presumably from a point inside of the kiln’s exterior wall and beneath the parapet. Indeed, the over three-foot discrepancy between the vertical height of the exterior wall and the vertical height of the interior lining indicates that the crown is stiffened and anchored in place by multiple courses of brick masonry around its circumference. The crown is constructed of refractory brick wedges laid vertically in a clay slurry binder. If the kiln were again bisected by a line spanning its north-south axis, a total of sixty-three courses would be counted on either side of the imaginary divide, extending from the top of the crown down to its base along the interior wall.

At the crown’s apex is a large vent—an oculus measuring approximately 1’10” in diameter. This vent served two important purposes. It enabled increased ventilation during the cooling of the kiln, but also provided an opening from which workers could extract sample brick during glazing to access glaze coverage. According to Bray, workers would ascend the crown quickly—so as to avoid burning their feet on the hot surface—and hook glaze specimens using a long metal pole. A layer of loose common brick, similar to the lagging described earlier, would provide workers places to step on their harrowing trip to the top of the crown. The thickness of the crown along the margins of the oculus is 9”—exactly what one would expect from one wythe of refractory brick, oriented vertically along its stretcher end. Lower along the crown’s surface are ten evenly-spaced peep holes, where workers could examine the brick intermittently during the cooling, testing shrinkage with long, metal poles. Measuring 4.25” across and 5.5” high,

102 Archie Bray, Jr., telephone interview by author, March, 21, 2012.
these holes are each positioned exactly above corresponding fireboxes and bag walls. When not in use, each hole would have been capped with a refractory wedge and the oculus itself sealed with terra cotta disk in order to better conserve heat circulating within the kiln.

**Comparisons Among the Kilns**

While the five kilns of the WCMC complex resemble each other closely in form and bonding pattern, there are several differences between them that merit mention. First, in regard to overall dimension, the glazing kilns, Nos. 7 and 8, are the largest among the five surviving prototypes. The vertical height of their exterior walls, averaging over 11’, is greater than Kiln Nos. 4 and 5, whose heights fall just over 10’. Kiln No. 6 sports the shortest wall at just over 9’.

Therefore, though all of the kilns feature seven bands, those on Kiln Nos. 4, 5, and 6 are slightly narrower and situated more closely together. The two bands lowest to the ground are, on all of the kilns, either severely deteriorated or missing completely.

Kiln Nos. 4, 6, and 8 each feature two doors oriented, like those on Kiln No. 7, at polar ends of the structure. Kiln No. 5 sports just one door through which ware must have been set and drawn. Kiln Nos. 4, 5, and 6 also feature only eight fireboxes—two fewer than Kiln Nos. 7 and 8. There appears to be no significant deviation among the kilns in the size of the firebox openings themselves, although the degree of damage to the walls immediately surrounding the fireboxes on Kiln Nos. 4 and 5 makes it difficult to accurately gauge how large the furnace openings originally were. In accordance with their number of fireboxes, Kiln Nos. 4 and 5 feature eight inspection holes in their crowns, as opposed to ten. These holes are positioned roughly six feet higher along their respective crowns than are those on Kiln Nos. 7 and 8. Though Kiln No. 6 is the only kiln not to feature inspection holes, all of the surviving kilns are equipped with a center oculus.
Although exact measurements could not be obtained for the crowns of each kiln—indeed, the crowns of Kiln Nos. 4, 5, and 6 were deemed unsafe for full documentation—the crowns on Kiln Nos. 4 and 5 appear to be smaller than those of 7 and 8, both in terms of height and diameter. They also appear to be steeper, and exhibit a considerable amount of deformation. Finally, though each of the kilns features an open bottom, the checkered patterns of evenly spaced tile differ from structure to structure. The size of tile used in Nos. 6 and 8 are also larger than those in 4 and 5. Finally, as an observation worthy of further investigation, it seems that Kiln Nos. 4 and 5 feature interior kiln linings that are thicker than the lining in No. 7. These linings exhibit at least two wythes of refractory brick, as opposed to one.

**Kiln Maintenance**

The variety of construction methods and materials noted on each of the kilns is, in part, a product of the machines’ dogged repair. According to Bray, the kilns were maintained on an *ad hoc*, need-by-need basis: “Any time we found a bad place in the kiln wall, we’d tear out the bad part and rebuild it before we fired it the next time.” The fate of the company depended on the kilns’ functionality, so it seems that any and all failures were dealt with immediately, using whatever brick (regardless of age, appearance, or manufacture) happened to be available at the time. And of course, the prolonged brutality of firing provided for many such failures. “Oh yeah,” says Bray. “We rebuilt [bag walls] frequently. …Every firing you’d probably have to repair one or two bags, and every third or fourth firing you might have to rebuild a large portion of one or two.” The interior lining, bag walls and fireboxes were the areas exposed to the greatest heat and thus required the most frequent repair. Otherwise, repairs appear most often in the first tier of masonry, perhaps as a result of the expansion of the kiln bottom and the build-up of debris.

That the kiln lining, bag walls, fireboxes were in constant need of repair was not surprising. What the author absolutely did not suspect, however, was that the crowns of the kilns might also be subject to overhaul. Indeed, in 1935, the crown on Kiln No. 7 was replaced entirely—a fact furnished by Bray himself. Bray cannot recall whether or not that year’s earthquakes were the reason behind such a dramatic intervention: “I remember seeing the crown somewhat deformed… It was after the earthquake, so I’m sure the earthquake probably hurt it, too.” But he does remember his father constructing the wooden sweep to help mark the contours of the new crown, guiding the “local people” who came to lay up the fire brick dome. Apparently Kiln No. 7’s new top inspired great pride in those days, due it its being “so nice and even.” Alas, “I don’t think the kiln fired any better,” Bray adds.

Though Bray couldn’t recall witnessing any other major repairs in his lifetime, the author cannot help but wonder if the clash of brick colors on Kiln No. 4’s crown could indicate replacement having occurred there, as well. In this way, repairs constitute perhaps one of the most fascinating visual aspects of the WCMC kiln complex. Spotting their occurrence, noting their differences from one another, imagining why they were necessary, and wondering to what extent they served their purpose—the interpretive value encapsulated by *ad hoc* repairs at the kiln complex is a theme for this study’s fourth chapter. Similarly, the ability of such repairs to speak to the kilns’ long term material degradation is a subject for the next chapter. For now, it is enough merely to recognize the ubiquity of repair, and to understand why Bray and his men would have needed to so urgently tend to such work.

2.3 The Significance of Historic Kilns for the 21st-Century Bray

Since 1951, the Archie Bray Foundation and its brickyard progenitor have coexisted peacefully on the western margins of Montana’s capital city. Though, on occasion, the artists of the Bray have likely hoped, if not prayed, for some kind of divine intervention to liberate them
from the aging plant—the author thinks here of David Shaner’s harrowing 1966 bid to save the foundation from a government auction block—the relationship between the two ceramic centers must ultimately be framed as a symbiosis. From the time in the 1940s that local brothers Hank and Peter Meloy first fired their experimental works in Archie’s beehive kilns, to the period in the 1980s when Robert Harrison adorned the newly re-acquired brickyard with ebullient outdoor installations, the bond between the Bray and its industrial neighbor has been one defined by tolerance, kindness, and the relentless pursuit of quality work in the medium of clay. In this spirit alone, one may assert the importance of the brickyard to the fundamental identity of the Archie Bray Foundation and argue, accordingly, for the conservation of its kilns. There are, of course, several other reasons why preserving the kilns of the former WCMC would enhance the mission and image of the residency center as it moves forward into its second half-century of existence.

Preservationists often employ one of several, somewhat predictable strategies when urging clients, governments, or the broader public to value and protect the sites they deem significant. For one, they may point to a site’s historical value—its having witnessed a seminal historical event, its having hosted a seminal historical persona, et cetera—as justification for its preservation. As far as the history of American ceramics is concerned, the kilns of the WCMC very causally satisfy this criterion, as it is documented in multiple sources—and confirmed by Archie Bray, Jr., himself—that Peter Voulkos and Rudy Autio, like Hank and Peter Meloy before them, fired early pots and sculptures alongside brick in the industrial grade machines. It was the summer of 1951, and the two impoverished artists, both still enrolled in graduate school, had

104 Patricia Failing, “The Archie Bray Foundation: A Legacy Reframed,” in A Ceramic Continuum: Fifty Years of the Archie Bray Influence, ed. Peter Held (Seattle: University of Washington Press, 2001), 50-1. Having defaulted on a loan from the Small Business Administration, the Western Clay Manufacturing Company was put up for public auction on April 15, 1966. Included in the land, buildings, and equipment tagged for sale were the facilities of the Archie Bray Foundation, down to the potter’s wheels and kilns. Shaner and the organization orchestrated a competitive bid to purchase the Foundation’s property, but then had to free the pottery from the infrastructure—water lines, gas lines, et cetera—of the plant, which was sold to the Medicine Hat Brick and Tile Company (I-XL Industries) of Alberta, Canada.

come to Helena to assist Archie Bray, Sr., in laying the foundations for his nascent pottery. Pugging clay, carting ware, and laying brick by day, the duo worked nights on their own artistic endeavors, reportedly in the corner of the tile shop’s drying floor.\textsuperscript{106} Before the pottery’s gas-powered, high-fire reduction kiln was complete, Voulkos and Autio had no choice but to fire their work in Archie’s beehives. Archie—though later vexed by the young men’s forays into abstract expressionism, a mode he rather hilariously dubbed, “ribs, guts and belly buttons Art”—consented, and the rest is history.\textsuperscript{107}

But perhaps this story is deserving of a deeper, more nuanced recitation. Yes, Voulkos and Autio fired work in the brick kilns and later became giants in American ceramic art. Recalling the chronology of Western Clay, however, one will remember that the beehive kilns went offline in 1957, seven years after their use by Voulkos and Autio. By that time, the once-imagined pottery had become a reality, amassing firing means of its own (including a salt kiln, porcelain-ready muffle kiln, and a state-of-the-art electric kiln). In fact, as work at the brickyard slowed and Archie Bray, Jr., thrust into leadership after his father’s death, contemplated a fateful investment in two tunnel kilns, the young Foundation was buzzing with activity, even attracting potting legends Bernard Leach, Shoji Hamada, and Marguerite Wildenhain to Helena as guests.\textsuperscript{108} With brickyards across the nation beginning to downsize, consolidate, or shut altogether in the face of the increasingly popular concrete masonry unit, perhaps the use of the WCMC kilns by a pair of precocious artists was an event of broader historical weight. Perhaps the kilns themselves represent the nexus of clay as a utilitarian building material and clay as a medium for artistic expression—a turning point, from a fading, industrial tradition to one of limitless, creative potential. That Archie’s kilns had a hand in firing objects belonging to both traditions is a special

\textsuperscript{106} That Autio and Voulkos worked in the drying room of the tile shop was another fact corroborated by Archie Bray, Jr. See Appendix B.
\textsuperscript{107} Newby and Jiusto, “‘A Beautiful Spirit,’” 26.
\textsuperscript{108} Ibid., 22.
thing—a narrative that could be reinforced and retold by the conservation of the kilns as they stand today.\textsuperscript{109}

Another criterion for significance readily evoked by preservationists has to do with a building or site’s typological rarity. If a building is identified as being among few of its type—take, as a correlative example, a stunning, \textit{buncheong}-style Joseon Dynasty vase—it is often deemed an “endangered species,” an object of study, and, therefore, significant. Significance resulting from rarity is further compounded, then, if the survivor in question has undergone minimal alterations or modification over time. The already-rare building or site can then be said to have high integrity, as well. (Imagine: a \textit{buncheong} vase free of chips, cracks, or any other blemishes marring its immaculate surface!) Quite simply, the economics that govern perceptions of value in the world of ceramics apply to the worlds of architecture and preservation, as well. And here, the kiln complex scores high marks yet again.

In 1894, one year before Nicholas Kessler acquired the present-day site of the WCMC with Charles Bray as its foreman, at least twenty-seven brickyards were active in the state of Montana. By the time of its closure in 1960, the WCMC was joined by just two other facilities—one in Lewistown, the other in Billings—as Montana’s last surviving brickyards.\textsuperscript{110} Finally, as of 2007, not a single brickmaking establishment remained in the state. In fact, the closest states to report at least one establishment were Washington, Colorado, and Utah (with five, five, and three establishments, respectively), and that before the financial crisis of 2008 and subsequent decline in new construction.\textsuperscript{111} Thus, if a modern brickyard has become a rarity in today’s American Northwest, then certainly a historic yard which features kiln technology dating to the pre-war era is a rare and significant find. The physical integrity of the kiln complex, meanwhile, is stunning.

\textsuperscript{109} The prospect of identifying some of the pieces Voulkos and Autio created that summer and then exhibiting them in the kiln or kilns in which they were fired is especially exciting.

\textsuperscript{110} Quivik, \textit{Western Clay Manufacturing Company: An Historical Analysis}, 5, 15.

True, the frequent repairs made to the kilns during their era of use call into question here the relevance of the much-loved preservation buzzwords “original fabric.” But the half-setting of fired sewer pipe that patiently awaits removal from Kiln No. 8—a wait that is now approaching its sixtieth year—reveals the extent to which the kiln complex was, in every sense of the word, left untouched. Patchwork alterations and evident deterioration aside, the WCMC kiln complex is amazingly complete. It is the industrial, architectural equivalent of an entire case of Joseon Dynasty vases.

As with historical value, though, the values of rarity and integrity that are so easy to attribute to the kilns of Western Clay may also be reframed in a way which makes a more interesting, and perhaps more meaningful, case for the structures’ conservation. That a set of five, early twentieth-century brick kilns would survive over forty years of repeated firing, let alone another sixty years of disuse in Montana’s unforgiving climate, is improbable—a situation seen at very few other sites in the United States. But that the brickyard site itself has experienced such a graceful transformation—from a place of industry to a place of creativity, and all within the broader realm of clay—is an occurrence of true rarity.

In essence, what has happened on the grounds of the Bray is a type of adaptive reuse. But unlike the myriad condo developments, shopping malls, or chic cafes to have populated similar historic industrial sites across the country, the Bray is the genetic offspring of the site it inhabits. The buildings of the Bray cluster respectfully around the ruins of their parent, encroaching on them only when vitally necessary. Artists pug clay, mix glazes, and fire kilns. They sit outside, toss the baseball, and talk shop. After their work is done, the product is of course different from products past—where brick once left the site by rail, today collectible pots and sculptures leave in brown UPS trucks. But when a visitor to the kiln complex comes across

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112 See Appendix A.
an anonymous piece of art hidden amongst the leaves and broken brick, the message resonates: on Country Club Lane in Helena, clayworking continues.

Ceramicist Akio Takamori once sketched the Western Clay brickyard as a reclined, anthropomorphic figure, complete with brick kiln breasts and pottery spewing forth from its chimney-stack head. Now the Bray’s de facto logo, this sketch is perhaps the most perfect expression of the site’s wholeness. Indeed, at the Bray there is a kind of balance in the air—ethereal, but somehow there—which surely contributes to the foundation’s value as “a fine place to work.” In the author’s opinion, that balance is the effect of a landscape in which the path from industry to art, from brickyard to studio, and from past to present, is fully legible and fully intact. Call it rarity, integrity, or simply, “character”—this balance represents Western Clay’s most fundamental significance, and as a place, the Bray wouldn’t be the same without it. Preserving the plant’s most distinctive feature, its beehive kilns, is a good first step toward ensuring that the Bray’s balance lives on for the future benefit of residents, alumni, and guests alike.

A final anecdote illustrates the impact that the preservation of the kiln complex could potentially have on people’s experience of the Bray. With light pouring through their center oculi and the resonant sound quality of their domed confines, the kilns treat their guests to a visual and aural show. But they also offer the perfect opportunity to learn about brick—perhaps the world’s most ubiquitous building material—via direct contact with historic material. The author experienced this firsthand in July 2012, when a gentleman wandered into the complex to examine the pilot restoration work that was nearing completion on Kiln No. 7. The man said that his father had been a brick mason in St. Paul, Minnesota, and would have been “tickled pink” to see a downdraft kiln up close. Circling the kiln several times, asking questions about its operation and construction, the man was obviously affected by what he saw. Of course, the brick-firing details he left with that day were likely less significant to him than the memories of his mason father that were conjured up by the kiln. But such vivid associations are the benefit of being able to learn by
sight, smell, and touch. The entire brickmaking process is legible on the grounds of the Bray, and though not immediately related to the Bray’s mission as a place for excellence in the ceramic arts, the site’s didactic potential and the ease with which it could be harnessed for the edification of visitors are simply undeniable. As a teaching tool, as an embodiment of a turning point in the history of American ceramics, and as an important contributor to the Bray’s rare, inscrutable aura of balance, the kiln complex is a significant asset and worthy of conservation.
3. Diagnostic Analysis of Conditions On-Site at the WCMC Kiln Complex

From the onset, it was clear that this project would need to incorporate some degree of materials-based analysis. Otherwise, the formation of a clear, accurate diagnosis regarding the current physical state of the WCMC kiln complex—and, therefore, recommendations for the site’s conservation—would never advance beyond guesswork and good intentions. Indeed, though buildings are often repaired or altered based solely upon what their underlying issues may potentially be, such an approach here, at an industrial heritage site of notable rarity and significance, would be highly inadvisable.

The following chapter therefore elucidates efforts made to better understand how and why the kilns exhibit the symptomatic deterioration they do. Divided into sections encompassing field observations, supplemental, laboratory-based analysis, and factors pertaining to the kilns’ environment and past use, the chapter ultimately concludes with a series of hypotheses and treatment recommendations, as well as suggestions for further monitoring and testing. The conclusions reached in this portion of the study, combined with the interpretive suggestions outlined in the following chapter, comprise the heart of the conservation program introduced in this study and hopefully applied in the future stabilization and reuse of the kiln complex.

3.1 Basic Material and Structural Observations

This initial section summarizes the author’s qualitative observations of the wooden shed and kiln masonry conditions at the kiln complex. Though later reviewed, digitized, and reassessed, this information originates largely from notes taken in the field in June and early July 2012. Unlike the section on Kiln No. 7’s design and construction from the previous chapter, the following paragraphs focus on the degradation of building materials, as opposed to those materials’ assembly, proportions, or functions. Associated graphics—including a full, exterior
conditions survey for Kiln No. 7 inserted in the text and diverse images found in the figures section—should be referenced throughout.

3.1.1 The Sheds

In the previous chapter, the sheds—those structures which surround the kilns and give them a distinctive, flying-saucer-like look—were mentioned as a possible manifestation of Charles Bray’s English birth. If this was true at their construction, the sheds have, over the intervening century, become very much Montanan—an irregular assemblage of faded, wooden members, nailed together and repeatedly modified with frontier-style practicality and expediency. The complex’s two shed networks—that spanning Kiln Nos. 4 and 5 and that spanning Nos. 7 and 8—are technically independent of each other. A line running west to east between Kiln Nos. 4 and 7 marks a kind of border, where the roof of one shed descends to meet a wall structure totally separate from its companion’s (Fig. 3.1). Nonetheless, on both sides of this divide, the sheds consist of a similar set of components and thus face a similar set of conservation issues.

Put simply, the sheds are comprised of walls and a roof. The walls feature post-like members, set either on brick footings or several inches into the topsoil. Lintel-like members tie the posts to one another, while boards, which are nailed into the posts and lintels, effectively sheath off and protect the spaces surrounding the kilns themselves. The roof, then, features rafters, which rest either on the lintels or posts, are attached via clips to the kilns’ uppermost iron band, and are occasionally sistered. Purlins span the rafters and provide a means for the attachment, by nail, of plates of flat and corrugated metal roofing. Stretching between the kilns, finally, additional, massive horizontal members help bear the sloping rooflines. Beam is an appropriate label for these members, if only to differentiate them from the smaller lintels that span post-to-post on the sheds’ outer elevations.
Collectively, the sheds’ rather gruff and jumbled appearance belies the severity of their condition, for, at least as far as decay is concerned, things are not as bad as they seem. In June 2012, when the author and Christopher Taleff, a colleague in architecture from New York’s Cooper Union, surveyed each of the 205 wooden members comprising the sheds, several load-bearing posts were found to exhibit the punkiness indicative of rot. In few instances, however, did such punkiness exceed two inches in height or penetrate the surface further than the tip of a trowel (Fig. 3.2). In fact, the most problematic posts were limited chiefly to the areas surrounding Kiln Nos. 4 and 5, where old, recycled railroad ties have been built into the structure. Resistance drilling revealed some of these ties to feature hollow, interior voids—perhaps a result of creosote, a brown oil preservative commonly used to treat railroad ties, not having permeated the entire breadth of the piece. Even in such extreme cases, though, the remaining cross-sections of healthy, rot-free railroad tie appeared capable of bearing rafter loads. Similarly, several charred rafters on the western flank of Kiln No. 5—members apparently toasted by the heat of the kiln—appeared to retain enough of their cross-sections to maintain structural viability. Although an engineer would obviously have to register his or her professional opinion in order for the Bray to retain such historic (but ostensibly compromised) members in new designs, the author believes that, in many cases, impromptu alterations made to the sheds have resulted in their over-engineering. In other words, wooden members used to construct, replace, or bolster parts of the structure were often more than capable of bearing their assigned loads. Such generous building standards have thus enabled the wood to survive and succeed in situ for quite some time, despite limited rot and the occasional conflagration.

Of course, there are several instances where the sheds’ over-engineering is less of a saving grace. In certain spots, member fixity (or a lack thereof) poses substantial risk to the

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113 Punky wood is usually soft, pliable, and moist to the touch. Punky wood may appear discolored, as well, and will usually give way when prodded with an awl.
structures’ continued survival. The 2012 survey found that of the ninety-two rafters assessed in the complex, eight were disengaged at the rafter-kiln interface. Three rafters lacked fixity at the rafter-post or rafter-lintel interface, while one rafter lacked fixity at both ends and was found to be, essentially, floating in space (Fig. 3.3). Additionally, the long spans covered by many rafters and beams—particularly in those zones between the respective kiln pairs—vastly exceed what would be standard, up-to-code practice in today’s engineering world.\(^{114}\) Some rafters are sistered or met at half-span by upright supports, but noticeable deflections and cracks tracing the slope of the wood grain are particularly disturbing among other members which have not yet been assisted in such ways. That compromised members are still able to bear the shed roofs and periodic snow and wind loads is a testament to the improbable variability of wood. How long such members will continue to perform, however, and whether or not any architect or engineer would be brazen enough to approve redesigns that retained them, are major uncertainties at this point.

Though the shed conditions mentioned thus far would stand out to any engineer or conservator touring the site for the first time, one final condition must be added to this list—a condition that revealed itself to the author slowly, only after he had spent several hours beneath the sheds on a blustery, Montana day. Despite assurance from Helena natives that the area is not typically such a violent, windy place, the author was impressed by the racket produced almost daily as stiff breezes pulled through the site. The noises he heard were the slaps of corrugated metal roofing panels against each another, purlins, and rafters, alike. Indeed, with each gust of wind, air would travel through already existing holes in the roofing, catching the remaining metal sheets and forcing them up and outward like sails from a mast. During especially strong periods of wind, the pressure differentials generated by air currents streaming above, beneath, and around the contours of the piecemeal shed roofs seemed almost enough to bring the entire structure to the

\(^{114}\) This fact was generously pointed out in the field by Ron Anthony, a wood conservation specialist based in Colorado.
ground. The fixity of the roofing to the roof structure is, like the fixity of the rafters to the kiln and posts, something to monitor carefully. Equally critical could be the areas where the roof has collapsed altogether, as these gaps enable wind to infiltrate the sheds and exert added, internal stress on surviving material.

3.1.2 The Kilns

The bulk of the author’s observations on kiln masonry conditions are represented in the digitized conditions survey of Kiln No. 7’s exterior elevations, which can be found at the conclusion of this section. As stated in the previous chapter, Kiln No. 7 was elected as a model for detailed surveying due to its relatively stable outward appearance. Also, because a northeast portion of the kiln underwent trial conservation in July 2012—a process which included poulticing, grouting, repointing, and brick reattachment—execution of a full survey of its pre-treatment conditions seemed prudent. Before discussing the specifics of that exercise, however, the author will put forth observations made on the material states of Kiln Nos. 4, 5, and 8.\(^\text{115}\)

Generally speaking, Kiln Nos. 4 and 5 are in worse material condition than Nos. 7 and 8, their younger counterparts to the north. Kiln No. 5, for example, has suffered a serious collapse on its northern face, wherein five to six wythes of exterior brickwork have peeled off the structure from grade up to its fourth tier (Fig. 3.4). Thus, the kiln’s iron bands are either disengaged or missing entirely along much of its bottom three tiers. Efflorescence—as indicated by the appearance of powdery white zones of salt crystallization on the face of the masonry—is pervasive across the entire surface area of the structure, as well. Indeed, salts have accumulated to such an extent that, in some brick joints, all visible traces of mortar have been usurped by powdered salt (Fig. 3.5). Invasive vegetation poses a formidable threat to Kiln No. 5’s structural wellbeing, as several root systems have taken hold in the masonry core of the kiln walls. In the

\(^{115}\) Again, Kiln No. 6 eluded investigation on account of safety and accessibility concerns.
southeastern quadrant of the kiln, one root has grown to a diameter approaching six inches and is well ensconced in the brickwork. As mentioned in the previous chapter, kiln walls were generally laid up not in alkaline mortar, but in clay. During the kiln’s era of use, this clayey bedding material was crucial in enabling the movement of masonry during heating. In the absence of heat, however, the material is quite an inviting habitat for vegetation—a kind of topsoil scattered amongst the brick.

To the north of Kiln No. 5, the picture of decay at Kiln No. 4 is perhaps even more extreme. A major structural collapse affects multiple wythes of masonry along the kiln’s northeast side (Fig. 3.6). Iron banding is absent entirely on the bottom two tiers, and is compromised by severe decay and physical displacement on the third. Salts have effloresced and accumulated to a similar, heavy extent across the majority of the kiln’s surface area, and one notices in some brick joints the same phenomenon of mortar having reverted to powdery, crystalline salt. Perhaps more so than on Kiln No. 5, invasive vegetation has taken hold in Kiln No. 4. A tree nearly one foot in diameter snakes through the masonry just to the right of the door on the kiln’s western face (Fig. 3.7). Though the tree has been lobbed off flush with the kiln’s parapet, the remaining woody mass is problematic in its capacity to destabilize brick. Indeed, an invasive plant of such impossible girth presents a serious conundrum for a masonry wall. If it continues grow, it will induce further stress within the wall. If it should die and decompose, however, it will leave a large void in its stead. Finally, of particular concern on Kiln No. 4 is the crown, whose undulating contours indicate especial frailty. No other crown in the complex—even that on Kiln No. 6—exhibits such worrisome distortion.

Kiln No. 8 exhibits a level of deterioration that falls, in its severity, somewhere between Nos. 4 and 5, and No. 7. Masonry collapses on Kiln No. 8 are not as deeply damaging as those on Nos. 4 and 5. Instead, collapses on Kiln No. 8 are largely surface phenomena, concentrating around the fireboxes and affecting, at most, the two outermost wythes of brick. Kiln No. 8 does
exhibit several modes of masonry deformation, however, which could represent an initial step toward the widespread collapse seen on the southern kilns. These deformation modes, as well as their potential causes, will be discussed further in later sections of this chapter. For now, it suffices to define them as in-plane displacement (a vertical sagging of the brickwork), out-of-plane displacement (the tendency for the masonry to lean out of the vertical plane of the kiln wall), and, finally, rotation (whereby the brick’s horizontal and vertical positions remain fixed while the unit rotates on a central axis). In the lower courses of Kiln No. 8’s western elevation, bulging—the occurrence of any two deformation modes to create a ballooning out of the masonry—is particularly severe. This appears to be no new problem, however, as several iron buckstays have been driven into the ground along this margin of the kiln, perhaps in a past effort to mitigate the outward displacement of brick (Fig. 3.8). The substantial efflorescence, mortar loss, and corrosion of metal components seen on Kiln No. 8 differ to no notable degree from any of the other kilns. For that reason, it is appropriate to move now to the higher resolution survey of Kiln No. 7, as the information and conclusions gleaned from that exercise speak, in many ways, to the material issues facing all of the kilns in the complex.

**Kiln No. 7 – Conditions Survey**

A graphics-based, symptomatic conditions survey is valuable in its illustrations of single conditions. So may a conservator trace, for example, the path of efflorescence across various parts of a façade. The ability to see several such conditions together, however, side by side and one over the other, adds additional value to the diagnostic process. Being able to absorb a holistic picture of deterioration—an image in which multiple conditions are mapped in concert—allows the conservator to begin to see correlations, and potentially causalities, between conditions as they act out on a building’s surface.

116 For graphic representations of the brick masonry deformation modes defined here, please refer to the conditions glossary which precedes a conditions survey of Kiln No. 7’s exterior at the conclusion of the following section.
The author thus went to great lengths digitizing conditions drawings of Kiln No. 7 produced on site by preservation students during a University of Pennsylvania field course in June 2012. Bringing together the notes and drawings of as many as ten different individuals, the author used several computer programs to overlay conditions on black and white images of the kiln’s exterior, taking care to orient each condition in its proper spatial location. Ultimately, the material realities of the kiln could be accounted for using sixteen independent conditions—three conditions applicable to its metal banding, and thirteen to its brickwork. Each condition, in turn, was assigned its own unique symbology, or graphic code, for visual representation. The end result is a series of kiln elevations which depict pathologies via the animation of observed indicators of decay. After adjusting the layout of this digital montage, the author ultimately decided to leave each individual condition “turned on,” or activated in the display, so as to achieve as complete a picture as possible of the forces acting on the kiln. With the computer work behind him, the author was then able to mine the survey for relevant information. Noting the frequency and magnitude of conditions was of obvious use in assessing deterioration at Kiln No. 7. Noting the conditions’ patterns of appearance, however, as well as the apparent visual relationships between these patterns, was of particular use in understanding the mechanics of decay at work on the structure over time.

Among the patterns most immediately noticeable on the survey were those pertaining to salt deposition. Efflorescence is present across the entire circumference of Kiln No. 7, but is limited largely to the first tier—the first twelve to fourteen brick courses above grade. In many cases, the condition is most pronounced on and around the firebox openings. Efflorescence’s inverse, so to speak, is a condition called encrustation—the crust-like deposition of material on

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the surface of the masonry. In only one area—split between the survey’s Sections 6 and 7—is encrustation observed below the kiln’s second metal band. Erosion, then, which is defined as the disaggregation of material on the surface of the brick, is a condition strongly tied to the recrystallization of soluble salts in brick pores. Not surprisingly, erosion is present on the survey in or around many areas which exhibit efflorescence, as well.

The masonry deformation conditions briefly discussed in regard to Kiln No. 8 are most definitely present on Kiln No. 7, and are also interesting to interpret based on their patterns of appearance. The majority of deformation occurs in the bottom, first tier of kiln masonry. In fact, every instance which the author deems a bulging zone falls within the first twelve to fourteen courses of brick above grade. Many of these bulging zones feature a vertigo-inducing combination of rotation and out-of-plane displacement. Of the deformation modes to occur in upper levels of the kiln, two types seem to be most prevalent: in-plane displacement above fireboxes, kiln doors, or areas of extreme deformations lower in the kiln; and out-of-plane displacement at the very top of the kiln wall, between the fifth and sixth bands or above.

Partial loss and total, or unit, loss are two conditions which, like erosion, seem to be linked to other, more fundamental deterioration mechanisms. Unit loss, for example, which is defined as the total absence of one or more brick units, occurs overwhelmingly in areas exhibiting one or more deformation modes. Logically, then, this condition is seen most commonly in the first, lowest tier of the kiln, as well as in the upper reaches of the fourth tier. Partial loss, meanwhile, entails the loss of at least a quarter of a brick unit and is confined mainly to the first tier. Partial loss most commonly appears in and around the fireboxes and near areas exhibiting extreme efflorescence. The metal conditions—corrosion, band displacement, and total band

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118 Many of the masonry conditions used in this study were derived from definitions in L. Franke and I. Schumann, “Damage Atlas: Classification and Analyses of Damage Patterns Found in Brick Masonry,” European Commission on the Protection and Conservation of European Cultural Heritage, Research Report No. 8 (Vol. 2), 1998.
119 See Sections 4, 5, 10, and 12.
120 See Sections 1, 2, 4-6, and 8-12 for examples of in-plane displacement; see Sections 1, 4-8, and 10-13 for examples of out-of-plane displacement high up in the kiln wall.
absence—follow a similar trend. Although corrosion exists, variously, among all seven of the kiln’s iron bands, it is heavily concentrated in the lowest tier of the kiln—areas associated with efflorescence. And nowhere along the kiln are bands three through seven missing or displaced.

The conditions that seem to appear indiscriminately are negative slope, cracking, and mortar loss (i.e., open joints). Negative slope of grade at the base of Kiln No. 7 occurs rather randomly, and bears no discernible connection to other conditions. Cracking, then, is perhaps the condition that appears most seldom on the survey, and is thus of lesser concern relative to other, more ubiquitous conditions. Mortar loss, however, is widespread and very disconcerting. One could make the argument that open joints appear most frequently around areas affected by the masonry deformation conditions, but frankly, the condition is so pervasive—and among all of the kilns, not just No. 7—that such a claim is of little use in considering diagnoses and recommendations for potential remediation.

Repair and vegetation, finally, are the two surveyed conditions which distinguish Kiln No. 7 from its neighbors. Ostensibly, Kiln No. 7 seems to have undergone surface repairs to a greater extent that the other kilns which survive in the complex. And, in many cases, these repairs appear not to have completely resolved the issues they were meant to address. As illustrated by the continued bulging and in-plane displacement of a large repair on the lowest tier of the kiln’s eastern flank, most repairs served, at best, to slow or hamper the wear of kiln elements that was already well underway. Nonetheless, Kiln No. 7 is fortunate to have been patched up as much as it was—an element of its history that has perhaps saved it from the fates of Kiln Nos. 4 and 5. No. 7 is also fortunate to have been spared, thus far, the heavy growth of invasive vegetation observed on its neighbors to the south. The only vegetation seen on Kiln No. 7 exists atop its parapet—along the exposed walkway once used by workers to inspect and

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121 The author founds this claim on field notes and rough photographic evidence. More detailed inspection is in order, not only to validate this claim, but to characterize, classify, and potentially date the various repairs made to each of the kilns in the WCMC complex.

122 See survey sections 4-6 for the bulging zone of repair.
sample ware during firing. Due to decisions made in photographing the kiln, much of this vegetation eludes representation in the conditions survey presented here. However, the small plants and root systems that do exist along the top of the kiln wall penetrate the masonry, at most, a depth of two to three brick courses. There are no large, mature trees to contend with here, as there are in the beleaguered remains of Kiln Nos. 4 and 5.

### 3.1.3 Notes on the Documentation Process

Anyone familiar with conditions surveys will quickly note the imperfections in this particular effort. The author would like to elaborate briefly on those imperfections, and not because he wishes to excuse them, or eschew personal responsibility for them. Instead, because a beehive kiln is—as a cylindrical, multi-tiered volume—an extremely difficult structure to capture and represent in two, digital dimensions, an explanation of the documentation method followed here, the shortcomings inherent in that method, and the several opportunities for its improvement could be useful in the future. Indeed, should conservators soon find themselves needing to survey a structure of similar form—be it another kiln at the Bray, a Montana grain silo, an Atlantic coast lighthouse, or even a wedding cake!—a brief note on process could be of considerable help.

So, to begin with this survey’s imperfections, the author might first point out the strange, prime number of survey sections. When given a whole pizza, for example, how many people would chose to divide it into thirteen slices? And yet, the plan of Kiln No. 7 has been parsed out here into thirteen sections of disparate size. This awkward division scheme resulted in an array of problems pertaining to the survey’s graphic display and legibility. Sharing paper space elegantly among thirteen images of unequal width was difficult. And with each section occupying an irregular portion of the kiln’s elevation, conveying to readers where one section ends and the next begins proved challenging, as well. Ultimately, the author chose here to depict two kiln sections per sheet, leaving section thirteen stranded, for better or worse, on the last page. And to better
delineate one survey section from the next, the author employed a combination of transparencies, dotted lines, and explicit section labels.

Essentially, a conditions survey is only as strong as its photographs, and in the case of this survey, photographs were not taken with an eye for rational kiln division and the prevention of distortion. Indeed, the photographs used here were actually intended to recreate images captured one year earlier by Joseph Elliott, prior to the mass removal of debris from the kiln. Thus, the conditions team set up a before-and-after scenario—pre-cleaning images from 2011 versus post-cleaning images from 2012 (Fig. 3.9). Though effective in illustrating the power of cleaning, these photos were not ideal for use in a conditions survey. They were taken with considerable redundancy and overlap (such that fifteen original photographs ultimately yielded thirteen survey sections), and, in several cases, at angles oblique to the kiln face. This, in turn, resulted in considerable distortion once the author attempted to square the photos using editing software. Thus, many of the photographs are not perfectly to scale, and some of the surveyed conditions (especially those located along the margins of the images) are unrepresentative of their actual size. To complicate matters further, poor lighting and composition resulted in omissions of visual information—features that could not be recovered despite best efforts during editing.123

In the future, survey teams should decide upon the division of the kiln plan into even, equal-sized survey sections prior to taking their first photograph. They should position their camera such that the lens is fixed at the center of the section to be photographed and pointed in a direction perpendicular to the kiln wall. Surveyors must also remember that each tier of the kiln sports a different circumference. Thus, any flattened image that seeks to capture the entire kiln wall will inevitably incorporate a degree of distortion associated with the progressive depth of each tier. To limit this distortion, teams might consider photographing, rectifying, and surveying

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123 In Sections 1-3,5, and 13, for example, the top, seventh metal band has been omitted from the image’s original frame.
each of the kiln’s four tiers independently. (The four, independent tiers would then be reassembled later, in a clearly delineated graphic layout.) When selecting an appropriate scale of reference, teams should also take care not to measure the height of the kiln wall from the ground up. Due to structural settlement and the irregular accumulation of debris at the kiln’s base, the level of grade varies significantly along the kiln’s circumference. Teams should measure the vertical height of several brick courses in the center of their image, or apply evenly spaced targets using a laser level, to establish an accurate scale of reference for photo-rectification later.

Finally, and most fundamentally, the author recommends teams check and double-check the overlap of conditions—from one section to the next—as they complete their surveys. This particular survey was plagued by irregularities at the borders of adjacent sections. (Patches of corrosion, for example, exist on the margins of bands in Section 10, but are absent in Section 9, where they should logically continue.) Of course, this survey was conducted within the context of a field course. The surveyors had limited time to complete their task, and, as a didactic exercise, the basics of the survey process were emphasized perhaps to a greater extent than accuracy and precision. Nevertheless, the value of such a survey depends upon the consistency with which it portrays conditions as they exist in the field, and the irregularities present in this survey led the author to doubt its reliability on several occasions. Overall, the survey of Kiln No. 7 represents a lot of hard work and honest intentions. Insofar that it has alerted the author of areas for future improvement, it has proved to be a productive educational experience, as well.
<table>
<thead>
<tr>
<th>Masonry Conditions</th>
<th>Structural Deformation Modes</th>
<th>Metal Conditions</th>
</tr>
</thead>
</table>

**Mortar Loss**

The partial or total loss of pointing mortar, resulting in an open joint. This condition also includes joints exhibiting weakened or disaggregated mortar.

**Cracking**

Cracks spanning individual brick units or a series of units via mortar joints. This condition includes step cracks affecting multiple courses of brick, but does not include pre-existing cracks and defects in brick that are the result of variability in manufacture.

**Partial Loss**

The absence of at least one quarter of a given brick unit, such that the original shape of the unit is compromised.
**Erosion**

The disaggregation or wearing away of material on the surface of the brick, as evidenced by overall textural change and the apparent loss of fire-skin on individual brick units.

**Unit Loss**

The total absence of one or more individual brick units.

**Efflorescence**

A formation of soluble salts, commonly white, transported to and deposited on the surface of the brick by capillary action and evaporation, respectively.
**Encrustation**

The crust-like deposition of leached mortar or brick constituents on the surface of the masonry wall. This condition is characterized by strong adhesion and a dense, even glassy, appearance.

**Vegetation**

The presence of higher plant forms, living or dead, on or within the masonry wall.

**Repair**

All changes made to the brick masonry, as evidenced by alterations in coursing or the appearance of substitute brick of disparate type.
**Negative Slope**

The inward sloping of the immediate ground surface at the base of the kiln. Such a slope directs water toward the structure, as opposed to diverting it away.

**In-Plane Displacement**

The physical displacement of a brick unit, course, or area, such that the impacted area remains within the vertical plane formed by the kiln wall at any given point. Provided the kiln is viewed in elevation, in-plane displacement would encompass the movement of the masonry in the x and y Cartesian axes.

**Out-of-Plane Displacement**

The physical displacement of a brick unit, course, or area, such that the impacted area falls out of the vertical plane formed by the kiln wall at any given point. Provided the kiln is viewed in elevation, out-of-plane displacement would encompass the movement of the masonry in the z Cartesian axis.
Rotation

The inward or outward pivot of a brick unit or course. This condition does not encompass total physical displacement of the brick unit, but rather its simple rotation along a fixed axis.

Bulging Zone

Any area in which multiple masonry deformation conditions (i.e., rotation, in-plane displacement, and/or out-of-plane displacement) converge, resulting in a dramatic, outward tumbling or ballooning effect.
**Corrosion**

The chemical deterioration of the iron banding, as evidenced by flaking, embrittlement, and increased friability across portions of the band surface. This condition includes corrosion that has penetrated the metal entirely.

**Band Missing**

The total absence of an iron band.

**Band Displaced**

A band that, while still present on the kiln, no longer occupies its original position.

*Special thanks to members of the 2012 Conservation Praxis for photo contributions, and to Joe Torres for his 3-D models.*
Kiln No. 7 Plan view
Scale: 1/8" = 1'
0' 4' 8'
N
ARCHIE BRAY FOUNDATION FOR THE CERAMIC ARTS - HELENA, MT
ARCHITECTURAL CONSERVATION LABORATORY AND RESEARCH CENTER
GRADUATE PROGRAM IN HISTORIC PRESERVATION
SCHOOL OF DESIGN - UNIVERSITY OF PENNSYLVANIA
SPONSORED BY:
MONTANA PRESERVATION ALLIANCE
PROJECT DIRECTOR:
FRANK G. MATERO
FIELD SUPERVISORS:
MEREDITH KELLER & JOSEPH TORRES BRETT STURM
DIGITIZED AND PREPARED BY:
WESTERN CLAY MANUFACTURING CO.
SITE RECORDING:
JUNE 2012
KILN NO. 7 EXTERIOR ELEVATIONS CONDITION SURVEY SECTIONS
SHEET NO.:

Masonry Conditions
- Mortar loss
- Cracking
- Partial loss
- Erosion
- Unit loss

Structural Deformation Modes
- Negative slope
- In-plane displacement
- Out-of-plane displacement
- Rotation
- Bulging zone

Metal Conditions
- Corrosion
- Band displaced
- Band missing

Sample location
Section limits
3.2 Supplemental Material Analysis

The observations generated during the conditions survey process represented an important, first step in establishing connections and causalities related to the kilns’ material maladies. Augmenting, and challenging, those ideas with information gleaned in a controlled, laboratory environment, was the next best step in the diagnostic process. For that, the author submitted various field samples to a series of standard testing procedures. Though the ultimate efficacy of the tests varied somewhat, the process of first selecting the tests, and then realizing which ones were revealing and why, proved highly informative.

The rationale for the selected test sequence is presented in the methodology below. Here, the author refines some initial, field- and survey-based hypotheses by describing the laboratory procedures he thought would provide corroborating or refuting data. In the end, not every test was useful in diagnosing conservation problems at the kilns. In fact, some procedures were ultimately deemed unnecessary or impossible for reasons that are presented alongside germane test results in Section 3.2.2. This laboratory-based portion of the study concludes with a discussion of those results and their ultimate influence on recommendations issued for the material remediation of the kilns. While laboratory work may leave some feeling mired in technical jargon and procedural minutiae, what follows should not obstruct the simple cause-and-effect pathologies that are, for the most part, the cornerstones of architectural conservation.

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1 The laboratory analysis undertaken in this study is focused chiefly on the masonry component of the greater kiln complex. For details pertaining to the potential conservation of the complex’s distinctive wooden sheds, please refer to Section 3.1.1.
3.2.1 Methodology

According to Grimm, the physical properties of brick that are important in assessing the durability of brick masonry assemblies include:

- Porosity
- Pore size distribution
- Water absorption
- Saturation coefficient
- Capillarity
- Drying rate
- Rate of water absorption
- Water permeability
- Air permeability
- Salt content
- Tensile strength
- Compressive strength
- Shear strength

Considering this project’s budget, however, as well as the time allotted for its completion, the notion of testing each sample retrieved from the kiln complex with regard to all of Grimm’s enumerated properties seemed fanciful at best. For certain, such a stringently deductive, “top down” approach would have, in its attempt to test every brick deficiency imaginable, squandered time, money, and man-hours. Perhaps worse, though, would have been its failure to respond to the tangible symptoms, or mechanisms, of deterioration observed firsthand in the field—the truest barometer of building health.

Therefore, in devising a testing sequence appropriate to the scope and goals of this project, the author sought a more inductive approach—working backwards from observed (and surveyed) failures to plausible causative factors and, ultimately, quantifiable material properties. To pare down Grimm’s extensive list of testable brick properties into something more manageable and holistic, the most troubling deterioration mechanisms observed on the kilns were considered first, as they alone indicate larger, systemic issues that could jeopardize the structures’ long-term survival. Those most problematic mechanisms included:

- Mortar loss
- Encrustation
- Partial/Unit loss
- Erosion
- Efflorescence
- Various deformations

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Based on a fundamental grasp of building pathology—but prior to conducting any confirming analysis in the lab—the author then matched the observed mechanisms above with potential causative factors as follows:

<table>
<thead>
<tr>
<th>Observed Failure Mechanism</th>
<th>Possible Causative Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortar loss</td>
<td>Water infiltration and conveyance</td>
</tr>
<tr>
<td>Partial/unit loss</td>
<td>Salt hydration and recrystallization</td>
</tr>
<tr>
<td></td>
<td>Freeze/thaw cycling</td>
</tr>
<tr>
<td></td>
<td>Thermal expansion and contraction</td>
</tr>
<tr>
<td>Efflorescence</td>
<td>Water infiltration and conveyance</td>
</tr>
<tr>
<td>Encrustation</td>
<td>Salt hydration and recrystallization</td>
</tr>
<tr>
<td>Erosion</td>
<td>Freeze/thaw cycling</td>
</tr>
<tr>
<td></td>
<td>Leaching mortar constituents</td>
</tr>
<tr>
<td>Various deformations</td>
<td>Water infiltration and conveyance</td>
</tr>
<tr>
<td></td>
<td>Thermal expansion and contraction</td>
</tr>
<tr>
<td></td>
<td>Corrosion and failure of iron banding</td>
</tr>
<tr>
<td></td>
<td>Hygroscopic expansion and contraction of wall constituents</td>
</tr>
</tbody>
</table>

**Table 3.1** – Possible cause-and-effect scenarios driving deterioration of Kiln No. 7

While this initial list of factors was never considered to be complete and wholly accurate, the exercise was useful in pinpointing vulnerable or complicit materials (e.g., the role of mortars in the encrustation of brick), and in brainstorming how one might substantiate such vulnerability and complicity (e.g., the chemical identification of deposited crusts). In many ways, then, devising a testing regime pursuant to inductive, “bottom up” reasoning required the application of deductive, “top down” principles in building pathology. Like all critical thinking, diagnostic thinking obliges the conservator to navigate those murky waters between what the published technical literature suggests, what accumulated experience suggests, and what can be observed firsthand.

**Kiln Clay**

For example, in seeking to explain worrisome deformation modes observed along portions of the kiln walls, the author delved into his memory banks, conjuring up a project he had
done on the thermal expansion of a steel bridge in midsummer sun. Deductive reasoning would naturally lead one to suspect thermal expansion as a culprit in the deformation of a kiln, as well, given a kiln’s sole purpose of housing and withstanding extreme heat. The author was also willing to consider an early, inductive suspicion, however, that the infiltration of water into the masonry walls of Kiln No. 7 via open mortar joints and an exposed parapet could play a contributing role in deformations noticed, above all, in the lower brick courses. The presence of a downward vector for water movement within the wall—a percolation from the kiln’s crown toward its base—seemed likely. The notion that vegetation observed along the length of the parapet could further contribute to the retention of moisture in the wall seemed plausible, as well.

Thinking that the wall’s internal constituents—namely, the clay used in kilns both as a mortar and bedding material—could be dimensionally unstable in the presence of water, the author extracted twelve samples from the wall of Kiln No. 7 with the intent of determining their percentage moisture content. Sampling was dictated by location, as well as access to the wall core, and alas, moisture levels tested low for each sample. Nonetheless, the extent to which, over its century of service, the sampled clay had remained hydrophilic needed, still, to be determined. If, indeed, the clay displayed water-activated expansion and contraction, its swelling and shrinking during wetting could account for unwanted brick movement and the continued deformation of the kiln walls.

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3 As the majority of the kiln foundation is protected from wetting by the shed roof, wetting via capillary rise is of lesser concern.
4 In total, fifteen samples of clay mortar and bedding material were extracted from Kiln No. 7 in July 2012. Twelve of those samples—henceforth referred to as “minute”—were extracted at various heights and depths across the kiln elevation using a masonry drill. (See Kiln No. 7 conditions survey for minute sample locations.) Immediately sealed in metal soil containers upon extraction, these samples were fit for moisture content evaluation upon returning to the University of Pennsylvania. Sample size was limited by difficulties in extraction, however, and ranged from roughly 3 to 19 grams—thus the modifier “minute.” The three remaining samples were extracted by hand, stored in plastic bags, and range from roughly 60 to 230 grams. Labeled “bulk,” these samples were not evaluated for moisture content but were tested for hygroscopic activity along with the minute samples. Please refer to Appendix E for more information on the samples obtained from the kiln complex.
5 Please refer to Appendix E for the full presentation of these results.
So, by employing diagnostic reasoning that was partly observation-based (inductive) and partly knowledge-based (deductive), a testing sequence took shape for clay samples extracted from the walls of Kiln No. 7:

1. **Oven-drying of twelve minute samples to ascertain percent moisture content**, as specified in Method B of ASTM Standard D2216-10: Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.⁶

   i. Twelve test specimens are weighed in a container of known mass to the nearest 0.01 g (M¹). As the total mass of the WCMC specimens would obviously fail to meet the minimum sample mass as specified in the standard (20 grams of material passing the 2-mm sieve), sieving is bypassed and the samples are placed directly in the oven.

   ii. Specimens are dried in an oven at approximately 110°C for 22 hours, sufficiently above the ASTM-specified minimum of 12-16 hours.

   iii. Dried specimens are weighed to the nearest 0.01 g (M²). Assuming that the mass of the container (Mᶜ) remains constant during drying, the calculated difference between the sample mass after drying and the mass of the container (M² – Mᶜ) is equal to the mass of the specimens’ solid particles.

   iv. Similarly, provided Mᶜ remains constant, the calculated difference between the sample mass before and after drying (M¹ – Mᶜ) must equal the moisture lost to evaporation. As a percentage of the total mass of the specimen’s solids, or

\[
\left(\frac{M^1 - M^2}{M^2 - M^c}\right) \times 100
\]

---

⁶ This and other referenced ASTM Standards may be found in Appendix E.
this value equals, to the nearest 0.1 %, the moisture content of a clay mortar or bedding material sample as extracted from the masonry wall of Kiln No. 7.

2. Organization and consolidation of minute and bulk clay mortar samples into groups by Munsell color value.

i. To prepare for further analysis of the clay samples’ hygroscopic activity, the various clay samples extracted from Kiln No. 7 are grouped by Munsell color value and combined. This consolidation should help avoid difficulties stemming from otherwise prohibitively-small sample sizes. Also, assuming that samples of a similar hue have experienced similar levels of heating (and thus similar, attendant chemical changes) during the kiln’s era of operation, such organization by color should not interfere with the author’s ability to potentially correlate the activity of the clay samples with their positioning (i.e., depth or height from grade) within the kiln wall.

3. Calculation of each color group’s activity number (A) using the plasticity index (PI), as specified in ASTM Standard D4318-10: Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

i. The combined clay groups are allowed to dry at room temperature and prepared according to the Dry Preparation Method. Samples are pulverized in a mortar and pestle and passed through a 425-μm (No. 40) sieve. The material initially retained on sieve is pulverized repeatedly, until all clots of soil had passed into the pan below. Retained material was set aside.

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7 The Munsell color system classifies colors based on three color dimensions: hue, value (lightness), and chroma (color purity). Created by Albert H. Munsell in the first decade of the twentieth century, the Munsell system was adopted by the USDA as the official color system for soil research in the 1930s and remains a staple color classification scheme in the field of architectural and materials conservation.

8 Of course, the possibility exists that sample color could have more to do with the clay’s original composition than with its chemical or physical response to extreme heat over years of kiln firing. Either way, consolidating the disparate clay samples by color seemed to be the most prudent way of increasing sample size without jeopardizing potential correlative relationships in resulting data.
ii. The particles passing the 425-μm (No. 40) sieve are weighed and sieved yet again. The percentage, by mass, of clay particles passing a 2-μm sieve is calculated for later use in determining the groups’ activity number. The particles are then re-mixed.

iii. The retained material from Step 1 is washed in deionized water and passed once more through the No. 40 sieve. The suspended fines are added to the previously sieved soil, while the aggregate material retained on the sieve is discarded. Deionized water is mixed into the sieved soil, bringing it to a plastic, paste-like state. The soil is then covered to prevent the loss of moisture.

iv. The liquid limit test proceeds under Method B – One-point Limit. Roughly 100 grams of each prepared sample group are alternatively transferred to the cup of a Casagrande device, spread to a maximum thickness of 10 mm, and grooved down the center. The cup crank is turned at a rate of approximately 2 drops per second, until the two halves of the soil cake came into contact at the groove along a distance of 13 mm. The number of drops required to close the groove (N) is recorded, and, as specified in the standard, must fall between 20 and 30 blows. A soil slice perpendicular to the groove is removed and its water content (%MC) determined in accordance with the ASTM D2216 procedure described above. The entire process is conducted in two trials for each sample group. The number of drops required to close the groove (N) in each trial may not differ by more than 2 drops. The liquid limit for each trial ($LL^x$) is calculated using the following equation:

$$LL^x = \%MC \times \frac{N}{25}^k$$

where $k = 0.121$ and $x =$ the trial number (i.e., 1 or 2).
The liquid limit for the sample group (LL), then, is the average of the two trial liquid-limit values, rounded to the nearest whole number and reported without percent designation.

v. The plastic limit test then proceeds as follows. At least 20 grams of each prepared, wetted sample group is selected and worked to a consistency at which it can be rolled without sticking to the hands. (Deionized water may be added, or the mixture blotted with paper toweling as necessary.) A 1.5 to 2.0-gram portion is then rolled between the palm and a ground-glass plate into a thread, achieving a diameter of 3.2 mm in no more than 2 minutes. Once having reached desired thickness, the thread is broken into several pieces, reformed into an ellipsoidal mass, and re-rolled. This process repeats until the thread crumbled under hand pressure and can no longer be rolled to a diameter of 3.2 mm. The portions of the crumbed thread are gathered and sealed in a closed container of known mass. The entire process repeats until two sealed containers containing at least 6 grams each of re-rolled, crumbed soil have been collected for all sample groups. The water content of the containers (%MC) is determined in accordance with the ASTM D2216 procedure described above. The average of the two water content values is computed for each sample group and rounded to the nearest whole number, yielding the value for the sample’s plastic limit (PL), reported without percent designation.

vi. The plasticity index (PI) for each sample group is calculated using the following equation:

\[ PI = LL - PL \]

If either the liquid limit or plastic limit cannot be determined, or if the plastic limit is equal to or greater than the liquid limit, the soil is deemed non-plastic.
vii. Finally, the activity number (A) for each sample group is calculated as the ratio of the plasticity index (PI) to the percentage, by mass, of clay particles having an equivalent diameter smaller than 2 μm.


i. In anticipation that the consolidated color groups will exhibit a range of activity in the presence of water, the author is prepared to submit outlying samples for further characterization via X-ray diffraction analysis. Though the analysis will be conducted by technicians at the University of Pennsylvania’s Laboratory for Research on the Structure of Matter (LRSM), the slides for such an examination must be prepared by the author by suspending each sample’s finely sieved clay particles in vacuum grease on a glass slide.

Kiln Brick

The conveyance of moisture through the brick units of a kiln’s wall is an inexorable reality. It was important, then, for this study to evaluate proxy brick—recovered samples matching those built into the kiln—in an effort to link observable deterioration mechanisms such as efflorescence, encrustation, and erosion, to quantifiable, moisture-related brick properties such as porosity, saturation coefficient, pore size, and even mode of manufacture.\(^9\)

Identifying brick porosity was chosen as an important first step. In general, porosity is understood to mean “the ratio of the volume of air contained within the boundaries of a dry material to the [material’s] total volume (solid matter plus air), expressed as a percentage.”\(^10\) In lieu of measuring total effective porosity by mercury intrusion, the author intended to measure porosity gravimetrically, by water absorption. Generally speaking, the more water a brick

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\(^9\) Proxy brick were selected and shipped back to the University of Pennsylvania on the basis of a typology constructed by the author during field work in July 2012. This typology may be found in Appendix C. For notes on the appearance of the various brick types across the elevation of Kiln No. 7, please refer to Section 2.2.3.

\(^10\) Grimm, 207.
absorbs, the more porous it is. With greater porosity comes greater risk of damage via the internal strains imposed by soluble salt hydration and recrystallization, freeze/thaw cycling, or the thermal expansion of entrapped water.

By comparing the results of two water absorption methods—the 24-hour cold water submersion test and the 5-hour boiling water submersion test—the saturation coefficient would then be determined for each relevant sample. The saturation coefficient, also known as the $c/b$ ratio, is an approximation of the ratio of easily filled pore space to total pore space. Knowledge of such a ratio would prove helpful in making basic assumptions about a brick’s ability to accommodate salt deposition or frost using the totality of its accessible pore space.¹¹

Like porosity, pore size was chosen as another brick property possibly contributing to the material’s observable deterioration at the kiln complex. As small pores tend to trap water and saline solutions, brick with larger pores are generally more durable. A brick’s rate of water absorption—also referred to as initial rate of absorption (IRA) or suction—is a basic indicator of pore size and was tested according to the procedure described below.

In the eyes of the author, measuring porosity and pore size would enhance this study’s ability to comment on the origins of observed salt damage and deposition on Kiln No. 7. Such tests would also shed light on the likelihood of damage via freeze/thaw cycling in kiln masonry. Because few conditions on the kiln correspond symptomatically to freeze/thaw damage, however, the performance of the actual freeze/thaw test on proxy brick samples—a procedure which is rather time-consuming and tedious—was deemed unnecessary here. The same could not be said for the positive identification of salts deposited on the external surfaces of representative sample brick. Determining the exact nature of bloomed salts—be they sulfates or chlorides, for example—is important in understanding the origin of the salt and its vector for aqueous

¹¹ Grimm has remarked that this ratio may sometimes vary drastically among similar specimens, and indeed, even within the confines a single brick. The heterogeneous nature of ceramic materials was, at first, not considered a viable reason for the alteration or altogether abandonment of the enumerated test procedures. See Sections 3.2.2 and 3.2.3 for further discussion of the difficulties inherent in brick testing. *Ibid.*, 208.
transmission within the structure. To that end, salt identification tests were run on brick exhibiting both efflorescence and encrustation.

As opposed to the clay tests listed in sequence above, the brick tests were not intended to pursue a single, loosely-hypothesized pathology that could explain an entire family of deterioration mechanisms (e.g., the role of hydrophilic clay in kiln wall deformation). Instead, the following tests represent a more purely inductive attempt to strategically gather data on the material characteristics of selected samples, as these data could likely illuminate many of the conservation problems on display across Kiln No. 7 and others:


   i. Although the ASTM Standard calls for half brick in this and the following, 5-hour submersion procedure, the author feels it unwise to cut in half perfectly intact, historic brick taken from the immediate vicinity of Kiln No. 7. Therefore, the brick specimens remain whole as they are first dried in an oven at approximately 110°C for 24 hours. The brick are set to cool before an electric fan for at least 2 hours, until they are no longer noticeably warm to the touch. At this point, the brick are weighed to the nearest 0.1 g (M1).

   ii. The brick are submerged, without preliminary partial immersion, in clean distilled water at 15 to 30°C for 24 hours.

   iii. The brick are removed from the water bath, wiped with a damp cloth and weighed to the nearest 0.1 g (M2). This process is completed for each specimen within 5 minutes of its removal from the water.
iv. The cold water absorption is calculated to the nearest 0.1 % for each specimen as

\[
\text{Absorption, \%} = \frac{\left( M^2 - M^1 \right)}{M^1} \times 100
\]


i. The brick subjected to cold-water submersion above are returned to the water bath such that the water, still at 15 to 30°C, can circulate freely on all sides of the specimen.

ii. The water is heated to boil within 1 hour, and then boiled continuously for the following 5 hours. The water is allowed to cool to 30°C, at which point the specimens are removed, wiped with a damp cloth, and weighed to the nearest 0.1 g (M²). This process is completed for each specimen within 5 minutes of its removal from the water.

iii. The boiling water absorption was calculated to the nearest 0.1 % for each specimen as follows:

\[
\text{Absorption, \%} = \frac{\left( M^2 - M^1 \right)}{M^1} \times 100
\]

iv. The saturation coefficient is calculated to the nearest 0.01 as follows:

\[
\text{Saturation coefficient} = \frac{M^{2C} - M^1}{M^{2B} - M^1}, \text{ where}
\]

\[
M^{2C} = \text{saturated weight of the specimen after 24-hour, cold water submersion;}
\]

\[
M^{2B} = \text{saturated weight of the specimen after 5-hour, boiling water submersion;}
\]

\[
M^1 = \text{dry weight of the specimen}
\]

i. Brick specimens are dried and cooled in accordance with the procedure described above.

ii. The length and width of each specimen’s flat, bedding plane (i.e., the surface of each brick that will come into contact with water in the following steps) are measured to the nearest 0.05 in. Each specimen is weighed to the nearest 0.5 g.

iii. A testing tray is constructed to meet the following specifications:

   a. Tray is watertight, having an inside depth of at least 0.5 in.

   b. Tray provides a plane, horizontal surface, so that an area at least 8 in. long and 6 in. wide will be level when tested by a spirit level.

Two supports—rectangular in cross section, approximately 0.25 in. high when laid flat and no more than 0.5 in. wide—are placed at the bottom of the tray. These supports hold the brick specimens, which are tested individually.

iv. The tray is filled with distilled water, such that once each brick specimen is positioned horizontally on the supports, enough water is displaced to cover exactly 0.125 in. of its height. To ensure the proper water level is attained, a saturated brick (submerged completely in water for at least 3 hours beforehand) is employed as reference. For greater accuracy, a line is struck across each specimen brick indicating a height of 0.125 in. along its stretcher face.

v. Each specimen is set in place horizontally, with zero time counting as the moment of contact between the brick and water. During the 1-minute period of contact, the water level of the tray is maintained at a height of 0.125 in. along the stretcher face of the specimen. Distilled water may be added to the tray as necessary.

vi. At the end of the 1-minute period of contact, the specimen is removed from the water, wiped with a damp cloth, and weighed to the nearest 0.5 g. Wiping is
completed within 10 seconds of the specimen’s removal from the tray; weighing
is completed within 2 minutes.

vii. The difference in grams between each specimen’s dry and wet weights represents
the weight in grams of water absorbed by the specimen during its 1-minute
period of water contact. For brick having a horizontal surface area (calculated
using the length and width measured above) within 0.75 in.\(^2\) of 30 in.\(^2\), the net
weight gain represents the initial rate of absorption in 1 minute, reported to the
nearest 0.1 g/min/30 in.\(^2\).

viii. For specimens having a horizontal surface area below or beyond 30 \pm 0.75\ in.\(^2\),
the equivalent water weight gain (and thus the specimen’s initial rate of
absorption) is calculated as follows:

\[
X = 30 \times (\Delta M / LW),
\]

where

\(X\) = initial rate of absorption corrected to 30 in.\(^2\) of horizontal surface area;

\(\Delta M\) = gain in weight of specimen, g;

\(L\) = length of specimen, in.;

\(W\) = width of specimen, in.

ix. For cored brick samples, net horizontal surface area is calculated and substituted
as \(LW\) in the equation above.\(^{12}\)

---

\(^{12}\) For brick absorption determinations such as those procedures described above, ASTM Standard C67-12 calls for a
sample population of at least ten individual brick specimens per lots of 1,000,000 brick or fewer. For each 500,000
additional brick, five specimens are to be selected and tested (e.g., 20 specimens for 2,000,000-brick lots). In the case
of the WCMC kiln complex, it was virtually impossible to determine the number of brick built into each kiln.
Furthermore, sampling was limited both by a.) the number of loose or spare brick in the kiln complex which visibly
matched brick types built into the kilns, and b.) the cost of packaging and shipping each specimen from Helena to
Philadelphia. Thus, deviations from the norms set by ASTM with respect to sample population were inevitable. See
Section 3.2.2 for more information regarding difficulties inherent in brick testing.
4. Semi-qualitative identification of salts on samples exhibiting both efflorescence and encrustation

i. Using a mortar and pestle, the samples are ground to a fine, homogeneous powder. A small portion (0.5-1 gram) of each sample is set aside in a glass dish for the analysis of carbonates. The remainder of each sample is mixed with 25 ml deionized water and agitated with a glass rod for two, five-minute cycles, allowing fifteen minutes of rest in between.

ii. The sample, in solution, is washed in a funnel lined with fine filter paper. The salt solution which passes through the filter paper should be clear—otherwise the solution must be washed and filtered again.

iii. Using a small pipette, drops of the solution are placed on a series of EM Quant Sulfate, Nitrate, Nitrite, and Chloride Tests. The presence and approximate concentration of a salt are indicated, respectively, by the strip’s change in color and the intensity of that change. The results are recorded using a series of plus or minus signs befitting the salt’s intensity.

iv. The dry portion of the sample retained prior to wetting, agitation, and filtering is placed under a stereo microscope and mixed with several drops of hydrochloric acid. The bubbling of carbon dioxide gas emitted from the sample indicates the presence of insoluble carbonates. Bubbling of greater intensity signifies a higher concentration of carbonates.

3.2.2 Testing

The following section describes those procedures that were ultimately executed in the laboratory, as well as the applicable results. As the reader will undoubtedly notice, those

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13 Aspects of the procedure for this analysis were borrowed from Jeanne Marie Teutonico, A Laboratory Manual for Architectural Conservators (Rome: ICCROM, 1988), 58-65.
procedures which proved possible and useful in the end do not correspond, letter-for-letter, to the author’s initial goals and intentions. Unforeseen issues regarding sample response to stimuli, sample size, and the suitability of lab facilities did arise, in some cases altering the design and implementation of certain tests. Deviations from the original test methods are explained below. In concert, they serve as a reminder of the flexibility and resourcefulness required by any conservator attempting to tailor standards from the realm of material science to suit practical realities in the realm of historic architecture. A full discussion of the following results, as well as their potential impact on kiln stabilization and remediation, follows in Section 3.2.3.

**Kiln Clay**

The oven-drying and Munsell-based classification of samples extracted from Kiln No. 7 proceeded as intended. Only one sample—Minute Sample No. 3, obtained 9.5 inches above grade at Firebox No. 6—exhibited what could be considered high moisture content at 20.17% (Fig. 3.10). Although the twelve minute samples lent themselves easily to color classification, yielding three distinct color groups, there was no apparent correlation between sample color and positioning within the kiln wall (Fig. 3.11).14

The course of clay-based analysis first changed with the application of the series of Atterberg Limits tests to the consolidated color groups and the bulk samples. Indeed, not one of the six groups responded to the addition of water as the author had expected. The hand-rolling procedure necessary in determining plastic limit proved exceedingly difficult with the samples. For the determination of the liquid limit, then, agitation in a Casagrande device was impossible. After sieving, only one sample—Bulk Sample no. 2—was large enough to satisfy the 100-gram weight limit imposed on the test by the ASTM standard. And this sample, when wetted only slightly, became too fluid to sustain more than nine up and down blows of the instrument (Fig.

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14 For full results, see “Sample Information – Clay Bedding Material” and “Clay Test- Moisture Content of Clay Bedding Material,” located in Appendix E.
In failing to submit to either hand-rolling or testing via a Casagrande device, the samples revealed themselves to be non-plastic. Thus, the Atterberg Limits lost relevancy and the author was forced to reevaluate the nature of deterioration in the kiln’s masonry walls. Almost immediately, the author began to suspect that what he had first assumed were samples of raw clay were, instead, samples of fired clay.

Regrettably, X-ray diffraction proved impossible within the time constraints of this project. Whether or not such a detailed analysis of Kiln No. 7’s “clay” samples is even necessary, however, is, highly debatable. To confirm the ceramic, water-inert identity of the samples, the author turned to a University of Pennsylvania archaeologist specializing in the analysis of ancient pottery. The archaeologist recommended simply allowing the samples to sit in water for a period of several hours. If the samples reverted to slip-like states of prolonged suspension in water, their clay minerals had likely survived. If, however, the samples seemed unaffected by the water, quickly falling out of solution and settling at the bottom of the vessel, it was likely that their clay minerals had been rendered ceramic. Heeding the archaeologist’s advice, the author conducted the water test (Fig. 3.13). Lo and behold, the samples again behaved as ceramics.

**Kiln Brick**

From the onset, the brick-testing component of the study was fraught with difficulties pertaining to sample size, material heterogeneity, and the capacity of the available facilities to accommodate prescribed procedures. The water absorption tests were derailed early by the tenuous logistics involved in the boiling as many as six whole bricks for a period of five hours. Then, after considering more deeply the disparity between the enormous population of brick built piecemeal into Kiln No. 7 and the meager, one-specimen-per-type population of proxy samples retrieved and shipped to Philadelphia, questions arose surrounding the ability of such tests to contribute, whatsoever, to the meaningful understanding of the kiln.
Wanting to obtain at least some measure of data on the sample brick’s performance in water, however, the author pursued the initial rate of absorption, or suction, test (Fig. 3.15). Six of the brick types seen most frequently in Kiln No. 7’s original fabric and *ad hoc* repairs were submitted to the one-minute absorption trials as described in the previous section.\(^{15}\) The following, somewhat puzzling results were obtained:

<table>
<thead>
<tr>
<th>Brick Type</th>
<th>Corrected IRA (g/min./30 in.(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>B4</td>
<td>11.44</td>
</tr>
<tr>
<td>B6</td>
<td>53.22</td>
</tr>
<tr>
<td>B7</td>
<td>5.10</td>
</tr>
<tr>
<td>C4</td>
<td>6.57</td>
</tr>
<tr>
<td>D2</td>
<td>5.74</td>
</tr>
<tr>
<td>D5</td>
<td>5.71</td>
</tr>
</tbody>
</table>

*Table 3.2 – Results obtained for initial rate of absorption among Kiln No. 7 brick\(^{16}\)*

Why the B6 brick should absorb upwards of ten times the amount of water absorbed by its counterparts is a question that defies ready explanation. The author expected B6, a repressed brick, to exhibit larger pores and thus a higher rate of initial absorption, than later, denser, extruded samples. But such a spike in water absorption—a value dwarfing even those results obtained for B7, a brick of similar age and manufacture—was simply baffling. Though the specter of human error on the part of the tester is, of course, ever-present, the author is more willing to interpret this deviation as an indication of brick’s extreme variability. Perhaps this particular sample was under-fired and, thus, highly porous. Perhaps only a portion of the brick was under-fired, and that portion, alone, was enough to skew the results. Not knowing the exact history of any given brick (e.g., the conditions of its firing), it is difficult to draw broad conclusions about the material using as reference the character and performance of just one

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\(^{15}\) Because the digital balance in the ACL could not safely accommodate its mass, Type A1 refractory brick was excluded from this test.

\(^{16}\) For full results, see “Brick Test – Initial Rate of Absorption (Suction),” located in Appendix E.
specimen. Indeed, in light of brick’s extraordinary heterogeneity, the author’s frustrations at having failed to complete more extensive absorption tests have been placated somewhat.

Unfortunately, then, the only component of the brick tests not to undergo alteration or outright cancellation was salt identification, which was carried out, as planned, on salty brick fragments taken from Firebox No. 9 and encrustation removed from a brick in Kiln No. 7’s uppermost tier. EM Quant strips were used to detect the presence of sulfates, chlorides, nitrites, and nitrates in ground, solubilized, and filtered samples (Fig. 3.14). The results of this analysis, paired with the results of a quick, chemical test for carbonates, are presented below.

<table>
<thead>
<tr>
<th>Sample</th>
<th>SO₄</th>
<th>Cl⁻</th>
<th>NO₂⁻</th>
<th>NO₃⁻</th>
<th>CO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firebox Fragments</td>
<td>+</td>
<td>+++</td>
<td>-</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Encrustation</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>++</td>
</tr>
</tbody>
</table>

*Table 3.3 – Identification of salts present in Kiln No. 7 efflorescence and encrustation*

Luckily, when the colored strips available for sulfates yielded inconclusive results, it was possible to carry out a chemical spot test for verification. In the case of the sample crust, mixing the solubilized sample with two drops of dilute hydrochloric acid and two drops of a ten-percent solution of barium chloride produced a strong, positive reaction of white, barium sulfate precipitate.

**3.2.3 Discussion of Results**

That the soil samples extracted from within Kiln No. 7’s masonry were non-plastic—and indeed, not clay at all—was a revelation. Perhaps the kiln walls were laid up using a binder that was mostly brick dust. Or, the clay originally used in construction was rendered ceramic by the extreme heat coursing through the kiln over its many years of use. Either way, the notion that the
walls’ primary binding agent might be active and expansive in the presence of water was refuted, and a new set of concerns arose regarding the structure’s stability—concerns that are voiced in the conclusion of this chapter.

Though disappointing, the inability of the brick testing regime to produce any new or revealing data on the character and performance of brick built into Kiln No. 7 is, in the long run, unlikely to influence decisions made on the conservation of the structure. The brickwork on display at the WCMC kiln complex is a tapestry of types and manufacturing techniques. In the walls of each kiln, extruded brick coexist alongside repressed brick, with even the odd, handmade brick scattered amongst them (see, for example, Type B1). Each brick conveys water and saline solutions; each brick is subject to mechanical damage via freeze/thaw cycling and the recrystallization of salts. Some brick—by virtue of the clay comprising them, flaws in their formation, or an ill-fated spot in the kiln—will inevitably prove more vulnerable than others. But the prolonged boiling of single, representative specimens will not enable the conservator to pinpoint, in a structure composed of thousands, those most troublesome or compromised units. Even if one could distinguish weak brick from the stronger, how might one extract them from a load-bearing wall built with hundreds of interlocking, historic pieces?

At the least, the brick-related component of laboratory analysis enabled the author to identify observed efflorescence as largely nitrate and chloride salts. Conversely, the observed encrustation was revealed to be composed primarily of sulfate and carbonate salts. As described below, these facts were critical in understanding the origins and mechanics associated with these conditions. Otherwise, no form of brick testing—be it via soaking, boiling, or freezing—could have altered what the author has come to know and appreciate through his firsthand experience with the material. Brick is incredibly variable, but also incredibly resilient, stuff.
3.3 The Effects of the Environment and Prior Use on Material State

If the gathering of qualitative observations marked the first step in the diagnostic process, and the refinement of those observations via laboratory analysis the second, the final step in understanding deterioration at the WCMC kiln complex was to consider factors pertaining to the local environment and the site’s use over time. The following commentary thus incorporates information regarding Helena’s climate and kilns’ operation during the era of Western Clay, accessing, in the end, these factors’ role in the wood and masonry decay evident at the complex. Though the deterioration of architecture is always a product of context, the goal of this section is to establish, specifically, which aspects of deterioration directly reflect the site’s environmental situation and its historic employment in the repeated firing of heavy clay products.

“By the standards of a vast majority of people who live outside the Arctic, western Montana is a ‘cold’ place.” So write a group of meteorologists in a 2009 report on climate and ecosystem change in western Montana. But as temperature data collected over the past century suggest, places in western Montana—places like Helena—are not as consistently cold as one might think. “The intermountain regions of western Montana not only have a large climatological difference in cool and warm season temperatures,” continue Pederson et al. They are “also prone to large and rapid variations in temperature on extremely short time scales.” For brick and mortar, such variations in temperature can be quite detrimental. For, when water trapped in these materials’ interstitial pores is subjected to cyclical freezing and thawing, the internal stress generated by the reoccurring expansion and contraction of ice crystals can wreak havoc. In this era of climate change, the number of freeze/thaw days in Montana—days during which the minimum temperature falls at or below 32°F—is gradually decreasing. On average,

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18 Ibid.
however, conditions still exist for freeze/thaw damage on a remarkable 170 days per year.\textsuperscript{19}

Almost every other day, then, masonry elements at the kiln complex are exposed to potentially destructive forces resulting from the simple phase change of interstitial moisture.

Of course, in the absence of interstitial moisture, the freeze/thaw damage described above is, naturally, of lesser concern. Luckily, despite sometimes volatile swings in temperature, Helena is still a rather dry place. A modest 11.6 inches of water-equivalent precipitation constitute the yearly norm, while annual relative humidity levels average 45\% at 4 pm.\textsuperscript{20} The structural deformation of kiln walls, the partial loss of brick units, the erosion of surfaces—all of these conditions could plausibly result from ice jacking. The relative paucity of local, atmospheric moisture leads one doubt, however, the sole culpability of freeze/thaw in such widespread damage. Indeed, when moisture is present at the kiln complex, it does not linger for long. The author recalls, for example, surveying shed members on a summer afternoon in 2012. Although a rain event had swept through the area the night before, every wood piece prodded with an awl was bone dry, nearly to grade. Thus, the dryness of the Helena air could be the primary factor behind both the relatively rot-free survival of much of the original, wooden shed components, and the sparing of the kiln masonry from significant freeze/thaw damage.

Yes, water is a rare commodity around the kiln complex. That certainly does not mean, however, that its seldom appearance has had no hand whatsoever in the material problems plaguing the industrial site today. Archie Bray, Jr., for instance, recalls no salt damage on the kilns during or at the end of their use in the late 1950s.\textsuperscript{21} How could it be that chloride-heavy efflorescence—so pervasive today on Kiln No. 7’s lowest tier—never appeared as workers literally assaulted the masonry with sodium chloride, heaving shovel upon shovel of rock salt into

\begin{itemize}
\item \textsuperscript{19} Ibid., 9.
\item \textsuperscript{20} For reference, Philadelphia receives an average of 41.4 inches of water-equivalent precipitation annually, at an average of 67.5\% relative humidity. Helena precipitation data are accessible online via the Western Regional Climate Center at http://www.wrcc.dri.edu/.
\item \textsuperscript{21} Archie Bray, Jr., telephone interview by author, March, 21, 2012.
\end{itemize}
the fireboxes for the glazing of face brick? Quite simply, the kiln was dry. The brick surfaces within and around the fireboxes were no doubt laced with volatilized chlorides, but because the kiln was functioning and almost constantly heated from within, the opportunities for such salts to travel in aqueous solution were few and far between. Nowadays, when the kiln is wetted by rain or snowfall, moisture has the opportunity to slowly percolate through its walls, from the crown down to grade. In the lowest tier of the kiln, where chlorides linger most, a kind of industrial fallout in the pores of brick, this trickle is enough to set salts in motion. As rain- and snow-related moisture—now a saline cocktail—migrates toward the surface of the wall and evaporates, the solubilized chlorides crystallize and are left behind in visible, white splotches. Wetting episodes in Helena may be too infrequent or too short for sustained freeze/thaw damage, but even the most limited wetting is enough to prompt efflorescence.

In the upper portions of the wall, the lack of efflorescence may be the result of a greater physical distance from the fireboxes and hence, from the chloride clouds of the glazing process. But indeed, salts are still at play there, as carbonate and sulfate crusts which cling doggedly to brick faces and, especially, mortar joints. If the mortars used in building this part of the kiln were contaminated with calcium sulfate (or gypsum), the wetting of the kiln now, decades after its use, could again be to blame for these unsightly deposits. In the way water lures chlorides to the surface of the lowest kiln tier, so here could it enable the migration of soluble sulfates—from gypsum deep within mortar joints to recrystallized crusts on the surface. But why, then, are sulfate-based deposits limited to the upper tiers of the kiln? If spawned by contaminated mortar, would such deposits not be detectable on lower parts of Kiln No. 7—areas which were also finished with a wythe of mortared brick? And what accounts for the carbonates present in the crusts? Why, again, would carbonates be detected only at the heights of the kiln?

Here, an alternative explanation may be put forth—one which pertains less to climate (wetting in the present) and more to use (pollution in the past). Until 1931, the five downdraft
kilns of the WCMC were fired with coal. One can only imagine how dirty the air circulating beneath the shed roofs must have been during this multi-day process. The burning of coal generates high levels of sulfur dioxide (SO₂) and carbon dioxide (CO₂). Reacting with free oxygen in the air, sulfur dioxide becomes sulfur trioxide, which in turn, reacts with atmospheric moisture to produce sulfuric acid (H₂SO₄). Carbon dioxide, on the other hand, reacts with atmospheric moisture to become carbonic acid (H₂CO₃). Both acids, sulfuric and carbonic, attack calcium carbonate (CaCO₃), a primary ingredient in lime- and Portland cement-based mortars. Sulfuric acid transforms calcium carbonate into calcium sulfate, or gypsum, while carbonic acid transforms it into bicarbonate. Both compounds are soluble—both may migrate with moisture and recrystallize on masonry surfaces. Encrustation at Kiln No. 7 not only corresponds, chemically, to the sulfate and carbonate products of these reactions. It is at its most pronounced just under the shed roofs—areas where sulfur dioxide and carbon dioxide would have collected during firing. Thus, encrustation may be a historic condition—a byproduct of industrial pollution enshrined on the face of the now-dormant structure that spawned it.

There is, finally, the issue of structural deformation. If the bedding material within the kiln walls is neither hydrophilic nor expansive, as was previously thought, and if the chances for frost jacking due to lingering, interstitial moisture are slim, what, then, is to blame for the disconcerting bulges in kiln masonry? Well, it is interesting to note that the pattern of masonry deformations seen on the kilns—bulges in first tier, out-of-plane displacement in upper tier—correspond to deformations observed among operating kilns by Carl Harrop. Briefly touched upon in Section 2.1.1 in the previous chapter, these deformations come about as follows. With each firing, the crevasses of the kiln are increasingly filled with debris—brick fragments, dust, and the vast quantities of sand used to prevent fired brick from fusing together. The kiln expands during firing, but, due to this accumulation of rubble, never contracts fully to its pre-firing

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dimensions. Consequently, where the kiln bottom meets the wall and the accretion of debris is most extreme, outward bulges in the structure begin to develop. Up high, then, where both the internal temperature of the kiln and the outward trust from its crown are at their extremes, a well-designed and sufficiently-banded kiln will succeed in redirecting the tremendous lateral forces downward. Inevitably, however, some brick are pushed out of the plane of the wall. Some are even crushed behind the iron bands.  

The kilns of the WCMC were obviously well-designed. The plant’s historical reputation for quality and the kilns’ evident longevity testify to this fact. Archie Bray, Jr., does not recall there being significant structural damage among the kilns of Western Clay at the plant’s closure. The kilns were fired, and thus persistently repaired, he asserts, right up until the bitter end. Nonetheless, the author believes strongly that the deformation conditions apparent today originate in the kilns’ decades of use. Though perhaps unpronounced, or at least masked behind multiple repairs, the deformation conditions known to all downdraft kilns—the bulges at grade, the displacement of brick units up high, and the accompanying open mortar joints or cracks—were established at the WCMC kiln complex well before 1960. In the intervening fifty years, then, these conditions worsened. For the first time in their history, the kilns were allowed to become completely wet in the rain and snow. Though seldom, these precipitation events saw the percolation of moisture through the entirety of the wall sections. Salts were set in motion, and their recrystallization no doubt led to the further failure of mortar joints in the kiln exterior. Invasive vegetation also began to thrive, and the pressure from burgeoning root systems helped weaken joints further. These open mortar joints enabled the increased entry of water into the masonry, triggering a dangerous feedback loop of salt migration and plant growth. Open joints also proved to be an “exit wound” of sorts. Here, the kiln’s binding element, its clay-turned-

\[\text{23 Harrop, “Kiln Expansion and Bracing,” 68-70, 79-80. See Section 2.1.1 for more information.}\]

\[\text{24 Archie Bray, Jr., telephone interview by author, March, 21, 2012.}\]
ceramic bedding material, has been washed and flushed out of the masonry by the pound. No longer active and absorptive when wet, this soil, which likely accumulated over time as the kilns continued to expand and fill with debris, is highly erodible, and may be found inches deep at the mouths of open joints along the base of every kiln in the complex (Fig. 3.16). Robbed of this bolstering material, the kiln walls have begun to sag and deflect even more, snapping header brick which once served to tie the successive wythes of masonry together. And so the decay continues—a process that began during the kiln’s era use, but that has uncertainly been exacerbated by prolonged exposure to weather and the cessation of regular maintenance and repair.

3.4 Hypothesis Formulation and Treatment Recommendations

Salt deposits seen within the WCMC kiln complex vary in appearance, origin, and the severity of their implications. The encrustation observed in the upper reaches of the kiln is, for example, chiefly an aesthetic concern. It is the result of bygone industrial circumstances. Where once airborne sulfuric and carbonic acids—pollution products generated by the burning of coal within a confined space—attacked the calcium carbonate in the kilns’ outer wythe of mortared brick, relatively clean air abounds. Thus, encrustation is, essentially, a dormant condition. Where the crust has led to the failure of mortar joints, it should be cleared and the joints repaired. Otherwise, it may be left. The only practical methods for its removal—either mechanically (using a hammer and chisel) or chemically (using a dilute, acid-based cleaner)—needlessly risk further damage to the brickwork. It is admittedly an eyesore, but at the least, the crust may be appreciated as a vestige of what must have been a filthy industrial process.

The same approach may not be taken, however, with efflorescence in the lower tiers of the kiln. The heavy deposition of chlorides on the surface of brick contributes to erosion and may result in further partial or total unit loss. Salts can be coaxed out of the brickwork using wet
paper poultices—a technique, like several techniques to follow, which was utilized at the kiln complex in July 2012 to successful effect. When applied, the wet paper sets salts on or near the surface of the brick into solution. As the poultice dries, then, it pulls the solubilized chlorides from the wall and into its own fibers. Once fully dried, the stiff, salty paper poultice is easily pulled from the face of the kiln. Several rounds of poulticing may be necessary to sufficiently desalinate the areas around the fireboxes that exhibit heavy efflorescence and friability.

Most critically, the kilns must be kept as dry as possible. Preventing or inhibiting the masonry’s infiltration by moisture via rain and snow will not only impede the migration of efflorescence-causing salts. It will also help hinder the above-mentioned internal erosion and run-off of the masonry’s inert, ceramic core—a process which, in the author’s judgment, constitutes the single biggest threat to the structures’ future survival. Open joints must be diligently sealed using flexible, lime-based mortar. This will heal the kilns’ “exit wounds,” thereby preventing the further escape of water-borne ceramic material from the kiln wall during precipitation events. Where major voids already exist in the wall, grouting should be employed to bolster the structure, unite detached brick wythes, and prevent the further run-off of the wall’s ceramic binder. Where collapses are already in progress, loose brick should be re-laid and the wythes reconnected, where possible, with header brick and pins. Other techniques might also be considered to further prevent water from permeating the kiln. The installation of a low permeability synthetic membrane has been suggested, which, along with weep spouts, a layer of clay, and a flashing detail, would essentially waterproof the exposed kiln parapet. Soft capping might also be considered—a procedure which would employ local turf grasses and thin layer of topsoil to essentially transform the kiln parapets into strips of green roof. The author fully endorses this method. Not only will it help capture moisture at the extreme top of the wall, it will put select species of vegetation to good use—controlling their growth to add a certain natural aesthetic to the wall system.
The sheds, finally, represent a major obstacle in the overall conservation of this site. Most important is the covering of large holes and gaps in the surviving roofs. This could be achieved via temporary fixes (i.e., tarps), or via repairs of a more permanent nature, such as the installation of metal patches and corrugated replacement panels.\textsuperscript{25} Plugging the holes in the shed roofs will help keep the kilns dry, and block the unwanted, potentially de-stabilizing penetration of wind into weakened areas of the shed structure as it whips across the site. Similarly, the sheds’ worn and often piecemeal side sheathing should be shored up, as the gaps in these panels provide an additional entry point for wind and wind-driven moisture. Several easy repairs could be made to stiffen cracked, deflected, or visibly overburdened shed members. Rafters, beams, and lintels may all be sistered or supported at mid-span by additional posts. Chip Clawson has dutifully begun this process in the immediate vicinity of Kiln Nos. 7 and 8, and it would be wise (and relatively inexpensive) to continue it throughout the entire complex. Several schemes have been proposed for reestablishing the shed-to-kiln connection via metal clips on the ends of the shed rafters. Originally, these clips were attached to the uppermost iron band on each kiln. The author is somewhat wary of stiffening this connection, especially considering the tenuous material state of some areas of the shed. Until the sheds have been sufficiently stabilized—perhaps via the cable system proposed by Christopher Taleff following his 2012 investigation—it would be wise to avoid tethering them to the kilns. In the event of a partial shed collapse, the kilns might thus be at least partly spared the destruction.

3.5 Suggestions for Further Monitoring and Analysis

Given more time and resources, the material analysis of the WCMC kiln complex might proceed in a number of productive ways. X-ray diffraction might indeed be performed on samples extracted from the kiln masonry, if only to confirm and substantiate their seemingly

\textsuperscript{25} Worn, recycled, or patinated panels might be used in repair work, so as to provide the best visual match to existing material.
ceramic identity. Similar analysis might also be run on mortar samples, to better identify the binder used and potential contaminants. The author would also recommend performing trial consolidation on brick types identified in kiln construction. The especially-friable and salt-beleaguered, A-type refractory brick is an ideal candidate for such a test. The author retrieved a suitably-crumbled sample, but was unable to perform the consolidation within this project’s time frame. If anything, several quick trials might reveal what consolidant works best, and under what circumstances.

Similarly, the kilns’ deteriorated metal banding must be examined more completely and assessed for treatment. On account of the author’s lack of familiarity in the field of metals conservation, the kiln bands and associated metal components have, regretfully, been denied in this study the attention and consideration they rightly deserve. It is clear that, on each kiln, the three lowest bands have experienced the most corrosion and detachment. High levels of salinity and the outward pressure of masonry deformations have likely intensified the severity of metal conditions in these regions of the kilns. More work is needed, both to better explain the mechanics of band deterioration, and to formulate strategies for its neutralization. Time is certainly of the essence for these highly vulnerable, historic materials.

Finally, if given a second opportunity, the author would likely choose, again, to forgo many of the brick tests outlined in ASTM Standard C67-12. Deriving accurate, broadly-applicable results from the analysis of single, proxy brick specimens is simply an inadequate way of judging brick durability and performance. Variability is literally fired into the material. Even within the confines of a solitary brick unit, inconsistencies in porosity, pore size, and mineral composition prevent a conservator from drawing conclusions that might speak meaningfully to the health of a larger structure. To that effect, the entire range of brick tests—from freeze/thaw and submersion to thin-section analysis and X-ray diffraction—is rather ineffective in revealing new insights on the character of historic brick, the sample sizes of which are invariably limited.
If anything, the author might pursue a more focused survey of the material state of later, extruded brick types—those labeled Types C and D in Kiln No. 7’s field typology—relative to the state of early, handmade and repressed brick types seen on the kilns. Casually, the author can state that in comparison to their aged counterparts, the newer brick are not as ostensibly afflicted by efflorescence, erosion, and partial loss. One can assume, however, that these brick were built into the kiln during later campaigns of repair, and thus did not bear the brunt of multiple decades of firing. Nonetheless, the best way of assessing durability might be to take a closer look at the materials in situ as opposed to testing them on a sample-by-sample basis, in a laboratory several time zones away.
4. Lessons in the Conservation of Industrial Heritage

The second chapter of this study endeavored to show that no kiln exists in isolation—that brick kilns, as instruments of industry, exist within broader spectra of social change, economic flux, and technological refinement. Similarly, this chapter will demonstrate that the conservation of such artifacts is, itself, an act which does not occur in isolation. Conservation entails decision-making in the realms of material science, design, and interpretation, and is, by nature, an ever-evolving process. Those who intervene at heritage sites bring with them their own technical, aesthetic, and didactic predilections, which are inevitably influenced by the prevailing trends of the day. And to complicate matters further, public appraisals of history constantly change, as do commonly-held feelings of what does and does not merit safeguarding for future generations.

“The past as we know it is partly a product of the present,” writes David Lowenthal. “We continually reshape memory, rewrite history, refashion relics… We all want more or other than what we have been left.”

Thus, because conservation is a vocation defined by change, practitioners should be obliged to understand their place along the field’s historical trajectory before grabbing a trowel and getting to work. Only then may conservation build upon its many accomplishments and failures—correcting errors in material treatments, for example, or dispensing with the parochial biases of past interpretations. It was in this spirit that, prior to finalizing recommendations for the WCMC kiln complex, the author decided to devote the time and words to describe the past and current states of industrial heritage conservation. That examination unfolds below, in three parts.

As the entire notion of researching, recording, preserving, and interpreting industrial sites is still a rather new impulse within the greater realm of heritage conservation, this chapter begins with a synopsis of the rise of industrial heritage conservation as an independent, specialist pursuit.

The field’s origins in a much-disputed sub-discipline known as “industrial archaeology” are clarified first. Then, the process by which industrial heritage conservation blossomed into an international phenomenon is recounted second. Here, the author elaborates on the organizations involved in the advocacy, documentation, and protection of industrial heritage, summarizing high points from the international charters that now codify the field’s best practices.

Once the interdisciplinary origins and contemporary standards of industrial heritage conservation are apparent, the author then discusses a framework for interpretation at the WCMC kiln complex. In essence, this section attempts to negotiate a balance between the site’s engineering, architectural, and social science-related values that might otherwise vie for expression in how the complex is first preserved and then presented to the public. The goal here is not simply to deem one perception of the site more valid than others. Instead, the author seeks to understand how the site’s several inherent, equally important and interesting narratives might ultimately coalesce to produce a lucid, rich, and engaging experience for visitors. From there, several guidelines are offered for interpreting the site holistically, with special regard given to ad hoc alterations, past patterns of circulation, and building function. Indeed, without such planning in place, it would be difficult to apply the material treatments recommended in the previous chapter, or plan for the creation of supplemental interpretive media, in any meaningful way.

Finally, the chapter examines two examples of heavy clay manufacturing sites which have undergone successful conservation on large scales. The first case study is the Medalta Potteries of Medicine Hat, Alberta—a site particularly germane to Western Clay as it also plays host to a residency program in the ceramic arts. The second case study is the Ziegeleipark Mildenberg, or “Brickyard Park,” of Zehdenick-Mildenberg, Germany, a bona fide brickmaking campus which has been transformed into an attractive and engaging tourist destination. To conclude the chapter, the author vets elements from both case studies for their applicability to
Western Clay, thus coming one step closer to determining the best possible method for conservation at the Bray’s historic brickyard.

4.1 What is Industrial Heritage Conservation?

In his groundbreaking, 1963 manifesto Industrial Archaeology, Kenneth Hudson employs a memorable metaphor in defending the still nascent, largely amateurish field of industrial archaeology. “To objectors,” he writes, “‘Industrial Archaeology’ is an impossible mongrel, the ugly offspring of two parents [that is, Industry and Archaeology] who should never have been allowed to breed.”27 Referring to dogmatic scholars of classical archaeology who resented the use of the term “archaeology” to describe the investigation of sites as “new” as nineteenth-century textile mills, Hudson’s language is as colorful as it is provocative. As a label tailored to fit almost exclusively the university-sponsored excavation of prehistoric remains, archaeology, he writes, has been appropriated by academics whose “…principal evidence is normally to be found buried under several feet of soil and rubbish.”28 Such a rigid, insular semantic association, he continues, both “…deprives students of later periods of civilization of a very useful word,” and “…denies the essential continuity of both scholarship and civilization.”29 Advocating for a definition of archaeology as, simply, the past tense of anthropology, Hudson’s book gave voice to a burgeoning local movement of industrial documentarians in the United Kingdom and made strong the case for the recordation of disused industrial sites at the dawn of deindustrialization.

Fifty years later, clamor over the definition of industrial archaeology, the field’s theoretical underpinnings, and its relationship vis-à-vis classical archaeology has yet to subside in journal publications and edited compendia.30 The influence of Hudson’s “mongrel” discipline in

28 Ibid., 14.
29 Ibid.
the conservation and management of the built environment is, however, of little dispute. Archaeologists, writes Australian conservator Kate Clark, “…have a great deal to contribute to the discussion of what to protect and why simply because they specialize in reading that fabric and finding in it the narratives that can inform decisions. Industrial archaeology is particularly relevant because the remains of the past two hundred years dominate the landscape today.”31 In tracing the path of industrial heritage conservation, then, a path which now leads to Helena and the Bray, it makes sense to begin in Britain with Hudson, his “mongrel” pursuit, and the rise of formalized industrial archaeological practice.

4.1.1 Antecedents in Industrial Archaeology

That the systematic documentation of industrial sites began in the United Kingdom is an acknowledged fact and quite logical, given that the Industrial Revolution itself originated in the British Isles in the eighteenth century.32 Of course, the popular urge to record and preserve the artifacts of industry did not come about in the age of William Blake, for example, who regarded with horror the furnaces and factories he saw flourish in his native England.33 As Neil Cossons has observed, the so-called smokestack industries themselves needed to diminish, and the economic and social disruption at their departure needed to subside, before “a more dispassionate perspective” on the study and preservation of industrial sites could prevail.34

Though an affection for old machines and transport systems had begun to develop in Britain prior to the Second World War—a phenomenon illustrated by the founding of the Newcomen Society in 1920—the 1950s-era policy of “comprehensive redevelopment” was the

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33 See Blake’s poem “And did those feet in an ancient time” (1808) for what many consider the poet’s most eloquent, prophetic critique of the “dark Satanic Mills” of the Industrial Revolution.
34 Neil Cossons, “Perspective,” in Perspectives on Industrial Archaeology, 11.
primary catalyst in the birth of industrial archaeology as a term and recognized pursuit. As part of its redevelopment plan, the British government went about the wholesale removal of obsolete industrial infrastructure. “The result,” writes R. A. Buchanan, a professor of the history of technology at the University of Bath, “was a spate of destruction of inner-city regions that had escaped the hazards of bombing during the war, and a positive blizzard of new development which was frequently tasteless and shoddy.” Sensing that a swath of British heritage was being squandered, academics such as Michael Rix, a lecturer in English literature at the University of Birmingham, began to advocate for the preservation of industrial relics as a means of safeguarding Britain’s own national ethos. Rix coined the term “industrial archaeology” in a 1955 article in *Amateur Historian*, laying the groundwork for the discipline in what may be read as a characteristically-English, self-flagellating tone:

Great Britain as the birthplace of the Industrial Revolution is full of monuments left by this remarkable series of events. Any other country would have set up machinery for the scheduling and preservation of these memorials…but we are so oblivious of our national heritage that apart for a few museum pieces, the majority of these landmarks are neglected or unwittingly destroyed.

Following Rix’s lead, the Council of British Archaeology created the Industrial Archaeology Research Committee (IARC) in 1959, enlisting in it an assemblage of architectural professionals, engineers, museum curators, journalists, and academics. Britain’s first “Survey of Industrial Monuments” was carried out, with former Newcomen Society president Rex Wailes employed to recommend to the Ministry of Public Buildings and Works those sites especially deserving of legislative protection. The first National Record of Industrial Monuments (NRIM) was compiled, as well, which was ultimately incorporated into the National Monuments Record

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35 Buchanan, “The origins of industrial archaeology,” 20. The Newcomen Society is a British learned society devoted to the history of engineering and technology. It takes its name from Thomas Newcomen, an inventor associated with the development of the steam engine. An American branch—the Newcomen Society of the United States—was founded in 1923, but closed in 2007 due to declining membership.

36 Ibid.

and is housed today in the English Heritage Archive at Swindon. Finally, the IARC commissioned Kenneth Hudson to write the above-quoted book *Industrial Archaeology*, whose 1963 publication immediately followed the 1962 demolition of the Doric portico at Euston Station, London’s first main-line railway terminus (Fig. 4.1). The “arrogant vandalism” of the Euston Station was a galvanizing event for promoters of industrial archaeology, and brought the issue of industrial heritage conservation before the British public in rather spectacular fashion.\(^{38}\)

Despite the trauma at Euston Station and the increasing number of academics and hobbyists involved in industrial archaeology, the field’s strong interdisciplinary roots coupled with its early lack of official university affiliation led to persistent, implied criticisms that the pursuit was little more than a shallow, weekend diversion, popular among amateurs but wanting in intellectual rigor. As late as the 1970s, one academic went as far as to deem industrial archaeology the perfect excuse “to get a girl up in the Pennines on a sunny day.”\(^{39}\) The romantic appeal of derelict industrial sites aside, such wanton condescension in academic circles left its mark on the early publications of industrial heritage proponents like Kenneth Hudson, who, as already demonstrated above, readily rebuked critics of the field with acerbity of his own. Nonetheless, it became apparent over time that industrial archaeology would manifest itself less as a well-defined, university-accredited degree track and more as a vehicle for adult education and active conservation in planning policy, legislative protection, and museum curation.\(^{40}\) Perceived as a failure by some, industrial archaeology’s inability to infiltrate the academy in any

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\(^{38}\) Buchanan, “The origins of industrial archaeology,” 19. Indeed, for the budding industrial archaeological movement in Britain, the demolition at Euston Station seems to be a catastrophe analogous to the demolition of McKim, Mead and White’s Pennsylvania Station in New York City, which began the following year and is often credited with spawning the architectural preservation movement in the United States.

\(^{39}\) Ibid., 21.

\(^{40}\) Ibid. The Ironbridge International Institute for Cultural Heritage, operated by the University of Birmingham and the Ironbridge Gorge Museum Trust, confers Master of Arts degrees in heritage management. Dr. Marilyn Palmer, meanwhile, leads classes in industrial archaeology within the University of Leicester’s School of Archaeology and Ancient History. In the United States, Michigan Technological University is the only academic institution to confer graduate degrees in the field—a Master of Science in industrial archaeology and a Ph.D. in industrial heritage and archaeology.
formal way perhaps endowed the field with more flexibility and accessibility than it might have otherwise known.

For example, if the founding of the IARC represented the first national attempt to catalogue and assert the importance of industrial monuments in Britain, that cause was carried forth in the 1960s by a proliferation of enthusiastic local and regional societies devoted to industrial heritage documentation and conservation. The Greater London Industrial Archaeological Society, the Cornish Engines Preservation Society, and the Bristol Industrial Archaeological Society are but a few of the groups formed in the 1960s which further executed the research and recording of industrial sites across Britain. For the dissemination of such work, the discipline acquired in 1964 its first journal, *The Journal of Industrial Archaeology*, edited by Kenneth Hudson, and ultimately, conferences were arranged for paper presentations and field outings. Between 1966 and 1970, annual conferences were held in Bath that proved to be extremely influential. A laboratory for the growth of the industrial heritage movement, the Bath Conferences played host to representatives from across Britain and beyond, including Marie Nisser of the University of Stockholm and Robert Vogel, Curator in Mechanical and Civil Engineering at the Smithsonian Museum of History and Technology.

Thus, a precedent for international exchange in the realm of industrial heritage had been set, and in 1967, Vogel and the Smithsonian invited Kenneth Hudson to speak before a seminar of American preservationists and museum professionals in Washington, D.C.. A watershed moment in the industrial archaeological movement of the United States occurred shortly thereafter, when a group of architecture students on summer break embarked on the New England Textile Mills Survey, a documentation project initiated by Vogel, the National Park Service’s Historic American Buildings Survey (HABS), and the Merrimack Valley Textile Museum (Fig. 4.2). The success of Vogel’s survey culminated in the 1969 establishment of the Historic American Engineering Record (HAER) by the National Park Service and the American Society of Civil
The founding of the joint American and Canadian Society for Industrial Archaeology (SIA) followed in Washington in October 1971. As an international nonprofit group devoted to the documentation and preservation of industrial sites, the SIA was the first organization of its kind in the world. So, in a relatively short span of time, industrial archaeology had caught on in North America and won its own institutional framework. And unlike the British movement, which grew locally and sought legitimacy among archaeologists in academia, the American movement began from the top down and was unabashed in its ties to preservation advocacy. American industrial archaeology was born “…without a ready-made foundation of community-based societies,” writes Ted Sande in the first issue of IA, the journal of the SIA. “[We] are now reaching outward to establish this vital network,” he continues. “Initially, this interest seems best sparked by the historic preservation cause.”

As developments in industrial heritage unfolded west of the Atlantic, the British secured with the 1967 formation of the Ironbridge Gorge Museum Trust in Coalbrookdale, Shropshire, a collection of landmarks largely considered to be birthplace of modern industry. The Trust manages thirty-five historic industrial sites within the Ironbridge Gorge, including the furnace in which Abraham Darby I first used coke to smelt iron in 1709 (Fig. 4.3). Meanwhile, in 1971, the Bath Conferences, having exhausted the industrial sites accessible from Bath for visitation, took to the road, landing that year in Bradford, the following year in Glasgow, and on the Isle of Man in 1973, where the conference officially founded the Association for Industrial Archaeology (AIA), Britain’s counterpart to the SIA.

43 In discovering that iron could be smelted using coke, a derivative of bituminous coal, Darby essentially freed the iron industry from the limits imposed by the use of charcoal as a primary fuel source. Charcoal, which is a product derived from trees and other vegetable matter, could be produced only as fast as the plants themselves could grow. In 1986 Ironbridge became the fourth site of an industrial nature to be inscribed on UNESCO’s World Heritage List, and is a paragon in the effective conservation and interpretation of industrial heritage at the landscape scale.
For industrial heritage worldwide, however, the year 1973 held greater significance, as the First International Conference for the Conservation of Industrial Monuments convened that May at Ironbridge under the direction of Neil Cossons. Cossons, who had left a prestigious position as deputy director of the Liverpool Museum to lead the brand new Ironbridge Gorge Museum Trust, arranged an ambitious but successful conference, guiding a large group of overseas visitors to British industrial landmarks like the Derwent Valley Mills in Derbyshire, a site often associated with the advent of the modern factory system. So successful was Cossons’ gathering, in fact, that the West German delegation immediately called for a second conference at the Ruhr Mining Museum in Bochum, which was ultimately held in September 1975. Though the Germans pressed then for the establishment of a permanent, international organization for the conservation of industrial heritage, a formal constitution was not agreed upon until a third conference, arranged for early June 1978 by Marie Nisser of Sweden. And so, Hudson’s “mongrel” had completed its long journey, from Michael Rix’s quasi-nationalistic, 1955 plea for the preservation of England’s industrial heritage to the formation of a multinational research and advocacy group, the International Committee on the Conservation of the Industrial Heritage, or TICCIH.

4.1.2 International Collaboration and the Current Approach to Industrial Heritage Conservation

Since its formal establishment in 1978, TICCIH has led international conversations on industrial heritage through its triennial conferences and the publication of both a newsletter, the TICCIH Bulletin, and a journal, Patrimoine de l’industrie. The formation of sub-committees have enabled the organization to coordinate the study and conservation of industrial heritage sites.

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44 Though water-power was first introduced to England at John Lombe’s silk mill in Derby, it was Richard Arkwright who, in the 1770s, patented his water frame, which enabled unskilled workers to spin cotton continuously. Arkwright’s system of mechanical production spread throughout Britain and later the United States, as did his paternalistic ideas of providing housing and education for his labor force. Arkwright’s Derwent Valley Mills were inscribed on the World Heritage List in 2001.
by type, as well, encompassing, among others, sites of agriculture and food production, mines and collieries, textile manufacturing sites, and rail infrastructure. The early focus of TICCIH-sponsored projects remained fixed, geographically, on Europe and North America, but that trend began to shift in the 1990s. Germany and Spain emerged as pioneers in the conservation of large-scale industrial landscapes, and under the presidency of Eusebi Casanelles, longtime director of the Museum of Science and Technology of Catalonia in Barcelona, TICCIH expanded its membership base into South America, Asia, and the former Soviet Union. Its sixteen-member board now includes national representatives from countries such as South Africa, Australia, Romania, and Chile, and the 2012 TICCIH Congress was held in Taipei, Taiwan, further illustrating the organization’s expanded worldview.

Such a broadened global presence may in part be the result of TICCIH’s connection to the International Council on Monuments and Sites (ICOMOS), and thus, to the United Nations Educational, Scientific and Cultural Organization’s World Heritage List inscription process. In 1972, the seventeenth session of the UNESCO General Conference adopted the Convention Concerning the Protection of World Cultural and Natural Heritage, better known as the World Heritage Convention. A well-intentioned but ultimately Euro-centric document, the Convention set in place an intentionally-vague definition of what constitutes “cultural heritage,” as well as prescriptions for identifying, cataloguing, and protecting sites of “outstanding universal value” on a World Heritage List. The World Heritage Committee (WHC) was charged with the implementation of the Convention, and has convened every year since to inscribe new sites to the

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46 Prior to the 2012 congress, the only TICCIH congresses to have occurred off the European continent were the 1984 congress in Lowell, Massachusetts, the 1994 congress split among Montreal and Ottawa, Canada, and the 2003 congress held in Moscow.
List and determine allocations from the World Heritage Fund for the management of sites in special need of financial assistance.\(^{48}\)

In the first fourteen years of its existence—that is, from 1978 to 1991—the World Heritage List saw only six sites inscribed which bore some sort of connection to industrial production.\(^ {49}\) Conscious of imbalances within the list—European sites, as well as urban sites, Christian sites, and “high” (as opposed to vernacular) architectural sites were also found to be overrepresented—the WHC adopted in 1995 its Global Strategy for a Representative, Balanced and Credible World Heritage List. The initiative helped extend the Convention’s notion of “outstanding universal value,” ultimately expanding it to encompass industrial sites of international significance. Having little expertise in the field of industrial heritage, ICOMOS—one of three advisory bodies to formally report to the WHC—had already solicited collaboration from TICCIH and its then-president, Louis Bergeron of France, in 1993. Under the Global Strategy, then, TICCIH was given the ability to submit directly to the WHC its recommendations for industrial sites worthy of consideration as candidates for the World Heritage List.\(^ {50}\)

Inclusion on a TICCIH list has by no means guaranteed inscription on UNESCO’s list, but, as the increasing number of industrial sites inscribed during the 1990s indicates, TICCIH’s involvement in the WHC’s selection process has helped raise awareness among international heritage experts of the importance of industrial sites. Seventeen new industrial heritage sites appeared on the World Heritage List between 1991 and 2000, the year in which collaboration between TICCIH and ICOMOS was formalized in a document ratified at the eleventh TICCIH Congress in London. Therein, the two organizations expressed their mutual desire that

\(^{48}\) See http://whc.unesco.org/en/convention/ for more information on the 1972 World Heritage Convention and UNESCO’s World Heritage List. The World Heritage Committee is comprised of twenty-one of UNESCO’s 190 sovereign states parties. The legal term of office for each Committee member is six years, although most States Parties voluntarily cede their membership after four years, thus allowing other States Parties the chance to participate.

\(^{49}\) Cleere, “The World Heritage Convention,” 33. This is not an altogether surprising statistic, considering the impetus for the World Heritage Convention itself was Egypt’s decision in the 1950s to construct the Aswan High Dam, a project of industrial nature which forced the relocation of twenty-two monuments and architectural complexes, including the Abu Simbel temples.

\(^{50}\) Ibid., 32, 39.
knowledge “...be widely shared by all specialists with a view of facilitating and encouraging...the preservation of mankind’s industrial heritage wheresoever situated.”51 Since 2000, TICCIH has thus served as the “scientific consultative body for ICOMOS” in matters relating to the study and preservation of world industrial heritage, and as of 2012, an online count revealed approximately sixty of the 962 World Heritage Sites to be related in some way to the industrial past.52 ICOMOS has benefitted from the expertise of TICCIH members well-versed in industrial history and archaeological practices. TICCIH, meanwhile, has greatly benefitted from ICOMOS’ prominence in heritage advocacy on the international stage.

In addition to its having achieved global diversity and a measure of influence in international heritage circles, TICCIH’s most notable accomplishment has been its codifying of conservation principles in charter documents. Under Casanelles’ leadership, the organization passed in 2003 the Nizhny Tagil Charter (NTC) at the twelfth TICCIH Congress in Moscow. Then, in November 2011, the Joint ICOMOS-TICCIH Principles for the Conservation of Industrial Heritage Sites, Structures, Areas and Landscapes (better known as the “Dublin Principles”) were adopted by the seventeenth General Assembly of ICOMOS. Largely a reiteration of the NTC, the Dublin Principles are nonetheless significant in that they represent general corroboration, on the part of ICOMOS and hence UNESCO, of the industrial heritage conservation principles already set in place by TICCIH. Insofar that these charter documents standardize acceptable methods for the restoration and interpretation of historic sites of production, the international movement for industrial heritage conservation can be brought to bear directly on the future conservation of the WCMC kiln complex at the Bray.

52 Ibid. See http://whc.unesco.org/en/list/ for an interactive map of the UNESCO World Heritage List. Of the sixty industrial sites on the list, nearly half involve the mining or extractive industries. The two sites of an industrial nature to be inscribed in 2012—the Nord-Pas de Calais Mining Basin in France and the Major Mining Sites of Wallonia in Belgium—are both historic sites of coal extraction.
Aside from their official defining of “industrial heritage,” “industrial archaeology,” and the two terms’ historical period of interest, the NTC and Dublin Principles emphasize the importance of the recording and documentation of industrial sites, as well as their protection legally by supervising governments.53 Perhaps most importantly, however, the charters specify several conservation principles that, depending on the nature of the industrial site at hand, should be prioritized and practiced above all others. The preservation of functional integrity, for example, is an idea stressed in both documents. In other words, because industrial heritage sites are almost always process-oriented, the legibility of the site—i.e., its ability to communicate the production methods of a bygone era—may be jeopardized if machinery or other components crucial in the site’s past function are removed or destroyed.54 The concept of reversibility—i.e., the notion that any material intervention should respect patina and marks of use, leaving a minimum impact on surviving historic material—is similarly emphasized.55 Reconstruction of lost or severely damaged elements is deemed appropriate in the NTC only in the cases that a.) the holistic integrity of the site depends upon it, or b.) the site has suffered some kind of malevolent destruction or vandalism. Otherwise, preservation in situ, with minimal dismantling or relocation of historic fabric, is considered preferable.56 Finally, preservation, as it is defined in the NTC, need not be limited to tangible heritage: “The human skills involved in many old or obsolete industrial processes are a critically important resource whose loss may be irreplaceable. They need to be carefully recorded and transmitted to younger generations.”57

53 “The Nizhny Tagil Charter for the Industrial Heritage,” adopted by the General Assembly of TICCIH at the 12th TICCIH Congress in Moscow on 17 July 2003, and the “Joint ICOMOS-TICCIH Principles for the Conservation of Industrial Heritage Sites, Structures, Areas and Landscapes,” adopted by the 17th ICOMOS General Assembly in Dublin on 28 November 2011. Both documents are attached in Appendix F and available online, in multiple languages, at http://www.ticcih.org/documentation.php. In both documents, the stated historical period of interest for industrial heritage extends forward from the late eighteenth century, or Industrial Revolution, to the present day.
54 See Article 5, Section I of the NTC, and Article II, Section 9 of the Dublin Principles.
55 See Article 5, Section VI of the NTC, and Article III, Section 11 of the Dublin Principles.
56 See Article 5, Sections VII and III of the NTC.
57 See Article 5, Section VIII of the NTC.
Among most conservators nowadays, none of the charter tenets mentioned thus far would represent especially radical or divergent approaches to heritage. In their consideration of adaptive reuse, however, the Nizhny Tagil Charter and the Dublin Principles are somewhat more forward-thinking. Adaptive reuse, the process of adapting old structures for purposes other than those originally intended, is by no means a new idea. In his 1976, SIA-sponsored study *Working Places: the Adaptive Use of Industrial Buildings*, Walter Kidney cites King Christian IV of Denmark’s 1619 transformation of an old anchor forge into a naval church as an early, industrial instance of adaptive reuse. Over three centuries later, the 1964 conversion of San Francisco’s Ghirardelli Chocolate Company headquarters into an integrated retail and dining complex called Ghirardelli Square would be recognized as the first major industrial adaptive reuse project in America. Myriad examples—driven in part by building booms in the 1970s and 80s, as well as by historic rehabilitation tax credits written into the Tax Reform Act of 1976—were to follow the Ghirardelli model, while the 2004 conversion of the American Tobacco Campus in Durham, North Carolina, into a shopping, dining, and arts complex illustrated the model’s persistence into the twenty-first century. But some conservators now question whether Ghirardelli-style “adhocism”—that is, the improvisation of new, unrelated uses for previously disused industrial sites—has led to, at best, the mere beautification of industrial heritage, and, at worst, its grotesque disfigurement in the name of gentrification and corporate marketing (Fig. 4.4). Such is the conundrum with adaptive reuse, writes Duncan Hay. “It requires alteration of the places that we

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59 Duncan Hay, “Preserving Industrial Heritage: Challenges, Options, and Priorities,” *Forum Journal* 25, no. 3 (2011): 11-22. New York’s Bell Telephone Laboratory (now the Westbeth’s artists’ housing, 1970); Pittsburgh’s Pittsburgh and Lake Erie Railroad station (now a hotel, office, and entertainment complex, 1976); and Boston’s Charlestown Navy Yard (medical research laboratories and luxury loft apartments, 1978-1990s) are but to name a few.

want to save, sometimes to the point that important parts of their character are lost and we are left wondering…whether it was worth the effort.”

Nizhny Tagil and the Dublin Principles are frank in their acceptance of adaptive reuse as a pragmatic, appealing, and often effective way of ensuring the conservation of disused industrial sites. Both in preventing the waste of building materials, and in contributing to the economic and psychological stability of communities facing “the sudden end [of] long-standing sources of employment,” adaptive reuse may even qualify as a truly sustainable mode of development. The charters depart significantly from the Ghirardelli model, however, in that they implore developers and conservators to concoct new uses for industrial sites which respect significant material components and patterns of prior circulation or activity. Indeed, the NTC recommends new uses “…be compatible as much as possible with the original and principle use.” In setting such high standards for thoughtfulness (or deference) as regards prior use, the charters promote a form of continuity via conservation. As the recycling of humanity’s collective industrial past marches forward, such a policy will hopefully inspire an increased cultural awareness of everything from historic production methods to workers’ conditions and rights.

In the final comments of chapter two, the Archie Bray Foundation was characterized as a unique instance of adaptive reuse—a sort of organic extension of the industrial site it abuts. Yes, in many ways, the Bray satisfied the prescriptions of the NTC and Dublin Principles before they were set down on paper. After all, if the crafting of pottery does not represent the compatible use of a site once devoted to brickmaking, what does? Therefore, it would be an even greater shame to depart now, in impending conservation work at the Bray, from the principles outlined in the charters and embodied by the first fifty years of the organization’s growth. To that end, the

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61 Hay, “Preserving Industrial Heritage.”
62 See Article 5, Section V of the NTC, and Article III, Section 10 of the Dublin Principles.
63 See Article 5, Section IV of the NTC, and Article III, Section 10 of the Dublin Principles.
following section introduces a method for how conservators might organize, emphasize, and honor the site’s many compelling, surviving features.

4.2 Engineering? Architecture? Art? Interpreting the WCMC Kiln Complex

Article II of the Nizhny Tagil Charter rehashes the litany of non-economic values attributable to industrial heritage. To the extent that it illustrates obsolete methods in manufacturing, engineering, and construction, industrial heritage exhibits technological and scientific value. In the quality of its architectural design or planning, industrial heritage may exhibit aesthetic value, as well. As a material record of the lives and identities of the working class, industrial heritage may claim social value, while rarity, as embodied by the survival of singular processes, site typologies, or landscapes, adds “particular value” to industrial heritage and “should be carefully assessed.” Some of these values—particularly those pertaining to identity, obsolescence, and rarity—were discussed in the second chapter’s statement on the significance of the kiln complex, and it is encouraging to find them echoed in an international charter. There is really no doubt that the kilns possess value. Things become slightly unclear, however, once one poses the question, “Which value is most important?”

Indeed, of the site’s several narratives—its past as a brick-firing hub, its modern role as a distinctive backdrop for the Bray—which one warrants the most emphasis in future presentations? Once conservation is complete and the public streams in, should visitors leave the site understanding, above all else, how a downdraft brick kiln fired its charge? Or is the beehive kiln’s modern-day rarity—a consequence of technological refinement and consolidation in the heavy clay industries—the most important story to tell? Should the kiln be cast as a symbol of harmony between the Bray and its industrial parent, or, to strike a more whimsical chord, should the visual resemblance between a beehive kiln and a bowl thrown on the potter’s wheel dominate visitor perceptions? These are all questions of interpretation—questions known to stewards of
heritage sites everywhere. And although the easiest answer might be to address the site’s multiple narratives equally, preserving and interpreting their material manifestations in effusive detail, such an exhaustive approach risks eliciting a variety of problematic responses: boredom, confusion, or, in the case that visitors feel overwhelmed by a surfeit of information, ire.

Legendary National Park Service interpreter Freeman Tilden makes a strong point when he writes, “…You do not make a scene more beautiful by calling it beautiful. In a sense, you make it a little less so. … Let us cultivate the power that lies in understatement.”

Must one determine, then, the relative importance of the kiln complex’s narrative facets in order to conserve the site in a provocative, informative, yet understated way? To do so would be ambitious, but also highly subjective—an attempt to resolve the character of the site at an arbitrary moment in time. May we deem, in 2013, the kiln complex to be above all else a site of historic engineering? That measured drawings of the kilns were disqualified by the National Park Service (NPS) in consideration for HABS’ Peterson Prize is one indication that, at least in the eyes of the NPS, construal of the site as a relic of engineering might be more appropriate than its construal as a work of architectural or aesthetic merit. The author has personally observed, however, the oohs, ahhs, and comparisons to the Pantheon uttered by most every first-time visitor to the complex. Surely, to interpret the kilns solely as machines would be to ignore the ethereal qualities—the dust dancing in the beams of light, the echoes of footfalls, the gleam of the glazed walls—that have endeared them to artists at the Bray for years (Fig. 4.5). So, if an overly egalitarian approach to conservation risks overstatement, and an overly selective approach risks partiality, some kind of middle path is in order. The kiln complex requires an interpretive

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65 In recent conversations, both Chip Clawson, long-time facilities manager at the Bray, and Chere Jiusto, former Bray resident artist and current executive director of the Montana Preservation Alliance, cited the kilns’ physical beauty and experiential appeal as justification for their future protection. Chip Clawson, telephone interview by author, February 1, 2013, and Chere Jiusto, telephone interview by author, February, 7, 2013.
approach that will accommodate the diversity and mutability of the site—a conservation strategy
that succinctly conveys the site’s mechanics without smothering its charm.

There is a growing acceptance among curators of industrial heritage sites, writes Barrie
Trinder, an expert on industrial heritage in Britain, “that the focus of interpretation should be on
landscapes.” Such low-key (but large-scale) interpretation, he continues, is able to provide
different kinds of experiences for different kinds of visitors, all in a relatively environmentally-
friendly, discreet, and flexible format.66 At first reading, Trinder’s use of the term landscape set
off bells in the author’s head. In the world of heritage conservation, landscape is loaded—a word
burdened with complex connotations and a long lineage of scholarship.67 What landscapes are,
how they are delimited, and how they should be conserved are quandaries which have permeated
the highest levels of heritage management, from the NPS to the WHC.68 For that reason, the
author was initially hesitant to employ the word in envisioning an interpretive scheme at the Bray.
If one perceives the kiln complex as a landscape, however, and begins to imagine the site’s
conservation as such, the “middle path” mentioned above seems much closer at hand.

Suppose one bypasses the dialectic surrounding heritage landscapes and simply borrows
an NPS term, historic vernacular landscape, for application to the case of Western Clay. A
historic vernacular landscape, writes Charles Birnbaum, is “a landscape that evolved through use
by the people whose activities or occupancy shaped [it].”69 It reflects the physical, biological,

and cultural character of everyday life and is often functional, implying an allowable—and indeed necessary—degree of change over time.\textsuperscript{70} Ostensibly, such a term is a good fit for Western Clay. As a conglomeration of multiple, disparate structures, the complex grossly exceeds the one-building scale. Furthermore, where the line between it and the surrounding ecology is blurred by invasive vegetation or structural collapse, the complex appears to blend into (or rise up from) the contours of the Montanan countryside (Fig. 4.6). Finally, the site is, or was, functional, and with minimal effort, visitors could be aided in identifying and understanding the past functions of buildings and building elements that survive today in legible states.

That historic vernacular landscapes evolve, however, and are shaped over time by multiple users in un-designed, or even improvised, ways—this is the element of the term which renders it most appealing in interpreting a site like the kiln complex. If one perceives the complex as a historic vernacular landscape, the many subjective decisions involved in its conservation—e.g., what values to emphasize, what material elements to preserve, what eras to prioritize in rehashing the site’s history—all inevitably succumb to the idea of holism. No part of the site and no period in its past need trump another, because it is the full trajectory of the site—its expansion and contraction, and the full tapestry of its \textit{ad hoc} material modifications—that gives the place its worth.

The five downdraft brick kilns of Western Clay, for example, were at various points built, fired, damaged, reconstructed, augmented, abandoned, reacquired, and adorned with scattered, anonymous works of art. Assuming that visitors possess neither the will nor the patience to endure presentations of each episode in intricate detail, should the conservator select one episode to emphasize over all the others? Such a decision would not only be ethically dubious—in interpreting the complex as a historic vernacular landscape, it would prove counterproductive, as well. Emphasizing the kilns’ design and operation, for instance, at the expense of their

\textsuperscript{70} \textit{Ibid.}
abandonment and subsequent decay, would lead visitors away from establishing a holistic image of the site. It would deny the special continuum of stewardship and production that links Archie Bray, Sr., to David Shaner and Steven Young Lee beyond. At worst, such compartmentalized treatment of the kilns would sentimentalize their industrial past, turning a blind eye to their more intangible, aesthetic values of the present. “It is far better that the visitor… leave with one or more whole pictures in his mind,” writes Tillman, “than with a mélange of information that leaves him in doubt as to the essence of the place, and even in doubt as to why the area has been preserved at all.” The key to ensuring such holism for future visitors to the WCMC kiln complex will be the site’s perception and treatment as an ever-changing landscape—an accumulation, a sedimentation, of structures and stories, analogous to the geological strata of the Montanan terrain itself.

So how would such a landscape-centric interpretive scheme play out in actual conservation work? An obvious guideline would be the preservation of alterations made to the complex over time, for alterations are precisely the features most capable of illustrating the site’s full story, from Charles Bray’s building campaigns at the turn of the nineteenth century to the construction of the Shaner Building at the turn of the twentieth. Repairs and modifications made to the site are easy to isolate, and will require very little clarification in order to make them comprehensible to visitors. For example, the kilns had a tendency to expand, via thermal movement, at their bases—hence the incongruous brick repairs on the southeast quadrant of Kiln No. 7; hence the iron buckstays supporting Kiln No. 8, at grade, on its western flank (Fig. 3.8). In the 1930s, the availability of natural gas gave the plant an opportunity to cut labor by using mechanical burners to fire brick as opposed to shoveled coal—hence the meshwork of gas lines that link the tile shop to the kilns. In the 1950s, then, Archie Bray, Jr., was determined to induce a better draft in Kiln Nos. 7 and 8—hence the kilns’ stack which has been chopped in half and

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fitted with a mechanical exhaust fan. Preserving traces of these physical details in all their messy splendor will heighten visitors’ awareness of the pragmatism and resilience required in successfully running a brick business. Perhaps more importantly, however, it will communicate to them the reality that brickyards—and industrial landscapes, at large—mirror in their material the diverse external forces that act on them over time. In the case of fuel and exhaust modifications, the need to modernize production was the agent of change. In the case of the filling of Kiln No. 7’s open bottom floor with gravel and soil (a change that occurred this century), liability and the risk associated with public access spurred material alteration. If visitors are to understand and appreciate the interplay between the built landscape and economic, social, and political forces of change, material irregularities at the site must be stabilized, emphasized, and protected from both regularization and beautification.

That said, though conservation must ideally draw attention to material change over time, it must take care not to needlessly promote or instigate new change which claims neither precedent in the past nor immediate justification in the present. For example, since the Bray reacquired its brickyard neighbor in 1984 under the daring leadership of Kurt Weiser and Chip Clawson, artists have wandered the site, leaving the occasional piece of art amidst its ruins. Ranging from large, anthropomorphic figures to minute, delicate slip casts, these works impart a fanciful and even mystical feeling to the industrial site—as though the artists sought to pacify some heavy clay deity with the tribute of their work (Fig.4.7). In any event, the interaction between the artist and the industrial site has never been obligatory, and thus retains a quiet spontaneity which only enhances the tradition’s beauty. Over the summer of 2012, an idea took hold among students from the University of Pennsylvania to promote the conservation of the WCMC kiln complex through the crafting of new, artist-made bricks for insertion into the masonry gaps along Kiln No. 7’s exterior. At first, such an idea struck this author, too, as an enjoyable, creative way to draw attention (and perhaps even donor support) to the stabilization
and potential reuse of the beehive kilns. After some deeper reflection, however, the idea grew less and less appealing. It began to seem like a well-veiled effort at prettification, begging the question of whether or not some nasty, industrial aspect of the kilns needed disguising. It also seemed as though an artist-made brick campaign would suddenly standardize, or even commodify, a practice that had been occurring on its own accord for nearly thirty years.

Though not as cynical and curmudgeonly as his argument might suggest, the author would gladly recommend a few alternative ideas for promoting kiln conservation at the Bray, in the case that some additional advocacy is desired. Perhaps a contest among local schoolchildren for the best and most imaginative rendering of the kilns—either on paper or in clay—would spark interest in the Helena community and result in some admirable artistic creations. Or a series of public demonstrations—either wheel-throwing or, better yet, hand brickmaking—could be held in the kiln complex to draw locals into the space for the first time. Indeed, the author strongly supports the use of the kilns in inspiring creativity and artistic production of any sort. It is just the thought of suddenly imposing a brick campaign on the resident artists of the Bray, and then building the results permanently into the skin of a historic kiln, that leads him to baulk. In a worst case scenario, such a program would lead to feelings of resentment among artists who lack the time or interest to participate, and would incorporate into the kilns new material lacking in context. It is important that conservators leave an honest mark of their work when intervening in the material fabric of a heritage site. In the case of the kilns, however, perhaps the virgin whiteness of a newly repointed joint—not the garish glaze of a custom-made art brick—would suffice as that mark.

In suggesting a final few guidelines for interpreting the WCMC kiln complex, the author would like to return to the notions of circulation patterns and functional integrity, two ideas presented in the charters mentioned above. As prescribed by TICCIH and ICOMOS, past patterns of circulation should be preserved and, where possible, resuscitated in the present to
enhance the experience of continuity at historic sites of production. There is no shortage of such patterns at the WCMC kiln complex, and like the material alterations that have accrued on the brickmaking landscape, these patterns may be identified and explained with little effort. The paths taken by the clay products themselves survive in part and are eligible for preservation. Crucial here are the transition points between the tile shop’s two drying floors and the kiln complex—that is, the first-story door on the shop’s eastern elevation, and the second-story door and ramp on its northern elevation (Fig. 3.1)—and the transition points between the kiln complex and outbound transportation, be it by railcar or truck bed. Those points would include the loading platform between Kiln Nos. 7 and 8, as well as the sliding doors cut roughly into the shed walls along the northern flank of the complex (Fig. 4.8). Unfortunately, the path between the brick drying tunnel and Kiln No. 6 was lost with the demolition of the brick plant in the late 1990s. Kiln No. 6 could be potentially incorporated into the remainder of the complex, however, by emphasizing the gas network (a material alteration and circulation path) or the sheds themselves, which also indicate where workers and product may have circulated.72

At last, because the functional integrity of the kiln complex is, thanks to the survival rate of its various parts, relatively high, the challenge of communicating the methods by which the complex churned out finished product is manageable, indeed. With interpretive help in the form of limited graphics or text describing the principles of downdraft kiln operation, most visitors will likely be able to identify the kilns’ components and way in which such components worked in concert to fire brick. A foreseeable obstacle, however, will be the interpretation of the subterranean elements of the downdraft kiln—the elaborate networks of flues which terminate at the stacks—which Archie Bray, Jr., himself, admonished the author not to overlook.73

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72 It is reasonable to assume that the sheds would not have been erected where their cover would serve no practical purpose. The sheds should thus be interpreted as more than just a manifestation of Charles Bray’s English lineage. They are a credible, material record of how people and goods circulated through the kiln complex during its era of industrial use.

73 Archie Bray, Jr., telephone interview by author, March, 21, 2012.
of a downdraft kiln’s operation, these underground elements are every bit as crucial as the more glamorous, above-ground structure. It is difficult to justify purposefully deconstructing an extant, intact kiln bottom in order to expose the flues to a curious public. Perhaps the Bray could engage in some exploratory excavation—between Kiln Nos. 4 and 5, for example, or perhaps around the conjectural footprint of Kiln Nos. 1-3—in the hopes that a flue could be uncovered and made visible. Should that approach prove too difficult or costly, the interpretation of underground elements via some kind of graphic display or three-dimensional model might have to suffice. The extant, open bottom floors of Kiln Nos. 4, 5, and 8, would also convey, in the least, the principle of draft and the downward movement of heat from the kiln chamber outward, through the flues and to the stacks beyond.

4.3 Case Studies in Heavy Clay

The author has thus offered some personal opinions on how conservators might best perceive, preserve, and communicate the diverse facets of the WCMC kiln complex. The desired end result is provocative, informative, yet understated conservation—a job that will treat visitors to an honest, holistic experience of the site’s story, spanning its time as Western Clay’s brick-firing nucleus to its current role as a contributor to the special character of the Archie Bray Foundation. In this, the chapter’s final section, the author will present two sites which have undergone conservation in a manner he considers ideal. It will be evident to most readers that some elements from the interpretive guidelines already outlined are echoed in the case studies to follow. Those elements of the case studies which are new, intriguing, and potentially applicable to the future conservation of the WCMC kiln complex will be outlined and discussed at the chapter’s conclusion.
4.3.1 The Medalta Potteries of Medicine Hat, Alberta

From Helena, one need not look far to find an example of how clay-related industrial heritage may be successfully conserved and repurposed. For just over three hundred miles north, in Medicine Hat, Alberta, a nonprofit organization called the Friends of Medalta Society has orchestrated the remarkable transformation of Canada’s one-time manufacturing hub for all things ceramic—pottery, brick, pipe, and tile—into a world-class center for ceramic art and industrial history. That the clay-related histories of Medicine Hat and Helena are intertwined is clear. A brick company from Medicine Hat, I-XL Industries, acquired and mothballed Western Clay after Archie Bray, Jr., declared bankruptcy in 1960. In turn, the Friends took inspiration from the Archie Bray Foundation in the late 1990s, as they sought to establish in Medicine Hat an international ceramic arts residency program of their own.\footnote{This fact was relayed to the author by Christopher Taleff, a colleague from the Cooper Union in New York, who spent two days in Medicine Hat in the summer of 2012, extensively touring the Historic Clay District with Medalta’s Aaron Nelson.} Though the author has thus far been unable to visit Medicine Hat in person, he will introduce what he has learned about preservation efforts there from a distance, suggesting aspects of that work which might be worth examining further, or even emulating, at the Bray.

The manufacturing might of Medicine Hat grew up around the city’s high density rail network. The Canadian Pacific Railway reached the Medicine Hat area in 1883, and by 1912, the fledging city, which fell strategically between Winnipeg and Vancouver, claimed nearly 1,100 kilometers of track within its municipal boundaries—the most of any place in Canada.\footnote{Most of the following information on the history of Medicine Hat industrial ceramics was culled from Medalta’s extensive website, http://medalta.org/, as well as from designation forms on the Canadian Register of Historic Places, available at http://www.historicplaces.ca/en/home-accueil.aspx.} The 1904 discovery of a massive stock of natural gas, then, combined with plentiful clay deposits along the banks of the South Saskatchewan River, set up perfect conditions for, specifically, the mass production of ceramics. In 1912, the Medicine Hat Pottery Company began manufacturing...
functional stoneware, and was reorganized in 1924 as Medalta Potteries, Ltd. Between 1928 and
1950, the Medalta Potteries would churn out upwards of two-thirds of all the pottery sold in
Canada. Hycroft China was established in 1938, and offered more delicate, ornate vessels than its
Medalta rival. Brickmaking, meanwhile, emerged early as a viable industry with the 1886
founding of Medicine Hat Brick & Tile—a facility that was ultimately acquired by I-XL in 1929.
The monolithic Alberta Clay Products followed in 1909, and with its massive complex of
eighteen downdraft kilns, soon became the largest producer of heavy clay products in Canada
(Fig. 4.9).

As in the United States, however, competition from overseas—paired with forces of
consolidation and modernization within the ceramics industries, at large—would gradually bring
Medicine Hat’s golden age of production to an end. In 1954, Medalta was the first of the local
concerns to close, while Hycroft held on until the late 1980s. A catastrophic fire shuttered
Alberta Clay Products in 1961, while the I-XL brick plant subsisted until June 2010, at which
point a destructive episode of flooding forced its closure, as well. These several industrial sites,
along with the remains of the later National Porcelain Company, are all situated in an area of
Medicine Hat called the North Flats. Together, they comprise a landscape now known as the
Medicine Hat Clay Industries National Historic Site, which was recognized by the Canadian
Register of Historic Places in 2000 and formally listed in April 2009. Today, the Friends of
Medalta Society manages two elements of this site: the independently-listed Medalta Potteries
National Historic Site (maintained by the Friends since the group’s inception in 1974), and the
150-acre National Historic Clay District, which encompasses the 1930s-era Hycroft China factory
and warehouse, as well as the highly-intact I-XL brick plant, which was donated to the Friends
after its flooding.76 Though their futures are secured, both the Hycroft and the I-XL await further

76 The official designation of the National Historic Clay District is slightly unclear. On Medalta’s website, the National
Historic Clay District is indeed said to include the Hycroft China and I-XL Brick & Tile plants, but the District’s
establishment is given no date. Meanwhile, the District does not appear on the Canadian Register of Historic Places.
development, tentatively as museums interpreting Medicine Hat’s china and brick industries. Only the Medalta Potteries site has undergone conservation and reuse, and as such, will assume the focus of the remaining discussion below.

The idea to revive the Potteries as a museum and ceramic arts center began as the brainchild of Jim Marshall and Jack Forbes in the mid-1970s. Looking on in 2013, Marshall and Forbes’s achievement—especially considering most of the work in reviving Medalta has been volunteer-based—is truly impressive. In 1988, when conservation at Medalta began, the site consisted of five, interconnected production buildings dating from 1912 to the 1930s, as well as four, intact round downdraft kilns dating between 1920 and 1926.\footnote{Anne Hayward, \textit{The Alberta Pottery Industry, 1912-1990: A Social and Economic History} (Hull, Quebec: Canadian Museum of Civilization, 2001), 164.} The ruins of five other associated structures, a narrow-gauge internal rail network, and intact, \textit{in-situ} machinery further enhanced the special character of the site, and provide for, today, obvious comparisons to the surviving physical fabric of Western Clay. In 1994, an initial exhibit on Medicine Hat’s pottery legacy opened in the Hycroft China factory and achieved a notable degree of popularity, hosting over 9,000 visitors in 1996 alone. In 1997, then, exhibitions were relocated to the Medalta buildings, which opened that year for the first time since the plant’s closure.\footnote{\textit{Ibid.}, 164-5.} By the completion of work, which didn’t come in full until 2011, the Friends of Medalta Society had transformed several of the four downdraft kilns into galleries housing pieces of Medalta pottery from the massive, and entirely donated, Tony Schlachter Collection (Fig. 4.10). They had transformed a former warehouse building into the “Working Pottery,” a space which, with the help of original machines and tools, recreates the ambience of a functioning production pottery. Here, visitors observe how the workers turned, jiggered, and cast Medalta wares—an old jiggerman who worked at the plant in the 1950s even comes in once a week to demonstrate (Fig. 4.11).
adjacent building, a lively display of text, graphics, historic photographs, and more Medalta pots trace the story of the plant’s workers, products, and factory site (Fig. 4.12). Finally, excavations done in a third building in 2010 uncovered the foundations and flue networks of two older pottery kilns. Stabilized as ruins, these archaeological features enable the site to further communicate how and where Medalta production wares were fired (Fig. 4.13).

Of course, not all construction at Medalta occurred within the confines of historic buildings. In 2011, the Friends opened the Shaw International Centre for Contemporary Ceramics, a state-of-the-art, 12,000 square-foot home for the Medalta International Artists in Residence Program, first established in 1998. In that the conservation of its historic facilities pre-dated its agenda in contemporary art, Medalta is a sort of inverse of what the Bray could ultimately become. It seems, however, that the site’s preserved and interpreted historic resources are nothing but an asset for those artists who apply to take up residence there. Atmosphere and inspiration aside, residents are able to display their work in the intriguing gallery spaces created during Medalta’s redesign (Fig. 4.14). Their work also enjoys increased exposure to visitors who come to the site primarily to visit the “Working Pottery” and other exhibits.

Indeed, the conservation and interpretation of the original pottery site proved so popular, the Friends of Medalta Society were able to construct, in the final phase of the project, an additional gallery building, which opened in 2010. The design for the new gallery featured an outdoor space capable of hosting as many as 1,400 people for concerts and other summer events. These special events—combined with museum entrance fees, gallery rentals for weddings, and an active school field trip program that includes a turn at the popular, do-it-yourself “Clay Table”—make up the diverse revenue streams which appear to be powering the site’s success. Given the proximity of Medalta to Helena, the author looks forward to making a pilgrimage to Medicine Hat to examine the exhibitions there more carefully. It does not take a visit, however, to see that well-planned, well-executed conservation work at a site of high integrity can make for both an
entertaining, didactic experience for visitors, as well as a serious, productive environment for artists. In pursuing conservation work at the Bray, there is no doubt that the Medalta is a wonderful model to follow.

### 4.3.2 Ziegeleipark Mildenberg of Zehdenick, Germany

If Medalta represents the case study most immediately similar to the Bray, the next case represents the extreme of what the Bray and its brickyard could become. Located near Mildenberg, Germany, a village of 832 inhabitants nestled within the larger, “city” limits of Zehdenick (pop. 13,684), the Ziegeleipark is a brickmaking landscape like no other the author has encountered. And though, like Medalta, the Ziegeleipark eluded visitation for the purposes of this study, the organization’s sophisticated website, staff, and a couple of extensive academic works associated with the site have provided enough information to enable its use here in envisioning future work at Western Clay.

Today’s Ziegeleipark is a forty-two-hectare site positioned on the river Havel, roughly fifty kilometers north of Berlin in the former East German region of Brandenburg. Of Germany’s sixteen Bundesländer, or federal states, Brandenburg is, due to an aging population and anemic manufacturing sector, the least prosperous. Today’s malaise, however, should in no way obscure Brandenburg’s history as a former lynchpin in the production of building materials for central Europe. Indeed, in the late nineteenth century, several factors converged to transform Zehdenick from a quiet, agricultural community of roughly 2,000 inhabitants in 1820 into a brickmaking mecca—home to upwards of 3,000 workers, alone—by 1900.\(^{79}\) As is often the case in industry, improvements made to transportation infrastructure had a profound influence on growth.

Between 1878 and 1888, Brandenburg’s road, canal, and rail networks all expanded to encompass

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Zehdenick and link it to Berlin, the new capital of Bismarck’s German Reich.80 Then, in 1887, as crews began the construction of a railway bridge over the Havel, massive deposits of clay were found on both banks of the river north of town. Formed approximately 13,000 years ago, at the end of Europe’s last glacial period, the Zehdenicker clays were residual—the result of a slow but steady accumulation of sediment carried by ice melt flowing off receding continental ice sheets. Though not of the quality suitable for Sichtklinker, or face brick, the Zehdenicker deposits were easily accessible—found near the surface and extending up to twelve meters in depth—and therefore ideal for producing Hintermauersteine, or common brick.81

Berlin, meanwhile, found itself in the midst of an unprecedented growth spurt that began with German unification in 1871 and would continue, essentially unabated, until the outbreak of the First World War in 1914. During this time, the city overhauled its sewer, canal, and railway systems, while inner-city neighborhoods swelled with the construction of Mietshäuser, or apartment houses, to accommodate soaring populations (Fig. 4.15). Though the façade of a typical Mietshaus would have been plastered over in the Jugendstil mode of the day, its inner skeleton required approximately 1.4 million common brick.82 Thus, the timing was right for a proliferation of brickmaking in Zehdenick, just a short jaunt north on the Havel. “A very large part of Berlin’s stock of apartment houses built between 1888 and 1914, as well as many public buildings from the Weimar period and post-war era, are composed of Zehdenicker brick,” reports Carsten Benke.83 At its height in 1911, as Archie Bray, Sr., was busy finishing his degree at Ohio State, the Zehdenick brick industry employed over 6,000 men on thirty-two independent brickyards. That year, between 600 and 700 million brick were fired in the town’s sixty-three brickyards.

80 Ibid., 32.
81 Ibid., 31-2. Hintermauerstein can be literally translated as “behind-the-wall stone.”
82 Ibid., 10.
83 Ibid., 33.
Hoffmann-style continuous kilns, with the vast majority shipped by canal to supply the tireless masons of Berlin (Fig. 4.16).

Brickmaking continued in the Zehdenick area through the cataclysms of world war and into the Cold War years of the German Democratic Republic. In 1951, the remaining private brickyards were consolidated into the state-owned and operated Volkseigener Betrieb “Ziegelwerke Zehdenick,” an operation employing twenty-five kilns. Throughout the 1950s, as many as 3,000 men produced the brick needed to help rebuild the shattered fabric of Berlin. In the late 1960s and early 70s, however, as the East German economy floundered, production methods modernized, and reinforced concrete usurped the common brick, employment dwindled and Zehdenick’s operations shrank from nine brickmaking complexes to six. By the fall of the GDR, only 870 workers remained. German reunification in 1990 and the associated reforms of the East’s manufacturing sector sealed the industry’s fate. By the end of that year, each and every brickyard in Mildenberg-Zehdenick had been decommissioned and shuttered.

And so, the physical remains of a mighty industrial legacy—and arguably the material birthplace for much of Germany’s capital—were left to the elements. The importance of Zehdenick’s brickmaking landscape seems to have been immediately recognized, however, and beginning in 1991, only twelve months after the last kiln had cooled, a private, nonprofit group known as Technische Denkmale, e. V., or “the Society for Monuments of Technology,” undertook the maintenance of two of Zehdenick’s largest brickyards—the F. Hornemann Ziegelei (founded 1890), and the G. Stackebrandt Ziegelei (founded 1904, see Fig. 4.17). Although the Society fell short of its goal of establishing on the site the Märkisches Ziegelei- und Technikmuseum, it did succeed in opening the area to limited public visitation in 1994, even resuscitating an old narrow-

84 Ibid., 41.
85 Ibid., 43.
86 Ibid., 44.
gauge railway, which in its previous life had hauled clay among the brickyards.\textsuperscript{87} Indeed, a larger and more financially capable entity would have to intervene, and in 1997, help arrived in the form of the \textit{Gesellschaft für Museum und Technik Mildenberg} (GMT), a limited liability corporation established by the local, county government of Oberhavel. Vowing to preserve the Hornemann and Stackebrandt facilities for public enjoyment and edification, Oberhavel agreed to bear twenty percent of restoration costs, while the remaining eighty percent would be culled from a variety of public sources, including the state (Brandenburg), the federal republic of Germany, and the European Union.\textsuperscript{88} As before, Zehdenick’s proximity to Berlin proved vital: the GMT would boost the economic viability of the project by marketing the site to day-trippers fleeing the metropolis. From the late 1990s onwards, the site’s image—from its new name, “Ziegeleipark Mildenberg,” to its new slogan, “\textit{Das Technikmuseum in der Natur}”—was geared toward Berliners hoping to escape the city for an informative jaunt through Brandenburg’s bucolic, clay-oriented landscape.

According to Ulrich Gries, such heavy emphasis on marketing and promotion in the park’s early years detracted from the research and curation of its material resources.\textsuperscript{89} In stark contrast to the Ironbridge Gorge Museum Trust, for example, which partnered with the University of Birmingham to create the Ironbridge Institute, a center for research and training in industrial archaeology and heritage management, the GMT left curatorial duties largely in the hands of volunteers. And instead of being led by a collections staff or research team, the park was run by a chief executive officer and marketing director. Focusing primarily on developing tourist infrastructure, identifying and conserving the site’s most impressive structures, and fine-tuning

\textsuperscript{87} Ulrich Gries, “Bausteine für den Kulturtourismus? Erhaltungs- und Inwertsetzungsperspektiven für das Erbe der Zehdenciker Ziegelindustrie,” PhD diss., Universität Trier, 2007, 224. \textit{Märkisches Ziegelei- und Technikmuseum} may be loosely translated into the “Brandenburg Museum of Brickmaking Technology.” \textit{Mark}, a term dating back to the Middle Ages, is synonymous essentially with the term kingdom, or \textit{Reich}. Oftentimes the federal state of Brandenburg is still referred to, somewhat nostalgically, as \textit{Mark Brandenburg}.

\textsuperscript{88} \textit{Ibid}., 225-6.

\textsuperscript{89} \textit{Ibid}., 226.
the site’s public image, the business-minded leadership of the GMT ultimately moved away from the term *Technikmuseum*, as well, opting for the more family- and tourist-friendly *Park* designation. 90 All in all, the Ziegeleipark adopted a conservation strategy that situated the site somewhere between a museum of industry and a theme park.

What consequences did this hybrid approach have on the site’s didactic value? In a rather pointed analysis, Gries describes the park’s exhibitions as a multi-generational patchwork of the classic, three hundred-word informational tablets known to museum goers everywhere. Erected in a piecemeal manner, and without the consideration of broad themes or interdisciplinary conclusions, the tablets presented information on topics such as clay preparation; clay transportation; Friedrich Hoffmann, inventor of the Hoffmann continuous kiln; and the living conditions of seasonal workers in Zehdenick. Nowhere, however, were more uncomfortable themes presented and discussed—themes including the forced nationalization of the brickmaking industry by the communist regime of the GDR, or the expropriation of Jewish-owned businesses by the National Socialists in the 1930s.91 Based on information made available through the Ziegeleipark’s website, however, the author believes that much of the park’s original interpretive material has, since Gries’ writing in 2007, been replaced by more modern, interactive and video displays. To what extent the content of the park’s exhibitions have also been updated is an important, albeit unanswered, question.

Early, curatorial missteps notwithstanding, it is worth examining other aspects of the visitor experience at the Ziegeleipark in brainstorming how clay-related industrial heritage can be communicated in exciting, informative, and relevant ways. Building conservation work proceeded in two stages at the park—from 1997 to 2003, and from 2007-2008—and has resulted in a stunningly attractive and complete post-industrial landscape (Fig. 4.18). There are myriad

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opportunities for visitors to observe the brickmaking process and learn about the role that Zehdenicker brick played in the construction of Berlin. Visitors have access to brick production buildings, a blacksmith shop, workers barracks, and the inner workings of an original Hoffmann-style kiln dating to 1897, which, of course, houses a permanent exhibit on Friedrich Hoffmann, who was a Prussian himself (Fig. 4.19). Much of the park’s machinery—including the original steam engine which powered the primary brick-production building—has been retained and revived, and is thus capable of stunning tour groups with deafening noise. And, as alluded to above, many of the former transportation networks within the park have been preserved. Today, where once the cargo consisted of clay and brick, original steam locomotives now cart families and tourists from stop to stop. The system of canals—the historical lifeline between Zehdenick’s brickyards and the construction sites of Berlin—is intact, as well. Recreational boating on these waterways has emerged as yet another draw for visitors to the park. Canoes, paddle boats, and even floating bungalows for overnight camping may be rented from the Ziegeleipark’s “harbor” facility.

So, while the Ziegeleipark might not boast the interpretive sophistication necessary to land itself on the World Heritage List, it appears to be a lovely place—a place where people can experience authentic and finely-conserved brickmaking heritage firsthand, all in the confines of a dynamic outdoor environment (Fig. 4.20). The park’s seemingly energetic and creative staff has developed an internet presence that enthusiastically promotes visitation and special events.92 In the spring of 2013, alone, the Ziegeleipark will host the fifteenth annual cross-country cup for runners from local Oberhavel schools; the fourteenth annual Dampfspektakel, a congress of Brandenburg’s vintage steam-engine enthusiasts; and the special Handwerkertage. Held from April to October on the first weekend of each month, the “Handworker Days” enable visitors to

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92 See the Ziegeleipark’s German homepage, which was fully redesigned over the winter of 2012-2013, at http://www.ziegeleipark.de/index.html. One-page PDF fliers describing the park are available, additionally, in English and Polish. The park has also recently developed its own channel on YouTube, available at http://www.youtube.com/user/Ziegeleipark, which features several video tours of the site.
learn the techniques of traditional brickmaking, hands-on, in truly authentic surroundings (Fig. 4.21). Each participant leaves with their own personally hand-modeled and struck brick.

From weddings to Easter egg hunts, from brickmaking demonstrations to the annual Spätsommernacht (where clamp kilns are built and fired late into the summer night), the Ziegeleipark appears to be an exceedingly vibrant industrial heritage site. Though its curation may leave something to be desired, to argue that the park somehow fails in the larger mission of conserving and promoting the industrial past would be tenuous at best. Between its opening in 1997 and 2006, the most recent year for which data was found, the number of visitors to the Ziegeleipark rose steady, from 10,000 to 40,000 annually, topping out at 44,615 guests in 2002.93 In achieving such steady visitation, the Ziegeleipark has not only exposed a great many people to Zehdenick’s brickmaking legacy—it has also secured its own economic survival, which is a battle facing most every publically-owned and operated heritage site nowadays.94 Indeed, the Ziegeleipark is a model for industrial heritage conservation founded on the notion that learning—and, perhaps more pragmatically, financial solvency—must be firmly grounded in activity and enjoyment on the part of the visitor.

4.3.3 Potential Applications for the WCMC Kiln Complex

If TICCIH’s Nizhny Tagil Charter is the measure of a well-conserved industrial heritage site, both the Medalta Potteries and the Ziegeleipark represent, without a doubt, jobs well done. The preservation of functional integrity and wholeness has been achieved to the greatest extent possible. Through the continued use of buildings, machines, and transportation networks (be it for pottery-making, brickmaking, or recreational boating), the sites’ new identities defer to and respect original material, processes, and patterns of circulation. Meanwhile, events such as the

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94 According to its website, the Ziegeleipark is no longer managed by the GMT, Gesellschaft für Museum und Technik Mildenberg. Instead, the institution appears to be managed by WInTO GmbH – Wirtschafts-, Innovations- und Tourismusförderung Oberhavel, a limited liability corporation affiliated with the county government of Oberhavel and dedicated to the development of the region economy through innovation and tourism.
Handwerkertage in Zehdenick or the “Clay Table” at Medalta involve the public in hands-on demonstrations of the ceramic craft, thus communicating the human skills involved in traditional production to younger generations.

In fact, Medalta and the Ziegeleipark paint such tidy pictures for the preservation of what must have been decrepit, depleted industrial landscapes, one is tempted, especially from the vantage point of the United States, to dismiss the sites as fanciful, “only in Germany” or “only in Canada” dream projects. Yes, the average German day-tripper is perhaps more curious about the provenience of brick than the average American day-tripper, who might prefer eighteen holes of golf to a stroll through a Hoffmann-style brick kiln. And certainly, the public sector’s generous investment in the Ziegeleipark’s conservation—which was also a product of post-1989 political dynamics and the staggering amounts of financial aid directed toward Brandenburg from West Germany—would have no parallel in the U.S., especially given the prevailing tax- and spending-adverse attitudes in modern American governance. When examining both the Medicine Hat and Mildenberg examples, however, there are some take-away lessons to consider for Western Clay—lessons perhaps less obvious than, for instance, their sensitive treatment of ad hoc material alterations. In Medalta’s case, the lesson lies in the harmony that exists between the site’s dual personalities—its role as a museum and its role as a center for contemporary art. In Mildenberg’s case, then, the lesson lies in the park’s willingness to establish regional, and even international, networks of engagement.

In reading about Medalta, the author was most impressed by the apparent historical awareness of the artists who apply to complete residencies there. “I came up here to spend a year to develop my art practice, which is contemporary ceramics,” says Evan Hobart, a former artist in residence at Medalta. “I’ve always been interested in old equipment...because there’s a story
behind it, there’s something kind of mystical about it.”95 According to current artistic director and former consultant to the Bray, Aaron Nelson, part of the site’s appeal for artists is its historical authenticity. “Medalta is about authenticity. You can’t put a shovel in the ground anywhere in these thirty-two acres and not hit a piece of pottery sherd, which is crazy.”96 Of course, some would claim that nearly all ceramicists, by virtue of the age of their craft, are mindful of history. And indeed, there have been countless resident artists at the Bray whose attitudes and work have reflected an appreciation for the site’s past. Robert Arneson’s “Brick” (1975) and Robert Harrison’s “Potters Shrine” (1985-7) are just two pieces that come to mind when one reflects on the intersection of contemporary art and brickyard heritage at the Bray.

What Medalta has so masterfully done, however, is to spatially blur the lines between its “museum self” and “art center self.” Contemporary works are displayed in the plant’s historic downdraft kilns. Clayworkers circulate through the museum spaces, interacting with visitors and even demonstrating techniques. Current ceramic production, as well as community classes and workshops, find their way into historic spaces, while references and relics from Medalta’s history as a production pottery work their way, in turn, into newly constructed spaces. To be fair, the continuity of craft is even more acutely evident at Medalta than it is at the Bray—pottery is created at the site now by contemporary artists, just as it was during the Potteries’ original era of production. (At the Bray, very few of the residents attempt brickmaking.) But, if conservation occurs at the Bray as it has at Medalta, the author would recommend that the foundation’s contemporary artists follow the lead of those in Medicine Hat, engaging in the site’s historical spaces as much as possible. No, they should not be obliged to create bricks to fill in lacunae in the kiln elevations. But if artists were able to exhibit their work, or even create new work, in the preserved portions of the brickyard, it would do much to animate the site and enhance that

95 Excerpt from a video interview posted online at http://www.youtube.com/watch?v=PbPHxIS5g0M.
96 Ibid.
ceramic continuum which stretches back to Autio and Voulkos, who, themselves, once created art in the utilitarian confines of Western Clay.

As described above, the Ziegeleipark has done a marvelous job of enticing members of the Oberhavel community within its gates for community-building events. A high-school cross country meet, a gathering of local steam engine buffs, and a chance for local children to play with clay on a class field-trip: these are the kinds of events that establish goodwill and with it, the potential for repeat visitation and even financial support among the site’s most important stakeholder group—its neighbors. The Archie Bray Foundation of course has a long history of involvement in its local community. The artists of the Bray have instructed Helena’s citizenry in pottery classes since the Foundation’s inception, and in the early years, none other than Peter Voulkos himself threw production ware stamped with an anonymous “ABF” for sale in local stores.97 If the kiln complex or brickyard as a whole should undergo conservation and be reopened to the public, however, the Bray would do well to follow the Mildenberg example and reach beyond Helena for opportunities to promote awareness of its heritage resources, and of clay-related industrial heritage at large.

The Ziegeleipark’s collaboration with partner sites at regional and international levels via heritage corridors is extensive. The park finds itself listed, first, on the German Tonstrasse, or “Clay Street”—a 215-kilometer circuit which links a series of clay-related destinations in the region north of Berlin. Highlights along the Tonstrasse include the Tile Stove Museum of Velten; the over seventy abandoned clay pits around Zehdenick, many of which have filled with water to form a scenic network of lakes; a still-functioning, 128-hectare, open clay pit; the Ziegeleipark, of course; and numerous potteries and pottery galleries.98 Conceived of by an association for tourism in northern Brandenburg, the Tonstrasse is an inventive attempt at heritage promotion via

98 Access the Tonstrasse online at http://www.deutschetonstrasse.de/.
thematic similarity, and, like the Ziegeleipark itself, is cleverly marketed to day-trippers departing Berlin.

Akin to the Tonstrasse, but broader both thematically and geographically, is the multinational European Route of Industrial Heritage (ERIH), of which the Ziegeleipark is also a part. ERIH opened in 2004 as cooperative project among tourism bodies, academic institutions, and nonprofit groups to promote the transnational transfer of knowledge in industrial heritage conservation. Building on the successful model of the Ruhr Industrial Heritage Route, which opened in 1999 and grew to encompass 900 sites across 400 kilometers in Germany’s Ruhr Valley, ERIH was also very much an effort in “Network Marketing”—the idea that a grouping of sites can achieve a level of branding power unattainable for any individual site.99 Led originally by the United Kingdom, Netherlands, and Germany, the main route has grown to include eighty “anchor points”—that is, outstanding industrial monuments such as the Ziegeleipark, for which some form of tourist infrastructure already exists—in thirteen countries.100 At present, the ERIH now encompasses over 1,000 sites in forty-three European countries. Ranging from factories to industrial museums and landscapes, sites on the ERIH enjoy the benefits associated with allegiance to an international brand. Sites may be included on one of twelve European Theme Routes (e.g., the industrial landscape route, the iron and steel route, or the salt route), or on a regional route stemming from one of the enumerated anchor points. Additionally, member sites are featured in multilingual promotional literature, and are permitted to use ERIH graphics in their own materials. According to Wolfgang Ebert, a developer of the network, visitation among member sites has climbed by an average of one-third since the route’s founding.101

The author describes the Tonstrasse and the ERIH—the heritage corridors of the Ziegeleipark Mildenberg—not only as a way of suggesting how much work needs to be done to

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100 Access the European Route of Industrial Heritage online at http://www.erih.net/.
101 Ebert, “Industrial heritage tourism,” 205.
properly enhance the visibility of industrial heritage in the United States. For the Bray and its brickyard, the intent here is rather to inspire thought beyond the boundaries of Country Club Avenue in west Helena. Surely, if conservation of the kiln complex is to occur, the Bray and its supporters must devote their attention to their own heritage resources first. However, collaboration with nearby sites of production (e.g., the copper meccas of Butte and Anaconda) or with sites bearing thematic likeness to the Bray (e.g., the Medalta Pottery) could be pursued to help promote the story of Helena’s brickyard beyond its corner of Montana. The protection of industrial heritage is, by itself, a difficult task. Hence, as one may read on the ERIH website, it is an issue that “[can] be appropriately tackled through cooperation…” The creative energy stimulated by cooperation and exchange is, no doubt, a familiar concept to past and current resident artists at the Bray. The author would thus encourage the organization to approach the potential conservation of its kiln complex with the same eye for network-building and collaboration.
5. A Conservation Program for the WCMC Kiln Complex

Included in lieu of a standard conclusions chapter, this program is a distillation of the previous chapters and is intended for quick reference by those most concerned with the immediate future of the Bray’s historic brick kilns. With the exception of a few final additions, this program contains mostly elements which are elaborated upon at length elsewhere in the thesis. For further reading, please refer first to the Table of Contents, Introduction, and Index.

5.1 Material Significance

For a non-profit organization devoted to excellence in the ceramic arts, a complex of five industrial grade brick kilns should be considered a significant asset. The kiln complex of the former Western Clay Manufacturing Company embodies value in the following ways:

- **History**
  - Downdraft kilns typify a mode of brick manufacture that is extinct in this country. The kiln sheds constitute an especially unusual physical feature.
  - Peter Voulkos and Rudy Autio fired artistic works alongside brick in Archie Bray’s beehive kilns during the summer of 1951.
  - The kilns signify both the consolidation and modernization of industrial brickmaking, and the rise of the American movement in ceramic arts. The site is thus a kind of watershed in this country’s relationship with clay.

- **Rarity, Integrity, and “Character”**
  - The site is one of six places known in the United States where round downdraft (“beehive”) brick kilns survive.
  - The complex is a tapestry of repair work, so the notion of “original fabric” is not directly applicable here. The site is, however, whole—it retains all of the components and artifacts illustrative of its past use.
As a backdrop, the kiln complex contributes to the Bray’s a special aura as a place of creativity hatched in the shadow of heavy industry.

**Didactic Potential**

- The necessary components are in place to easily and effectively elucidate the steps of traditional brickmaking processes.
- Even ruined or inaccessible structures (e.g., Kiln Nos. 4, 5, and 6) can be utilized as visual examples to convey information on brick-firing.
- In recounting the history of the WCMC, one essentially tells the story of urban development and architecture in the state of Montana.
- With the kiln complex as a didactic tool, the Bray can better communicate its own roots as an organization founded in heavy clay manufacturing.

### 5.2 Material Limitations

At present, the following material conditions threaten the continued survival of **KILN NOS. 4-8**: 

**Structural Deformation**

- At each kiln, the displacement of brick units occurs in three distinct modes, all of which predominate in the lowest tier of masonry and around the fireboxes.
- Deformation is most extreme at Kiln Nos. 4-6, where major collapses have already taken place.
- Although Kiln No. 4’s crown is perhaps the most compromised element in the complex, lateral stresses in the lowest tiers of Kiln Nos. 7 and 8 have caused header brick to fail in tension. As a result, sizable voids exist between successive wythes of brick, signaling future instability.
• **Invasive Vegetation**
  
  o Vegetation growth is most serious on Kilns No. 4 and 5, where trees between six and twelve inches in diameter have displaced brickwork and greatly jeopardize the stability of the kiln walls.

• **Salt Damage**
  
  o Efflorescence is apparent on each kiln. It is a likely contributor to the erosion and partial loss of brick in the lowest tier of masonry and around the fireboxes. Encrustation higher up in the kilns, though unsightly, is probably stagnant and inert.
  
  o The corrosion of metal kiln components (e.g., iron banding, turnbuckles, and springs) is most extreme in and around areas exhibiting efflorescence. Though likely unessential to the kilns’ structural health, these components contribute greatly to the kilns’ functional integrity (i.e., their wholeness as machines).

These observable conditions are the result of the following factors:

• **Past Industrial Use**
  
  o The deformation of the kilns mirror structural maladies described in industry literature on downdraft brick-firing from the early twentieth century.
  
  o Effloresced chlorides are a vestige of the rock salt used to glaze face brick, while sulfate and carbonate crusts in the upper tier of the kilns are likely attributable to pollution resulting from the burning of coal in the confined shed spaces.

• **Infiltration of Moisture**
  
  o The percolation of water through the kiln walls solubilizes salts, promotes vegetation growth, and contributes to the run-off of the walls’ internal binder—the “clay” that once enabled the masonry to expand and contract during heating. This material is now mostly ceramic dust—the result of either prolonged heating
or replacement by debris. It is non-expansive in water and thus highly erodible. For each pound of it lost, the kilns walls grow increasingly unsound.

- **Open Mortar Joints**
  - Mortar loss appears indiscriminately across every kiln in the complex, and open joints are the fulcrum in the negative feedback loop of masonry deterioration:
    - Open joints are exacerbated by structural deformation, invasive vegetation growth, and the recrystallization of soluble salts.
    - Open joints facilitate the infiltration of water into the brickwork, which (as described above) is the driving force behind wall erosion and deformation, vegetation growth, and soluble salt migration.
    - Thus, open joints beget more open joints, culminating eventually in masonry collapse, as evidenced on Kiln Nos. 4-6.

At present, the following material conditions threaten the continued survival of the SHEDS:

- **Lack of Member Fixity**
  - There are eleven instances in the kiln sheds where rafters are disengaged, either from the kiln or from a post or lintel. One rafter lacks fixity at both ends—a tenuous position given wind and snow loading in the Montanan climate. The corrosion of connection hardware is most often to blame for fixity loss.

- **Dangerous Spans**
  - Several beams and rafters span lengths deemed inappropriate for their breadth.
  - Some members exhibit sloped grain and are thus vulnerable to shear forces. In many cases, cracks have already developed along patterns of crooked grain.

- **Sporadic Roof Coverage**
  - Gaps in the metal roofing enable the infiltration of wind-driven precipitation into the shed spaces, wetting the kilns and promoting the decay of shed elements.
Gaps also enable the uninhibited passage of wind through the kiln complex. Local zones of high pressure and turbulence beneath areas of surviving roofing may contribute to the further destabilization of the shed structure.

These observable conditions are the result of the following factors:

- **Poor Construction**
  - The sheds were constructed in a quick and highly improvised manner. Some areas are over-engineered, featuring robust members that are more than capable of carrying assigned loads. Other members, unfortunately, have been built into positions for which they are under-sized and ill-suited.

- **Lack of Maintenance**
  - Considering their upkeep ended in 1960, the sheds have performed admirably—a testament to Helena’s dryness and the variability of wood as a building material.

### 5.3 Guidelines for Conservation, Interpretation, and Reuse

In keeping with standards established by the International Committee for the Conservation of the Industrial Heritage, potential conservation work at the kiln complex should emphasize or incorporate the following concepts:

- **Functional Integrity** – Mentioned above in reference to the kilns’ iron banding, functional integrity refers to a site’s ability to illustrate each step of its past industrial use.

- **Reversibility** – Material interventions at historic industrial sites should leave patina and marks of use intact, exerting a minimum impact on surviving historic material.

- **Limited Reconstruction** – The reconstruction of lost or severely damaged elements is appropriate only when the functional integrity of the site depends upon it.
• **Intangible Forms of Heritage** – The human skills involved in an industrial site’s traditional operation, as well as the working or living conditions endured there by laborers in the past, should be conveyed to visitors.

• **Appropriate Use** – Any new uses of a historic industrial site should be as compatible as possible with its original, principle use.

With these considerations in mind, the kiln complex might best be preserved as a *historic vernacular landscape*, an approach which will embrace the whole of the site’s history, from its expansion under Charles Bray to its use by Peter Voulkos and Rudy Autio to fire artistic work. The author recommends the following strategies for the future interpretation of the site:

• **Preserve and Accentuate Evidence of Ad Hoc Alterations and Repair** – Features such as the buckstays bolstering the western flank of Kiln No. 8 (Fig. 3.8), or the mechanical exhaust fan grafted onto the stack serving Nos. 7 and 8, illustrate the pragmatism and ingenuity required in traditional brickmaking.

• **Preserve and Accentuate Routes of Circulation** – Loading ramps, gas lines, and doors cut into the sheds illustrate how and where products, resources, and people coursed through the complex. Visitors should understand that the kiln complex was but one stop on a brick’s path from the clay pit to the building site.

• **Exposé and Emphasize the Role of Unseen Kiln Components** – A downdraft kiln’s engine, so to speak, was the network of subterranean flues which linked the firing chamber to an exhaust stack to induce heat flow. Conservators might consider revealing part of this critical-but-concealed network in the already ruinous Kiln Nos. 4, 5, or 6.

• **Allow for the Continuation of Anonymous Art Placement** – Since 1984 and perhaps earlier, resident artists at the Bray have scattered work around the kiln complex on their own accord. There is no need to force or formalize this otherwise-organic symbiosis between the artists and their industrial neighbor.
Given the complex’s value, its present material state, and the above guidelines for conservation and interpretation, the complex could be reused to meet the following purposes. Each reuse scenario would potentially generate revenue for and/or enhance the public image of the Archie Bray Foundation.

- **Active Interpretation – Heavy Clay [in Kiln Nos. 4-6] to Artistic Clay [in 7 and 8]**
  - Kiln Nos. 4-6 are stabilized with their interiors made off-limits to the public.
    - Informative panels along their exteriors explain downdraft kiln function, the larger brickmaking process at Western Clay, and the use of Western Clay products in Helena’s built environment.
    - The flue system of one kiln is partially excavated and displayed.
    - The entrance to the kiln complex is reestablished in the north, ushering visitors through a reconstructed sliding door in the shed wall and down the wooden ramp between Kiln Nos. 7 and 8 (Fig. 4.8). Visitors will thus descend into the kiln complex where brick once ascended on its path to train cars and markets beyond.
  - Kiln Nos. 7 and 8, meanwhile, are stabilized and opened to the public.
    - Kiln No. 8, with its half-setting of sewer pipe, houses an exhibition on the site’s transition from industry to art. Resident work is displayed atop the kiln’s unloaded sewer pipe, thereby evoking images of Voulkos and Autio’s work being fired alongside heavy clay wares in 1951.
    - Kiln No. 7 is used alternatively as a gallery and teaching space. Brickmaking—hand-molding and repressing—may be demonstrated to visitors. Or, instructors might hold wheel-throwing or hand-building workshops within the kiln.
• **Passive Interpretation** – Exhibition/Performance/Reflection in Nos. 7 and 8
  
  o Should the Bray wish to forgo a larger interpretive effort, Kiln Nos. 4-6 could be closed entirely from the public, with stabilization occurring only at Nos. 7 and 8.
  
  o Details regarding kiln function and history are presented in a truncated format, perhaps on one or two informational panels located at the current entrance to the kiln complex. Otherwise, visitors are allowed to peruse Kiln Nos. 7 and 8 and reach their own conclusions as to the site’s meaning.
  
  o The program of use in Kiln Nos. 7 and 8 is flexible, alternating from the exhibition of resident work to music and dance performances. The Bray might merely open the spaces for reflection, leaving Kiln No. 7 empty and the pipe in No. 8 undisturbed and unabandoned.
  
  o The unique visual and aural qualities of the kiln spaces will attune audiences to beauty in its many forms. The circular floor plans of the spaces provide for intuitive circulation as galleries, and during performances, a focal point is easily established in the center of the kiln with audiences congregating along the structure’s circumference. Given the kilns’ resonance, no voice amplification should be required.

5.4 **Necessary First Steps**

If either of the above conservation scenarios are to occur, the Bray should move quickly to mitigate current deterioration and prevent further material losses to the kilns and their sheds.

Initial steps for conservation are presented in chronological order below.

1. **Secure the sheds.** Ensure workers’ safety by supporting visually compromised members at mid-span. Sister compromised rafters and ensure fixity at all rafter-lintel and rafter-
post connections. Patch gaps in roofing or cover with tarps. Consider, as a final step, employing a structural engineer to reestablish and stiffen the kiln-rafter connection.

2. **Clean the kilns.** Rake mortar joints, clear vegetation, and remove all extraneous debris and collapsed masonry from Kiln Nos. 4-6 and 8. This process, already done at Kiln No. 7, is important in accessing the extent of damage. Collect loose brick for reuse later.

3. **Desalinate masonry.** Employ several rounds of wet paper poultices in areas exhibiting extreme efflorescence. This process is enjoyable—reminiscent of papier-mâché—and will excite volunteers.

4. **Fill voids.** In areas where successive brick wythes have peeled apart, fill voids with brick fragments and a low-strength, lime-cement mortar. Where possible, situate salvaged brick in voids as headers spanning detached wythes, so as to reestablish lateral stability in the wall. Stainless steel pins may serve a similar function.

5. **Repoint extensively.** Repairing open mortar joints is critical in preventing the continued wetting of the kiln, the recrystallization of salt on brick surfaces, and the run-off of the kiln walls’ vulnerable, ceramic bedding material. Again, the use of a low-strength, lime-cement mortar is preferable.

6. **Rebuild.** While the total reconstruction of the kiln walls is neither necessary nor desirable, limited reconstruction, especially around the fireboxes, may be necessary to illustrate past function. In all cases, salvaged brick types and appropriate bonding patterns should be employed to match surrounding areas.

7. **Waterproof the kiln parapet.** As per recommendations made by Christopher Taleff, the installation of weep spouts, a layer of clay, flashing, and a low permeability synthetic membrane beneath the top course of brick should be considered to inhibit the wetting of

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102 For the pilot conservation of Kiln No. 7 in July 2012, a mortar consisting of one part natural hydraulic lime (St. Astier NHL5), two parts sand, and one part soil (for color and strength reduction) was used for grouting and repointing. If this work has survived the intervening winter season with no signs of distress or decay, the author would advocate its continued use throughout the remainder of the kiln complex.
the kiln walls via their exposed parapets. A lower cost, and perhaps more attractive, solution would be to “soft cap” the kiln parapets, using local turf grasses and topsoil to establish a layer of resilient, absorptive, but nondestructive vegetation along the top of the kiln walls.\footnote{For more information on soft capping please see *Soft Capping Historic Walls: A Better Way of Conserving Ruins?* eds. Zoë Lee, Heather Viles, and Chris Wood (Unpublished report undertaken by English Heritage and the Oxford University Centre for the Environment, 2009), available online at http://www.geog.ox.ac.uk/research/landscape/rubble/swc/resources.html.}

With these steps taken, the kilns will be stabilized for continued deliberation as to their future use. Pursuing the “Active Interpretation” course described above would likely entail additional work—e.g., partial excavation of flues in Kiln No. 4, 5, or 6, preparation of interpretive panels, and installation of electric lighting in Kiln Nos. 7 and 8 for more elaborate art exhibitions and demonstrations. If the Bray should chose to pursue “Passive Interpretation,” however, conservation efforts would essentially reach completion with the steps outlined above.

### 5.5 Ideas for Broader Application

Of all the ideas put forth in this thesis, perhaps those most appealing to the author involve collaboration with other sites of industrial heritage and contemporary craft. The prospect for some form of partnership between the Archie Bray Foundation and the Medalta Potteries is particularly exciting, as the parallels between the two organizations are uncanny. Not only are they both the progeny of heavy clay manufacturing companies—outfits known to interact, and compete, across the American-Canadian border. Both institutions also excel in contemporary ceramics, and could showcase current work being created north and south of the border in the medium of clay. Furthermore, the I-XL brick plant was recently bequeathed to Medalta and sits fully intact—a 2013 version of what Western Clay must have been in the mid-1960s. If Medalta and the Bray could somehow pursue the conservation of their respective brickyards concurrently—emphasizing, of course, the interplay which already exists between I-XL (the
larger, more modern plant) and Western Clay (the antiquated, mothballed competitor)—the results would be fantastic. For those interested in contemporary ceramics and industrial heritage conservation, such a development would be eminently fascinating and eminently marketable.

Another potential boon for conservation at the Bray is the possibility of finding kindred centers for contemporary art which have grown up (or aspire to grow up) on sites of previous industrial production. In Philadelphia, for example, the Center for Art in Wood—an institution dedicated to promoting the use of wood, or wood with mixed media, in artistic design—has considered relocating their galleries and workspaces to the old John Grass Wood Turning Company, which closed in 2003. Just a few blocks from the Center’s current location in downtown Philadelphia, the Grass Company building retains many of the original, early twentieth-century, belt-driven machines and implements used to create everyday objects—balustrades, bowls, and bowling pins—from wood. Unfortunately, the Center for Art in Wood has been unable to complete the move to the Grass Company. Nonetheless, a network could be formed between organizations like the Center and the Bray to promote this notion of instating contemporary art-making in historic buildings once devoted to similar crafts in similar media. The author envisions such a campaign resonating deeply among members of an emerging generation of artists and small-scale craftspeople in the United States who, like proponents of the Arts and Crafts Movement over a century earlier, seek a form of continuity and authenticity in their work and work environments as a kind of salve in an otherwise frenetic, increasingly digital, modern world. Building a coalition of such like-minded, creative establishments would boost the public image of the Archie Bray Foundation and potentially draw support to any conservation work undertaken there. Perhaps more importantly, however, it could inspire similar projects elsewhere in the country, further promoting the preservation and productive reuse of the battered

104 See http://www.woodturningcenter.org/JohnGrass/ for more information.
remains of American industry. So might we remind ourselves of the significance handwork once held in our society—so might we be mindful of the true joy such work still may bring.
6. Bibliography


Quivik, Fredric L. Montana Historical and Architectural Inventory: Western Clay Manufacturing Company. Prepared as part of the site’s nomination to the National Register of Historic Places: 1985.


Figure 2.1 - A drawing from Greaves-Walker’s *Clay Plant Construction and Operation* depicts a round downdraft kiln in section. The author has provided arrows to show the flow of heat within such a kiln.

Figure 2.2 - Another illustration from Greaves-Walker’s *Clay Plant Construction and Operation* depicts a typical downdraft firebox, both in elevation and section. Notice the bag wall (or simply, “bag”) depicted in the extreme right of the section.
Figure 2.3 (top) - A view from inside Kiln No. 8 illustrates the kiln’s open bottom. Also apparent is the half-setting of sewer pipe, never fully drawn after the kiln’s final firing around 1957. Photo courtesy of Joseph E. B. Elliott.

Figure 2.4 - An illustration from Carl Harrop’s 1915 paper on kiln expansion and bracing demonstrates the proper springing of a kiln crown. An arch of small radius distributes outward thrust along several joints. Springing the crown off a standard skewback, on the other hand, concentrates trust along one plane of shear.
Figure 2.5 (top) - A section of a clamp kiln taken from Edward Dobson’s *Rudimentary Treatise* reveals both the massive, monolithic scale of a clamp as well as its prominent, inward slope.

Figure 2.6 - Workers scove a brick kiln in Madagascar. Source: *Small Scale Brickmaking*
Figure 2.7 - Workers draw fired brick from a scove kiln. The device, with its breadth and retractable roof, easily accommodates two teams of horses with carts. Source: Hopkins, *Clays and Clay Industries of Pennsylvania*

Figure 2.8 - A Roman updraft brick and tile kiln, excavated near St. Albans in Hertfordshire, England. Source: Davey, *A History of Building Materials*
a. Open kilns.—The most common form of open kilns is what is known as the “Scotch kiln.” Fig. 2 represents, in transverse section, the essential points of construction of the “Scotch kiln.” An oblong space is enclosed to the requisite height by side and end walls, a space about 8 or 9 feet wide being left vacant in the middle of the two ends to allow of access to the interior. The “green” bricks are built up so as to fill the enclosed area, but so too as to leave channels or passages through the kiln from side to side at the base, corresponding to which extemporised passages are permanent opposite openings in the side walls. These

Figure 2.9 - A drawing of a Scotch kiln in section shows the permanent nature of the fire tunnels at the base of the setting. Source: Ballard, “On Effluvium Nuisances”

Figure 2.10 - A seventeenth-century Scotch kiln excavated in the late 1930s by National Park Service archaeologists at Jamestown, Virginia. Source: Davey, *A History of Building Materials*
Figure 2.11 - Minton’s downdraft porcelain kiln, patented in 1873 and used in the Staffordshire potteries. Source: Ballard, “On Effluvium Nuisances”
Figure 2.12 - A 1920 issue of the Brick and Clay Record advertises the Minter System for firing multiple downdraft brick kilns in a continuous, fuel-efficient cycle.
Figure 2.13 - The Hoffmann Ringofen, or ring kiln, illustrated in plan, section, and elevation. Over time, the shape of the kiln evolved from a circle (left) to an oval (right), so as to accommodate more brick. Source: Klasen, *Fabriken für die Thon-Industrie*

Figure 2.14 - This schematic depicts the firing of a Hoffmann continuous kiln featuring eighteen individual chambers. Outside air enters the kiln through Chamber 14, which has cooled and is being unloaded. The air is drawn through cooling chambers until it reaches Chambers 4 and 5, which are at “full fire.” Now fully heated, the air then travels through Chambers 6-12, helping to further dry newly-set green brick. Finally, it exits the system via dampers (Schieber) and a central exhaust stack beyond. Source: Klasen, *Fabriken für die Thon-Industrie*
Figure 2.15 - Though Schmidt and Firestone purported to run their Hoffmann kiln design business out of Helena, they failed to attract the business of the town’s most prominent heavy clay manufacturers the Brays. Source: F. G. Matero

Figure 2.16 (bottom) - J. P. Rowe’s 1908 image of the kiln complex depicts Kiln No. 4 (center) and potentially Kiln Nos. 3 (left), 1, or 2 (right).
Figure 2.17 - A Sanborn map last updated in 1922 depicts Kiln No. 3 to the southeast of Kiln No. 7. Gone by this point are Kilns No. 1 and 2. Source: Reid, (In)Forming and Pressing Matters

Figure 2.18 (bottom) - An early image of either the Kessler or Western Clay brickyard depict what could be two of Kiln Nos. 1-3. Source: Montana Historical Society
Figure 2.19 (top) - This aerial view of the Western Clay Manufacturing Company was captured circa 1956, shortly before construction of the tunnel kilns and the final firing of the downdraft kilns. The author recommends confirming that date, however, as the alteration of the stack serving Kilns No. 7 and 8 has, in this image, not yet occurred. According to Quivik, that modification took place in 1953. Source: the Archie Bray Foundation for the Ceramic Arts

Figure 2.20 - An image from an explosion in Tier 1 of Kiln No. 7 show many of the wall’s header brick (indicated here with fuchsia dots) to have failed in tension. Photo by author.
Figure 2.21 (top) - A dry-laid model of Kiln No. 7, Tier 3, in section. The refractory brick on the extreme left represent the kiln’s interior lining. Green dots denote tie-in header brick confirmed to exist; the fuchsia dot indicates a tie-in header brick which could not be directly seen, but was instead presumed to exist based on the patterns and orientation of surrounding brick. Photo by author.

Figure 2.22 - Archie Bray, Sr., salts Kiln No. 7. Source: ACL Files
Figure 3.1 (top) - Here, where the ramp descends from the second floor of the tile shop, a divide exists between the two shed structures. The shed roofs protecting Kiln Nos. 4 and 5 rest atop steel I-beams, while those serving Kiln Nos. 7 and 8 meet wooden posts. Photo courtesy of Joseph E. B. Elliott.

Figure 3.2 - A trowel indicates the presence of punky wood at the base of a plank of shed wall sheathing. Photo courtesy of Christopher Taleff.
Figure 3.3 - The loss of fixity between corresponding wooden members is a major problem facing the continued survival of the kiln complex’s wooden sheds. Photo courtesy of Christopher Taleff.

Figure 3.4 (bottom) - In a major collapse along the northern face of Kiln No. 5, the third tier of brick masonry appears to peel off the structure. Photo by author.
Figure 3.5 - Mortar joints have reverted to powdered salt on Kiln No. 5. Photo by author.

Figure 3.6 - A major collapse threatens a firebox on the northeastern elevation of Kiln No. 4. Photo by author.
Figure 3.7 - Invasive vegetation has thrived to a frightening extent on Kiln No. 4, as evidenced by the large tree entrenched on its western side. Photo by author.

Figure 3.8 - I-beam buckstays driven into the ground at the base of Kiln No. 8’s western flank indicate that the deformation of the kiln in its lowest tier is not just a recent problem. Photo by author.
Figure 3.9 - Images taken in 2012 by the conditions survey team for Kiln No. 7 (right) set up for a dramatic contrast with Joseph Elliott’s images taken prior to cleaning in 2011 (left).

Figure 3.10 - The moisture contents of twelve soil samples extracted from the wall of Kiln No. 7 were assessed via oven drying. Photo by author.
Figure 3.11 - The twelve minute soil samples were sieved and combined by color for the further analysis of their behavior in water. Three bulk samples obtained from fireboxes and the interior lining of Kiln No. 7 were tested, as well. Photo by author.

Figure 3.12 (bottom) - Bulk Sample No. 2, as prepared in the cup of a Casagrande devise, prior to the second failed attempt at a liquid limit test. The sample was barely moist enough to mold into the cup, yet still too fluid to sustain more than nine blows in the device. Photo by author.
Figure 3.13 - One hour following agitation, Bulk Sample No. 2 appeared to settle at the bottom of a petry dish filled with water. Indeed, the sample exhibited the water absorptive behavior not of clay, but rather of brick dust. Photo by author.

Figure 3.14 - Using EM Quant salt identification strips, a saline solution derived from crushed brick fragments of Firebox No. 9 was revealed to contain a high concentration of the chloride salts one might associate with sodium chloride, the rock salt used to glaze ware fired in Kiln No. 7. Photo by author.
Figure 3.15 (top) - Brick Type B6, among the most common types seen in Kiln No. 7, was tested for its initial rate of water absorption. The seemingly aberrant value obtained for this brick, in particular, calls into question the logic of testing limited populations of such highly variable, historic materials. Photo by author.

Figure 3.16 - The highly erodible, ceramic material which binds together the walls of Kiln No. 7 is slowly bleeding out of the structure. It is found at the kiln’s base and, as pictured, inches deep between successive wythes of bulging masonry. Photo by author.
Figure 4.1 - The Doric portico at Euston Station, London. Referred to colloquially as the Euston Arch, the portico was demolished amid controversy in 1962. Source: the Euston Arch Trust (date unknown)

Figure 4.2 - The new Pemberton Mill in Lawrence, MA, photographed in 1967 by the Smithsonian’s Robert Vogel as part of the New England Textile Mills Survey. Source: Library of Congress
Figure 4.3 - The Old Furnace at Coalbrookdale, Shropshire, where Abraham Darby I first used coke to smelt iron. From 1709, Darby cast pots and kettles in the furnace, which has been enclosed by a modern museum building. Source: Ironbridge Gorge Museum Trust

Figure 4.4 - Baltimore’s Pratt Street Power Plant, built in 1900 and home to ESPN Zone, Hard Rock Cafe, and other corporate tenants from the late 1990s onward. Source: Capital Retail Group
Figure 4.5 - The interior of Kiln No. 4 exhibits the ethereal qualities that have endeared the kilns to visitors and artists for years. Photo by author.

Figure 4.6 - When perceived as a whole, the WCMC kiln complex appears to blend into (or rise up from) the contours of the surrounding Montanan landscape. Photo by author.
Figure 4.7 - A trio of clay figures take tea alongside Kiln No. 8. Photo by author.

Figure 4.8 - The former loading ramp between Kiln Nos. 7 and 8 not only demonstrates a pattern of prior circulation. It also proved to be a handy staging ground for a large brick typology. Photo by author.
Figure 4.9 (top) - An aerial photograph depicts the staggering scale of brick production at the Alberta Clay Products plant in Medicine Hat. Source: www.medalta.org (date unknown)

Figure 4.10 - One of the four restored downdraft kilns at Medalta houses company wares from the massive Tony Schlachter collection. Photo courtesy of Christopher Taleff.
Figure 4.11 (top) - In the “Working Pottery,” visitors to Medalta experience the ambience of a functioning production pottery. Photo courtesy of Christopher Taleff.

Figure 4.12 - The former drying room houses the main museum exhibit at Medalta. Photo courtesy of Christopher Taleff.
Figure 4.13 - Excavations of the subterranean workings of a downdraft pottery kiln abut Medalta’s modern gift shop and administrative desk. Photo courtesy of Christopher Taleff.

Figure 4.14 - Medalta residents display their work in another of the restored and repurposed downdraft kilns. Source: www.medalta.org
Figure 4.15 (top) - “Tempo der Gründerjahre” by Friedrich Kaiser (1875). Zehdenicker brick would have helped fuel the explosive development of Berlin’s built environment under Bismarck. Source: Bildarchiv Preußischer Kulturbesitz

Figure 4.16 - The millions of common brick produced in Zehdenick reached Berlin by canal, as depicted in this 1920s-era photograph. Source: Landesbildarchiv Berlin
Figure 4.17 - An image taken in 1945 by Allied bombers illustrates the massive scale of brickmaking in Zehdenick. The Hoffmann kilns are ovals amid long rows of drying brick. Source: Gries, “Bausteine für den Kulturtourismus?”

Figure 4.18 - A contemporary aerial view of the Ziegeleipark conveys the large scale of the conservation work accomplished there. Source: www.ziegeleipark.de
Figure 4.19 - An exhibit on Hoffmann continuous kilns, staged inside of a Hoffmann continuous kiln, instructs visitors on historic brick-firing methods at the Ziegeleipark Mildenberg. Source: www.ziegeleipark.de

Figure 4.20 - At the Ziegeleipark’s “Picknickwiese,” or picnic meadow, visitors can lounge in wooden chairs fashioned out of carts formerly used to carry brick. Source: www.ziegeleipark.de
Figure 4.21 - During the “Handwerkertage,” visitors to the Ziegeleipark (especially children), enjoy learning firsthand the techniques of traditional brickmaking. Source: www.ziegeleipark.de
**Survivor Kilns:**
*Extant Brick Kilns Listed on the National Register of Historic Places*

The following sites were found by manipulating the National Park Service’s National Register of Historic Places database, available online at http://nrhp.focus.nps.gov/natreg/docs/Download.html. Querying for listed properties that included terms such as “brick,” “clay,” “plant,” “yard,” “works,” et cetera, the author was ultimately able to find six listed properties (not including the Western Clay Manufacturing Company), which feature historic brick kilns, downdraft or otherwise. Google satellite imagery was used to confirm the survival of the kilns to the present day, as many of the sites were nominated to the register in the late 1970s and early 1980s.

Not pictured below are the several sites which could not be located on modern maps. The author can only assume those sites to be lost, along with their production buildings, kilns, and any other historic structures which might have augmented current understanding of historic brick manufacturing.

This exercise proves that the kiln complex at the former WCMC is not only rare, but also in relatively stable condition with respect to its peers. Clearly, the kiln sites to have fared the best over the years are those which have witnessed the consistent, productive use of adjoining land.

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**United Brick Corporation Brick Complex**

Address: 2801 New York Ave. NE
Washington, D.C.
Date Listed: October 3, 1978

*Of the twelve beehive kilns present on this site, only three appear to have retained their crowns. Built between 1927 and 1939, these kilns have sat disused on the federally-maintained grounds of the National Arboretum since 1972.*

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**American Firebrick Company**

Address: State Hwy. 27
Mica, Washington
Date Listed: March 9, 1982

*Constructed between 1903 and 1911, eight beehive kilns appear to have survived at this plant, which was acquired by Gladding McBean in 1929 and is still in operation.*
Guignard Brick Works

Address: 102 Granby Crossing
Cayce, South Carolina
Date Listed: February 13, 1995

Four beehive kilns remain at this former brickmaking site, established by the Guignard family in 1801. The kilns date to the 1920s, and were fired for the last time in 1956. A modern apartment complex envelopes the site today.

Green Brae Brick Yard

Address: 125 E. Sir Francis Drake Blvd.
Larkspur, California
Date Listed: March 24, 1978

The only surviving structure from the Remillard Brick Company, this rare Hoffmann kiln is said to have supplied brick used to rebuild San Francisco after the cataclysmic earthquake of 1906. The kiln has been transformed, incredibly, into a Melting Pot fondue restaurant.

Moses King Brick and Tile Works

Address: 734 N. Coal St.
Colchester, Illinois
Date Listed: August 8, 2001

From 1881 to 1970, the King Brick and Tile Works produced buff face brick and refractory brick for the steel furnaces of Gary, Indiana. Five beehive kilns dating as late as the 1950s survive at the site, which was acquired and maintained privately from 1990 until 2006, at which point the Moses King Brick and Tile Works National Historic District attained 501(c)(3) status.
Continental Clay Brick Plant

Address: 154 Charlestown Rd. (Route 9)
Martinsburg, West Virginia
Date Listed: December 10, 1980

Eight beehive kilns remain in relatively good condition at this still-functioning brick plant. Built circa 1917, the kilns are reportedly still used to dry sand.

Jenkins Brick Company

Address: 8th and Furnace Streets
Montgomery, Alabama
Date Listed: N/A

Likely built between 1923 and 1926, these ruinous downdraft kilns were once linked by underground flues and fired continuously via the Minter System (see pg. 25). Jenkins closed its Furnace Street brickyard in the 1970s but continues to use the site for stone-cutting and storage. Although it could not be found on the NRHP, the site underwent full HAER documentation in the summer of 2000.
A Conversation with Archie Bray, Jr.

The following interview with Archie Bray, Jr. (ABJ), was conducted by Brett Sturm and Joseph Torres of the Architectural Conservation Lab (ACL) via phone on March 20, 2013.

ACL: What can you tell us about Charles Bray?

ABJ: This is just stuff that I remember being told when I was very young. I understand he was an orphan, raised in an orphanage and apprenticed, and got out as a master as a clayworker. There’s a little town called Bray, west of London, and I think that’s probably where he came from. My Grandmother Bray came from Liverpool—they were both immigrants, of course. That’s about all I know about his background. …There are gaps in my memory and I’m getting kind of long in the ears. Some of it is getting kind of vague.

ACL: What can you tell us about the development of Western Clay, i.e., the order in which the beehive kilns were built?

ABJ: I’m going to guess a little bit for you, because they were numbered. 1 and 2 were no longer around. No. 3 was the first one that I remember seeing, and it wasn’t built quite the same as the other beehive kilns. It didn’t seem to have the underground part. No. 4, which was apparently the next beehive kiln built, was a regular beehive kiln. Regular beehive kilns had an integrated network of structure underneath the floor so that the draft went down through the material and out through the floor and then to a flue which led to the smokestack. The smokestack on Nos. 4 and 5 served the same two kilns. It got knocked down in the earthquake in, I think it was ’35, or thereabouts anyway, so it was rebuilt, and it actually was built with reinforcement and cement and so forth, so it’s a pretty solid stack and it serves both the Kiln Nos. 4 and 5.

If you can picture a series of underground tunnels or structure… So that the floor of the kiln was slotted, and then below that slot were passageways which had other slots in them, so that there were three levels of structure underneath the floor of the kiln. The third level led to the main flue which then went to the stack. The stack had a small opening, kind of a firebox in the side. There fires were built to induce the stack to start drawing, heating the air, and that way the draft got on the kiln. …Nos. 1 and 2 I don’t remember seeing at all. I know the little spaces on the ground, round space where they probably should have been. No. 3 I do remember seeing and it was, when I was very young, it was used as a kind of storage place. It stored barrels of oil and kerosene. And I don’t remember the proper floor and I don’t remember any smokestack, so I don’t know how No. 3 really worked, but it wasn’t built the same as 4, 5, 6, 7, and 8.

ACL: Was No. 3 located away from Nos. 4 and 5?
ABJ: Yes, if you stand at No. 7 and look east...to where the old railroad track used to be—that was out where No. 3 was. That would be 100 yards or more east. ...Maybe near that monument that they built. ...That’s where 3 used to be. As I said, when I was very young, I don’t remember the floor being slotted like the others were, so I don’t think it was a true downdraft—I don’t know how it worked. I never saw it fired, when I was young it was just used as a kind of storage place.

ACL: Do you remember when No. 3 was taken down and why?

ABJ: Well, it was taken down after the earthquake. I don’t recall the bags inside the kiln, fireboxes like they should have been and I don’t recall the kiln being damaged, but I do recall it gradually being taken down and ground up, the brick ground up and used as grog in the mixture of new clay. It was not near the size of the other kilns. 7 and 8 were both bigger—the biggest kilns—and they came latest, of course.

Now, I don’t remember... In your questions, you talk about 1885, way before my time. I do remember my grandfather, Grandfather Bray, being in the legislature. I think he was in the Second Montana Legislature. He was, I guess, a house representative, I don’t recall. I know I remember him being in the legislature, because at that time there was just a road and I remember being told how he had to walk through the snow to get to the legislature on time.

Now, No. 4 kiln. If you stood at the doorway of No. 7 and looked straight south, the first kiln you come to is No. 4. The second kiln you come to, further over, further south, is No. 5. ...I was never told really, but I think that [the numbers] correspond to the order in which they were built. ...6, which was quite a bit west up the track,...was a little bit smaller than the others, 7 of course you know, and 8 immediately west of it, and there wasn’t any 9 of course.

Now, 7 and 8 were the only kilns that were used for what we called face brick. In other words they were glazed—we used salt glazing—and also used zinc for the green color when they wanted it and so on. That was only 7 and 8. 6 was not that way, and of course 4 and 5 were not used for brick at all. They were only used for tile and flue lining and more open things. Common brick were fired in the downdraft, but common brick were fired of course in No. 6 totally, and the lower third of 7 and 8. They were not fired in either 4 or 5. The reason the lower third of 7 and 8 is the upper part of the kiln was always hotter, and that seemed to get the salt glaze and so on. As you got down in the kiln, the glaze didn’t come down that far and the brick were more just plain fired. And when you got down to the kiln floor, sometimes they were almost underfired.

ACL: Did each of kilns have its own personality in terms of performance?

ABJ: You’re right. Every kiln had its own personality, so to speak. 6 was just plain straightforward plain kiln. Its personality was that it fired pretty evenly, but just plain hot. Now 7 and 8 were kind of companion kilns, they both had glaze used. I did a lot of work trying to increase the draft in the flue which fed from No. 7 to the stack, which was wrecked in the
earthquake. I rebuilt it and put a motor, you know an exhaust fan, in it and got a little better draft in the kiln. And we got a little better firing. No. 7 also had a new crown in 1935. The old crown was torn out and down, you can see the difference in the color of the brick in the crown. The new crown was put in in '35. Everybody was proud of that new crown because it was so nice and even. I don’t think the kiln fired any better. I remember firing both 7 and 8. Well, 7 was considered a little better because it was considered to have a better draft than 8 did, but they were both good firing kilns and carried good glaze. We used salt glaze… The rock salt came in 100-pound or maybe greater than that, like 100-pound sacks at any rate, and it was stored in the room that used to be called the tile room—to the south of the kilns, it’s a brick room, had at that time had a good roof, and that’s why they stored the salt in it, so it wouldn’t get rained on. We also used zinc, little chips of raw zinc, and that was put in, like the salt, shoveled in the firebox when the kiln got up fairly hot around cone four in those days. And it made the green color. So that you had…the brick got dark from the temperature, then it got shiny from the salt, and green then from the zinc. So you had dark, shiny, green brick, which, when I was very young, was a fancy thing. Nobody else in the area made green, glazed brick. …We tried some other metal but it didn’t do anything. I don’t remember what it was.

ACL: Was the reconstruction of the crown in 1935 a result of earthquake damage?

ABJ: Yes. I remember seeing the crown somewhat deformed. And I’m sure, it was after the earthquake, so I’m sure the earthquake probably hurt it, too. You could see definite deformation in the old crown. And so that’s why it was torn out. And you can tell where…standing inside and look up at crown, you can see where the color of the brick changes in the crown, and from there on up it was all new crown.

ACL: Who built the new crown?

ABJ: The crown in No. 7 and the stack at No. 5 were the only things that were built when I was still around. The crown at No. 7 was built under my father’s instruction, but it was built just by the local people. We had some bricklayers and my father built a big sweep that held the shape of the crown right—it was mounted in the center of the kiln, plumb straight up and so on. They built the structure on the stack at No. 5. The stack at No. 5, which is new, was all built new then, and it has cement in the mortar and some reinforcing bars, so it’s a pretty strong stack. The kilns however were all built, and the only thing that was new as the crown on No. 7… Well, ask me another question, I don’t know.

ACL: (Laughter.) Was there frequent damage done to the fireboxes, were they rebuilt often?

ABJ: Yeah, occasionally. Near the firebox was always the hottest part, and occasionally it would get hot enough. Maybe when the kiln was loaded, it wasn’t set quite right and brick would topple into a firebox and the thing would be damaged so that when you unloaded the kiln, you’d have to tear down, take the brick out carefully and tear down the firebox and rebuild the whole portion. That little box of brick, where the fire comes in on the inside of the kiln, there was a little box of
brick—that’s called a bag. And that kept the fire from going straight into the kiln and made the fire then, the heat, go up and around the crown. Oh yeah, we rebuilt [the bags] frequently. I don’t know how often to tell you, but I would guess… Every firing you’d probably have to repair one or two bags, and every third or fourth firing you might have to rebuild a large portion of one or two.

(Archie’s cell phone rings, playing When the Saints Go Marching In.) Hang on just a second. Ok, go ahead.

ACL: Can you elaborate on the reconstruction of the crown?

ABJ: If you want to build a crown, you get the part which would be the center of the circle. (A crown would be part of a circle, part of a dome.) Right in that center, you put a pole straight up, made sure it was vertical. And from the top of there, from the height of that pole, you’d built a curved piece that came down, curved out, part of the radius of the crown. Now the pole then could rotate, that curve would rotate around and…you could then rotate the pole and that curve would swing around and give the location of the crown anywhere. Do you follow me at all?

ACL: Sure, yeah.

ABJ: Ok. That’s how you build a crown.

ACL: (Laughter). Would the crown then rest on the firebrick lining of the kiln, or would it rest on the outer walls, which were made from common brick?

ABJ: It would rest… Well I’m gonna tell you the inner wall, but actually there were three inner walls. The first one is the firebrick lining. And then outside of that was a common brick structure. Those two, and then the third one… Those three pieces held the real weight of the crown. Ok?

ACL: Were the kilns already damaged at the close of the plant in 1957?

[1957] is probably very close [to the correct date of the last firing.] The kilns were maintained. In spite of when the tunnel kiln was built, we did not abandon the other kilns. At least not 7 and 8 because Kiln Nos. 7 and 8 were still fired after the tunnel kiln was fired because that was the only way… The tunnel kiln could not produce what we called face brick. That was the glazed, dark colored or green colored brick. That was produced only in 7 and 8. They were maintained and still fired after the tunnel kiln to produce what we called face brick. Alright?

ACL: Can you describe the firing schedule?

ABJ: The first day you load the kiln. You load it with what are supposed to be completely dry brick. Then you start a low, very low fire and let the kiln warm up until it gets up to two or three
hundred degrees. And the brick begin to, well actually dry more, because the kiln begins to steam with the water coming out of what we called the dry brick… Once the steaming is done, the brick are now dry and the kiln is probably up to four hundred maybe—not quite five because when you look in, it isn’t quite red. Then you start, of course the fire’s gradually been increasing, you start bringing the fire up more and the kiln begins to get hot. You look in and it’s probably pretty red, then you take it up, keep increasing the fire. Originally it always fired to a cone, it was fired to cone four. Anyway, when you get it up to pretty whitish hot, that’s about where cone four would look. That’s when you salted it or zinced it—when it’s hot. Then after you got it salted, and when you salted it, then you’d reach in from the little hole in the top of the crown and bring out a sample brick and see what it looked like. When the sample brick was coming out it was real hot. You’d have to light a little match or something on it to see the color, see what it looked like. And then whether or not you needed more salt, and whether the zinc was taking [hold]. Once the sample brick, two or three maybe, looked alright, then you just plain shut the fires off and of course closed the firebox doors—you didn’t leave cold air in—and let it sit until it cooled down. Oh, four or five hours or six hours. Then you’d open up the firebox doors and let a little more cold air in. Then after about a day, or close to a day, we’d break open a little bit of the… Meanwhile the main door to the kiln (I forgot to tell you), once the kiln was loaded that main door was all closed up, bricked up solid and plastered over, so that it didn’t leak air. Then when the kiln cooled, you’d open the top of the door and pull out the brick, gradually pull more and more until finally you opened the door entirely and pulled all the brick out of it. The same thing in the back, on the door in the front and the door in the back of the kiln. Oh then it took a few days…

Now the kiln firing—if you started… It would take over a week to bring it up, check it, and cool it. So you didn’t just schedule them and do them every few days. A kiln firing…I think it would take about four or five, six days, to set it with the dry brick. Then about four or five, six days at least to heat it, fire it, then four or five days to cool it down enough and take the doors down, and then, we had a big fan, behind you an air blowing fan so that you could reach in and start bringing some brick out. But then to empty the kiln would take another, oh, week. Because it was so hot in there—it gradually cooled down. So the whole operation took a month.

ACL: Wow. Did you fire at all times of the year?

ABJ: You fired any time you wanted, it was at all times of the year. It didn’t make any difference whether it was hot or cold.

ACL: Was there a cycle in place—for example, when one kiln was being loaded another was being fired?

ABJ: No, there wasn’t any cycle. …No. 6 was just always plain red stuff—drain tile or brick or something. 4 and 5 were fired with just building tile, sometimes with a few common brick but that’s all. 7 and 8 were the only face brick kilns and there wasn’t a schedule. You did it by, the schedule was what you wanted for the end product. And if you knew you were gonna want face
brick in a month, then you started loading the kiln today. You’d start loading and firing the kiln and so forth and you’d start, about a month from then, getting face brick. But there wasn’t a schedule to do it. It was more of a schedule when you wanted the end product.

ACL: From where, again, were the sample bricks taken?

ABJ: At the top of the crown there is a hole… It must be fourteen, fifteen inches in diameter, right in the center of the top of the crown. If you look up there you’ll see it. We had kind of a big clay cover that we’d pull over that hole, and that had a hole in it. Anyway, it was down through that center cover at the top of the crown, you had a hook. You could reach in with a hook and put it in the hole in the brick and pull out a sample brick.

ACL: Wouldn’t the crown have been incredibly hot?

ABJ: Well, if you stood around a long time, your feet would get kind of hot. But we put an extra layer of common brick up the side of the crown, loose, and when you walked up the top of the crown when it was firing, you walked up on those common brick. You didn’t stand around you know, the thing was hot. You walked up, and did your thing, and got off.

The common brick would just lay there. It wasn’t cemented or anything, it was just laid there to walk on.

ACL: Did you have problems controlling the thermal expansion of the kilns during firing?

ABJ: If you notice the kiln, they have big steel straps around them. When the kiln was loaded and the doors were built up and plastered over, there were big screw-hook type things that fastened each of those steel straps. Oh damn, I can’t think of the name. Those hooks were tightened up very tight so that each of those big steel straps around the kiln were pulled around the kiln very tight, before you started the fire. Does it make sense to you?

ACL: Sure, definitely. Do you remember exterior salt damage during operation of the kilns?

ABJ: Well, salt damage on the inside of the kiln maybe some, but not a lot. And when we found damage we would tear out the damaged part and replace it before you reloaded the kiln. Of course, now you see, back in the old days before natural gas came in, the kilns…you had carloads of coal. The coal had to be dumped outside, picked up and wheeled inside, and put around by each firebox. Each firebox had to be hand-fired with a shovel of coal and the ashes dug out underneath and wheeled out. When the natural gas came in, Montana Fire Company, they did all that piping around the kilns, all that welding and the gas fireboxes—all that was put in with the natural gas.

ACL: Were masonry bulges a problem back then?
ABJ: Well, I don’t remember it. I’m sure that over the years since—it’s been a while since ’56 and ’57—there’s been a lot of deterioration. But any time we found a bad place in the kiln wall, we’d tear out the bad part and rebuild it before we fired it the next time. What you’re describing I’m sure is obvious now, I’m sure it wasn’t there in ’56, ’57, ’58. Of course that’s a while ago, I’m getting kind of old I guess.

ACL: (Laughter.) We all are. Do you remember Peter Voulkos and Rudy Autio firing their work in the beehive kilns during the summer of 1951?

ABJ: That’s correct. They did work…they first worked out in the old dryer, near the engine, then later in the pottery. They did all their work at the weekends or nights. And then the work was put in, they could put their work in any kiln they wanted, and they knew what was going to come, and it was fired in the kilns originally. There’s a, over at the University of Montana, it used to be in the library…there’s a big section of the wall…there’s red tile Rudy made, it was taken over there and put in that wall when it was built. It’s a sculpture of some sort. …I remember seeing Rudy make it, and I remember seeing it in the wall at the university, but I don’t remember any more.

ACL: Do you have any personal attachment to the kilns?

ABJ: Sure I do because, after all, as a little boy I grew up there. When I grew up, that was about the time that my grandfather formed what was then called the Western Clay Manufacturing Company and took over from Kessler. There used to be a little road from the brickyard up across Ten Mile Creek to the bridge and up to Kessler Brewery. …I grew up and played in all that area, so to me it was kind of home. Yes, it’s like any part where you grew up, it becomes somewhat sentimental. I spent four years as a pilot in WWII and even certain occasions there still stick in my mind a little sentimentally, some of the places where I knew the guys. That, I think, happens to everyone as they grow up. Certain points… Probably that’s good. I think one needs a place for the memory to locate. In my case, the old brickyard would be a good piece of it of course. I remember seeing the last of the big scove kilns fired, I don’t remember much about it, I remember seeing it fired and cooled down. It’s all gone, torn down now. Well, everything is gone now.

ACL: Well, we’re trying to make sure the beehive kilns will stand for at least a couple more years, so that people can see and understand what they were used for.

ABJ: Well don’t forget that intricate part of fluework underneath the kiln. That’s the key to a downdraft kiln really working.

Anytime you want information go ahead and email me, and I’ll try to call you or you can call me. At my age now I’m not real mobile, I don’t run around a lot, so you’ll get me on the phone pretty regularly.
# Brick Typology for Kiln No. 7 and Environ

The following typology was assembled in the field at the former WCMC in July 2012. It encompasses brick types built into Kiln No. 7 (indicated here by yellow background), as well as types retrieved from the kiln's immediate vicinity.

<table>
<thead>
<tr>
<th>Type</th>
<th>Short Name</th>
<th>Mode of Manufacture</th>
<th>Width</th>
<th>Length</th>
<th>Height</th>
<th>Notable Traits or Markings</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Fire Straight</td>
<td>Machine-pressed; repressed</td>
<td>4.50</td>
<td>9.00</td>
<td>2.50</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>Fire Split</td>
<td>Machine-pressed; repressed</td>
<td>4.50</td>
<td>9.00</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>Fire Soap</td>
<td>Machine-pressed; repressed</td>
<td>2.25</td>
<td>9.00</td>
<td>2.50</td>
<td></td>
</tr>
<tr>
<td>A4</td>
<td>Fire Arch 1</td>
<td>Machine-pressed; repressed</td>
<td>2.25 - 2.5</td>
<td>9.00</td>
<td>4.50</td>
<td></td>
</tr>
<tr>
<td>A5</td>
<td>Fire Arch 8</td>
<td>Machine-pressed; repressed</td>
<td>1.5 - 2.5</td>
<td>9.00</td>
<td>4.50</td>
<td></td>
</tr>
<tr>
<td>A6</td>
<td>Fire Wedge</td>
<td>Machine-pressed; repressed</td>
<td>0.25 - 2.5</td>
<td>9.00</td>
<td>4.50</td>
<td>Right triangle; fired clay surry evident</td>
</tr>
<tr>
<td>B1</td>
<td>Old Brick</td>
<td>Hand-molded; sand struck</td>
<td>3.75</td>
<td>7.75</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>Kessler Brick</td>
<td>Machine-pressed; repressed</td>
<td>4.00</td>
<td>8.00</td>
<td>2.50</td>
<td>&quot;KESLER HELENA.MONT.&quot;</td>
</tr>
<tr>
<td>B3</td>
<td>Switzer Brick</td>
<td>Machine-pressed; repressed</td>
<td>4.00</td>
<td>8.00</td>
<td>2.25</td>
<td>&quot;SWITZER&quot; stamped into frog</td>
</tr>
<tr>
<td>B4</td>
<td>WCMC Brick</td>
<td>Machine-pressed; repressed</td>
<td>4.00</td>
<td>8.50</td>
<td>2.50</td>
<td>&quot;WCMC HELENA MONT.&quot;</td>
</tr>
<tr>
<td>B5</td>
<td>WC Mfg Brick</td>
<td>Machine-pressed; repressed</td>
<td>4.00</td>
<td>8.00</td>
<td>2.50</td>
<td>&quot;WC MFG CO HELENA MONT.&quot;</td>
</tr>
<tr>
<td>B6</td>
<td>Groved Face</td>
<td>Machine-pressed</td>
<td>3.75</td>
<td>8.50</td>
<td>2.50</td>
<td></td>
</tr>
<tr>
<td>B7</td>
<td>Non Grooved Face</td>
<td>Machine-pressed</td>
<td>3.50</td>
<td>8.25</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>B8</td>
<td>Bolted Brick</td>
<td>Machine-pressed; repressed</td>
<td>4.00</td>
<td>8.00</td>
<td>2.25</td>
<td>Bolt-shaped indentations on bedding face</td>
</tr>
<tr>
<td>B9</td>
<td>Big Brick</td>
<td>Machine-pressed; repressed</td>
<td>4.00</td>
<td>8.00</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Short Name</td>
<td>Mode of Manufacture</td>
<td>Width</td>
<td>Length</td>
<td>Height</td>
<td>Notable Traits or Markings</td>
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<td>--------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>C1</td>
<td>Early Extruded</td>
<td>Extruded</td>
<td>3.50</td>
<td>8.00</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>Textured Face</td>
<td>Extruded</td>
<td>3.50</td>
<td>7.75</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>Dense Extruded</td>
<td>Extruded</td>
<td>3.75</td>
<td>7.75</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>Nail Combed</td>
<td>Extruded</td>
<td>3.75</td>
<td>8.00</td>
<td>2.25</td>
<td></td>
</tr>
<tr>
<td>C5</td>
<td>Chimney Brick</td>
<td>Extruded</td>
<td>3.50</td>
<td>8.00</td>
<td>4.50</td>
<td>A &quot;double&quot; brick</td>
</tr>
<tr>
<td>D1</td>
<td>Nail Combed w/ Three</td>
<td>Extruded</td>
<td>3.75</td>
<td>8.00</td>
<td>2.25</td>
<td>Three lightening holes</td>
</tr>
<tr>
<td>D2</td>
<td>Plain Three</td>
<td>Extruded</td>
<td>3.75</td>
<td>8.00</td>
<td>2.25</td>
<td>Three lightening holes</td>
</tr>
<tr>
<td>D3</td>
<td>Plain Ten</td>
<td>Extruded</td>
<td>3.75</td>
<td>8.00</td>
<td>2.25</td>
<td>Ten lightening holes</td>
</tr>
<tr>
<td>D4</td>
<td>Neat Combed w/ Ten</td>
<td>Extruded</td>
<td>3.50</td>
<td>8.00</td>
<td>2.25</td>
<td>Ten lightening holes</td>
</tr>
<tr>
<td>D5</td>
<td>Nail Combed w/ Ten</td>
<td>Extruded</td>
<td>3.75</td>
<td>8.00</td>
<td>2.25</td>
<td>Ten lightening holes</td>
</tr>
<tr>
<td>D6</td>
<td>Small Ten</td>
<td>Extruded</td>
<td>3.50</td>
<td>7.50</td>
<td>2.25</td>
<td>Ten lightening holes</td>
</tr>
<tr>
<td>E1</td>
<td>Sidewalk Paver</td>
<td>Molded; repressed</td>
<td>5.50</td>
<td>10.75</td>
<td>2.25</td>
<td>Most examples exhibit hatch on one bedding face</td>
</tr>
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</table>
# Testing Matrix for the Diagnostic Analysis of the WCMC Kiln Complex

**Western Clay Manufacturing Co. / Helena, MT**

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Sample Size</th>
<th>Preparation / Equipment</th>
<th>Test Location</th>
<th>Testing Period</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content of Clay Binder Samples</td>
<td>Oven Drying</td>
<td>12 samples; 3-18 g each</td>
<td>Scale, oven, metal soil containers, plastic holding trays</td>
<td>ACL</td>
<td>24 hrs.</td>
<td>ASTM D2216-10</td>
</tr>
<tr>
<td>Reactivity of Fireclay Extracted from Masonry Walls</td>
<td>Atterberg Limits</td>
<td>5 samples; ≤ 200 g each</td>
<td>Scale, oven, 425-µm (No. 40) sieve, 2-µm sieve, spatula, mixing bowl, deionized water, Casagrande device, glass plate, metal soil containers, paper towels, stopwatch</td>
<td>ACL</td>
<td>2 hrs. testing; 24 hrs. drying</td>
<td>ASTM D4318-00</td>
</tr>
<tr>
<td>Brick Porosity</td>
<td>Water Absorption by Weight (cold)</td>
<td>≤ 7 brick (Types A1, B4, B6, B7, C4, D2, and D5)</td>
<td>Scale, oven, water-tight vessel for brick submersion, deionized water, cloth, thermometer</td>
<td>ACL</td>
<td>28 hrs. prep.; 24 hrs. submersion</td>
<td>ASTM C67-12</td>
</tr>
<tr>
<td>Brick Porosity</td>
<td>Water Absorption by Weight (boiling)</td>
<td>≤ 7 brick (Types A1, B4, B6, B7, C4, D2, and D5)</td>
<td>Scale, oven, water-tight vessel for brick submersion, deionized water, cloth, thermometer, hot plate</td>
<td>ACL</td>
<td>6 hrs. submersion; 2 hrs. cooling</td>
<td>ASTM C67-12</td>
</tr>
<tr>
<td>Brick Pore Size</td>
<td>Initial Rate of Water Absorption (suction)</td>
<td>≤ 7 brick (Types A1, B4, B6, B7, C4, D2, and D5)</td>
<td>Scale, oven, water-tight vessel for brick submersion, deionized water, cloth, thermometer, spirit scale, brick supports (metal or otherwise), measuring tape, marking pen</td>
<td>ACL</td>
<td>28 hrs. prep.; 1 min. submersion</td>
<td>ASTM C67-12</td>
</tr>
<tr>
<td>Characterization of Salt Deposition</td>
<td>Chemical Spot Testing</td>
<td>2 brick exhibiting efflorescence and encrustation</td>
<td>Mortar and pestle, glass petry dish, deionized water, 250-ml glass beaker, glass stir rod, fine filter paper, funnel, pipette, EM Quant salt identification strips, test tubes and rack, stereo microscope, dilute hydrochloric acid</td>
<td>ACL</td>
<td>2 hrs. prep. and testing</td>
<td>n/a</td>
</tr>
</tbody>
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## Sample Information - Clay Bedding Material
**Kiln No. 7 / Western Clay Manufacturing Co. / Helena, MT**

<table>
<thead>
<tr>
<th>Type</th>
<th>Color Group</th>
<th>Sample No.</th>
<th>Munsell Value</th>
<th>Section</th>
<th>Tier</th>
<th>Course</th>
<th>Height (in. from grade)</th>
<th>Depth (in.)</th>
<th>Dry Mass (g.)*</th>
<th>Moisture Content*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Individual</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>1</td>
<td>1</td>
<td>5YR 4/6</td>
<td>1.2</td>
<td>1</td>
<td>9</td>
<td></td>
<td>24.00</td>
<td>12.25</td>
<td>5.95</td>
<td>7.39</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>5YR 5/6</td>
<td>3.4</td>
<td>1</td>
<td>7</td>
<td></td>
<td>16.00</td>
<td>23.50</td>
<td>10.58</td>
<td>12.29</td>
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<tr>
<td>1</td>
<td>5</td>
<td>5YR 5/6</td>
<td>3.4</td>
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<td>9.10</td>
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<td>126.00</td>
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<td>4.85</td>
</tr>
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<td><strong>Bulk</strong></td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
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<td>232.43</td>
<td>unknown</td>
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<td>n/a</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
<td>56.95</td>
<td>unknown</td>
</tr>
</tbody>
</table>

*Values were obtained using ASTM D2216-10 Test Method B, conducted on 7/21/2012*
### Sample Information - Clay Bedding Material (con't.)
**Kiln No. 7 / Western Clay Manufacturing Co. / Helena, MT**

<table>
<thead>
<tr>
<th>Type</th>
<th>Color Group</th>
<th>Sample No.</th>
<th>Field Notes</th>
<th>Date Taken</th>
</tr>
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<tr>
<td><strong>Individual</strong></td>
<td>1</td>
<td>1</td>
<td>20&quot; right of Firebox 2; 24&quot; from grade; 12.25&quot; deep</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>4</td>
<td>Void sketched at mid-span; 16&quot; from grade; 23.5&quot; deep</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>5</td>
<td>8&quot; left of Firebox 3; 50.5&quot; from grade; 15.75&quot; deep</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>7</td>
<td>Between bag walls of Fireboxes 2 and 3; 54&quot; from grade; 18&quot; deep (from interior)</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>9</td>
<td>Over southern door's 3rd archivolt; 92&quot; from grade; 12.5&quot; deep</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>6.5&quot; left of Firebox 9; 15&quot; from grade; 16&quot; deep</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>8</td>
<td>Mid-span, adjacent to major repair; 48&quot; from grade; 14.75&quot; deep</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10</td>
<td>Over Firebox 6; 128.5&quot; from grade; 8.75&quot; deep</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>12</td>
<td>Over Firebox 3; approx. 121&quot; from grade; 10.75&quot; deep; registered 2.2% MC in field</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3</td>
<td>Firebox 6, 32&quot; left of northern door; 9.5&quot; from grade; 13&quot; deep</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>6</td>
<td>28&quot; left of Firebox 4; 65.5&quot; from grade; 9&quot; deep</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>11</td>
<td>20&quot; right of Firebox 5; approx. 126&quot; from grade; 8&quot; deep</td>
<td>7/6/2012</td>
</tr>
<tr>
<td><strong>Bulk</strong></td>
<td>1</td>
<td></td>
<td>Firebox 2; 2nd archivolt</td>
<td>7/6/2012</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td>Interior collapse; taken from same vicinity as Sample No. 7 above</td>
<td>7/8/2012</td>
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<td></td>
<td>3</td>
<td></td>
<td>Firebox 4; 2nd archivolt</td>
<td>7/6/2012</td>
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</table>
Clay Test - Moisture Content of Clay Bedding Material
ASTM D2216-10, Test Method B, conducted July 21-2, 2012
Kiln No. 7 / Western Clay Manufacturing Co. / Helena, MT

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Kiln Section</th>
<th>Tier</th>
<th>Course</th>
<th>Container Mass (M_c)</th>
<th>Container + Moist Specimen Mass (M¹)</th>
<th>Container + Dry Specimen Mass (M²)</th>
<th>Mass of Water (M¹-M²)</th>
<th>Mass of Solids (M²-M_c)</th>
<th>% Water Content</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1.2</td>
<td>1</td>
<td>9</td>
<td>21.89</td>
<td>28.28</td>
<td>27.84</td>
<td>0.44</td>
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<tr>
<td>2</td>
<td>9.10</td>
<td>1</td>
<td>6</td>
<td>21.67</td>
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<td>31.05</td>
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<td>4.69</td>
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<td>3</td>
<td>5.6</td>
<td>1</td>
<td>3</td>
<td>21.94</td>
<td>44.28</td>
<td>40.53</td>
<td>3.75</td>
<td>18.59</td>
<td>20.17</td>
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<td>4</td>
<td>3.4</td>
<td>1</td>
<td>7</td>
<td>21.64</td>
<td>33.52</td>
<td>32.22</td>
<td>1.3</td>
<td>10.58</td>
<td>12.29</td>
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<td>8.77</td>
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<td>24.75</td>
<td>0.36</td>
<td>3.15</td>
<td>11.43</td>
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<tr>
<td>7</td>
<td>interior</td>
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<td>29.62</td>
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<td>8</td>
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<td>27.81</td>
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<td>21.7</td>
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<td>0.12</td>
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</table>

* Oven temperature remained a consistent 110 degrees Celsius throughout.
* All figures for specimen and container mass recorded in grams.
* Balance readability at 0.01 g.
* Mass of samples fail to meet minimum requirement of 20 g, as specified in ASTM Standard D2216-10.
* Samples taken on 7/6/2012; last rain event prior to sampling 7/2/2012.
Brick Test - Initial Rate of Absorption (Suction)  
Kiln No. 7 / Western Clay Manufacturing Co. / Helena, MT

<table>
<thead>
<tr>
<th>Brick Type</th>
<th>Length (L)</th>
<th>Width (W)</th>
<th>Mass Dry (M¹)</th>
<th>Mass Wet (M²)</th>
<th>Weight Gain (ΔM)</th>
<th>Corrected Initial Rate of Absorption (g/min./30 in.²)</th>
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<tr>
<td>B4</td>
<td>8.250</td>
<td>3.750</td>
<td>2527.59</td>
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<tr>
<td>B6</td>
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<td>1982.42</td>
<td>2038.97</td>
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<td>53.22</td>
</tr>
<tr>
<td>B7</td>
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<td>3.750</td>
<td>1936.87</td>
<td>1942.13</td>
<td>5.26</td>
<td>5.10</td>
</tr>
<tr>
<td>C4</td>
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<td>3.750</td>
<td>2378.19</td>
<td>2384.76</td>
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<td>6.57</td>
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<tr>
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<td>2000.58</td>
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<tr>
<td>D5</td>
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<td>1932.11</td>
<td>1936.98</td>
<td>4.87</td>
<td>5.71</td>
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</table>

* Oven temperature remained a consistent 110 degrees Celsius throughout.  
* All figures for specimen mass recorded in grams; all dimensions recorded in inches.  
* Balance readability at 0.01 g.
Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile

This standard is issued under the fixed designation C67; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 These test methods cover procedures for the sampling and testing of brick and structural clay tile. Although not necessarily applicable to all types of units, tests include modulus of rupture, compressive strength, absorption, saturation coefficient, effect of freezing and thawing, efflorescence, initial rate of absorption and determination of weight, size, warpage, length change, and void area. (Additional methods of test pertinent to ceramic glazed facing tile are included in Specification C126.)

1.2 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

Note 1—The testing laboratory performing this test method should be evaluated in accordance with Practice C1093.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:
   C126 Specification for Ceramic Glazed Structural Clay Facing Tile, Facing Brick, and Solid Masonry Units
   C150 Specification for Portland Cement

2.2 AASHTO Standards:
   T 32-70 Specifications for Masonry Units

2.3 Other Standards:
   AASHTO No.: T 32-70

3. Terminology

3.1 Definitions—Terminology E6 and Terminology C1232 shall be considered as applying to the terms used in these test methods.

4. Sampling

4.1 Selection and Preparation of Test Specimens—For the purpose of these tests, full-size brick, tile, or solid masonry units shall be selected by the purchaser or by the purchaser's authorized representative. Specimens shall be representative of the lot of units from which they are selected and shall include specimens representative of the complete range of colors, textures, and sizes. Specimens shall be free of or brushed to remove dirt, mud, mortar, or other foreign materials unassociated with the manufacturing process. Brushes used to remove foreign material shall have bristles of plastic (polymer) or horsehair. Wire brushes shall not be used for preparing specimens for testing. Specimens exhibiting foreign material that is not removed by brushing shall be discarded to ensure that damaged or contaminated specimens are not tested.

4.2 Number of Specimens:
   4.2.1 Brick—For the modulus of rupture, compressive strength, abrasion resistance, and absorption determinations, at least ten individual brick shall be selected for lots of 1 000 000 brick or fraction thereof. For larger lots, five additional specimens shall be selected from each additional 500 000 brick or fraction thereof. Additional specimens are taken at the discretion of the purchaser.
   4.2.2 Structural Clay Tile—For the weight determination and for compressive strength and absorption tests, at least five tile shall be selected from each lot of 250 tons (226.8 Mg) or fraction thereof. For larger lots, five additional specimens shall be tested for each 500 tons (453.6 Mg) or fraction thereof. In no case shall less than five tile be taken. Additional specimens are taken at the discretion of the purchaser.

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* A Summary of Changes section appears at the end of this standard
4.3 Identification—Each specimen shall be marked so that it may be identified at any time. Markings shall cover not more than 5 % of the superficial area of the specimen.

5. Specimen Preparation

5.1 Weight Determination:

5.1.1 Dry—Dry the test specimens in a ventilated oven at 230 to 239°F (110 to 115°C) for not less than 24 h and until two successive weighings at intervals of 2 h show an increment of loss not greater than 0.2 % of the last previously determined weight of the specimen.

5.1.2 Cool—After drying, cool the specimens in a drying room maintained at a temperature of 75 ± 15°F (24 ± 8°C), with a relative humidity between 30 and 70 %. Store the units free from drafts, unstacked, with separate placement, for a period of at least 4 h and until the surface temperature is within 5°F (2.8°C) of the drying room temperature. Do not use specimens noticeably warm to the touch for any test requiring dry units. The specimens shall be stored in the drying room with the required temperature and humidity maintained until tested.

5.1.2.1 An alternative method of cooling the specimens to approximate room temperature shall be permitted as follows: Store units, unstacked, with separate placement, in a ventilated room maintained at a temperature of 75 ± 15°F (24 ± 8°C), with a relative humidity between 30 and 70 % for a period of 4 h and until the surface temperature is within 5°F (2.8°C) of the ventilated room temperature, with a current of air from an electric fan passing over them for a period of at least 2 h. The specimens shall be stored in the ventilated room with the required temperature and humidity maintained until tested.

5.1.3 Weighing and Report:

5.1.3.1 Weigh five dry full size specimens. The scale or balance used shall have a capacity of not less than 5000 g and shall be sensitive to 0.5 g.

5.1.3.2 Report results separately for each specimen to the nearest 0.1 g, with the average of all specimens tested to the nearest 0.1 g.

5.2 Removal of Silicone Coatings from Brick Units—The silicone coatings intended to be removed by this process are any of the various polymeric organic silicone compounds used for water-resistant coatings of brick units. Heat the brick at 950 ± 50°F (510 ± 28°C) in an oxidizing atmosphere for a period of at least 3 h. The rate of heating and cooling shall not exceed 300°F (166°C) per h.

Note 2—Where indicated for specific individual tests, additional specimen preparation may be required.

6. Modulus of Rupture (Flexure Test)

6.1 Test Specimens—The test specimens shall consist of whole dry full-size units (see 5.1.1). Five such specimens shall be tested.

6.2 Procedure:

6.2.1 Support the test specimen flatwise unless specified and reported otherwise (that is, apply the load in the direction of the depth of the unit) on a span approximately 1 in. (25.4 mm) less than the basic unit length and loaded at midspan. If the specimens have recesses (panels or depressions) plant them so that such recesses are on the compression side. Apply the load to the upper surface of the specimen through a steel bearing plate ½ in. (6.35 mm) in thickness and 1 ½ in. (38.10 mm) in width and of a length at least equal to the width of the specimen.

6.2.2 Make sure the supports for the test specimen are free to rotate in the longitudinal and transverse directions of the test specimen and adjust them so that they will exert no force in these directions.

6.2.3 Speed of Testing—The rate of loading shall not exceed 2000 lbf (8896 N)/min. but this requirement is considered as being met if the speed of the moving head of the testing machine immediately prior to application of the load is not more than 0.05 in. (1.27 mm)/min.

6.3 Calculation and Report:

6.3.1 Calculate and report the modulus of rupture of each specimen to the nearest 1 psi (0.01 MPa) as follows:

\[ S = \frac{3W(l/2 - x)}{bd^3} \]  

where:

- \( S \) = modulus of rupture of the specimen at the plane of failure, lbf/in.\(^2\) (Pa),
- \( W \) = maximum load indicated by the testing machine, lbf (N),
- \( l \) = distance between the supports, in. (mm),
- \( b \) = net width, (face to face minus voids), of the specimen at the plane of failure, in. (mm),
- \( d \) = depth, (bed surface to bed surface), of the specimen at the plane of failure, in. (mm), and
- \( x \) = average distance from the midspan of the specimen to the plane of failure measured in the direction of the span along the centerline of the bed surface subjected to tension, in. (mm).

6.3.2 Calculate and report the average of the modulus of rupture determinations to the nearest 1 psi (0.01 MPa).

7. Compressive Strength

7.1 Test Specimens:

7.1.1 Brick—The test specimens shall consist of dry half brick (see 5.1.1), the full height and width of the unit, with a length equal to one half the full length of the unit ± 1 in. (25.4 mm), except as described below. If the test specimen, described above, exceeds the testing machine capacity, the test specimens shall consist of dry pieces of brick, the full height and width of the unit, with a length not less than one quarter of the full length of the unit, and with a gross cross-sectional area perpendicular to bearing not less than 14 in.\(^2\) (90.3 cm\(^2\)). Test specimens shall be obtained by any method that will produce, without shattering or cracking, a specimen with approximately plane and parallel ends. Five specimens shall be tested.

7.1.2 Structural Clay Tile—Test five dry tile specimens in a bearing bed length equal to the width ± 1 in. (25.4 mm); or test full-size units.

7.2 Capping Test Specimens:

7.2.1 All specimens shall be dry and cool within the meaning of 5.1.1 and 5.1.2 before any portion of the capping procedure is carried out.
7.2.2 If the surface which will become bearing surfaces during the compression test are recessed or paneled, fill the depressions with a mortar composed of 1 part by weight of quick-hardening cement conforming to the requirements for Type III cement of Specification C150, and 2 parts by weight of sand. Age the specimens at least 48 h before capping them. Where the recess exceeds 1/8 in. (12.7 mm), use a brick or tile slab section or metal plate as a core fill. Cap the test specimens using one of the two procedures described in 7.2.3 and 7.2.4.

7.2.3 Gypsum Capping—Coat the two opposite bearing surfaces of each specimen with shellac and allow to dry thoroughly. Coat one of the dry shellacked surfaces of the specimen in a thin coat of neat paste of calcined gypsum (plaster of paris) that has been spread on an oiled nonabsorbent plate, such as glass or machined metal. The casting surface plate shall be plane within 0.003 in. (0.076 mm) in 16 in. (406.4 mm) and sufficiently rigid; and so supported that it will not be measurably deflected during the capping operation. Lightly coat it with oil or other suitable material. Repeat this procedure with the other shellacked surface. Take care that the opposite bearing surfaces so formed will be approximately parallel and perpendicular to the vertical axis of the specimen and the thickness of the caps will be approximately the same and not exceeding 1/16 in. (3.18 mm). Age the caps at least 24 h before testing the specimens.

Note 3—A rapid-setting industrial type gypsum is frequently used for capping.

7.2.4 Sulfur-Filler Capping—Use a mixture containing 40 to 60 weight % sulfur, the remainder being ground fire clay or other suitable inert material passing a No. 100 (150-μm) sieve with or without plasticizer. The casting surface plate requirements shall be as described in 7.2.3. Place four 1-in. (25.4-mm) square steel bars on each surface of the free portion of the specimen to form a rectangular mold approximately 1/2 in. (12.7 mm) greater in either inside dimension than the specimen. Heat the sulfur mixture in a thermostatically controlled heating pot to a temperature sufficient to maintain fluidity for a reasonable period of time after contact with the surface being capped. Take care to prevent overheating, and stir the liquid in the pot just before use. Fill the mold to a depth of 1/8 in. (6.35 mm) with molten sulfur material. Place the surface of the unit to be capped quickly in contact with the liquid, and hold the specimen so that its vertical axis is at right angles to the capping surface. The thickness of the caps shall be approximately the same. Allow the unit to remain undisturbed until solidification is complete. Allow the caps to cool for a minimum of 2 h before testing the specimens.

7.3 Procedure:

7.3.1 Test brick specimens flatwise (that is, the load shall be applied perpendicular to the bed of the brick with the brick in the stretcher position). Test structural clay tile specimens in a position such that the load is applied in the same direction as in service. Center the specimens under the spherical upper bearing within 1/16 in. (1.59 mm).

7.3.2 The testing machine shall conform to the requirements of Practices E4.

7.3.3 The upper bearing shall be a spherically seated, hardened metal block firmly attached at the center of the upper head of the machine. The center of the sphere shall lie at the center of the surface of the block in contact with the specimen. The block shall be closely held in its spherical seat, but shall be free to turn in any direction, and its perimeter shall have at least 1/4 in. (6.35 mm) clearance from the head to allow for specimens whose bearing surfaces are not exactly parallel. The diameter of the bearing surface shall be at least 5 in. (127.00 mm). Use a hardened metal bearing block beneath the specimen to minimize wear of the lower platen of the machine. The bearing block surfaces intended for contact with the specimen shall have a hardness not less than HRC60 (HB 620). These surfaces shall not depart from plane surfaces by more than 0.001 in. (0.03 mm). When the bearing area of the spherical bearing block is not sufficient to cover the area of the specimen, place a steel plate with surfaces machined to true planes within ± 0.001 in. (0.03 mm), and with a thickness equal to at least one third of the distance from the edge of the spherical bearing to the most distant corner between the spherical bearing block and the capped specimen.

7.3.4 Speed of Testing—Apply the load, up to one half of the expected maximum load, at any convenient rate, after which, adjust the controls of the machine so that the remaining load is applied at a uniform rate in not less than 1 nor more than 2 min.

7.4 Calculation and Report:

7.4.1 Calculate and report the compressive strength of each specimen to the nearest 10 psi (0.01 MPa) as follows:

\[
C = \frac{W}{A}
\]

where:

\[
C = \text{compressive strength of the specimen, lb/ft}^2 \quad \text{or} \quad \text{kg/cm}^2
\]

\[
W = \text{maximum load, lbf} \quad \text{or} \quad \text{kgf} \quad \text{(or N), indicated by the testing machine, and}
\]

\[
A = \text{average of the gross areas of the upper and lower bearing surfaces of the specimen, in.}^2 \quad \text{or} \quad \text{cm}^2
\]

Note 4—When compressive strength is to be based on net area (example: clay floor tile), substitute for A in the above formula the net area, in in.\(^2\) (or cm\(^2\)), of the fired clay in the section of minimum area perpendicular to the direction of the load.

7.4.2 Calculate and report the average of the compressive strength determinations to the nearest 10 psi (0.1 MPa).

8. Absorption

8.1 Accuracy of Weighings:

8.1.1 Brick—The scale or balance used shall have a capacity of not less than 2000 g, and shall be sensitive to 0.5 g.

8.1.2 Tile—The balance used shall be sensitive to within 0.2 % of the weight of the smallest specimen tested.

8.2 Test Specimens:

8.2.1 Brick—The test specimens shall consist of half brick conforming to the requirements of 7.1.1. Five specimens shall be tested.

8.2.2 Tile—The specimens for the absorption test shall consist of five tile or three representative pieces from each of these five tile. If small pieces are used, take two from the shell and one from an interior web, the weight of each piece being not less than 227 g. The specimens shall have had their rough edges or loose particles ground off and, if taken from tile that
have been subjected to compressive strength tests, specimens shall be free of cracks due to failure in compression.

8.3 5-h and 24-h Submersion Tests:

8.3.1 Procedure:

8.3.1.1 Dry and cool the test specimens in accordance with 5.1.1 and 5.1.2 and weigh each one.

8.3.1.2 Submerge the dry, cooled specimen, without preliminary partial immersion, in clean water (soft, distilled or rain water) at 60 to 86°F (15.5 to 30°C) for the specified time. Remove the specimen, wipe off the surface water with a damp cloth and weigh the specimen. Complete weighing of each specimen within 5 min after removing the specimen from the bath.

8.3.2 Calculation and Report:

8.3.2.1 Calculate and report the cold water absorption of each specimen to the nearest 0.1 % as follows:

\[
\text{Absorption, } \% = 100 \left( \frac{W_s - W_d}{W_d} \right) \quad (3)
\]

where:
- \( W_d \) = dry weight of the specimen, and
- \( W_s \) = saturated weight of the specimen after submersion in cold water.

8.3.2.2 Calculate and report the average cold water absorption of all specimens to the nearest 0.1 %.

8.4 1-h, 2-h, and 5-h Boiling Tests:

8.4.1 Test Specimens—The test specimens shall be the same five specimens used in the 5-h or 24-h cold-water submersion test where required and shall be used in the state of saturation existing at the completion of that test.

8.4.2 Procedure:

8.4.2.1 Return the specimen that has been subjected to the cold-water submersion to the bath, and subject it to the boiling test as described in 8.4.2.2.

8.4.2.2 Submerge the specimen in clean water (soft, distilled or rain water) at 60 to 86°F (15.5 to 30°C) in such a manner that water circulates freely on all sides of the specimen. Heat the water to boiling, within 1 h, boil continuously for specified time, and then allow to cool to 60 to 86°F (15.5 to 30°C) by natural loss of heat. Remove the specimen, wipe off the surface water with a damp cloth, and weigh the specimen. Complete weighing of each specimen within 5 min after removing the specimen from the bath.

8.4.2.3 If the tank is equipped with a drain so that water at 60 to 86°F (15.5 to 30°C) passes through the tank continuously and at such a rate that a complete change of water takes place in not more than 2 min, make weighings at the end of 1 h.

8.4.3 Calculation and Report:

8.4.3.1 Calculate and report the boiling water absorption of each specimen to the nearest 0.1 % as follows:

\[
\text{Absorption, } \% = 100 \left( \frac{W_s - W_d}{W_d} \right) \quad (4)
\]

where:
- \( W_d \) = dry weight of the specimen, and
- \( W_s \) = saturated weight of the specimen after submersion in boiling water.

8.4.3.2 Calculate and report the average boiling water absorption of all specimens to the nearest 0.1 %.

8.5 Saturation Coefficient:

8.5.1 Calculate and report the saturation coefficient of each specimen to the nearest 0.01 as follows:

\[
\text{Saturation coefficient} = \frac{(W_s^2 - W_d^2)(W_s^5 - W_d^5)}{W_d} \quad (5)
\]

where:
- \( W_d \) = dry weight of the specimen,
- \( W_s^2 \) = saturated weight of the specimen after 24-h submersion in cold water, and
- \( W_s^5 \) = saturated weight of the specimen after 5-h submersion in boiling water.

8.5.2 Calculate and report the average saturation coefficient of all specimens to the nearest 0.01.

9. Freezing and Thawing

9.1 Apparatus:

9.1.1 Compressor, Freezing Chamber, and Circulator of such design and capacity that the temperature of the air in the freezing chamber will not exceed 16°F (−9°C) 1 h after introducing the maximum charge of units, initially at a temperature not exceeding 90°F (30°C).

9.1.2 Trays and Containers, shallow, metal, having an inside depth of 1½ ± ⅛ in. (38.1 ± 12.7 mm), and of suitable strength and size so that the tray with a charge of frozen units can be removed from the freezing chamber by one man.

9.1.3 Balance, having a capacity of not less than 2000 g and sensitive to 0.5 g.

9.1.4 Drying Oven that provides a free circulation of air through the oven and is capable of maintaining a temperature between 230 and 239°F (110 and 115°C).

9.1.5 Thawing Tank of such dimensions as to permit complete submersion of the specimens in their trays. Adequate means shall be provided so that the water in the tank may be kept at a temperature of 75 ± 10°F (24 ± 5.5°C).

9.1.6 Drying Room, maintained at a temperature of 75 ± 15°F (24 ± 8°C), with a relative humidity between 30 and 70 %, and free from drafts.

9.2 Test Specimens:

9.2.1 Brick—The test specimens shall consist of half brick with approximately plane and parallel ends. If necessary, the rough ends may be smoothed by trimming off a thin section with a masonry saw. The specimens shall be free from shattering or unsoundness, visually observed, resulting from the flexure or from the absorption tests. Additionally, prepare specimens by removing all loosely adhering particles, sand or edge shards from the surface or cores. Test five specimens.

9.2.2 Structural Clay Tile—The test specimens shall consist of five tile or of a cell not less than 4 in. (101.6 mm) in length sawed from each of the five tile.

9.3 Procedure:

9.3.1 Dry and cool the test specimens as prescribed in 5.1.1 and 5.1.2 and weigh and record the dry weight of each.

9.3.2 Carefully examine each specimen for cracks. A crack is defined as a fissure or separation visible to a person with normal vision from a distance of one foot under an illumination of not less than 50 fc. Mark each crack its full length with an indelible felt marking pen.
9.3.3 Submerge the test specimens in the water of the thawing tank for 4 ± 1/2 h.

9.3.4 Remove the specimens from the thawing tank and stand them in the freezing trays with one of their head faces down. Head face is defined as the end surfaces of a whole rectangular brick (which have the smallest area). (See Note 5.) A space of at least 1/2 in. (12.7 mm) shall separate the specimens as placed in the tray. Pour sufficient water into the trays so that each specimen stands in 1/2 in. depth of water and then place the trays and their contents in the freezing chamber for 20 ± 1 h.

Note 5—The dimensions of some brick may prevent specimens from standing without support on one of their head faces. In such a case, any suitable rack or support that will achieve the 1/2 in. (12.7 mm) separation of specimens and the specimen standing in 1/2 in. (12.7 mm) depth of water will suffice.

9.3.5 Remove the trays from the freezing chamber after 20 ± 1 h and totally immerse them and their contents in the water of the thawing tank for 4 ± 1/2 h.

9.3.6 Freeze the test specimens by the procedure in 9.3.4 one cycle each day of the normal work week. Following the 4 ± 1/2 h thawing after the last freeze-thaw cycle of the normal work week, remove the specimens from the trays and store them for 44 ± 1 h in the drying room. Do not stack or pile units. Provide a space of at least 1 in. (25.4 mm) between all specimens. Following this period of air drying, inspect the specimens, submerge them in the water of the thawing tank for 4 ± 1/2 h, and again subject them to a normal week of freezing and thawing cycles in accordance with 9.3.4 and 9.3.5. When a normal 5-day work week is interrupted, put specimens into a drying cycle which may extend past the 44 ± 1 h drying time outlined in the procedures of this section.

9.3.7 Continue the alternations of drying and submersion in water for 4 ± 1/2 h, followed by 5 cycles of freezing and thawing or the number of cycles needed to complete a normal work week, until a total of 50 cycles of freezing and thawing has been completed. Stop the test if the test specimen develops a crack as defined in 9.4.3, breaks, or appears to have lost more than 3% of its original weight by disintegration as judged by visual inspection.

9.3.8 After completion of 50 cycles, or when the test specimen has been withdrawn from test as a result of disintegration, dry and weigh the specimen as prescribed in 9.3.1.

9.4 Calculations, Examination, Rating and Report:

9.4.1 Calculation—Calculate the loss in weight as a percentage of the original weight of the dried specimen.

9.4.2 Examination—Re-examine the surface of the specimens for cracks (see 9.3.2) and record the presence of any new cracks developed during the freezing-thawing testing procedure. Measure and record the length of the new cracks. Examine the specimens for disintegration during the freeze-thaw process.

9.4.3 Rating—A specimen is considered to fail the freezing and thawing test under any of the following circumstances:

9.4.3.1 Weight Loss—A separation or disintegration resulting in a weight loss of greater than that permitted by the referenced unit specification for the appropriate classification.

9.4.3.2 Cracking—A specimen develops a crack during the freezing and thawing procedure that exceeds the length permitted by the referenced unit standard for the appropriate classification. If none of the above circumstances occur, the specimens are considered to pass the freezing and thawing test.

9.4.4 Report—The report shall state whether the sample passed or failed the test. Any failures shall include the rating and the reason for classification as a failure and the number of cycles causing failure in the event failure occurs prior to 50 cycles.

10. Initial Rate of Absorption (Suction) (Laboratory Test)

10.1 Apparatus:

10.1.1 Trays or Containers—Watertight trays or containers, having an inside depth of not less than 1/2 in. (12.7 mm), and of such length and width that an area of not less than 300 in.2 (1935.5 cm2) of water surface is provided. The bottom of the tray shall provide a plane, horizontal upper surface, when suitably supported, so that an area not less than 8 in. (203.2 mm) in length by 6 in. (152.4 mm) in width will be level when tested by a spirit level.

10.1.2 Supports for Brick—Two noncorrodible metal supports consisting of bars between 5 and 6 in. (127.00 and 152.5 mm) in length, having triangular, half-round, or rectangular cross sections such that the thickness (height) will be approximately 1/8 in. (3.55 mm). The thickness of the two bars shall agree within 0.001 in. (0.03 mm) and, if the bars are rectangular in cross section, their width shall not exceed 5/16 in. (7.9 mm).

10.1.3 Means for Maintaining Constant Water Level—Suitable means for controlling the water level above the upper surface of the supports for the brick within ±0.01 in. (0.25 mm) (see Note 6), including means for adding water to the tray at a rate corresponding to the rate of removal by the brick undergoing test (see Note 7). For use in checking the adequacy of the method of controlling the rate of flow of the added water, a reference brick or half brick shall be provided whose displacement in 1/4 in. (3.18 mm) of water corresponds to the brick or half brick to be tested within ±2.5%. Completely submerge the reference brick in water for not less than 3 h preceding its use.

Note 6—A suitable means for obtaining accuracy in control of the water level may be provided by attaching to the end of one of the bars two stiff metal wires that project upward and return, terminating in points; one of which is 1/8 − 0.01 in. (3.18 − 0.25 mm) and the other 1/8 + 0.01 in. (3.18 + 0.25 mm) above the upper surface or edge of the bar. Such precise adjustment is obtainable by the use of depth plates or a micrometer microscope. When the water level with respect to the upper surface or edge of the bar is adjusted so that the lower point dimples the water surface when viewed by reflected light and the upper point is not in contact with the water, the water level is within the limits specified. Any other suitable means for fixing an maintaining a constant depth of immersion may be used if equivalent accuracy is obtained. As an example of such other suitable means, there may be mentioned the use of rigid supports movable with respect to the water level.

Note 7—A rubber tube leading from a siphon or gravity feed and closed by a spring clip will provide a suitable manual control. The so-called “chicken-feed” devices as a rule lack sensitivity and do not operate with the very small changes in water level permissible in this test.
10.1.4 Balance, having a capacity of not less than 3000 g, and sensitive to 0.5 g.

10.1.5 Drying Oven, conforming to the requirements of 9.1.4.

10.1.6 Constant-Temperature Room, maintained at a temperature of 70 ± 2.5°F (21 ± 1.4°C).

10.1.7 Timing Device—A suitable timing device, preferably a stop watch or stop clock, which shall indicate a time of 1 min to the nearest 1 s.

10.2 Test Specimens, consisting of whole brick. Five specimens shall be tested.

10.3 Procedure:

10.3.1 The initial rate of absorption shall be determined for the test specimen as specified, either oven-dried or ambient air-dried. If not specified, the initial rate of absorption shall be determined for the test specimens oven-dried. Dry and cool the test specimens in accordance with the applicable procedures 10.3.1.1 or 10.3.1.2. Complete the test procedure in accordance with 10.3.2, 10.3.3, and 10.3.4.

Note 8—There is no correlated relationship between the value of initial rate of absorption for ambient air-dried and oven-dried units. The test methods provide different information.

10.3.1.1 Oven-dried Procedure—Dry and cool the test specimens in accordance with 5.1.1 and 5.1.2.

10.3.1.2 Ambient Air-dried Procedure—Store units unstacked, with separate placement in a ventilated room maintained at a temperature of 75 ± 15°F (24 ± 8°C) with a relative humidity between 30 % and 70 % for a period of 4 h, with a current of air from an electric fan passing over them for a period of at least 2 h. Continue until two successive weighings at intervals of 2 h show an increment of loss not greater than 0.2 % of the last previously determined weight of the specimen.

10.3.2 Measure to the nearest 0.05 in. (1.27 mm) the length and width of the flatwise surface of the test specimen of rectangular units or determine the area of other shapes to similar accuracy that will be in contact with the water. Weigh the specimen to the nearest 0.5 g.

10.3.3 Adjust the position of the tray for the absorption test so that the upper surface of its bottom will be level when tested by a spirit level, and set the saturated reference brick (10.1.3) so that the upper surface of its bottom will be level when tested the specimen to the nearest 0.5 g, as the initial rate of absorption in 1 min.

10.3.4 Determine the final weight of the specimen to the nearest 0.1 g as follows:

\[
X = 30 \frac{W}{LB} \quad \text{(metric)} \quad \text{or} \quad X = 193.55 \frac{W}{LB} \quad \text{(6)}
\]

where:

\[
X = \text{gain in weight corrected to basis of 30 in.}^2 \quad (193.55 \quad \text{cm}^2) \quad \text{flatwise area},
\]

\[
W = \text{actual gain in weight of specimen}, \quad \text{g},
\]

\[
L = \text{length of specimen, in., (cm)}, \quad \text{and}
\]

\[
B = \text{width of specimen, in., (cm)}.
\]

10.4 Calculation and Report:

10.4.1 The difference in weight in grams between the initial and final weighings is the weight in grams of water absorbed by the brick during 1-min contact with the water. If the area of its flatwise surface (length times width) does not differ more than ±0.75 in.\(^2\) (4.84 cm\(^2\)) from 30 in.\(^2\) (193.55 cm\(^2\)), report the gain in weight of each specimen to the nearest 0.1 g, as its initial rate of absorption in 1 min.

10.4.2 If the area of its flatwise surface differs more than ±0.75 in.\(^2\) (4.84 cm\(^2\)) (±2.5 %) from 30 in.\(^2\) (193.55 cm\(^2\)), calculate the equivalent gain in weight from 30 in.\(^2\) (193.55 cm\(^2\)) of each specimen to the nearest 0.1 g as follows:

\[
X = \frac{30}{LB} \quad \text{(metric)} \quad \text{or} \quad X = 193.55 \frac{W}{LB}
\]

10.5 Calculate and report the average initial rate of absorption of all specimens tested to the nearest 0.1 g/min/30 in.\(^2\) (193.55 cm\(^2\)).

10.6 Report the method of drying as oven-dried (in accordance with 10.3.1.1) or ambient air-dried (in accordance with 10.3.1.2).

11. Efflorescence

11.1 Apparatus:

11.1.1 Trays and Containers—Watertight shallow pans or trays made of corrosion-resistant metal or other material that will not provide soluble salts when in contact with distilled water containing leachings from brick. The pan shall be of such dimensions that it will provide not less than a 1-in. (25.4-mm) depth of water. Unless the pan provides an area such that the total volume of water is large in comparison with the amount evaporated each day, suitable apparatus shall be provided for keeping a constant level of water in the pan.

11.1.2 Drying Room, conforming to the requirements of 9.1.6.

11.1.3 Drying Oven, conforming to the requirements of 9.1.4.

11.1.4 Brush, a soft-bristle brush.

11.2 Test Specimens:

11.2.1 The sample shall consist of ten full-size brick.
11.2.2 The ten specimens shall be sorted into five pairs so that both specimens of each pair will have the same appearance as nearly as possible.

11.3 Preparation of Specimens—Remove by brushing any adhering dirt that might be mistaken for efflorescence. Dry the specimens and cool them as prescribed in 5.1.1 and 5.1.2.

11.4 Procedure:

11.4.1 Set one specimen from each of the five pairs, on end, partially immersed in distilled water to a depth of approximately 1 in. (25.4 mm) for 7 days in the drying room. When several specimens are tested in the same container, separate the individual specimens by a spacing of at least 2 in. (50.8 mm).

Note 10—Do not test specimens from different sources simultaneously in the same container, because specimens with a considerable content of soluble salts may contaminate salt-free specimens.

Note 11—Empty and clean the pans or trays after each test.

11.4.2 Store the second specimen from each of the five pairs in the drying room without contact with water.

11.4.3 At the end of 7 days, inspect the first set of specimens and then dry both sets in the drying oven for 24 h.

11.5 Examination and Rating—After drying, examine and compare each pair of specimens, observing the top and all four faces of each specimen from a distance of 10 ft. (3 m) under an illumination of not less than 50 footcandles (538.2 lm/m²) by faces of each specimen from a distance of 10 ft. (3 m) under an illumination of not less than 50 footcandles (538.2 lm/m²) by an observer with normal vision. If under these conditions no difference is noted, report the rating as “not effloresced.” If a perceptible difference due to efflorescence is noted under these conditions, report the rating as “effloresced.” Report the appearance and distribution of the efflorescence.

11.6 Precision and Bias—No information is presented about either the precision or bias of the test method for efflorescence because the test result is nonquantitative.

12. Weight per Unit Area

12.1 Apparatus—A scale or balance sensitive to within 0.2 % of the weight of the smallest specimen.

12.2 Test Specimens—Weigh five dry full size structural clay tile units (see 5.1.1).

12.3 Calculation and Report:

12.3.1 Calculate the weight per unit area of each specimen as follows:

\[ W_w = \frac{n W_d}{A_{f1} + A_{f2}} \]  

(7)

where:

\[ W_w = \text{weight per unit area of the specimen, lb/ft}^2 \text{ (kg/m}^2\text{)}, \]

\[ n = \text{number of faces of the specimen (1 for split tile units or 2 for all other units)}, \]

\[ W_d = \text{dry weight of the specimen, lb (kg)}, \]

\[ A_{f1} = \text{area (height × length) of finished face of specimen, ft}^2 \text{ (m}^2\text{)}, \]

and

\[ A_{f2} = \text{area (height × length) of back face of specimen, ft}^2 \text{ (m}^2\text{)}. \]

12.3.2 Report the results of Eq 7 separately for each specimen to the nearest 1 g and the average to the nearest 1 g for all specimens tested.

13. Measurement of Size

13.1 Apparatus—Either a 1-ft (or metric) steel rule, graduated in \( \frac{1}{16} \)-in. (or 1-mm) divisions, or a gage or caliper having a scale ranging from 1 to 12 in. (25 to 300 mm), and having parallel jaws, shall be used for measuring the individual units. Steel rules or calipers of corresponding accuracy and size required shall be used for measurement of larger brick, solid masonry units, and tile.

13.2 Test Specimens—Measure ten whole dry full-size units. These units shall be representative of the lot and shall include the extremes of color range and size as determined by visual inspection. (The same samples may be used for determining efflorescence and other properties.)

13.3 Individual Measurements of Width, Length, and Height—Measure the width across both ends and both beds from the midpoints of the edges bounding the faces. Record these four measurements to the nearest \( \frac{1}{32} \) in. (1 mm) and record the average to the nearest \( \frac{1}{64} \) in. (0.5 mm) as the width. Measure the length along both beds and along both faces from the midpoints of the edges bounding the ends. Record these four measurements to the nearest \( \frac{1}{32} \) in. (1 mm) and record the average to the nearest \( \frac{1}{64} \) in. (0.5 mm) as the length. Measure the height across both faces and both ends from the midpoints of the edges bounding the beds. Record these four measurements to the nearest \( \frac{1}{32} \) in. (1 mm) and record the average to the nearest \( \frac{1}{64} \) in. (0.5 mm) as the height. Use the apparatus described in 13.1. Retest by the same method when required.

13.4 Report—Report the average width, length, and height of each specimen tested to the nearest \( \frac{1}{32} \) in. (0.8 mm).

14. Measurement of Warpage

14.1 Apparatus:

14.1.1 Steel Straightedge:

14.1.2 Rule or Measuring Wedge—A steel rule graduated from one end in \( \frac{1}{32} \)-in. (or 1-mm) divisions, or alternatively, a steel measuring wedge 2.5 in. (60 mm) in length by 0.5 in. (12.5 mm) in width by 0.5 in. (12.5 mm) in thickness at one end and tapered, starting at a line 0.5 in. (12.5 mm) from one end, to zero thickness at the other end. The wedge shall be graduated in \( \frac{1}{32} \)-in. (or 1-mm) divisions and numbered to show the thickness of the wedge between the base, AB, and the slope, AC, Fig. 1.

14.1.3 Flat Surface, of steel or glass, not less than 12 by 12 in. (305 by 305 mm) and plane to within 0.001 in. (0.025 mm).

14.1.4 Brush, a soft-bristle brush.

14.2 Sampling—Use the sample of ten units selected for determination of size.

14.3 Preparation of Samples—Test the specimens as received, except remove any adhering dirt by brushing.

14.4 Procedure:

14.4.1 Concave Surfaces—Where the warpage to be measured is of a surface and is concave, place the straightedge
lengthwise or diagonally along the surface to be measured, selecting the location that gives the greatest departure from straightness. Select the greatest distance from the unit surface to the straightedge. Using the steel rule or wedge, measure this distance to the nearest 1/32 in. (1 mm), and record as the concave warpage of the surface. See Fig. 2.

14.4.2 Concave Edges—Where the warpage to be measured is of an edge and is concave, place the straightedge between the ends of the concave edge to be measured. Select the greatest distance from the unit edge to the straightedge. Using the steel rule or wedge, measure this distance to the nearest 1/32 in. (1 mm), and record as the concave warpage of the edge. See Fig. 2.

14.4.3 Convex Surfaces—When the warpage to be measured is of a surface and is convex, place the unit with the convex surface in contact with a plane surface and with the corners approximately equidistant from the plane surface. Using the steel rule or wedge, measure the distance to the nearest 1/32 in. (1 mm) of each of the four corners from the plane surface. See Fig. 2. Record the average of the four measurements as the convex warpage of the unit.

14.4.4 Convex Edges—Where the warpage to be measured is of an edge and is convex, place the straightedge between the ends of the convex edge. Select the greatest distance from the unit edge to the straightedge. Using the steel rule or wedge, measure this distance to the nearest 1/32 in. (1 mm) and record as the convex warpage of the edge. See Fig. 2.

14.5 Report—Report all recorded warpage measurements of each specimen tested to the nearest 1/32 in. (0.8 mm).

15. Measurement of Length Change

15.1 Apparatus—A dial micrometer or other suitable measuring device graduated to read in 0.0001-in. (0.001-mm) increments, mounted on a stand suitable for holding the specimen in such a manner that reproducible results can be obtained, shall be used for measuring specimen length. Provisions shall be made to permit changing the position of the dial micrometer on its mounting rod so as to accommodate large variations in specimen size. The base of the stand and the tip of the dial micrometer shall have a conical depression to accept a 1/4-in. (6.35-mm) steel ball. A suitable reference instrument shall be provided for checking the measuring device.

15.2 Preparation of Specimen—Remove the ends of deeply textured specimens to the depth of the texture by cutting perpendicular to the length and parallel to each other. Drill a hole in each end of the specimen with a 1/4-in. (6.35-mm) carbide drill. Drill these holes at the intersection of the two diagonals from the corners. Place 1/4-in. (6.35-mm) steel balls in these depressions by cementing in place with a calcium aluminate cement. Any equivalent method for establishing the reference length is permissible.

15.3 Procedure—Mark the specimen for identification and measure to the nearest 0.0001 in. (0.001 mm) in a controlled environment and make subsequent measurements in the same controlled environment, ±2°F (±1°C) and ±5% relative humidity. Record the temperature and relative humidity. Apply a reference mark to the specimen for orientation in the
measuring device. Check the measuring device with the reference instrument before each series of measurements.

15.4 Report—When more than one specimen is tested, calculate and report the average length change of all specimens to the nearest 0.0001 in. (0.001 mm). The report shall include all individual recordings as well as the recorded laboratory temperature and relative humidity.

16. Initial Rate of Absorption (Suction)—Field Test

16.1 Scope—This test method is intended to serve as a volumetric means of determining the initial rate of absorption (IRA) of any size brick when weighing determination, described in Section 10 of these test methods, is impractical. This test method is applicable to assess the need for wetting the brick. This test method is performed on specimens taken from the field with no modification of moisture content, therefore, the IRA determined by this test method may differ from the IRA determined by the laboratory test method in Section 10, which requires drying the specimens.

16.2 Apparatus:

16.2.1 Absorption Test Pan—A watertight, rectangular pan, constructed of noncorroding material, with a flat, rigid bottom and inside depth of about 1¼ in. (38.1 mm). The inside length and width of the pan shall exceed the length and width of the tested brick by a minimum of 3 in. (76.2 mm) but not more than 5 in. (127.0 mm).

16.2.2 Brick Supports—Two noncorroding rectangular bars, ¼ in. (6.4 mm) in height and width and 1 in. (25.4 mm) shorter than the inside width of the pan in length. The brick supports can be placed on the bottom of the pan just before the test or permanently affixed to the bottom of the pan. The space between the supports should be about 4 in. (101.6 mm) shorter than the length of the tested brick. A device indicating the desired water level can be permanently attached to the end of one of the brick supports or suspended from the top of the pan (see Fig. 3 (a) and (b)). Any other device of equivalent accuracy for controlling the required water level, ¼ in. (3.2 mm) above the brick supports, can be used in place of that depicted in Fig. 3.

16.2.3 Timing Device—A suitable timing device that shall indicate a time of 1 min to the nearest 1 s.

16.2.4 Squeeze Bottle—A plastic squeeze bottle, 100 mL capacity.

16.2.5 Graduated Cylinder—A plastic or glass graduated measuring cylinder, 100 mL capacity.

16.3 Test Specimens—Select six whole brick in accordance with the requirements of Paragraph 4.1.

16.4 Procedure:

16.4.1 Completely immerse one brick specimen in a container of water for 2 h.

16.4.2 Measure to the nearest ¼ in. (1.6 mm) the length and width of the five remaining specimens at the surface that will be in contact with water. If the test specimens are cored, determine the area of the cores at the same surface.

16.4.3 Pre-wet and drain the absorption pan and place it on a flat, level surface.

16.4.4 Remove the pre-wetted specimen from the container, shake off the surface water, and place the specimen on brick supports in the pan. Pour water into the pan until the water reaches a level ¼ in. (3.2 mm) above the brick supports. (If using a pointed level water indicator, pour water into the pan until the water makes a minimum contact (dimpling effect).) Remove the pre-wetted brick, and tilt the brick sharply so that one corner serves as a drip point for clinging surface water to return to the pan. A gentle shake of the brick may be necessary to make the last drop fall. Put the pre-wetted brick back into the container of water.

16.4.5 Using the graduated cylinder, fill the squeeze bottle with exactly 100 mL of water.

16.4.6 Set the first test specimen squarely on the brick supports, counting zero time as the moment the brick contacts the water. At the end of 1 min ± 1 s lift the test specimen from water and tilt the brick sharply so that one corner serves as a drip point for clinging surface water to return to the pan. A gentle shake of the brick may be necessary to make the last drop fall.

16.4.6.1 Continue setting the remaining test specimens into the pan in the same way until all five specimens are tested. During the test add water to the pan, using the squeeze bottle, to keep the water level approximately constant at the ¼ in. depth. Refill the squeeze bottle with 100 mL of water when empty, recording each refill.

16.4.6.2 After the last specimen is tested, place the pre-wetted brick back in the pan and restore the original level with water from the squeeze bottle.

Note 12—Place the brick in contact with the water quickly, but without splashing. Set the brick in position with a rocking motion to avoid the entrapping of air on its under surface. Test brick with frogs or depressions in one flatwise surface with the frog or depression uppermost. Test molded brick with the struck face down.

16.4.7 Using the graduated cylinder, measure the volume of water remaining in the squeeze bottle.

16.5 Calculation and Report:

16.5.1 The number of refills plus the first full bottle, times 100 mL, minus the volume of water remaining in the squeeze bottle, is the total measured volume of water in millilitres absorbed by the five specimens.

\[ V_i = 100(n + 1) - V \]  \hspace{1cm} (8)

where:

- \( V_i \) = total measured volume of water absorbed by all tested specimens, mL.
An area of 30 in.² (193.5 cm²), report the total measured the number of specimens) differs by 6
water of a single specimen (sum of net surface areas divided by five, the number of tested specimens, as the IRA (Field) in g/min/30 in.²

\[
\text{ IRA (Field)} = \frac{V_t}{5}
\]  (9)

16.5.2 When the average net surface area in contact with water of a single specimen (sum of net surface areas divided by the number of specimens) differs by ±0.75 in.² (4.84 cm²) or less from 30 in.² (193.5 cm²), report the total measured absorbed volume of water divided by five, the number of tested specimens, as the IRA (Field) in g/l min/30 in.²

\[
\text{ IRA (Field)} = \frac{V_t}{5}
\]  (10)

16.5.3 If the average net surface area in contact with water differs by more than ±0.75 in.² (4.84 cm²) from 30 in.² (193.5 cm²), calculate the equivalent volume in 1 min for 30 in.² (193.5 cm²) of surface as follows:

\[
V_t = \frac{30 V_s}{A_s} = \frac{193.5 V_s}{A_s}
\]  (11)

where:

- \( V_t \) = average volume of absorbed water by a specimen, corrected to basis of 30 in.² (193.5 cm²) of surface, mL, and
- \( A_s \) = sum of net surface areas in contact with water of all tested specimens, in.² (cm²).

16.5.4 Report—Report the corrected volume (\( V_t \)) as the IRA (Field) in g/l min/30 in.²

16.6 Precision and Bias—Insufficient data is currently available for a precision and bias statement.

17. Measurement of Void Area in Cored Units

17.1 Apparatus:
17.1.1 Steel Rule or Calipers—As described in 13.1.
17.1.2 Graduated Cylinder—A glass cylinder with a capacity of 500 mL.
17.1.3 Paper—A sheet of smooth, hard-finish paper not less than 24 by 24 in. (610 by 610 mm).
17.1.4 Sand—500 mL of clean, dry sand.
17.1.5 Steel Straightedge.
17.1.6 Flat Surface—A level, flat, smooth, clean dry surface.
17.1.7 Brush—A soft-bristle brush.
17.1.8 Neoprene Mat—24 by 24 in. (610 by 610 mm) open-cell neoprene sponge ⅛ in. (6.4 mm) in thickness.
17.1.9 Balance—See 10.1.4.

17.2 Test Specimens—Use a sample of ten units selected as described for the determination of size (The samples taken for the determination of size may be used).

17.3 Preparation of Samples—Test the specimens as received, except remove any adhering dirt by brushing.

17.4 Procedure:
17.4.1 Measure and record the length, width, and depth of the unit as described for the determination of size.
17.4.2 Place the unit to be tested bed down (cores vertical) on the sheet of paper that has been spread over the neoprene mat on the flat surface.

17.4.3 Fill the cores with sand, allowing the sand to fall naturally. Do not work the sand into the cores. Using the steel straightedge, bring the level of the sand in the cores down to the top of the unit. With the brush, remove all excess sand from the top of the unit and from the paper sheet.

17.4.4 Lifting the unit up, allow all of the sand in the cores to fall on the sheet of paper.

17.4.5 Transfer the sand from the sheet of paper to the balance, weighing and recording to the nearest 0.5 g.

17.4.6 With a separate portion of the sand, fill a 500 mL cylinder to the exact 500 mL graduation by allowing the sand to fall naturally and without shaking or vibrating the cylinder. Transfer this sand to the balance, weighing and recording to the nearest 0.5 g.

17.5 Calculation and Report:

17.5.1 Determine the volume of sand held in the test unit as follows:

\[
V_t = \frac{500 \text{ mL}}{S_v} \times S_u
\]  (12)

where:

- \( V_t \) = volume of sand held in test unit,
- \( S_v \) = weight, in grams, of 500 mL sand contained in graduated cylinder, and
- \( S_u \) = weight in grams of sand held in test unit.

17.5.2 Determine the percentage of void as follows:

\[
\% \text{ Void area} = \frac{V_v}{V_t} \times \frac{1}{16.4} \times 100
\]  (13)

where:

- \( V_v \) = volume of sand determined in 17.5.1, mL, and
- \( V_t \) = length \( \times \) width \( \times \) depth recorded in 17.4.1, in.³

17.5.3 Report the results of Eq 12 in 17.5.2 for each specimen to the nearest 1 %, as the unit’s percentage of void area.

18. Measurement of Void Area In Deep Frogged Units

Note 13—The area measured corresponds to a section located ⅜ in. (9.5 mm) distant from the voided bed of the units.

18.1 Apparatus:
18.1.1 Steel Rule or Gage or Calipers (inside and outside)—as described in 13.1.
18.1.2 Steel Straightedge.
18.1.3 Marking Pen or Scribe.
18.1.4 Brush, a soft-bristle brush.

18.2 Test Specimens—Use a sample of 10 units selected as described for the determination of size. (The samples taken for the determination of size may be used.)

18.3 Preparation of Sample—Test the specimens as received except remove any adhering dirt by brushing.

18.4 Procedure:
18.4.1 Measure the length along both faces and the width along both ends at a distance of ⅜ in. (9.5 mm) down from the bed containing the deep frogs. Record the measurements to the nearest ⅜ in. (1 mm). Record the average of the two length measurements to the nearest ⅜ in. (1 mm) as the length of the
unit and the average of the two width measurements to the nearest 1/32 in. (1 mm) as the width of the unit.

18.4.2 With the steel straightedge parallel to the length of the unit and centered over the deep frog or frogs, inscribe a mark on both faces of the frog 3/8 in. (9.5 mm) below the underside of the steel straightedge (mark 1 on Fig. 4). With the steel straightedge parallel to the width of the unit and centered over the deep frog, inscribe a mark on both faces of each frog 3/8 in. (9.5 mm) below the underside of the steel straightedge (mark 2 on Fig. 4).

18.4.3 Measure and record to the nearest 1/32 in. (1 mm) the distance between the inscribed marks on a line parallel to the length of the unit for each frog, and measure and record to the nearest 1/32 in. (1 mm) the distance between the inscribed marks on a line parallel to the width of the unit for each frog.

18.5 Calculations and Report:

18.5.1 Using the recorded length and width measurements calculate the gross area of the unit ($A_u$) in the plane of the unit 3/8 in. (9.5 mm) down from the frogged bed.

18.5.2 Using the distance between the inscribed marks calculate the inside area of each deep frog ($A_f$) in the plane of the unit 3/8 in. (9.5 mm) down from the frogged bed (see Fig. 4).

18.5.3 Determine the percentage of void as follows:

$$\% \text{ Void area} = \frac{\sum A_f}{A_u} \times 100$$  \hfill (13)

where:

$\sum A_f$ = sum of the inside area of the deep frogs, and

$A_u$ = gross area of unit.

18.5.4 Report the results of the equation in 18.5.3 for each specimen to the nearest 1\% as the unit’s percentage of void area.

19. Measurement of Out of Square

19.1 Apparatus:

19.1.1 Steel Rule or Calipers, as described in 13.1.

19.1.2 Steel Carpenter’s Square.

19.2 Procedure:

19.2.1 Place one leg of a carpenter’s square adjacent to the length of the unit when laid as a stretcher. Align the leg of the square parallel to the length of the unit by having the corners of the face of the unit in contact with the leg of the square. Locate the square parallel to and at or within 1/4 in. (6.4 mm) of the face to be exposed. See Fig. 6.

19.2.2 Measure the deviation due to the departure from the 90° angle at each corner of the exposed face of the unit. Record the measurement to the nearest 1/32 in. (0.8 mm) for each corner. See Fig. 5.

19.3 Report—Report the recorded measurements for each specimen tested to the nearest 1/32 in. (0.8 mm) as the unit’s deviation from square.

20. Measurement of Shell and Web Thickness

20.1 Apparatus—a caliper rule graduated in not more than 1/64 in. (0.4 mm) divisions and having parallel jaws not less than 1/2 in. (12.7 mm) in length.

20.2 Test Specimens—Use a sample of five units as described for the measurement of size (samples taken for the determination of size are permitted to be used).

20.3 Preparation of Samples—Remove any shards or other projections interfering with measurement of the minimum parallel distance of two surfaces.

20.4 Procedure—For each unit, measure the shell thicknesses and, when required, the web thicknesses at the thinnest point of each element 1/2 in. (12.7 mm) into the unit from either direction and record to the nearest division of the caliper.
21. Breaking Load

21.1 Test Specimens—The test specimens shall consist of whole full-size units (see 5.1.1). Five such specimens shall be tested.

21.2 Procedure:

21.2.1 Test units that have been dried according to 5.1.1.

21.2.2 Unless specified and reported otherwise, support the test specimen flatwise (that is, apply the load in the direction of the height of the unit). The load shall be placed at the midspan, within 1/16 in. (2 mm) of the center. If the specimens have frogs or depressions, place the specimen so that the frogs or depressions are on the underside of the specimen. The supports for the specimen shall be solid steel rods 1 ± 1/8 in. (25.4 ± 10 mm) in diameter placed 1/2 ± 1/16 in. (12.7 ± 2 mm) from each end. The length of each support shall be at least equal to the width of the specimen. See Fig. 7.

21.2.3 Apply the load to the upper surface of the specimen through a steel bearing plate 1/4 in. (6.4 mm) in thickness and 1 1/2 in. (38.1 mm) in width and of a length at least equal to the width of the specimen.

21.2.4 Speed of Testing—The rate of loading shall not exceed 2000 lbf (8896 N)/min. This requirement shall be considered as being met if the speed of the moving head of the testing machine immediately prior to application of the load is not more than 0.05 in. (1.27 mm)/min.

21.3 Report:

21.3.1 Record the unit dimensions and span length.

21.3.2 Record the transverse breaking load, P, of each unit to the nearest lb (N).

21.3.3 Calculate and record the breaking load per width of unit as

\[ p = \frac{P}{w} \]

for each unit, lb/in. (N/mm). Report the average of the breaking loads per width of all the specimens tested as the breaking load of the lot.

22. Keywords

absorption; compressive strength; efflorescence; freezing and thawing; initial rate of absorption; length change; modulus of rupture; out-of-square; sampling; size; void area; warpage
Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

This standard is issued under the fixed designation D2216, the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 These test methods cover the laboratory determination of the water (moisture) content by mass of soil, rock, and similar materials where the reduction in mass by drying is due to loss of water except as noted in 1.4, 1.5, and 1.7. For simplicity, the word “material” shall refer to soil, rock or aggregate whichever is most applicable.

1.2 Some disciplines, such as soil science, need to determine water content on the basis of volume. Such determinations are beyond the scope of this test method.

1.3 The water content of a material is defined in 3.2.1.

1.4 The term “solid material” as used in geotechnical engineering is typically assumed to mean naturally occurring mineral particles of soil and rock that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement etc.) may require special treatment or a qualified definition of water content. In addition, some organic materials may be decomposed by oven drying at the standard drying temperature for this method (110°C). Materials containing gypsum (calcium sulfate dihydrate) or other compounds having significant amounts of hydrated water may present a special problem as this material slowly dehydrates at the standard drying temperature (110°C) and at very low relative humidity, forming a compound (such as calcium sulfate hemihydrate) that is not normally present in natural materials except in some desert soils. In order to reduce the degree of dehydration of gypsum in those materials containing gypsum or to reduce decomposition in highly/fibrous organic soils, it may be desirable to dry the materials at 60°C or in a desiccator at room temperature. Thus, when a drying temperature is used which is different from the standard drying temperature as defined by this test method, the resulting water content may be different from the standard water content determined at the standard drying temperature of 110°C.

Note 1—Test Method D2974 provides an alternate procedure for determining water content of peat materials.

1.5 Materials containing water with substantial amounts of soluble solids (such as salt in the case of marine sediments) when tested by this method will give a mass of solids that includes the previously soluble dissolved solids. These materials require special treatment to remove or account for the presence of precipitated solids in the dry mass of the specimen, or a qualified definition of water content must be used. For example, see Test Method D4542 regarding information on marine sediments.

1.6 This test standard requires several hours for proper drying of the water content specimen. Test Methods D4643, D4944 and D4959 provide less time-consuming processes for determining water content. See Gilbert for details on the background of Test Method D4643.

1.7 Two test methods are provided in this standard. The methods differ in the significant digits reported and the size of the specimen (mass) required. The method to be used may be specified by the requesting authority; otherwise Method A shall be performed.

1.7.1 Method A—The water content by mass is recorded to the nearest 1 %. For cases of dispute, Method A is the referee method.

1.7.2 Method B—The water content by mass is recorded to the nearest 0.1 %.

1.8 This standard requires the drying of material in an oven. If the material being dried is contaminated with certain chemicals, health and safety hazards can exist. Therefore, this standard should not be used in determining the water content of contaminated soils unless adequate health and safety precautions are taken.

1.9 Units—The values stated in SI units shall be regarded as standard excluding the Alternative Sieve Sizes listed in Table 1. No other units of measurement are included in this test method.


*A Summary of Changes section appears at the end of this standard

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TABLE 1 Minimum Requirements for Mass of Test Specimen, and Balance Readability1

<table>
<thead>
<tr>
<th>Sieve Size (100 % Passing)</th>
<th>Method A</th>
<th>Method B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen Mass</td>
<td>Water Content Recorded to ±1 %</td>
<td>Specimen Mass</td>
</tr>
<tr>
<td>75.0 mm</td>
<td>5 kg</td>
<td>10</td>
</tr>
<tr>
<td>37.5 mm</td>
<td>1 kg</td>
<td>10</td>
</tr>
<tr>
<td>19.0 mm</td>
<td>250 g</td>
<td>1</td>
</tr>
<tr>
<td>9.5 mm</td>
<td>50 g</td>
<td>0.1</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>20 g</td>
<td>0.1</td>
</tr>
<tr>
<td>2.00 mm</td>
<td>20 g</td>
<td>0.1</td>
</tr>
</tbody>
</table>

1 If water content data is to be used to calculate other relationships, such as moist or dry mass, wet or dry unit weight or total or dry density, then specimen mass up to 200 g must be determined using a balance accurate to 0.01 g.

1.10 Refer to Practice D6026 for guidance concerning the use of significant figures that shall determine whether Method, A or B is required. This is especially important if the water content will be used to calculate other relationships such as moist mass to dry mass or vice versa, wet unit weight to dry unit weight or vice versa, and total density to dry density or vice versa. For example, if four significant digits are required in any of the above calculations, then the water content must be recorded to the nearest 0.1 %. This occurs since 1 plus the water content (not in percent) will have four significant digits regardless of the value of the water content is; that is, 1 plus 0.1/100 = 1.001, a value with four significant digits. While, if three significant digits are acceptable, then the water content can be recorded to the nearest 1 %.

1.11 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:

D653 Terminology Relating to Soil, Rock, and Contained Fluids
D2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4220 Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4542 Test Method for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer
D4643 Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Heating

D4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester
D4959 Test Method for Determination of Water (Moisture) Content of Soil By Direct Heating
D5079 Practices for Preserving and Transporting Rock Core Samples
D6026 Practice for Using Significant Digits in Geotechnical Data
D7263 Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens
E145 Specification for Gravity-Convection and Forced-Ventilation Ovens

3. Terminology

3.1 Refer to Terminology D653 for standard definitions of terms.

3.2 Definitions:

3.2.1 water content by mass (of a material)—the ratio of the mass of water contained in the pore spaces of soil or rock material, to the solid mass of particles in that material, expressed as a percentage. A standard temperature of 110 ± 5°C is used to determine these masses.

3.3 Definitions of Terms Specific to This Standard:

3.3.1 constant dry mass (of a material)—the state that a water content specimen has attained when further heating causes, or would cause, less than 1 % or 0.1 % additional loss in mass for Method A or B respectively. The time required to obtain constant dry mass will vary depending on numerous factors. The influence of these factors generally can be established by good judgement, and experience with the materials being tested and the apparatus being used.

4. Summary of Test Method

4.1 A test specimen is dried in an oven at a temperature of 110 ± 5°C to a constant mass. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

5. Significance and Use

5.1 For many materials, the water content is one of the most significant index properties used in establishing a correlation between soil behavior and its index properties.
5.2 The water content of a material is used in expressing the phase relationships of air, water, and solids in a given volume of material.

5.3 In fine-grained (cohesive) soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limits as determined by Test Method D4318, is used to express its relative consistency or liquidity index.

Note 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself ensure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 Drying Oven—Vented, thermostatically-controlled, preferably of the forced-draft type, meeting the requirements of Specification E145 and capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

6.2 Balances—All balances must meet the requirements of Specification D4753 and this section. A Class GP1 balance of 0.01 g readability is required for specimens having a mass of up to 200 g (excluding mass of specimen container) and a Class GP2 balance of 0.1 g readability is required for specimens having a mass over 200 g. However, the balance used may be controlled by the number of significant digits needed (see 1.10).

6.3 Specimen Containers—Suitable containers made of material resistant to corrosion and change in mass upon repeated heating, cooling, exposure to materials of varying pH, and cleaning. Unless a dessicator is used, containers with close-fitting lids shall be used for testing specimens having a mass of less than about 200 g; while for specimens having a mass greater than about 200 g, containers without lids may be used (see Note 3). One uniquely numbered (identified) container or number-matched container and lid combination as required is needed for each water content determination.

Note 3—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial mass determination, and to prevent absorption of moisture from the atmosphere following drying and before final mass determination.

6.4 Desiccator (Optional)—A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium sulfate. It is preferable to use a desiccant that changes color when it needs to be reconstituted.

Note 4—Anhydrous calcium sulfate is sold under the trade name Drierite.

6.5 Container Handling Apparatus, heat resistant gloves, tongs, or suitable holder for moving and handling hot containers after drying.

6.6 Miscellaneous, knives, spatulas, scoops, quartering cloth, wire saws, etc., as required.

7. Samples

7.1 Soil samples shall be preserved and transported in accordance with Practice D4220 Section 8 Groups B, C, or D soils. Rock samples shall be preserved and transported in accordance with Practice D5079 section 7.5.2, Special Care Rock. Keep the samples that are stored prior to testing in non-corrodible airtight containers at a temperature between approximately 3 and 30°C and in an area that prevents direct contact with sunlight. Disturbed samples in jars or other containers shall be stored in such a way as to minimize moisture condensation on the insides of the containers.

7.2 The water content determination should be done as soon as practicable after sampling, especially if potentially corroding containers (such as thin-walled steel tubes, paint cans, etc.) or plastic sample bags are used.

8. Test Specimen

8.1 For water contents being determined in conjunction with another ASTM method, the specimen mass requirement stated in that method shall be used if one is provided. If no minimum specimen mass is provided in that method then the values given below shall apply. See Howard* for background data for the values listed.

8.2 The minimum specimen mass of moist material selected to be representative of the total sample is based on visual maximum particle size in the sample and the Method (Method A or B) used to record the data. Minimum specimen mass and balance readability shall be in accordance with Table 1.

8.3 Using a test specimen smaller than the minimum indicated in 8.2 requires discretion, though it may be adequate for the purposes of the test. Any specimen used not meeting these requirements shall be noted on the test data forms or test data sheets.

8.4 When working with a small (less than 200 g) specimen containing a relatively large gravel particle, it is appropriate not to include this particle in the test specimen. However, any discarded material shall be described and noted on the test data form/sheet.

8.5 For those samples consisting entirely of intact rock or gravel-size aggregate, the minimum specimen mass shall be 500 g. Representative portions of the sample may be broken into smaller particles. The particle size is dictated by the specimen mass, the container volume and the balance being used to determine constant mass, see 10.4. Specimen masses as small as 200 g may be tested if water contents of only two significant digits are acceptable.

9. Test Specimen Selection

9.1 When the test specimen is a portion of a larger amount of material, the specimen must be selected to be representative of the water condition of the entire amount of material. The manner in which the test specimen is selected depends on the purpose and application of the test, type of material being tested, the water condition, and the type of sample (from another test, bag, block, etc.).

9.2 For disturbed samples such as trimmings, bag samples, etc, obtain the test specimen by one of the following methods (listed in order of preference):

9.2.1 If the material is such that it can be manipulated and handled without significant moisture loss and segregation, the material should be mixed thoroughly. Select a representative portion using a scoop of a size that no more than a few scoopfuls are required to obtain the proper size of specimen defined in 8.2. Combine all the portions for the test specimen.

9.2.2 If the material is such that it cannot be thoroughly mixed or mixed and sampled by a scoop, form a stockpile of the material, mixing as much as possible. Take at least five portions of material at random locations using a sampling tube, shovel, scoop, trowel, or similar device appropriate to the maximum particle size present in the material. Combine all the portions for the test specimen.

9.2.3 If the material or conditions are such that a stockpile cannot be formed, take as many portions of the material as practical, using random locations that will best represent the moisture condition. Combine all the portions for the test specimen.

9.3 Intact samples such as block, tube, split barrel, etc, obtain the test specimen by one of the following methods depending on the purpose and potential use of the sample:

9.3.1 Using a knife, wire saw, or other sharp cutting device, trim the outside portion of the sample a sufficient distance to see if the material is layered, and to remove material that appears more dry or more wet than the main portion of the sample. If the existence of layering is questionable, slice the sample in half. If the material is layered, see 9.3.3.

9.3.2 If the material is not layered, obtain the specimen meeting the mass requirements in 8.2 by: (1) taking all or one-half of the interval being tested; (2) trimming a representative slice from the interval being tested; or (3) trimming the exposed surface of one-half or from the interval being tested.

Note 5—Migration of moisture in some cohesionless soils may require that the entire sample be tested.

9.3.3 If a layered material (or more than one material type is encountered), select an average specimen, or individual specimens, or both. Specimens must be properly identified as to location, or what they represent, and appropriate remarks entered on the test data forms or test data sheets.

10. Procedure

10.1 Determine and record the mass of the clean and dry specimen container and its lid, if used along with its identification number.

10.2 Select representative test specimens in accordance with Section 9.

10.3 Place the moist test specimen in the container and, if used, set the lid securely in position. Determine the mass of the container and moist specimen using a balance (see 8.2 and Table 1) selected on the basis of the specimen mass or required significant digits. Record this value.

Note 6—To assist in the oven drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

10.4 Remove the lid (if used) and place the container with the moist specimen in the drying oven. Dry the specimen to a constant mass. Maintain the drying oven at 110 ± 5°C unless otherwise specified (see 1.4). The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors. The influence of these factors generally can be established by good judgment and experience with the materials being tested and the apparatus being used.

10.4.1 In most cases, drying a test specimen overnight (about 12 to 16 h) is sufficient, especially when using forced draft ovens. In cases where there is doubt concerning the adequacy of drying to a constant dry mass, see 3.3.1 and check for additional loss in mass with additional oven drying over an adequate time period. A minimum time period of two hours should be used, increasing the drying time with increasing specimen mass. A rapid check to see if a relatively large specimen (> than about 100 g of material) is dry; place a small strip of torn paper on top of the material while it is in the oven or just upon removal from the oven. If the paper strip curls the material is not dry and requires additional drying time. Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

10.4.2 Since some dry materials may absorb moisture from drying specimens that still retain moisture, dried specimens shall be removed before placing moist specimens in the same oven; unless they are being dried overnight.

10.5 After the specimen has dried to constant mass, remove the container from the oven (and replace the lid if used). Allow the specimen and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents or heat transmission or both. Determine the mass of the container and oven-dried specimen using the same type/capacity balance used in 10.3. Record this value. Tight fitting lids shall be used if it appears that the specimen is absorbing moisture from the air prior to determination of its dry mass.

10.5.1 Cooling in a desiccator is acceptable in place of tight fitting lids since it greatly reduces absorption of moisture from the atmosphere during cooling.

10.6 A copy of a sample data sheet is shown in Appendix X1. Any data sheet can be used, provided the form contains all the required data.

11. Calculation

11.1 Calculate the water content of the material as follows:

\[ w = \left( \frac{M_{\text{cm}} - M_{\text{ds}}}{M_{\text{cm}} - M_{\text{c}}} \right) \times 100 = \left( \frac{M_{\text{c}}}{M_{\text{c}} - M_{\text{ds}}} \right) \times 100 \]  

where:

\[ w \] = water content, %

\[ M_{\text{cm}} \] = mass of container and moist specimen, g

\[ M_{\text{ds}} \] = mass of container and oven dry specimen, g

\[ M_{\text{c}} \] = mass of container, g

\[ M_{\text{w}} \] = mass of water (\[ M_{\text{cm}} - M_{\text{ds}} \]), g, and

\[ M_{\text{d}} \] = mass of oven dry specimen (\[ M_{\text{c}} - M_{\text{ds}} \]), g.

12. Report: Test Data Form/Sheet

12.1 The method used to specify how data are recorded on the test data sheets or forms, as given below, is the industry
standard, and are representative of the significant digits that should be retained. These requirements do not consider in situ material variation, use of the data, special purpose studies, or any considerations for the user’s objectives. It is common practice to increase or reduce significant digits of reported data commensurate with these considerations. It is beyond the scope of the standard to consider significant digits used in analysis method for engineering design.

12.1.1 Test data forms or test data sheets shall include the following:

12.1.2 Identification of the sample (material) being tested, such as boring number, sample number, test number, container number etc.

12.1.3 Water content of the specimen to the nearest 1 % for Method A or 0.1 % for Method B, as appropriate based on the minimum mass of the specimen. If this method is used in concert with another method, the water content of the specimen should be reported to the value required by the test method for which the water content is being determined. Refer to Practice D6026 for guidance concerning significant digits, especially if the value obtained from this test method is to be used to calculate other relationships such as unit weight or density. For instance, if it is desired to express dry unit weight, as determined by D7263 to the nearest 0.1 lb/ft³ (0.02 kN/m³), it may be necessary to use a balance with a greater readability or use a larger specimen mass to obtain the required significant digits the mass of water so that the water content can be determined to the required significant digits. Also, the significant digits in Practice D6026 may need to be increased when calculating phase relationships requiring four significant digits.

12.1.4 Indicate if test specimen had a mass less than the minimum indicated in 8.2.

12.1.5 Indicate if test specimen contained more than one material type (layered, etc.).

12.1.6 Indicate the drying temperature if different from 110 ± 5°C.

12.1.7 Indicate if any material (size and amount) was excluded from the test specimen.

12.2 When reporting water content in tables, figures, etc., any data not meeting the requirements of this test method shall be noted, such as not meeting the mass, balance, or temperature requirements or a portion of the material is excluded from the test specimen.

13. Precision and Bias

13.1 Statements on Precision:

13.1.1 Precision—Test data on precision is not presented due to the nature of the soil or rock materials tested by this test method. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation.

13.1.2 Subcommittee D18.03 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

13.1.3 Bias—There is no accepted reference value for this test method, therefore, bias cannot be determined.

14. Keywords

14.1 aggregate; consistency; index property; laboratory; moisture analysis; moisture content; soil; water content

5 Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D13-1108.
## APPENDIX

(Nonmandatory Information)

### X1. WATER CONTENT OF SOIL AND ROCK SAMPLE DATA SHEET

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Committee D18 has identified the location of selected changes to these test methods since the last issue, D2216–05, that may impact the use of these test methods. (Approved July 1, 2010)

1. Replaced “has to” with “must” in 1.10.
2. Added the “heat resistant” to “gloves” in 6.5.
4. Added “or required significant digits” in 10.3.
5. Revised 10.4.1 to clarify the process of obtaining and checking to determine if a specimen had reached constant mass.
6. Added “that still retain moisture” in 10.4.2.
7. Replaced “its being heated” with “heat transmission” in 10.5.
8. Added “as determined by D7263” in 12.1.3.
9. Added Footnote A to Table 1 reflecting balance requirements outlined in 6.2.

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1. Scope*

1.1 These test methods cover the determination of the liquid limit, plastic limit, and the plasticity index of soils as defined in Section 3 on Terminology.

1.2 Two methods for preparing test specimens are provided as follows: Wet preparation method, as described in 10.1. Dry preparation method, as described in 10.2. The method to be used shall be specified by the requesting authority. If no method is specified, use the wet preparation method.

1.2.1 The liquid and plastic limits of many soils that have been allowed to dry before testing may be considerably different from values obtained on non-dried samples. If the liquid and plastic limits of soils are used to correlate or estimate the engineering behavior of soils in their natural moist state, samples should not be permitted to dry before testing unless data on dried samples are specifically desired.

1.3 Two methods for determining the liquid limit are provided as follows: Method A. Multipoint test as described in Sections 11 and 12. Method B. One-point test as described in Sections 13 and 14. The method to be used shall be specified by the requesting authority. If no method is specified, use Method A.

1.3.1 The multipoint liquid limit method is generally more precise than the one-point method. It is recommended that the multipoint method be used in cases where test results may be subject to dispute, or where greater precision is required.

1.3.2 Because the one-point method requires the operator to judge when the test specimen is approximately at its liquid limit, it is particularly not recommended for use by inexperienced operators.

1.3.3 The correlation on which the calculations of the one-point method are based may not be valid for certain soils, such as organic soils or soils from a marine environment. It is strongly recommended that the liquid limits of these soils be determined by the multipoint method.

1.4 The plastic limit test is performed on material prepared for the liquid limit test.

1.5 The liquid limit and plastic limit of soils (along with the shrinkage limit) are often collectively referred to as the Atterberg limits. These limits distinguish the boundaries of the several consistency states of plastic soils.

1.6 The composition and concentration of soluble salts in a soil affect the values of the liquid and plastic limits as well as the water content values of soils (see Method D4542). Special consideration should therefore be given to soils from a marine environment or other sources where high soluble salt concentrations may be present. The degree to which the salts present in these soils are diluted or concentrated must be given careful consideration.

1.7 The methods described herein are performed only on that portion of a soil that passes the 425-µm (No. 40) sieve. Therefore, the relative contribution of this portion of the soil to the properties of the sample as a whole must be considered when using these tests to evaluate properties of a soil.

1.8 The values stated in SI units are to be regarded as the standard, except as noted below. The values given in parentheses are for information only.

1.8.1 The standard units for the resilience tester covered in Annex A1 are inch-pound, not SI. The SI values given are for information only.

1.9 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026.

1.9.1 For purposes of comparing a measured or calculated value(s) with specified limits, the measured or calculated value(s) shall be rounded to the nearest decimal or significant digits in the specified limits

1.9.2 The procedures used to specify how data are collected/recorded or calculated, in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that generally should be retained. The procedures do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user’s objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this

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*A Summary of Changes section appears at the end of this standard
standard to consider significant digits used in analysis methods for engineering design.

1.10 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:
C702 Practice for Reducing Samples of Aggregate to Testing Size
D75 Practice for Sampling Aggregates
D420 Guide to Site Characterization for Engineering Design and Construction Purposes (Withdrawn 2011)3
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D1241 Specification for Materials for Soil-Aggregate Subbase, Base, and Surface Courses
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
D3282 Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction
D4318 Test Method for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer
D6026 Practice for Using Significant Digits in Geotechnical Data
E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 Definitions:
3.1.1 For common definitions of terms in this standard, refer to Terminology D653.
3.1.2 Atterberg Limits—Originally, six “limits of consistency” of fine-grained soils were defined by Albert Atterberg: the upper limit of viscous flow, the liquid limit, the sticky limit, the cohesion limit, the plastic limit, and the shrinkage limit. In current engineering usage, the term usually refers only to the liquid limit, plastic limit, and in some references, the shrinkage limit.
3.1.3 Consistency—the relative ease with which a soil can be deformed.
3.1.4 Liquid limit (LL, \( w_L \))—the water content, in percent, of a soil at the arbitrarily defined boundary between the semi-liquid and plastic states.
3.1.4.1 Discussion—The undrained shear strength of soil at the liquid limit is considered to be approximately 2 kPa (0.28 psi).
3.1.5 Plastic limit (PL, \( w_p \))—the water content, in percent, of a soil at the boundary between the plastic and semi-solid states.
3.1.6 Plastic soil—a soil which has a range of water content over which it exhibits plasticity and which will retain its shape on drying.
3.1.7 Plasticity index (PI)—the range of water content over which a soil behaves plastically. Numerically, it is the difference between the liquid limit and the plastic limit.
3.1.8 Liquidity index—the ratio, expressed as a percentage of (1) the water content of a soil minus its plastic limit, to (2) its plasticity index.
3.1.9 Activity number (A)—the ratio of (1) the plasticity index of a soil to (2) the percent by mass of particles having an equivalent diameter smaller than 2 µm.

4. Summary of Test Method

4.1 The specimen is processed to remove any material retained on a 425-µm (No. 40) sieve. The liquid limit is determined by performing trials in which a portion of the specimen is spread in a brass cup, divided in two by a grooving tool, and then allowed to flow together from the shocks caused by repeatedly dropping the cup in a standard mechanical device. The multipoint liquid limit, Method A, requires three or more trials over a range of water contents to be performed and the data from the trials plotted or calculated to make a relationship from which the liquid limit is determined. The one-point liquid limit, Method B, uses the data from two trials at one water content multiplied by a correction factor to determine the liquid limit.
4.2 The plastic limit is determined by alternately pressing together and rolling into a 3.2-mm (1⁄8-in.) diameter thread a small portion of plastic soil until its water content is reduced to a point at which the thread crumbles and can no longer be pressed together and re-rolled. The water content of the soil at this point is reported as the plastic limit.
4.3 The plasticity index is calculated as the difference between the liquid limit and the plastic limit.

5. Significance and Use

5.1 These test methods are used as an integral part of several engineering classification systems to characterize the fine-grained fractions of soils (see Practices D2487 and D3282) and to specify the fine-grained fraction of construction materials (see Specification D1241). The liquid limit, plastic limit, and plasticity index of soils are also used extensively, either

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3 For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard’s Document Summary page on the ASTM website.

4 The last approved version of this historical standard is referenced on www.astm.org.

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individual or together, with other soil properties to correlate with engineering behavior such as compressibility, hydraulic conductivity (permeability), compactibility, shrink-swell, and shear strength.

5.2 The liquid and plastic limits of a soil and its water content can be used to express its relative consistency or liquidity index. In addition, the plasticity index and the percentage finer than 2-µm particle size can be used to determine its activity number.

5.3 These methods are sometimes used to evaluate the weathering characteristics of clay-shale materials. When subjected to repeated wetting and drying cycles, the liquid limits of these materials tend to increase. The amount of increase is considered to be a measure of a shale’s susceptibility to weathering.

5.4 The liquid limit of a soil containing substantial amounts of organic matter decreases dramatically when the soil is oven-dried before testing. Comparison of the liquid limit of a sample before and after oven-drying can therefore be used as a qualitative measure of organic matter content of a soil (see Practice D2487.)

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740, generally, are considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 Liquid Limit Device—A mechanical device consisting of a brass cup suspended from a carriage designed to control its drop onto the surface of a block of resilient material that serves as the base of the device. Fig. 1 shows the essential features and critical dimensions of the device. The device may be operated by either a hand crank or electric motor.

6.1.1 Base—A block of material having a resilience rebound of at least 77 % but no more than 90 %. Conduct resilience tests on the finished base with the feet attached. Details for measuring the resilience of the base are given in Annex A1.

6.1.2 Rubber Feet, supporting the base, designed to provide dynamic isolation of the base from the work surface.

6.1.3 Cup, brass, including cup hanger, of 185 to 215 g.

6.1.4 Cam—Designed to raise the cup smoothly and continuously to its maximum height, over a distance of at least 180° of cam rotation, without developing an upward or downward velocity of the cup when the cam follower leaves the cam. (The preferred cam motion is a uniformly accelerated lift curve.)

NOTE 2—The cam and follower design in Fig. 1 is for uniformly accelerated (parabolic) motion after contact and assures that the cup has no velocity at drop off. Other cam designs also provide this feature and may be used. However, if the cam-follower lift pattern is not known, zero velocity at drop off can be assured by carefully filing or machining the cam and follower so that the cup height remains constant over the last 20 to 45° of cam rotation.

6.1.5 Carriage, constructed in a way that allows convenient but secure adjustment of the height-of-drop of the cup to 10 mm (0.394 in.), and designed such that the cup and cup hanger assembly is only attached to the carriage by means of a removable pin. See Fig. 2 for definition and determination of the height-of-drop of the cup.

6.1.6 Motor Drive (Optional)—As an alternative to the hand crank shown in Fig. 1, the device may be equipped with a
motor to turn the cam. Such a motor must turn the cam at $2 \pm 0.1$ revolutions per second and must be isolated from the rest of the device by rubber mounts or in some other way that prevents vibration from the motor being transmitted to the rest of the apparatus. It must be equipped with an ON-OFF switch and a means of conveniently positioning the cam for height-of-drop adjustments. The results obtained using a motor-driven device must not differ from those obtained using a manually operated device.

6.2 Flat Grooving Tool—A tool made of plastic or noncorroding-metal having the dimensions shown in Fig. 3. The design of the tool may vary as long as the essential dimensions are maintained. The tool may, but need not, incorporate the gauge for adjusting the height-of-drop of the liquid limit device.

NOTE 3—Prior to the adoption of this test method, a curved grooving tool was specified as part of the apparatus for performing the liquid limit test. The curved tool is not considered to be as accurate as the flat tool.
described in 6.2 since it does not control the depth of the soil in the liquid limit cup. However, there are some data which indicate that typically the liquid limit is slightly increased when the flat tool is used instead of the curved tool.

6.3 Gauge—A metal gauge block for adjusting the height-of-drop of the cup, having the dimensions shown in Fig. 4. The design of the tool may vary provided the gauge will rest securely on the base without being susceptible to rocking, and the edge which contacts the cup during adjustment is straight, at least 10 mm ( 3⁄8 in.) wide, and without bevel or radius.

6.4 Water Content Containers—Small corrosion-resistant containers with snug-fitting lids for water content specimens. Aluminum or stainless steel cans 2.5 cm (1 in.) high by 5 cm (2 in.) in diameter are appropriate.

6.5 Balance, conforming to Specification D4753, Class GP1 (readability of 0.01 g).

6.6 Mixing and Storage Container—A container to mix the soil specimen (material) and store the prepared material. During mixing and storage, the container shall not contaminate the material in any way, and prevent moisture loss during storage. A porcelain, glass, or plastic dish about 11.4 cm (4 1⁄2 in.) in diameter and about 10 cm (3 to 4 in.) deep is adequate.

6.7 Plastic Limit:

6.7.1 Ground Glass Plate—A ground glass plate of sufficient size for rolling plastic limit threads.

6.7.2 Plastic Limit-Rolling Device (optional)—A device made of acrylic conforming to the dimensions shown in Fig. 5.4 The type of unglazed paper attached to the top and bottom plate (see 16.2.2) shall be such that it does not add foreign matter (fibers, paper fragments, etc.) to the soil during the rolling process.

6.8 Spatula—A spatula or pill knife having a blade about 2 cm ( 3⁄8 in.) wide, and about 10 to 13 cm (3 to 4 in.) long.

6.9 Sieve(s)—A 200-mm (8-in.) diameter, 425-µm (No. 40) sieve conforming to the requirements of Specification E111 and having a rim at least 5 cm (2 in.) above the mesh. A 200-mm (No. 10) sieve meeting the same requirements may also be needed.

6.10 Wash Bottle, or similar container for adding controlled amounts of water to soil and washing fines from coarse particles.

6.11 Drying Oven, thermostatically controlled, preferably of the forced-draft type, capable of continuously maintaining a temperature of 110 ± 5°C (230 ± 9°F) throughout the drying chamber.

6.12 Washing Pan, round, flat-bottomed, at least 7.6 cm (3 in.) deep, and slightly larger at the bottom than a 20.3-cm (8-in.) diameter sieve.

7. Reagents and Materials

7.1 Purity of Water—Where distilled water is referred to in this test method, either distilled or demineralized water may be used. See Note 7 covering the use of tap water.

8. Sampling and Specimen

8.1 Samples may be taken from any location that satisfies testing needs. However, Practices C702, D75, and D420 should be used as guides for selecting and preserving samples from various types of sampling operations. Samples in which specimens will be prepared using the wet-preparation method (10.1) must be kept at their as–sampled water content prior to preparation.

8.1.1 Where sampling operations have preserved the natural stratification of a sample, the various strata must be kept separated and tests performed on the particular stratum of interest with as little contamination as possible from other strata. Where a mixture of materials will be used in construction, combine the various components in such proportions that the resultant sample represents the actual construction case.

8.1.2 Where data from these test methods are to be used for correlation with other laboratory or field test data, use the same material as used for those tests where possible.

8.2 Specimen—Obtain a representative portion from the total sample sufficient to provide 150 to 200 g of material passing the 425-µm (No. 40) sieve. Free flowing samples (materials) may be reduced by the methods of quartering or splitting. Non-free flowing or cohesive materials shall be mixed thoroughly in a pan with a spatula or scoop and a representative portion scooped from the total mass by making one or more sweeps with a scoop through the mixed mass.

9. Calibration of Apparatus

9.1 Inspection of Wear:

9.1.1 Liquid Limit Device—Determine that the liquid limit device is clean and in good working order. Check the following specific points.

9.1.1.1 Wear of Base—The spot on the base where the cup makes contact should be worn no greater than 10 mm ( 3⁄8 in.) in diameter. If the wear spot is greater than this, the base can be machined to remove the worn spot provided the resurfacing
9.1.1.2 Wear of Cup—Replace the cup when the grooving tool has worn a depression in the cup 0.1 mm (0.004 in.) deep or when the rim of the cup has been reduced to half its original thickness. Verify that the cup is firmly attached to the cup hanger.

9.1.1.3 Wear of Cup Hanger—Verify that the cup hanger pivot does not bind and is not worn to an extent that allows more than 3 mm (1⁄8 in.) side-to-side movement of the lowest point on the rim.

9.1.1.4 Wear of Cam—The cam shall not be worn to an extent that the cup drops before the cup hanger (cam follower) loses contact with the cam.

9.1.1.5 Rubber Feet—The feet should prevent the base from bouncing or sliding on the work surface. Replace rubber feet that become hard, cracked, or brittle from age.

9.1.2 Grooving Tools—Inspect grooving tools for wear on a frequent and regular basis. The rapidity of wear depends on the material from which the tool is made, and the types of soils being tested. Soils containing a large proportion of fine sand particles may cause rapid wear of grooving tools; therefore, when testing these materials, tools should be inspected more frequently than for other soils.

NOTE 4—The width of the tip of grooving tools is conveniently checked using a pocket-sized measuring magnifier equipped with a millimeter scale. Magnifiers of this type are available from most laboratory supply companies. The depth of the tip of grooving tools can be checked using the depth-measuring feature of vernier calipers.

9.2 Adjustment of Height-of-Drop—Adjust the height-of-drop of the cup so that the point on the cup that comes in contact with the base rises to a height of 10 ± 0.2 mm. See Fig. 2 for proper location of the gauge relative to the cup during adjustment.

NOTE 5—A convenient procedure for adjusting the height-of-drop is as follows: place a piece of masking tape across the outside bottom of the cup parallel with the axis of the cup hanger pivot. The edge of the tape away from the cup hanger should bisect the spot on the cup that contacts the base. For new cups, placing a piece of carbon paper on the base and allowing the cup to drop several times will mark the contact spot. Attach the cup to the device and turn the crank until the cup is raised to its maximum height. Slide the height gauge under the cup from the front, and observe whether the gauge contacts the cup or the tape. (See Fig. 2.) If the tape and cup are both simultaneously contacted, the height-of-drop is ready to be checked. If not, adjust the cup until simultaneous contact is made. Check adjustment by turning the crank at 2 revolutions per second while holding the gauge in position against the tape and cup. If a faint ringing or clicking sound is heard without the cup rising from the gauge, the adjustment is correct. If no ringing is heard or if the cup rises from the gauge, readjust the height-of-drop. If the cup rocks on the gauge during this checking operation, the cam follower pivot is excessively worn and the worn parts should be replaced. Always remove tape after completion of adjustment operation.

10. Preparation of Test Specimen

10.1 Wet Preparation Method—Except where the dry method of specimen preparation is specified (10.2), prepare the specimen for testing as described in the following sections.

10.1.1 Material Passes the 425-µm (No. 40) Sieve:
10.1.1.1 Determine by visual and manual methods that the specimen from 8.2 has little or no material retained on a 425-µm (No. 40) sieve. If this is the case, prepare 150 to 200 g of material by mixing thoroughly with distilled or demineralized water on the glass plate or mixing dish using the spatula. If desired, soak the material in a mixing/storage dish with a small amount of water to soften the material before the start of mixing. If using Method A, adjust the water content of the material to bring it to a consistency that would require about 25 to 35 blows of the liquid limit device to close the groove (Note 6). For Method B, the number of blows should be between about 20 and 30 blows.
10.1.2 If, during mixing, a small percentage of material is encountered that would be retained on a 425-µm (No. 40) sieve, remove these particles by hand (if possible). If it is impractical to remove the coarser material by hand, remove small percentages (less than about 15 %) of coarser material by working the material (having the above consistency) through a 425-µm sieve. During this procedure, use a piece of rubber sheeting, rubber stopper, or other convenient device provided the procedure does not distort the sieve or degrade material that would be retained if the washing method described in 10.1.2 were used. If larger percentages of coarse material are encountered during mixing, or it is considered impractical to remove the coarser material by the procedures just described, wash the sample as described in 10.1.2. When the coarse particles found during mixing are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-µm sieve, but remove by hand or by washing.

10.1.3 Place the prepared material in the mixing/storage dish, check its consistency (adjust if required), cover to prevent loss of moisture, and allow to stand (cure) for at least 16 h (overnight). After the standing period and immediately before starting the test, thoroughly remix the soil.

Note 6—The time taken to adequately mix a soil will vary greatly, depending on the plasticity and initial water content. Initial mixing times of more than 30 min may be needed for stiff, fat clays.

10.1.2 Material Containing Particles Retained on a 425-µm (No. 40) Sieve:

10.1.2.1 Place the specimen (see 8.2) in a pan or dish and add sufficient water to cover the material. Allow the material to soak until all lumps have softened and the fines no longer adhere to the surfaces of the coarse particles (Note 7).

Note 7—In some cases, the cations of salts present in tap water will exchange with the natural cations in the soil and significantly alter the test results if tap water is used in the soaking and washing operations. Unless it is known that such cations are not present in the tap water, distilled or demineralized water should be used. As a general rule, water containing more than 100 mg/L of dissolved solids should not be used for either the soaking or washing operations.

10.1.2.2 When the material contains a large percentage of particles retained on the 425-µm (No. 40) sieve, perform the following washing operation in increments, washing no more than 0.5 kg (1 lb) of material at one time. Place the 425-µm sieve in the bottom of the clean pan. Transfer, without any loss of material, the soil-water mixture onto a 425-µm (No. 40) sieve until it approaches the liquid limit. Transfer the soil-water mixture over a 2.00-mm (No. 10) sieve nested atop the 425-µm sieve, rinse the fine material through and remove the 2.00-mm sieve. After washing and removing as much of the coarser material as possible, add sufficient water to the pan to bring the level to about 13 mm (½ in.) above the surface of the 425-µm sieve. Agitate the slurry by stirring with the fingers while raising and lowering the sieve in the pan and swirling the suspension so that fine material is washed from the coarser particles. Disaggregate fine soil lumps that have not slaked by gently rubbing them over the sieve with the fingertips. Complete the washing operation by raising the sieve above the water surface and rinsing the material retained with a small amount of clean water. Discard material retained on the 425-µm sieve.

10.1.2.3 Reduce the water content of the material passing the 425-µm sieve (No. 40) sieve to a point where it approaches the liquid limit. Reduction of water content may be accomplished by one or a combination of the following methods: (a) exposing to air currents at room temperature, (b) exposing to warm air currents from a source such as an electric hair dryer, (c) decanting clear water from surface of the suspension, (d) filtering in a Büchner funnel or using filter candles, or (e) draining in a colander or plaster of Paris dish lined with high retentivity filter paper. If a plaster of Paris dish is used, take care that the dish never becomes sufficiently saturated that it fails to absorb water into its surface. Thoroughly dry dish between uses. During evaporation and cooling, stir the material often enough to prevent over-drying of the fringes and soil pinnacles on the surface of the mixture. For materials containing soluble salts, use a method of water reduction (a or b) that will not eliminate the soluble salts from the test specimen.

10.1.2.4 If applicable, remove the material retained on the filter paper. Thoroughly mix this material or the above material on the glass plate or in the mixing dish using the spatula. Adjust the water content of the mixture, if necessary, by adding small increments of distilled or demineralized water or by allowing the mixture to dry at room temperature while mixing on the glass plate. If using Method A, the material should be at a water content that would require about 25 to 35 blows of the liquid limit device to close the groove. For Method B, the number of blows should be between about 20 and 30. Put, if necessary, the mixed material in the storage dish, cover to prevent loss of moisture, and allow to stand (cure) for at least 16 h. After the standing period and immediately before starting the test, thoroughly remix the specimen.

10.2 Dry Preparation Method:

10.2.1 Dry the specimen from 8.2 at room temperature or in an oven at a temperature not exceeding 60°C until the soil clods will pulverize readily. Disaggregation is expedited if the material is not allowed to completely dry. However, the material should have a dry appearance when pulverized.

10.2.2 Pulverize the material in a mortar with a rubber-tipped pestle or in some other way that does not cause breakdown of individual particles. When the coarse particles found during pulverization are concretions, shells, or other fragile particles, do not crush these particles to make them pass a 425-µm (No. 40) sieve, but remove by hand or other suitable means, such as washing. If a washing procedure is used, follow 10.1.2.1-10.1.2.4.

10.2.3 Separate the material on a 425-µm (No. 40) sieve, shaking the sieve by hand to assure thorough separation of the finer fraction. Return the material retained on the 425-µm sieve to the pulverizing apparatus and repeat the pulverizing and sieving operations. Stop this procedure when most of the fine material has been disaggregated and material retained on the 425-µm sieve consists of individual particles.

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6 S and S 595 filter paper available in 320-mm circles has proven satisfactory. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.
10.2.4 Place material retained on the 425-µm (No. 40) sieve after the final pulverizing operations in a dish and soak in a small amount of water. Stir this mixture and transfer it to a 425-µm sieve, catching the water and any suspended fines in the washing pan. Pour this suspension into a dish containing the dry soil previously sieved through the 425-µm sieve. Discard material retained on the 425-µm sieve.

10.2.5 Proceed as described in 10.1.2.3 and 10.1.2.4.

MULTIPOINT LIQUID LIMIT—METHOD A

11. Procedure

11.1 Thoroughly remix the specimen (soil) in its mixing dish, and, if necessary, adjust its water content until the consistency requires about 25 to 35 blows of the liquid limit device to close the groove. Using a spatula, place a portion(s) of the prepared soil in the cup of the liquid limit device at the point where the cup rests on the base, squeeze it down, and spread it into the cup to a depth of about 10 mm at its deepest point, tapering to form an approximately horizontal surface. Take care to eliminate air bubbles from the soil pat, but form the pat with as few strokes as possible. Keep the unused soil in the mixing/storage dish. Cover the dish with a wet towel (or use other means) to retain the moisture in the soil.

11.2 Form a groove in the soil pat by drawing the tool, beveled edge forward, through the soil on a line joining the highest point to the lowest point on the rim of the cup. When cutting the groove, hold the grooving tool against the surface of the cup and draw in an arc, maintaining the tool perpendicular to the surface of the cup throughout its movement. See Fig. 6. In soils where a groove cannot be made in one stroke without tearing the soil, cut the groove with several strokes of the grooving tool. Alternatively, cut the groove to slightly less than required dimensions with a spatula and use the grooving tool to bring the groove to final dimensions. Exercise extreme care to prevent sliding the soil pat relative to the surface of the cup.

11.3 Verify that no crumbs of soil are present on the base or the underside of the cup. Lift and drop the cup by turning the crank at a rate of 1.9 to 2.1 drops per second until the two halves of the soil pat come in contact at the bottom of the groove along a distance of 13 mm (½ in.). See Fig. 7 and Fig. 8. The base of the machine shall not be held with the hand, or hands, while the crank is turned.

NOTE 8—Use of a scale is recommended to verify that the groove has closed 13 mm (½ in.).

11.4 Verify that an air bubble has not caused premature closing of the groove by observing that both sides of the groove have flowed together with approximately the same shape. If a bubble has caused premature closing of the groove, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving operation and repeat 11.1-11.3. If the soil slides on the surface of the cup, repeat 11.1-11.3 at a higher water content. If, after several trials at successively higher water contents, the soil pat continues to slide in the cup or if the number of blows required to close the groove is always less than 25, record that the liquid limit could not be determined, and report the soil as nonplastic without performing the plastic limit test.

11.5 Record the number of drops, N, required to close the groove. Remove a slice of soil approximately the width of the spatula, extending from edge to edge of the soil cake at right
angles to the groove and including that portion of the groove in which the soil flowed together, place in a container of known mass, and cover.

11.6 Return the soil remaining in the cup to the dish. Wash and dry the cup and grooving tool and reattach the cup to the carriage in preparation for the next trial.

11.7 Remix the entire soil specimen in the dish adding distilled water to increase the water content of the soil and decrease the number of blows required to close the groove. Repeat 11.1-11.6 for at least two additional trials producing successively lower numbers of blows to close the groove. One of the trials shall be for a closure requiring 25 to 35 blows, one for closure between 20 and 30 blows, and one trial for a closure requiring 15 to 25 blows.

11.8 Determine the water content, $W^\circ$, of the soil specimen from each trial in accordance with Test Method D2216.
11.8.1 Determination of initial masses (container plus moist soil) should be performed immediately after completion of the test. If the test is to be interrupted for more than about 15 minutes, determine the mass of the water content specimens already obtained at the time of the interruption.

12. Calculation

12.1 Plot the relationship between the water content, \( W_n \), and the corresponding number of drops, \( N \), of the cup on a semilogarithmic graph with the water content as ordinates on the arithmetical scale, and the number of drops as abscissas on a logarithmic scale. Draw the best straight line through the three or more plotted points.

12.2 Take the water content corresponding to the intersection of the line with the 25-drop abscissa as the liquid limit of the soil and round to the nearest whole number. Computational methods may be substituted for the graphical method for fitting a straight line to the data and determining the liquid limit.

**ONE-POINT LIQUID LIMIT—METHOD B**

13. Procedure

13.1 Proceed as described in 11.1-11.5 except that the number of blows required to close the groove shall be 20 to 30. If less than 20 or more than 30 blows are required, adjust the water content of the soil and repeat the procedure.

13.2 Immediately after removing a water content specimen as described in 11.5, reform the soil in the cup, adding a small amount of soil to make up for that lost in the grooving and water content sampling processes.

13.2.1 As an alternative to reforming the soil in the brass cup after removing the water content specimen, the soil remaining in the cup can be removed from the cup, remixed with the soil in the mixing container and a new specimen placed in the cup as described in 11.1.

13.3 Repeat 11.2-11.5

13.4 If the second closing of the groove requires the same number of drops or no more than two drops difference, secure another water content specimen. If the difference of the number of drops between the first and second closings of the groove is greater than two, remix the entire specimen and repeat the procedure, beginning at 13.1, until two successive closings having the same number of drops or no more than two drops difference are obtained.

**NOTE 9**—Excessive drying or inadequate mixing will cause the number of blows to vary.

13.5 Determine water contents of the two specimens in accordance with 11.8.

14. Calculation

14.1 Determine the liquid limit for each water content specimen using one of the following equations:

\[
LL^* = W_n \left( \frac{N}{75} \right)^{0.121} \\
\text{or} \\
LL^* = k \cdot W_n
\]

where:

- \( LL^* \) = one point liquid limit for given trial, %,
- \( N \) = number of blows causing closure of the groove for given trial,
- \( W_n \) = water content for given trial, %, and
- \( k \) = factor given in Table 1.

14.1.1 The liquid limit, \( LL \), is the average of the two trial liquid-limit values, to the nearest whole number (without the percent designation).

14.2 If the difference between the two trial liquid-limit values is greater than one percentage point, repeat the test as described in 13.1 through 14.1.1.

**PLASTIC LIMIT**

15. Preparation of Test Specimen

15.1 Select a 20-g or more portion of soil from the material prepared for the liquid limit test; either, after the second mixing before the test, or from the soil remaining after completion of the liquid limit test. Reduce the water content of the soil to a consistency at which it can be rolled without sticking to the hands by spreading or mixing continuously on the glass plate or in the mixing/storage dish. The drying process may be accelerated by exposing the soil to the air current from an electric fan, or by blotting with paper, that does not add any fiber to the soil. Paper such as hard surface paper toweling or high wet-strength filter paper is adequate.

16. Procedure

16.1 From this plastic-limit specimen, select a 1.5 to 2.0 g portion. Form the selected portion into an ellipsoidal mass.

16.2 Roll the soil mass by one of the following methods (hand or rolling device):

16.2.1 **Hand Method**—Roll the mass between the palm or fingers and the ground-glass plate with just sufficient pressure to roll the mass into a thread of uniform diameter throughout its length (see Note 10). The thread shall be further deformed on each stroke so that its diameter reaches 3.2 mm (1/8 in.), taking no more than 2 min (see Note 11). The amount of hand or finger pressure required will vary greatly according to the soil being tested, that is, the required pressure typically increases with increasing plasticity. Fragile soils of low plasticity are best rolled under the outer edge of the palm or at the base of the thumb.

**NOTE 10**—A normal rate of rolling for most soils should be 80 to 90 strokes per minute, counting a stroke as one complete motion of the hand forward and back to the starting position. This rate of rolling may have to be decreased for very fragile soils.

**NOTE 11**—A 3.2-mm (1/8-in.) diameter rod or tube is useful for frequent comparison with the soil thread to ascertain when the thread has reached the proper diameter.

16.2.2 **Rolling Device Method**—Attach smooth unglazed paper to both the top and bottom plates of the plastic limit-rolling device. Place the soil mass on the bottom plate at the midpoint between the slide rails. Place the top plate in contact with the soil mass(es). Simultaneously apply a slight downward force and back and forth motion to the top plate so that the top plate comes into contact with the side rails within
2 min (see Notes 10 and 12). During this rolling process, the end(s) the soil thread(s) shall not contact the side rail(s). If this occurs, roll a smaller mass of soil (even if it is less than that mentioned in Section 16.1).

**Note 12**—In most cases, two soil masses (threads) can be rolled simultaneously in the plastic limit-rolling device.

16.3 When the diameter of the thread becomes 3.2 mm, break the thread into several pieces. Squeeze the pieces together, knead between the thumb and first finger of each hand, reform into an ellipsoidal mass, and re-roll. Continue this alternate rolling to a thread 3.2 mm in diameter, gathering together, kneading and re-rolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a 3.2-mm diameter thread (see Fig. 9). It has no significance if the thread breaks into threads of shorter length. Roll each of these shorter threads to 3.2 mm in diameter. The only requirement for continuing the test is that these threads can be reformed into an ellipsoidal mass and rolled out again. The operator shall at no time attempt to produce failure at exactly 3.2-mm diameter by allowing the thread to reach 3.2 mm, then reducing the rate of rolling or the hand pressure, or both, while continuing the rolling without further deformation until the thread falls apart. It is permissible, however, to reduce the total amount of deformation for feebly plastic soils by making the initial diameter of the ellipsoidal mass nearer to the required 3.2-mm final diameter. If crumbling occurs when the thread has a diameter greater than 3.2 mm, this shall be considered a satisfactory end point, provided the soil has been previously rolled into a thread 3.2 mm in diameter. Crumbling of the thread will manifest itself differently with the various types of soil. Some soils fall apart in numerous small aggregations of particles, others may form an outside tubular layer that starts splitting at both ends. The splitting progresses toward the middle, and finally, the thread falls apart in many small platy particles. Fat clay soils require much pressure to deform the thread, particularly as they approach the plastic limit. With these soils, the thread breaks into a series of barrel-shaped segments about 3.2 to 9.5 mm (1/4 to 3/8 in.) in length.

16.4 Gather the portions of the crumbled thread together and place in a container of known mass. Immediately cover the container.

16.5 Select another 1.5 to 2.0-g portion of soil from the plastic-limit specimen and repeat the operations described in 16.1 and 16.2 until the container has at least 6 g of soil.

16.6 Repeat 16.1-16.5 to make another container holding at least 6 g of soil. Determine the water content of the soil contained in the containers in accordance with Test Method D2216. See 11.8.1.

17. Calculation

17.1 Compute the average of the two water contents (trial plastic limits) and round to the nearest whole number. This value is the plastic limit, PL. Repeat the test if the difference between the two trial plastic limits is greater than the acceptable range for two results listed in Table 2 for single-operator precision, that is, 1.4 percentage points; i.e., (2.8 × 0.5).

**PLASTICITY INDEX**

18. Calculation

18.1 Calculate the plasticity index as follows:

\[ PI = LL - PL \]

where:

**FIG. 9 Lean Clay Soil at the Plastic Limit**
deviation. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the acceptable range of results cannot have more decimal places than the input data.

Results obtained by these test methods on a range of soil types may vary with soil type and method(s) used. Judgment is required when applying these estimates to another soil and method used. The single operator and multilaboratory standard deviation values given in Tables 2 and 3 are given in Tables 2 and 3. In performing these test methods, Method A and the Wet Preparation Method (except soil was air-dried) were used.

20.1 These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program. In this program, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single-test laboratory). A description of the soils tested is given in 20.1. The precision estimates vary with soil type and method(s) used. Judgment is required when applying these estimates to another soil and method used (Method A or B, or Wet or Dry Preparation Method).

20.1.2 The data in Table 2 are based on three replicate tests per soil type (triplicate test laboratory), while other laboratories performed three replicate tests per soil type. The single operator and multilaboratory standard deviation values given in Tables 2 and 3 are based on three replicate tests performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation values given in Tables 2 and 3 are based on three replicate tests performed by each triplicate test laboratory on each soil type.

18.1.1 Both LL and PL are whole numbers. If either the liquid limit or plastic limit could not be determined, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

19. Report: Test Data Sheet(s)/Form(s)

19.1 The terminology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in 1.9.

19.2 Record as a minimum the following information:

19.2.1 Sample/specimen identifying information, such as project name, project number, boring number, depth (m or ft).

19.2.2 Description of sample, such as approximate maximum grain size, estimate of the percentage of sample retained on the 425-µm (No. 40) sieve, as-received water content.

19.2.3 Details of specimen preparation, such as wet or dry (air-dried or oven-dried), method of removing particles larger than the 425-µm (No. 40) sieve.

19.2.4 Any special specimen selection process used, such as removal of sand lenses from an intact (undisturbed) sample.

19.2.5 Equipment used, such as hand rolled or mechanical rolling device for plastic limit, manual or mechanical liquid limit device, metal or plastic grooving tool.

19.2.6 Liquid limit, plastic limit, and plasticity index to the nearest whole number, omitting the percent designation. If the liquid limit or plastic limit tests could not be performed, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

19.2.7 Procedure by which liquid limit was performed, if it differs from the multipoint method.

20. Precision and Bias

20.1 Precision—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types are given in Tables 2 and 3. In performing these test methods, Method A and the Wet Preparation Method (except soil was air-dried) were used.

20.1.1 The data in Table 2 are based on three replicate tests performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation values given in Tables 2 and 3 are based on three replicate tests performed by each triplicate test laboratory on each soil type.

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20. Precision and Bias

20.1 Precision—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types are given in Tables 2 and 3. In performing these test methods, Method A and the Wet Preparation Method (except soil was air-dried) were used.

20.1.1 These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program. In this program, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single-test laboratory). A description of the soils tested is given in 20.1.5. The precision estimates vary with soil type and method(s) used. Judgment is required when applying these estimates to another soil and method used (Method A or B, or Wet or Dry Preparation Method).

20.1.2 The data in Table 2 are based on three replicate tests performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation values given in Tables 2 and 3 are based on three replicate tests performed by each triplicate test laboratory on each soil type.

18.1.1 Both LL and PL are whole numbers. If either the liquid limit or plastic limit could not be determined, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

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19.2.2 Description of sample, such as approximate maximum grain size, estimate of the percentage of sample retained on the 425-µm (No. 40) sieve, as-received water content.

19.2.3 Details of specimen preparation, such as wet or dry (air-dried or oven-dried), method of removing particles larger than the 425-µm (No. 40) sieve.

19.2.4 Any special specimen selection process used, such as removal of sand lenses from an intact (undisturbed) sample.

19.2.5 Equipment used, such as hand rolled or mechanical rolling device for plastic limit, manual or mechanical liquid limit device, metal or plastic grooving tool.

19.2.6 Liquid limit, plastic limit, and plasticity index to the nearest whole number, omitting the percent designation. If the liquid limit or plastic limit tests could not be performed, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

19.2.7 Procedure by which liquid limit was performed, if it differs from the multipoint method.

20. Precision and Bias

20.1 Precision—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types are given in Tables 2 and 3. In performing these test methods, Method A and the Wet Preparation Method (except soil was air-dried) were used.

20.1.1 These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program. In this program, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single-test laboratory). A description of the soils tested is given in 20.1.5. The precision estimates vary with soil type and method(s) used. Judgment is required when applying these estimates to another soil and method used (Method A or B, or Wet or Dry Preparation Method).

20.1.2 The data in Table 2 are based on three replicate tests performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation values given in Tables 2 and 3 are based on three replicate tests performed by each triplicate test laboratory on each soil type.

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19.2 Record as a minimum the following information:

19.2.1 Sample/specimen identifying information, such as project name, project number, boring number, depth (m or ft).

19.2.2 Description of sample, such as approximate maximum grain size, estimate of the percentage of sample retained on the 425-µm (No. 40) sieve, as-received water content.

19.2.3 Details of specimen preparation, such as wet or dry (air-dried or oven-dried), method of removing particles larger than the 425-µm (No. 40) sieve.

19.2.4 Any special specimen selection process used, such as removal of sand lenses from an intact (undisturbed) sample.

19.2.5 Equipment used, such as hand rolled or mechanical rolling device for plastic limit, manual or mechanical liquid limit device, metal or plastic grooving tool.

19.2.6 Liquid limit, plastic limit, and plasticity index to the nearest whole number, omitting the percent designation. If the liquid limit or plastic limit tests could not be performed, or if the plastic limit is equal to or greater than the liquid limit, report the soil as nonplastic, NP.

19.2.7 Procedure by which liquid limit was performed, if it differs from the multipoint method.

20. Precision and Bias

20.1 Precision—Criteria for judging the acceptability of test results obtained by these test methods on a range of soil types are given in Tables 2 and 3. In performing these test methods, Method A and the Wet Preparation Method (except soil was air-dried) were used.

20.1.1 These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program. In this program, some laboratories performed three replicate tests per soil type (triplicate test laboratory), while other laboratories performed a single test per soil type (single-test laboratory). A description of the soils tested is given in 20.1.5. The precision estimates vary with soil type and method(s) used. Judgment is required when applying these estimates to another soil and method used (Method A or B, or Wet or Dry Preparation Method).

20.1.2 The data in Table 2 are based on three replicate tests performed by each triplicate test laboratory on each soil type. The single operator and multilaboratory standard deviation values given in Tables 2 and 3 are based on three replicate tests performed by each triplicate test laboratory on each soil type.
the same material, using the same equipment, and in the shortest practical period of time should not differ by more than the single-operator $d_2$ limits shown in Table 2, Column 5. For definition of $d_2$, see Footnote C in Table 2. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory $d_2$ limits shown in Table 2, Column 5.

20.1.3 In the ASTM Reference Soils and Testing Program, many of the laboratories performed only a single test on each soil type. This is common practice in the design and construction industry. The data for each soil type in Table 3 are based upon the first test results from the triplicate test laboratories and the single test results from the other laboratories. Results of two properly conducted tests performed by two different laboratories with different operators using different equipment and on different days should not vary by more than the $d_2$ limits shown in Table 3, Column 5. The results in Table 2 and Table 3 are dissimilar because the data sets are different.

20.1.4 Table 2 presents a rigorous interpretation of triplicate test data in accordance with Practice E691 from pre-qualified laboratories. Table 3 is derived from test data that represents common practice.

20.1.5 Soil Types—Based on the multilaboratory test results, the soils used in the program are described below in accordance with Practice D2487. In addition, the local names of the soils are given.

**CH**—Fat clay, CH, 99% fines, LL=60, PI=39; grayish brown, soil had been air dried and pulverized. Local name—Vicksburg Buckshot Clay

**CL**—Lean clay, CL, 89% fines, LL=33, PI=13; gray, soil had been air dried and pulverized. Local name—Annapolis Clay

**ML**—Silt, ML, 99% fines, LL=27, PI=4; light brown, soil had been air dried and pulverized. Local name—Vicksburg Silt

20.2 Bias—There is no acceptable reference value for these test methods; therefore, bias cannot be determined.

21. Keywords

21.1 activity; Atterberg limits; liquid limit; plasticity index; plastic limit

ANNEX

(Mandatory Information)

A1. Resilience Tester

A1.1 A device for measuring the resilience of liquid limit device bases is shown in Fig. A1.1. The device consists of a clear acrylic plastic tube and cap, a ½-in. diameter steel ball, and a small bar magnet. The cylinder may be cemented to the cap or threaded as shown. The small bar magnet is held in the recess of the cap and the steel ball is fixed into the recess in the underside of the cap with the bar magnet. The cylinder is then turned upright and placed on the top surface of the base to be tested. Holding the tube lightly against the liquid limit device base with one hand, release the ball by pulling the magnet out of the cap. Use the scale markings on the outside of the cylinder to determine the highest point reached by the bottom of the ball. Repeat the drop at least three times, placing the tester in a different location for each drop. Tests should be conducted at room temperature.
FIG. A1.1 Resilience Tester

APPENDIX

X1. Sample Data Sheet

X1.1 See Fig. X1.1.
Committee D18 has identified the location of selected changes to this standard since the last issue (D4318 – 05) that may impact the use of this standard. (Approved January 15, 2010.)

(1) Corrected 1.6 to reference D4542 and added D4542 to Referenced Documents in Section 2.
(2) In 1.8 and 1.8.1, clarified use of SI units.
(3) Added 1.9 referencing D6026 and the use of significant digits and renumbered 1.9 as 1.10.
(4) In 6.1 and 6.1.1 reworded the requirements for the composition of the base and removed the word “rubber.” “Rubber” was also removed from the label in Fig. 1.
(5) In 6.1.2 removed the Durometer hardness requirement for the rubber feet.
(6) In 6.7.1 removed the dimensional requirements for the Ground Glass Plate.
(7) In 9.1.1.5 added guidance for replacement of rubber feet.
(8) In 11.1 changed “cup” to “dish” for consistency.
(9) In 11.3 added instruction that the base shall not be held during testing.
(10) In 13.2 to 13.5 clarified the instructions to allow two alternative test procedures.
(11) Section 19 was updated to comply with the D18.91 Special Memorandum on Report Section.
The Nizhny Tagil Charter for the Industrial Heritage

The International Committee for the Conservation of the Industrial Heritage (TICCIH)

17 July, 2003

TICCIH is the world organisation representing industrial heritage and is special adviser to ICOMOS on industrial heritage. The text of this charter was passed by the assembled delegates at the triennial National Assembly of TICCIH held in Moscow on 17 July, 2003.

Preamble

The earliest periods of human history are defined by the archaeological evidence for fundamental changes in the ways in which people made objects, and the importance of conserving and studying the evidence of these changes is universally accepted.

From the Middle Ages, innovations in Europe in the use of energy and in trade and commerce led to a change towards the end of the 18th century just as profound as that between the Neolithic and Bronze Ages, with developments in the social, technical and economic circumstances of manufacturing sufficiently rapid and profound to be called a revolution. The Industrial Revolution was the beginning of a historical phenomenon that has affected an ever-greater part of the human population, as well as all the other forms of life on our planet, and that continues to the present day.

The material evidence of these profound changes is of universal human value, and the importance of the study and conservation of this evidence must be recognised.

The delegates assembled for the 2003 TICCIH Congress in Russia wish therefore to assert that the buildings and structures built for industrial activities, the processes and tools used within them and the towns and landscapes in which they are located, along with all their other tangible and intangible manifestations, are of fundamental importance. They should be studied, their history should be taught, their meaning and significance should be probed and made clear for everyone, and the most significant and characteristic examples should be identified, protected and maintained, in accordance with the spirit of the Venice Charter\(^1\), for the use and benefit of today and of the future.

\(^1\) The ICOMOS ‘Venice Charter for the Conservation and Restoration of Monuments and Sites’, 1964.
1. Definition of industrial heritage

Industrial heritage consists of the remains of industrial culture which are of historical, technological, social, architectural or scientific value. These remains consist of buildings and machinery, workshops, mills and factories, mines and sites for processing and refining, warehouses and stores, places where energy is generated, transmitted and used, transport and all its infrastructure, as well as places used for social activities related to industry such as housing, religious worship or education.

Industrial archaeology is an interdisciplinary method of studying all the evidence, material and immaterial, of documents, artefacts, stratigraphy and structures, human settlements and natural and urban landscapes, created for or by industrial processes. It makes use of those methods of investigation that are most suitable to increase understanding of the industrial past and present.

The historical period of principal interest extends forward from the beginning of the Industrial Revolution in the second half of the eighteenth century up to and including the present day, while also examining its earlier pre-industrial and proto-industrial roots. In addition it draws on the study of work and working techniques encompassed by the history of technology.

2. Values of industrial heritage

i. The industrial heritage is the evidence of activities which had and continue to have profound historical consequences. The motives for protecting the industrial heritage are based on the universal value of this evidence, rather than on the singularity of unique sites.

ii. The industrial heritage is of social value as part of the record of the lives of ordinary men and women, and as such it provides an important sense of identity. It is of technological and scientific value in the history of manufacturing, engineering, construction, and it may have considerable aesthetic value for the quality of its architecture, design or planning.

iii. These values are intrinsic to the site itself, its fabric, components, machinery and setting, in the industrial landscape, in written documentation, and also in the intangible records of industry contained in human memories and customs.

iv. Rarity, in terms of the survival of particular processes, site typologies or landscapes, adds particular value and should be carefully assessed. Early or pioneering examples are of especial value.

3. The importance of identification, recording and research

i. Every territory should identify record and protect the industrial remains that it wants to preserve for future generations.

ii. Surveys of areas and of different industrial typologies should identify the extent of the industrial heritage. Using this information, inventories should be created of all the sites that have been identified. They should be devised to be easily searchable and should be freely accessible to the public. Computerisation and on-line access are valuable objectives.

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2 For convenience, 'sites' will be taken to mean landscapes, complexes, buildings, structures and machines unless these terms are used in a more specific way.
iii. Recording is a fundamental part of the study of industrial heritage. A full record of the physical features and condition of a site should be made and placed in a public archive before any interventions are made. Much information can be gained if recording is carried out before a process or site has ceased operation. Records should include descriptions, drawings, photographs and video film of moving objects, with references to supporting documentation. Peoples’ memories are a unique and irreplaceable resource which should also be recorded when they are available.

iv. Archaeological investigation of historic industrial sites is a fundamental technique for their study. It should be carried out to the same high standards as that of sites from other historical or cultural periods.

v. Programmes of historical research are needed to support policies for the protection of the industrial heritage. Because of the interdependency of many industrial activities, international studies can help identify sites and types of sites of world importance.

vi. The criteria for assessing industrial buildings should be defined and published so as to achieve general public acceptance of rational and consistent standards. On the basis of appropriate research, these criteria should be used to identify the most important surviving landscapes, settlements, sites, typologies, buildings, structures, machines and processes.

vii. Those sites and structures that are identified as important should be protected by legal measures that are sufficiently strong to ensure the conservation of their significance. The World Heritage List of UNESCO should give due recognition to the tremendous impact that industrialisation has had on human culture.

viii. The value of significant sites should be defined and guidelines for future interventions established. Any legal, administrative and financial measures that are necessary to maintain their value should be put in place.

ix. Sites that are at risk should be identified so that appropriate measures can be taken to reduce that risk and facilitate suitable schemes for repairing or re-using them.

x. International co-operation is a particularly appropriate approach to the conservation of the industrial heritage through co-ordinated initiatives and sharing resources. Compatible criteria should be developed to compile international inventories and databases.

4. Legal protection

I. The industrial heritage should be seen as an integral part of the cultural heritage in general. Nevertheless, its legal protection should take into account the special nature of the industrial heritage. It should be capable of protecting plant and machinery, below-ground elements, standing structures, complexes and ensembles of buildings, and industrial landscapes. Areas of industrial waste should be considered for their potential archaeological as well as ecological value.

II. Programmes for the conservation of the industrial heritage should be integrated into policies for economic development and into regional and national planning.

III. The most important sites should be fully protected and no interventions allowed that compromise their historical integrity or the authenticity of their fabric. Sympathetic adaptation and re-use may be an appropriate and a cost-effective way of ensuring the survival of industrial
buildings, and should be encouraged by appropriate legal controls, technical advice, tax incentives and grants.

IV. Industrial communities which are threatened by rapid structural change should be supported by central and local government authorities. Potential threats to the industrial heritage from such changes should be anticipated and plans prepared to avoid the need for emergency actions.

V. Procedures should be established for responding quickly to the closure of important industrial sites to prevent the removal or destruction of significant elements. The competent authorities should have statutory powers to intervene when necessary to protect important threatened sites.

VI. Government should have specialist advisory bodies that can give independent advice on questions relating to the protection and conservation of industrial heritage, and their opinions should be sought on all important cases.

VII. Every effort should be made to ensure the consultation and participation of local communities in the protection and conservation of their local industrial heritage.

VIII. Associations and societies of volunteers have an important role in identifying sites, promoting public participation in industrial conservation and disseminating information and research, and as such are indispensable actors in the theatre of industrial heritage.

5. Maintenance and conservation

I. Conservation of the industrial heritage depends on preserving functional integrity, and interventions to an industrial site should therefore aim to maintain this as far as possible. The value and authenticity of an industrial site may be greatly reduced if machinery or components are removed, or if subsidiary elements which form part of a whole site are destroyed.

II. The conservation of industrial sites requires a thorough knowledge of the purpose or purposes to which they were put, and of the various industrial processes which may have taken place there. These may have changed over time, but all former uses should be examined and assessed.

III. Preservation in situ should always be given priority consideration. Dismantling and relocating a building or structure are only acceptable when the destruction of the site is required by overwhelming economic or social needs.

IV. The adaptation of an industrial site to a new use to ensure its conservation is usually acceptable except in the case of sites of especial historical significance. New uses should respect the significant material and maintain original patterns of circulation and activity, and should be compatible as much as possible with the original or principal use. An area that interprets the former use is recommended.

V. Continuing to adapt and use industrial buildings avoids wasting energy and contributes to sustainable development. Industrial heritage can have an important role in the economic regeneration of decayed or declining areas. The continuity that re-use implies may provide psychological stability for communities facing the sudden end a long-standing sources of employment.

VI. Interventions should be reversible and have a minimal impact. Any unavoidable changes should be documented and significant elements that are removed should be recorded and stored safely. Many industrial processes confer a patina that is integral to the integrity and interest of the site.
VII. Reconstruction, or returning to a previous known state, should be considered an exceptional intervention and one which is only appropriate if it benefits the integrity of the whole site, or in the case of the destruction of a major site by violence.

VIII. The human skills involved in many old or obsolete industrial processes are a critically important resource whose loss may be irreplaceable. They need to be carefully recorded and transmitted to younger generations.

IX. Preservation of documentary records, company archives, building plans, as well as sample specimens of industrial products should be encouraged.

6. Education and training

I. Specialist professional training in the methodological, theoretical and historical aspects of industrial heritage should be taught at technical and university levels.

II. Specific educational material about the industrial past and its heritage should be produced by and for students at primary and secondary level.

7. Presentation and interpretation

I. Public interest and affection for the industrial heritage and appreciation of its values are the surest ways to conserve it. Public authorities should actively explain the meaning and value of industrial sites through publications, exhibitions, television, the Internet and other media, by providing sustainable access to important sites and by promoting tourism in industrial areas.

II. Specialist industrial and technical museums and conserved industrial sites are both important means of protecting and interpreting the industrial heritage.

III. Regional and international routes of industrial heritage can highlight the continual transfer of industrial technology and the large-scale movement of people that can be caused by it.

Endorsed

Eusebi Casanelles
President TICCIH

Eugene Logunov
TICCIH XII International Congress

Nizhny Tagil, 2003
Joint ICOMOS – TICCIH Principles for the Conservation of Industrial Heritage Sites, Structures, Areas and Landscapes

«The Dublin Principles»

Adopted by the 17th ICOMOS General Assembly on 28 November 2011

Preamble

Around the World, a great diversity of sites, structures, complexes, cities and settlements, areas, landscapes and routes bear witness to human activities of industrial extraction and production. In many places, this heritage is still in use and industrialisation is still an active process with a sense of historical continuity, while in other places it offers archaeological evidence of past activities and technologies. Besides the tangible heritage associated with industrial technology and processes, engineering, architecture and town-planning, it includes many intangible dimensions embodied in the skills, memories and social life of workers and their communities.

The global process of industrialisation observed over the past two centuries constitutes a major stage of human history, making its heritage particularly important and critical to the Modern World. Precursors and beginnings of industrialisation can be recognized in many parts of the world well back into ancient times through active or archaeological sites, and our attention extends to any examples of such process and its heritage. However, for our purposes, these joint principles’ primary interests coincide with the common notions of the Modern Era Industrial Revolution, marked by distinctive and dedicated production, transportation and power-generating or harnessing processes and technologies, trade and commercial interactions, and new social and cultural patterns.

Principes conjoints ICOMOS-TICCIH pour la conservation des sites, constructions, aires et paysages du patrimoine industriel

«Les principes de Dublin»

Adoptées par la 17e Assemblée générale de l’ICOMOS le 28 novembre 2011

Préambule

À travers le monde, la vaste diversité de sites, de constructions, de complexes, de villes et d’établissements, d’aires, de paysages ou de routes témoignent d’activités humaines d’extraction et de production industrielles. En de nombreux endroits, ce patrimoine est en opération et l’industrialisation constitue un processus actif chargé de continuité historique ; ailleurs, des ressources archéologiques révèlent les activités et technologies passées. Au patrimoine matériel lié aux procédés et techniques de l’industrie, du génie civil, de l’architecture ou de l’urbanisme, s’ajoute un patrimoine immatériel lié aux savoir-faire, à la mémoire ou à la vie sociale des ouvriers et de leurs communautés.

Le processus global d’industrialisation observé au cours des deux derniers siècles constitue une étape majeure de l’histoire humaine et son patrimoine revêt une importance significative dans le monde contemporain. En plusieurs parties du monde, les précurseurs et les débuts de l’industrialisation sont reconnus, remontant aux périodes anciennes, par des sites archéologiques ou actifs. Ces Principes conjoints s’intéressent à tout exemple de ce processus et de son patrimoine. Toutefois, l’intérêt premier de ces principes conjoints correspond aux concepts reconnus de Révolution industrielle de l’ère moderne, marquée par le développement et l’utilisation de processus et de technologies en matière de production, de transport et de génération d’énergie, d’échanges commerciaux et de pratiques sociales ou culturelles.
The industrial heritage is highly vulnerable and often at risk, often lost for lack of awareness, documentation, recognition or protection but also because of changing economic trends, negative perceptions, environmental issues or its sheer size and complexity. Yet, by extending the life-cycle of existing structures and their embodied energy, conservation of the built industrial heritage, can contribute to achieving the goals of sustainable development at the local, national and international levels. It touches the social as well as the physical and environmental aspects of development and should be acknowledged as such.

Over the past decades, growing research, international and interdisciplinary cooperation as well as community initiatives have greatly contributed to a better appreciation of the industrial heritage and increased collaboration between stewards, stakeholders and professionals. This progress has benefitted from the development of a corpus of international references and guidelines by ICOMOS – the International Council on Monuments and Sites, and the implementation of international recommendations and instruments such as the World Heritage Convention adopted by UNESCO in 1972. In 2003, The International Committee for the Conservation of Industrial Heritage (TICCIH) adopted its Nizhny Tagil Charter for the Industrial Heritage, a first international reference text of such recognition to guide protection and conservation in the field.

Acknowledging the particular nature of the industrial heritage and the issues and threats affecting it as a result of its relation to the contemporary economic, legal, cultural and environmental contexts, ICOMOS and TICCIH wish to expand their cooperation by adopting and promoting the dissemination and use of the following Principles to assist in the documentation, protection, conservation and appreciation of industrial heritage as part of the heritage of human societies around the World.

1 Definition: The industrial heritage consists of sites, structures, complexes, areas and landscapes as well as the related machinery, objects or documents that provide evidence of past or ongoing industrial processes of production, the extraction of raw materials, their transformation into goods, and the related energy and transport infrastructures. Industrial heritage reflects the profound connection between the cultural and natural environment, as industrial processes – whether ancient or

Le patrimoine industriel est très vulnérable, menacé de disparaître faute de sensibilité, de connaissance, de reconnaissance ou de protection, sous l’effet d’une économie en mutation, de perceptions négatives, d’enjeux environnementaux ou de sa propre taille ou complexité. La conservation du patrimoine bâti industriel prolonge pourtant la vie utile des constructions et de l’investissement énergétique qu’elles représentent. Sa contribution à la réalisation des objectifs du développement durable local, national et international, à ses dimensions sociales, physiques ou environnementales du développement doit être reconnue.

Au cours des dernières décennies, les progrès de la recherche, de la coopération internationale et interdisciplinaire et les initiatives communautaires ont contribué à valoriser le patrimoine industriel et la collaboration entre les détenteurs, les intéressés et les experts pour sa conservation. Ce progrès a bénéficié d’un corpus de références et d’orientations internationales élaboré par l’ICOMOS (Conseil international des monuments et des sites) et de la mise en œuvre d’instruments internationaux dont la Convention du patrimoine mondial adoptée par l’UNESCO en 1972. En 2003, le Comité international pour la conservation du patrimoine industriel (TICCIH) adoptait la Charte de Nizhny Tagil, un premier texte de référence international pour aider à la protection et la conservation du patrimoine industriel.

Reconnaissant la nature particulière du patrimoine industriel et des enjeux et menaces qui l’affectent de par sa relation avec l’économie, les lois, la culture ou les questions environnementales actuelles, l’ICOMOS et le TICCIH étendent leur coopération en adoptant ces Principes conjoints et en encourageant leur application et leur désémination pour aider à la connaissance, la protection, la conservation et la mise en valeur du patrimoine industriel comme partie du patrimoine des sociétés humaines à travers le monde.

1 Définition : Le patrimoine industriel comprend les sites, les constructions, les complexes, les territoires et les paysages ainsi que les équipements, les objets ou les documents qui témoignent des procédés industriels anciens ou courants de production par l’extraction et la transformation des matières premières ainsi que des infrastructures énergétiques ou de transport qui y sont associées. Il exprime une relation étroite entre l’environnement culturel et naturel puisque les procédés industriels – anciens ou
modern – depend on natural sources of raw materials, energy and transportation networks to produce and distribute products to broader markets. It includes both material assets – immovable and movable –, and intangible dimensions such as technical know-how, the organisation of work and workers, and the complex social and cultural legacy that shaped the life of communities and brought major organizational changes to entire societies and the world in general.

2 Industrial heritage sites are very diversified in terms of their purpose, design and evolution over time. Many are representative of processes, technologies as well as regional or historical conditions while others constitute outstanding achievements of global influence. Others are complexes and multiple site operations or systems whose many components are interdependent, with different technologies and historical periods frequently present. The significance and value of industrial heritage is intrinsic to the structures or sites themselves, their material fabric, components, machinery and setting, expressed in the industrial landscape, in written documentation, and also in the intangible records contained in memories, arts and customs.

1 - Document and understand industrial heritage structures, sites, areas and landscapes and their values

3 Researching and documenting industrial structures, sites, landscapes and the related machinery, equipment, records or intangible aspects is essential to their identification, conservation, and the appreciation of their heritage significance and value. Human skills and knowledge involved in old industrial processes are a critically important resource in conservation and must be considered in the heritage evaluation process.

4 Researching and documenting industrial heritage sites and structures must address their historical, technological and socio-economic dimensions to provide an integrated base for conservation and management. It requires an interdisciplinary approach supported by interdisciplinary research and educational programmes to identify the significance of


2 La grande diversité des sites du patrimoine industriel découle de leurs fonctions, de leurs formes et de leur évolution. Beaucoup illustrent des procédés, des technologies ou des conditions régionales ou historiques. Certains constituent des réalisations exceptionnelles ou influentes. Les complexes industriels, les opérations réparties sur de multiples sites ou les systèmes regroupent des composantes souvent d’époques ou de technologies différentes. L’intérêt du patrimoine industriel réside dans les constructions et les sites, dans leurs composantes matérielles et équipements, dans leur contexte et le paysage industriel qu’il forme, dans les documents ainsi que dans les dimensions immatérielles portées par la mémoire, les arts et les coutumes.

1 - Étudier et comprendre les constructions, sites, aires et paysages industriels et leur valeur patrimoniale

3 L’étude et la documentation des constructions, des sites et paysages industriels ainsi que des machines, des équipements, des archives ou de leurs dimensions immatérielles est nécessaire à leur identification, leur conservation et l’appréciation de leur intérêt et de leur valeur patrimoniale. Les savoir-faire liés aux anciens procédés industriels sont d’une grande importance dans la conservation et doivent être pris en compte par les processus d’évaluation patrimoniale.

4 L’étude et la documentation des constructions et des sites du patrimoine industriel doivent examiner leurs dimensions historiques, technologiques et socio-économiques afin de fonder leur conservation et leur gestion sur une connaissance intégrée alimentée par une approche interdisciplinaire et par des recherches et des programmes éducatifs qui
industrial heritage sites or structures. It should benefit from a diversity of sources of expertise and information including site surveys and recording, historical and archaeological investigation, material and landscape analysis, oral history and/or research in public, corporate or private archives. Research and preservation of documentary records, company archives, building plans, and specimens of industrial products should be encouraged. The evaluation and assessment of documents should be undertaken by an appropriate specialist in the industry to which they relate to determine their heritage significance. The participation of communities and other stakeholders is also an integral part of this exercise.

5 Thorough knowledge of the industrial and socio-economic history of an area or country or their links to other parts of the world is necessary to understand the significance of industrial heritage sites or structures. Single industry context, typological or regional studies, with a comparative component, aimed at key industrial sectors or technologies are very useful in recognizing the heritage values inherent in individual structures, sites, areas or landscapes. They should be accessible and searchable by the public, scholars as well as managers.

II - Ensure effective protection and conservation of the industrial heritage structures, sites, areas and landscapes

6 Appropriate policies, legal and administrative measures need to be adopted and adequately implemented to protect and ensure the conservation of industrial heritage sites and structures, including their machinery and records. These measures have to address the close relation between the industrial heritage, industrial production and the economy, in particular with respect to rules for corporations and investments, trades or intellectual property such as patents, and standards applicable to active industrial operations.

7 Integrated inventories and lists of structures, sites, areas, landscapes their setting and associated objects, documents, drawings and archives or intangible heritage should be developed and used as part of these effective

aident à énoncer leurs valeurs patrimoniales. Cette approche doit bénéficier de l’apport d’une diversité de sources d’expertise et d’information dont les études et relevés de site, les études historiques et archéologiques, les analyses matérielles ou paysagères ainsi que la consultation des archives publiques, d’entreprises ou privées. L’examen et la conservation des archives industrielles, des plans et d’échantillons ou d’exemples de production doivent être encouragés et leur évaluation devrait être menée par des spécialistes du type d’industrie auquel ils sont associés. La participation des citoyens, des communautés et d’autres intéressés est une partie intégrale de cette activité.

5 Une connaissance approfondie de l’histoire industrielle et socio-économique d’une ville, d’une région ou d’un pays ainsi que de leurs liens avec d’autres parties du monde est nécessaire pour comprendre l’intérêt patrimonial des constructions ou des sites industriels. Des études comparatives, typologiques ou régionales sur certains secteurs industriels ou certaines technologies sont utiles pour évaluer l’intérêt de constructions, de sites ou de paysages particuliers. Elles devraient être accessibles au public, aux chercheurs comme aux gestionnaires.

II - Assurer la protection et la conservation efficaces des constructions, sites, aires et paysages du patrimoine industriel

6 L’adoption et la mise en œuvre de politiques et de mesures légales et administratives adéquates sont nécessaires à la protection et à la conservation des constructions et des sites du patrimoine industriel y compris leurs équipements et documents. Ces mesures doivent tenir compte de la relation étroite entre le patrimoine industriel, la production et l’économie notamment quant aux règles sur les entreprises et sur les investissements, aux métiers, aux éléments de propriété intellectuelle comme les brevets et aux normes régissant les activités industrielles.

7 Des inventaires intégrés des constructions, sites, aires et paysages, leur contexte ainsi que des objets, documents, dessins, archives et patrimoine immatériel associés à l’industrialisation doivent être faits et utilisés
management and conservation policies and protection measures. These should benefit from a legal recognition, adequate conservation and management to ensure that their significance, integrity and authenticity are maintained. In the case of industrial heritage identified through fortuitous discovery, temporary protection should be granted to allow time necessary for proper heritage documentation and research.

8 In the case of active industrial structures or sites of heritage significance, it must be recognized that their continued use and function might carry some of their heritage significance and provide adequate conditions for their physical and economic sustainability as a living production or extraction facilities. Their specific technical characteristics and features need to be respected while implementing contemporary regulations such as building codes, environmental requirements or risk reduction strategies to address hazards of natural or human origin.

9 Protection measures should apply to buildings and their contents since completeness or functional integrity is especially important to the significance of industrial heritage structures and sites. Their heritage value may be greatly jeopardized or reduced if machinery or other significant components are removed, or if subsidiary elements which form part of a whole site are destroyed. Legal and administrative frameworks should be developed to enable authorities to respond quickly to the closure of operating industrial heritage sites and complexes to prevent removal or destruction of significant elements such as machinery, industrial objects or related records.

III - Conserve and maintain the industrial heritage structures, sites, areas and landscapes

10 Appropriate original or alternative and adaptive use is the most frequent way and often the most sustainable way of ensuring the conservation of industrial heritage sites or structures. New uses should respect significant material, components and patterns of circulation and activity. Specialist skills are necessary to ensure that the heritage significance is taken into account and respected in managing the sustainable use of these industrial heritage sites and structures.
Building codes, risk mitigation requirements, environmental or industrial regulations, and other standards should be implemented in an adapted way to take heritage dimensions into account when they are enforced through physical interventions.

Wherever possible, physical interventions should be reversible, and respect the age value and significant traces or marks. Changes should be documented. Reverting to a previous known state may be acceptable under exceptional circumstances for educational purposes, and must be based on thorough research and documentation. Dismantling and relocating are only acceptable in extraordinary cases when the destruction of the site is required by objectively proved overwhelming economic or social needs.

In case of prospective redundancy, decommissioning, and/or adaptation of industrial heritage sites or structures, the processes should be recorded including, for example, where components have to be demolished and machinery has to be removed. Their material form as well as their functioning and location as part of the industrial processes should be exhaustively documented. Oral and/or written stories of people connected with work processes should also be collected.

The industrial heritage is a source of learning which needs to be communicated in its multiple dimensions. It illustrates important aspects of local, national and international history and interactions over times and cultures. It demonstrates the inventive talents related to scientific and technological developments, as well as social and artistic movements. Public and corporate awareness and understanding for the industrial heritage are important means for its successful conservation.

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Les interventions physiques devraient être réversibles et respecter le caractère historique et les traces qui y contribuent. Les transformations devraient être documentées. Le rétablissement d’un état antérieur connu pourrait être recevable dans des cas exceptionnels à des fins éducatives ; il devrait reposer sur des recherches et une documentation complètes. Le démontage et le déplacement ne sont acceptables que lorsque des besoins impératifs économiques ou sociaux démontrés avec objectivité exigent la destruction du site.

En cas d’obsolescence de sites ou de constructions industriels d’intérêt patrimonial, les procédés devraient être documentés, notamment lorsque des composantes sont appelées à être démoliés ou des machines retirées. Leur forme, leur fonctionnement et leur position et leur rôle dans le procédé industriel doivent être documentés exhaustivement. L’histoire orale ou les récits de personnes associées à ces procédés et le travail de l’industrie doivent aussi être colligés.

IV - Present and communicate the heritage dimensions and values of industrial structures, sites, areas and landscapes to raise public and corporate awareness, and support training and research

IV - Présenter et communiquer les valeurs patrimoniales des constructions, sites, aires et paysages du patrimoine industriel pour sensibiliser le public et les entreprises et soutenir l’éducation et la recherche

Le patrimoine industriel est une source d’enseignements qui doivent être partagés dans leurs multiples dimensions. Il met en lumière des pans importants de l’histoire locale, nationale et internationale et les échanges de longue durée entre les cultures. Il témoigne des talents et de l’ingéniosité associés au progrès des sciences et des techniques ainsi que de l’évolution de la société ou des arts. L’éveil d’une conscience du patrimoine industriel dans la population et dans les entreprises contribue au succès de sa conservation.
Programmes and facilities such as visits of active industrial heritage sites and the presentation of their operations as well as the stories and intangible heritage associated with their history, machinery and industrial processes, industrial or city museums and interpretation centres, exhibitions, publications, websites, regional or trans-boundary itineraries should be developed and sustained as means to raise awareness and appreciation for the industrial heritage in the full richness of its meaning for contemporary societies. These should ideally be located at the heritage sites itself where the process of industrialisation has taken place and can be best communicated. Wherever possible, national and international institutions in the field of research and conservation of heritage should be empowered to use them as educational facilities for the general public and the professional communities.

La création et le maintien de programmes et d’équipements de mise en valeur du patrimoine industriel doivent être encouragés ; par exemple, les visites de sites en activité qui en exposent le fonctionnement et les récits ou le patrimoine immatériel associés à leur histoire, leurs machines ou leurs procédés, les musées de ville et les centres d’interprétation industriels, les expositions et les publications, le web ou des itinéraires régionaux ou transfrontaliers. Préférentiellement, ces programmes et équipements de diffusion devraient être situés sur le site patrimonial où le processus d’industrialisation s’est déroulé et où il peut être le mieux présenté. Autant que possible, les organisations nationales et internationales dans les domaines de l’étude et de la conservation du patrimoine devraient être en mesure d’utiliser ces sites à des fins éducatives pour le grand public et les milieux spécialisés.
9. Index

adaptive reuse – 49, 121-2
the Archie Bray Foundation for the Ceramic Arts – 1, 5, 45-6, 122, 131-2, 145, 154, 157-8
Architectural Conservation Lab – 1, 35
Association for Industrial Archaeology – 115
Autio, Rudy – 46-7, 145, 148, 153-4
Berlin, Germany – 136-9, 141, 145-6
Bray
Charles – 8-9, 23, 31, 36, 48, 53, 127, 153
Archie, Jr. – 4, 28, 31-2, 38, 46-7, 99, 102, 127, 130, 132
Archie, Sr. – 29, 36, 40, 47, 127, 137
the Center for Art in Wood – 158
continuous kilns
Hoffmann kilns – 26-8, 138, 140-1, 143
tunnel kilns – 4, 28, 47
corrosion – 58, 60-1, 64, 70, 80, 106, 150-1
Clawson, Chip – 105, 128
Cossons, Neil – 111, 116
deformation (of brick masonry) – 38, 44, 58, 60-1, 68-9, 79-81, 88, 99, 101-2, 106, 149-51
Deutsche Tonstrasse – 145-6
downdraft kilns
bottom – 7, 12, 15-6, 22, 31, 34, 42, 44, 102, 128, 131
crown – 11, 15-7, 25, 36-7, 41-5, 57, 81, 100, 102, 149
firebox – 14, 16-17, 20, 22, 34, 37-41, 43-5, 57, 59-60, 93, 96, 100, 104, 149, 15, 156
flues – 5, 8, 11-3, 15-7, 21, 25, 27, 42, 130-1, 135, 153-4, 157
lining – 11-2, 15, 25, 39, 41-2, 44-5
stack – 8, 13, 15-7, 25, 27, 32, 38, 50, 127, 130-1, 153

efflorescence – 56, 58-61, 66, 79-80, 86, 88, 92, 96-7, 99-100, 103-4, 107, 150, 156
erosion (of brick, of kiln wall binder) – 60, 66, 79-80, 86, 99, 103-4, 107, 150-1
European Route of Industrial Heritage – 146-7
industrial archaeology – 109-15, 117, 120, 139
the International Committee for the Conservation
of the Industrial Heritage (TICCIH) – 116-9, 129, 142
the International Committee for Monuments and Sites (ICOMOS) – 117-9, 129
Ironbridge Gorge Museum Trust – 116, 139
Kiln No. 3 (Western Clay) – 31-2
Kiln No. 4 – 31, 45, 57, 148-57
Kiln No. 5 – 34, 43, 54, 56-7, 148-57
Kiln No. 6 – 33-6, 43, 57, 130, 148-57
Kiln No. 7 – 35-44, 52-107, 127-8, 148-57
Kiln No. 8 – 33, 35, 49, 57-8, 60, 127, 148-57
Historic American Engineering Record - 114
historic vernacular landscape – 125-6, 153
Hudson, Kenneth – 110-1, 113-4, 116
Medicine Hat, Alberta
Hycroft China – 133-4

260
I-XL Industries – 132-3, 157
Medalta Potteries – 109, 132-6, 142-4, 147, 154
mortar (loss, repointing, et cetera) – 56, 58-61, 65, 79-80, 102-4, 129, 151, 156
Montana Preservation Alliance – 1
Rix, Michael – 112, 116
shed(s) – 1, 31-2, 36, 53-6, 99, 101, 105, 130, 148, 150-3, 155
Society for Industrial Archaeology – 115, 121
Tier 1 (Kiln No. 7) – 37-8
Tier 2 – 38
Tier 3 – 39
Tier 4 – 39-40
updraft kilns
  clamp – 7, 17-22, 27, 142
  scove kiln – 7, 17, 19-23, 26-7
  Scotch kiln – 7, 9, 20, 22-4, 26
Voulkos, Peter – 46-7, 145, 148, 153-4
World Heritage List (UNESCO) – 117-9, 141
Zehdenick, Germany – 109, 136-43, 145
Ziegeleipark Mildenberg – 109, 136-43, 145-6