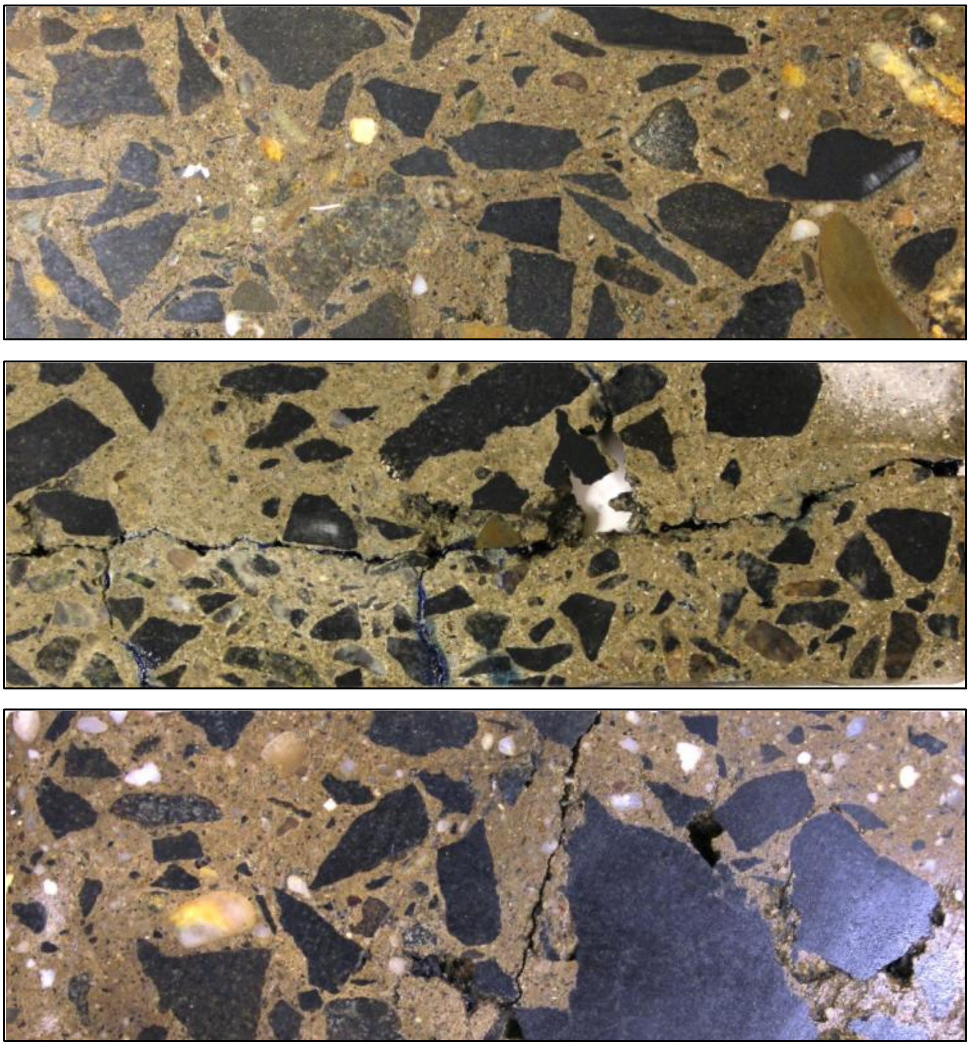
In Defense of Natural Cement:
A Critical Examination of the Evolution of Concrete Technology
at Fort Totten, New York

Richard M. P. Lowry



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Cover images: Sections of concrete from cores collected at Battery Graham (top), Battery Mahan (middle), and Torpedo Magazine 4 (bottom)

ABSTRACT

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at Fort Totten, New York

Richard M. P. Lowry
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There are a number of opportunities for academic research related to the historic concrete fortifications at Fort Totten at Willets Point in Queens, NY. Built by U.S. Army Corps of Engineers (USACE), whose headquarters was at Willets Point, these structures incorporate three significant fortification periods, including the Third System (1863-1867), the Post-Civil War era (1867-1884) and the Endicott period (1891-1905). These late 19th century structures represent a transformative period in the technological development of concrete which evolved from a simple mortar containing rocks to bulk out the mix, to an interdependent mixture of binder, sand and aggregate. In addition, the first fortifications at Fort Totten were built during the heyday of the natural cement industry and the last fortifications coincided with its demise, as portland cement came to dominate the market. The rivalry between American natural and portland cement manufacturers was fierce, and the biases engendered on both sides persisted long after the natural cement industry collapsed in the early 20th century. This has translated into the conventional view that there was an inherent problem in the natural cement concrete used to build these fortifications. However, for reasons of economy, the Corps of Engineers were prevented from using portland cement, until advances in domestic manufacturing permitted a reduction in costs.

Through historical and archival research, as well as the petrographic analysis of concrete samples, a more detailed assessment of the concrete used at Fort Totten was conducted. Using polarized light microscopy an analysis was conducted on the binder, the aggregates, the gradation, the water/cement ratio, and any deterioration in order to evaluate changes in the concrete mix design over time. These observations were then related to a conditions survey of the concrete structures at Fort Totten, to assess the performance of the concrete used to build these historic structures.

Laboratory work for this thesis was conducted at Columbia University GSAPP's Historic Preservation Conservation Laboratory and at Highbridge Materials Consulting, Inc.

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Richard M. P. Lowry 15 May 2013

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I would also like to thank John J. Walsh, who put up with me far longer than any reader should be expected to and always made time in his schedule to teach me the intricacies of concrete petrography. I am also grateful for the guidance of my reader, Professor Joan Berkowitz, who picked apart a very long, very dry thesis draft about 19th century concrete and helped whip it into shape.

I would also like to thank the staff of Highbridge Materials Consulting Ltd., John J. Walsh, Magdalena Malaj, Michael Pattie, Heather Hartshorn and Victoria Bendetti for sharing their laboratory with me.

I am also extremely grateful for the invaluable assistance provided by Ken Uracius and Chris Perry of Stone and Lime Imports Inc. in collecting the core and hand samples at Fort Totten. Similarly, this thesis would not have been possible without the support of the staff of the New York City Department of Parks and Recreation, especially John Krawchuk, Director of Preservation, along with Sgt. Marc Sanchez and the Fort Totten Park Rangers.

Finally, last but not least I wish to thank my bosses, Brian Franklin and Trevor Leach of the Bermuda Government Department of Planning, and Dr. Derrick Binns of the Ministry of the Environment and Planning, for supporting my return to postgraduate education and, most importantly, ensuring I had a job to come back to at its conclusion.

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1. Introduction

Unlike many of my fellow students in the Graduate School of Architecture, Planning and Preservation's Historic Preservation Program at Columbia University in the City of New York, I arrived on a two-year educational secondment from the Government of Bermuda. As the Heritage Officer within the Department of Planning I am responsible for administering and regulating the island's historic environment, which includes an enviable assemblage of extant fortifications spanning four centuries.[1] While I was able to deal with issues related to preservation planning, I was unable to address the material conservation needs of these limestone masonry and concrete structures. Therefore I came to Columbia to get acquainted with conservation science and the mysteries of mortar, cement, and concrete fortifications. When I began investigating possible thesis topics related to concrete and fortifications within the City of New York. Fort Totten, along the northeast coast of Queens, kept popping up. During my summer internship at New York City's Department of Parks and Recreation, my boss, John Krawchuk, Director of Preservation, took on my first site visit to Fort Totten. Once I had the chance to view these remarkable structures up close, my thesis topic was inevitable. Ever the historic preservation generalist, I decided to propose a thesis that combined archival research along with laboratory work. Now all I needed was a hook.

The ability to conduct research at Fort Totten itself was a major draw, as the site possessed concrete structures built throughout the second half of the 19th and the early 20th century, with both natural and portland cement.[2] This was a pivotal era in the history of construction, as concrete evolved from a simple mixture of mortar and rocks, to a better understood and more interdependent mixture of binder, coarse, and fine aggregates. Furthermore, the fortifications at Fort Totten encompass three different periods of fort building: the Third System, Post Civil War, and Endicott periods, so the site presents an excellent case study for a thesis on early concrete construction.

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[1] Harris, Edward C., (1997) *Bermuda Forts, 1612-1957*, Bermuda, Maritime Museum Press

[2] Natural cement is a hydraulic cement created from calcining a single source of an argillaceous (clay-bearing) limestone, whereas portland cement is an artificial hydraulic cement produced by clinkering measured amounts of limestone and clay at much higher temperatures.

Secondly, Fort Totten, or Willets Point as it was originally called until 1898, was the home of the US Army Corps of Engineers from 1867 to 1900. Its members were responsible for the design and construction of all US fortifications and so they would be at the forefront of 19th century concrete technology. Therefore, it has been argued in a recent study that “The resulting concentration of engineers at Willets Point [was] key to understanding the important role the post was to play over the next two decades in the development of a new modern system of defense. Moreover, the testing and experimental work undertaken by the Engineering School of Application at Willets Point ultimately laid much of the groundwork for the Endicott Report [on the future of US fortifications] in 1886.”[3]

The third and main issue was the development of a substantial natural cement industry in the US from the 1820s that then became integral to the construction of concrete fortifications from the 1860s. However, within the last few years of the 19th century, amidst a very bitter marketing war, the natural cement industry was dramatically overtaken by locally produced portland cement. During this time there appeared a general bias against natural cement that crept into various early 20th century treatises and the switch from natural cement was explained as desire for a better quality product that only portland cement could provide. A century later, Nelson Lawry of the Coastal Defense Study Group wrote how the US Army Corps of Engineers preferred to build the fortifications of Endicott Period (1890-1905) out of portland cement concrete but were forced by Congress to use cheaper and inferior natural cement. In addition he argued that the Corps was only allowed to switch after there were a series of dramatic failures of structures built with natural cement concrete.[4] This bias was perpetuated in the only comprehensive study on the Fort Totten fortifications conducted by Beyer Blinder Belle in 2000.[5] However, even a cursory inspection of Fort Totten will show that even the 1870s natural cement concrete structures are in much better condition than the portland cement concrete fortifications built between 1898 and 1905.

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[3] Beyer Blinder Belle, (2000) Fort Totten Battery: Historic Preservation & Interpretive Plan. Prepared for The State of New York Northeastern Queens Nature' and Historical Preserve Commission. April 2000, p. 2.6

[4] Lawry, Nelson, (1991) “Foundations for the Endicott System: A Question of Cement”, *Coast Defense Study Group News*, Feb. 1991

[5] Beyer Blinder Belle, (2000)

Therefore, the aims of this thesis will be to study the fortifications built at Fort Totten in order to better understand the evolution of concrete technology employed at the site, examine the differences between historic concrete made with natural cement and portland cement, and investigate the causes of any deterioration. The site of Willets Point will be described, summarizing its geology, the early history of the site, its strategic importance in defending New York Harbor, and the role of the Corps of Engineers in the development of concrete construction at Fort Totten. Next, from the Third System to the Endicott Period, the fortifications built at Fort Totten will be examined, primarily using the archival records of the Corps of Engineers. To establish what standards were available to the Corps of Engineers at Fort Totten, concrete technology employed during the 19th century will be investigated, drawing on contemporary treatises written by some of the early cement and concrete pioneers. However, there are limitations in what historical research can show in terms of how these structures were built, as well as how they have performed over the last century. Therefore, samples of concrete collected from the Fort Totten fortifications will be examined petrographically, both visually and using polarized light microscopy. This will include the examination of the constituent parts of the samples, identifying the binder and the aggregates used, investigating the mix design, as well as examining the water/cement ratio. After the results of these investigations have been presented, the quality of the natural cement and portland cement concrete will be assessed, to determine whether Lawry's assertions were correct as well as to place these structures in the context of the early development of 19th century concrete technology. Finally, the thesis will conclude with recommendations for further research on the historic concrete and fortifications at Fort Totten.

2. 19th Century Concrete Technology

The technology of concrete is not new and dates back to Classical Rome,[6]although for some unexplained reason, it disappeared from Western Europe for several centuries. While the technology was reintroduced during the 19th century, the concrete made during this period exhibited a substantial degree of experimentation and uncertainty about its material properties until the early 20th century. The history and technological developments of 19th century concrete in the United States has been covered by many contemporary writers.[7] However there are a few key technological developments relevant to the 19th century concrete fortifications built at Willets Point/Fort Totten that should be further studied.

One issue that needs to be considered is that cement chemistry is highly complex, and even today it is incompletely understood. While tentative, imperfect research into natural cement began in the late 18th century, some 50 years before portland cement was discovered, the natural cement industry had all but collapsed by the early 20th century. At this time the portland cement industry exploded, and with the establishment of organizations such as the Portland Cement Association in 1916, efforts into the production, marketing, and study of portland cement increased exponentially. Over the last 100 years far more modern scientific research has been conducted on portland cement than natural cement, and consequently portland cement is far better understood.

2.1. Natural cement

Natural cement may be defined as a "hydraulic cement produced by calcining a naturally occurring argillaceous limestone at a temperature below the sintering point and then grinding to a fine powder."[8] It should be noted that the majority of US natural cement is made from dolomitic limestone, which contains calcium and magnesium carbonate, while UK natural cements are made from high calcium limestone. When these rocks are heated to

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[6] Lechtman, H. N.; Hobbs, L. W. (1987), "Roman Concrete and the Roman Architectural Revolution", *Ceramics and Civilization* 3: 81–128

[7] Cummings (1898), Gillmore, Lt. Col. Quincy Adams, (1886) *Practical Treatise on Limes, Historic Cements, and Mortars*, New York, D. Van Nostrand, and Lesley, (1900)

[8] ASTM C219– 07a, p. 2

temperatures between 800°C and 900°C calcination will take place. The calcium in the limestone will combine with the alumino-silicates in the clay to form hydraulic minerals. For dolomitic limestone, magnesium oxide is produced along with calcium oxide during calcination, but these original minerals cannot be detected under the microscope, and so the process is still not fully understood. However, the natural cement grains may be identified by the texture of original dolomitic rock sources, but the chemistry of natural cement will be further discussed in Section 5.5. [9]

The hydraulic setting abilities of natural cement, along with its superior strength and fast setting time, when compared with any non-hydraulic lime mortars, lead to considerable advances in construction technology. Similar hydraulic materials had been used in antiquity, such as the lime-pozzolan cements described by Vitruvius, ca. 25 BC[10], but the use of such technology dwindled after the Roman period, and the history of its later 'rediscovery' is somewhat fragmented. Palladio noted hydraulic mortar produced from rocks mined in the hills of Padua during the 16th century[11], while the hydraulic material lauded as the 'king of cements', Dutch 'trass' or 'terras', was being manufactured in the Low Countries from the late 17th century.[12] It was John Smeaton's research into suitably hydraulic limes during the construction of the Eddystone Lighthouse off the Devon/Cornwall coast in 1756 which was a monumental breakthrough, because it is the first known systematic and scientific inquiry into hydraulic mortars. However, it was Rev. Dr. James Parker's 1796 patent for "a certain Cement or Terras to be used in Aquatic and other Buildings and Stucco Work" that can be considered the first commercially viable natural cement product.[13] In a moment of marketing genius, Parker developed the 'Roman cement' brand, which ensured his success and allowed

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[9] Walsh, John J., (2008) "Petrography: Distinguishing Natural Cement from Other Binders in Historical Masonry Construction Using Forensic Microscopy Techniques", *Journal of ASTM International*, Vol. 4, No. 1. January 2008, pp. 27

[10] Vitruvius Pollio, Marcus, (1914) *The ten books on architecture*, translated by Morris Hicky Morgan, Cambridge, Harvard University Press, Book II, Chapter VI, p46f

[11] Palladio, Andrea, (1965) *The four books of architecture*, translated by Isaac Ware (1738 ed.), New York: Dover Publications. Book I, Chapter V, p. 5, "In the hills of Padua, they dig a certain rugged and scaly stone, whose lime is very good for works exposed to the weather, or in the water, because it hardens immediately, and lasts a long time."

[12] Wilkes, John, (1817) *Encyclopaedia Londinensis*, London, Vol. 15, p. 455

[13] Hughes, David, Swann, Simon and Gardner, Alan (2007) "Roman Cement Part One: Its Origins and Properties", *Journal of Architectural Conservation*, 2007 Mar., v.13, n.1, p. 25-27

him to sell his patent to Samuel and Charles Wyatt in 1798.[14] Soon other sources of suitable high-calcium argillaceous limestones were discovered in the UK and competition between these cements became fierce. Until the development of portland cement in the mid-19th century, 'Roman cement' and its many copies, were amongst the premier cements in use throughout the UK and Europe, and this matter has been ably covered by Courland.[15]

In the US, natural cement has been inextricably linked with the development of canals and sourcing locally available 'dirty limestone' from which a hydraulic mortar could be made, and this has been ably covered by Werner and Burmeister.[16] An argillaceous limestone was first discovered in the US near Fayetteville, Onondaga Co., NY in 1818.[17] Canvass White, an engineer for the Erie Canal project, established a cement-works at nearby Chittenango, Madison Co., NY in 1819 and secured a patent covering his process for making hydraulic cement. As canal engineers sought to exploit local building materials, other sources of argillaceous limestones were discovered in Illinois, Kentucky, Indiana, Maryland, Pennsylvania and Virginia. Uriah Cummings noted that, "One can hardly realize the value of the properties which have been constructed with mortars and concretes made with this [natural] cement.[18] Indeed, Cummings listed some of the most iconic American structures of the 19th century, were built using natural cement, notably the Brooklyn Bridge.[19]

Natural cement was produced in many states, and Cummings noted that the superior natural cements were produced in Savannah, GA and Mankato, MN. [20] However, it was the natural cement manufactured in New York, particularly in the Rosendale area of Ulster Co., NY, that would come to dominate the market. Edison estimated that over half of all natural cements produced in America came from the Rosendale area in Ulster County, NY.[21] Indeed,

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[14] Parker then departed for the United States and where he disappeared from the historical record.
[15] Courland (2011), pp. 143-210
[16] Werner, Dietrich and Burmeister, Kurtis, (2007) "An Overview of the History and Economic Geology of the Natural Cement Industry at Rosendale, Ulster County, New York", *Journal of the ASTM International*, Vol. 4, No. 6, p. 7-19
[17] Cummings, Uriah, (1898) *American Cements*, Boston, Rogers & Manson, p. 18
[18] Ibid., p. 290
[19] Ibid. p. 296-298
[20] Ibid., p.21-22
[21] Edison, Michael P., (2008) "Formulating with Rosendale Natural Cement", J*ournal of ASTM International*, Vol. 4, No. 1, January 2008, p. 33

Baker reported that in 1905, although natural cement was made in fifty-eight works across sixteen States, nearly half of it was produced in the Rosendale district.[22]

Figure 1: Letterhead for the New York and Rosendale Cement Co., (1873)

Figure 2: Letterhead for the Giant Portland Cement Co., Egypt, Lehigh Valley, PA (1900)

Furthermore, Werner and Burmeister noted that Rosendale cement had a "widespread reputation of being of superior quality to the other brands [of natural cement]", as evidenced by its generally higher price.[23] The greatest advantage Rosendale cements had over their rivals was their location, in close proximity to the Hudson River. This facilitated transport to the metropolis of New York as well as to the Midwest via the Erie Canal. However, while many local sources of natural cement were used in order to reduce transport costs, it is worth noting that only Rosendale cement was used in constructing US fortifications, according to Cummings.[24] Indeed, Rosendale natural cement would become a generic term for all natural cements. For example, the US Army Corps of Engineers' 1920 *Report of Completed Works: Seacoast Fortifications* for the batteries at Fort Totten only gave two options for the type of cement used in construction: "Portland" or "Rosendale".[25]

Lawry has argued in 1991, "Natural rock is laminated and of varying and uneven distribution in composition. The disproportion is such that up to 25% of natural cement is in

[22] Baker, Ira O., (1909, 10th edition) *A treatise on masonry construction*, New York, J. Wiley & Sons, p. 56
[23] Dietrich and Burmeister (2007), p. 12
[24] Cummings, (1898) p. 298, It should be noted that Willets Point/Fort Totten was not specifically mentioned
[25] It should be noted that there were very few natural cement plants in operation during the 1920s, and by the end of the decade only one of the 15 plants in Rosendale was still in existence.

excess, that is, the fraction is inert and unable to combine chemically under low or high temperature."[26] Edison stated that the calcining process was variable and often left up to 25 % of the material under or over-burnt, which then had to be separated from the properly calcined rock. However, Edison did argue that natural cement manufacturers became quite accomplished at quarrying, mixing, and calcining the rocks from specific stratae to produce viable cements without the benefit of precise control over kiln temperatures or even the materials used.[27]

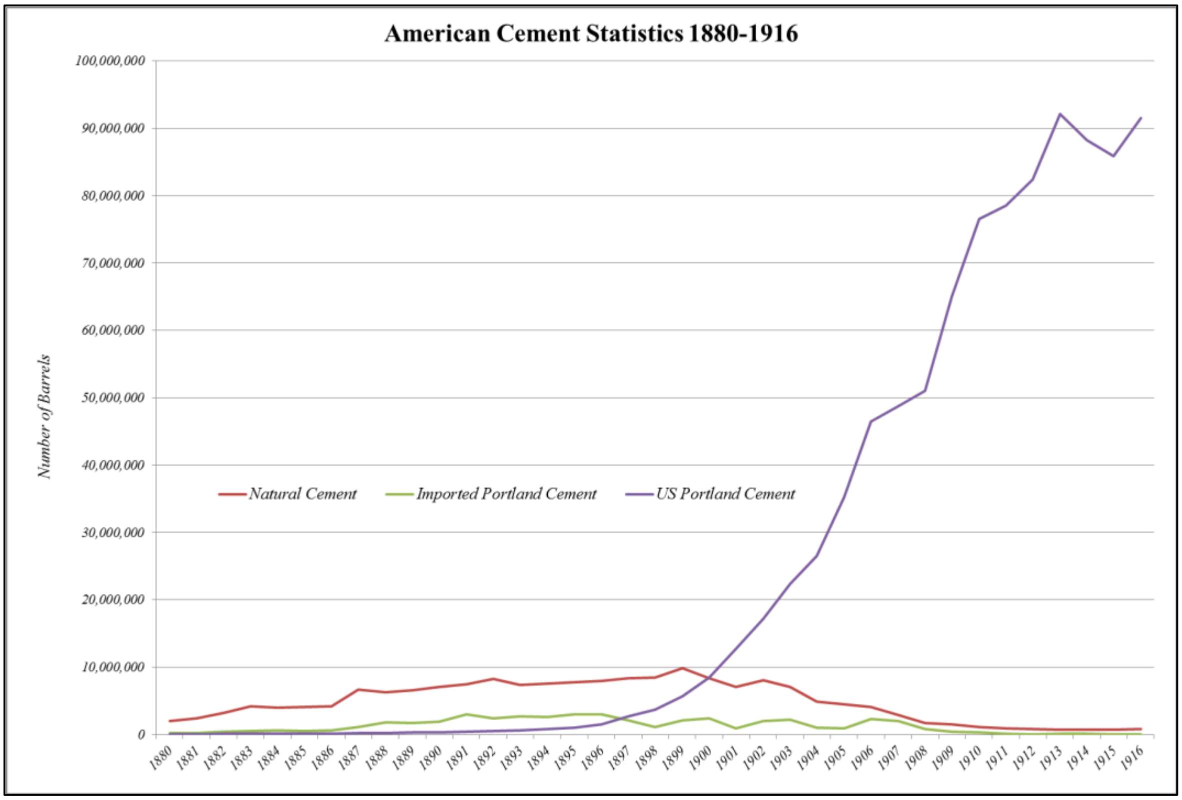

Figure 3: Cement Production Statistics (1880-1916)

By 1899, almost 10 million barrels[28] of natural cement were produced annually in the US, but by 1916, production had collapsed to just under 850 thousand barrels. The main reason for this decline was the general switch by the construction industry to American

[26] Lawry (1991), p. 11
[27] Edison, (2008), p. 33
[28] A barrel measured 4 cubic feet (4 bags to a barrel), equivalent to 376 pounds.

portland cement, whose industry had been growing steadily since the 1890s. By 1916 over 91½ million barrels of American portland cement were produced annually (See Figure 3).[29]

2.2. Portland cement

Portland cement is defined as "a hydraulic cement produced by pulverizing clinker, consisting essentially of crystalline hydraulic calcium silicates, and usually containing one or more of the following: water, calcium sulfate…and processing additions."[30] It is effectively an artificial hydraulic cement, where the precise quantities of its constituent parts, including limestone and clay can be measured and then kilned. Unlike the production of natural cement, kiln temperatures reach 1450°C and above to produce clinkered material. The calcium can combine with alumino-silicates to produce four main compounds: tri-calcium silicate (alite), di-calcium silicate (belite), tri-calcium aluminate, and calcium-aluminate-ferrite (ferrite). Portland cement sets as a hydration reaction, with the alite, belite, and tri-calcium aluminate combining with water to produce calcium silicate hydrate, calcium aluminate hydrate, calcium hydroxide, and other minor components. The chemistry of portland cement will be further discussed in Section 5.5.

The history of portland cement is just as complicated as its chemistry, and it has been ably covered in a number of works.[31] The invention of portland cement has been credited to Joseph Aspdin's 1824 patent, which launched the 'portland cement' brand, but it was probably the experiments conducted by his son, William, and those of Isaac Johnson, that produced the first truly clinkered hydraulic binders in the 1840s.[32] Like the Roman cement and Rosendale cement, portland cement would become a generic brand for a number of similar products. In 19th century America, portland cement was a primarily a European import (from Britain, France, and Germany) but by the early 1870s it was produced in the Lehigh Valley, PA, in Kalamazoo, MI, in Wampum, PA, and in South Bend, IN. Lesley noted in his 1900 edition of the *History of the Portland Cement Industry*, that of the six

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[29] Lesley, Robert Whitman, (1924) *History of the Portland Cement Industry in the United States*, New York, International Trade Press. p. 72-73. In 1918

[30] ASTM C219, p. 3

[31] Courland, (2011) and Francis, (1977)

[32] Francis, Maj. A. J., (1977) The Cement Industry: 1796-1914: A History, London: David and Charles

original US portland cement works, three failed. He attributed this to the high labor costs, an unfair bias towards imported portland cements, and the comparatively lower costs of US natural cement.[33] Eventually the American portland cement industry improved, and by 1897 domestic production had exceeded imports of portland cement. Furthermore, by 1900, portland cement production had exceeded natural cement production (see Figure 3). One of the major innovations that facilitated the production of portland cement was the rotary kiln, developed by Frederick Ransome in 1885, but not perfected until turn of the century. This allowed not only a more controlled and constant temperature, but a continuous production of high quality clinkered cement.

While the initial setting time of portland cement was longer than that of natural cement, it reached its ultimate strength much more quickly. Cummings noted that portland cement reached half of its ultimate strength in seven days, compared with one eighth of the ultimate strength for natural cement during the same time period.[34]

Portland cement had been used in US coastal fortifications as early as the 1870s, but usually only as a 'waterproof' coating, due to its comparatively high manufacturing and importation costs. Natural cement mortar, however, was the backbone of Gen. Joseph Totten's Third System masonry fortifications (1816-1865), the massively built cast-in-place concrete batteries and magazines of the Post-Civil War period (1867-1885), as well as the early fortifications of the Endicott Period (1890-1905). After about 1897, however, portland cement concrete began to replace natural cement concrete in US coastal fort construction. This change was first attributed to simple economics, a view espoused by Col. Eben E. Winslow as early as 1920, claiming (incorrectly) that portland cement was not manufactured in America in the early 1890s and therefore it had to be imported at great expense.[35] Thus, he argued, 'Natural or Rosendale' cements were used to build the majority of the US Atlantic coastal fortifications because they were manufactured in America and were far less expensive

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[33] Lesley 1900, p. 12-14, In 1898, the bulk cost of cement was \$0.98/barrel compared with \$2.00 for portland cement.
[34] Cummings (1898), p. 272ff
[35] Winslow, Col. Eben Eveleth, (1920), *Notes of Seacoast Fortification Construction*, Washington, Government Printing Office, p.15

to make. By the Spanish American War (1898), he continued, there had been a rapid development in the American portland cement industry, increasing production and reducing costs, which permitted its wholesale adoption by the US Army Corps of Engineers (USACE).

In addition, Nelson Lawry has suggested that quality was another factor in the desire to switch from natural to portland cement, noting that during the late 1890s there was a succession of failures recorded in fortifications built with natural cement concrete. He argued that, "Many of the early gun batteries and almost all of the Abbot quad mortar batteries were so constructed, that after a period of frantic patching, they faced either major rebuilding or early abandonment."[36] Preventing moisture penetration through the concrete fortifications into the subterranean magazines, where the gunpowder and ammunition were stored, was a perennial problem for the Corps of Engineers.[37] However, Lawry admitted that other factors, such as the structural design of the emplacements and the concrete mix design, including the water/cement ratio, as well as the type, shape, and gradation of the aggregate used, all could have contributed to any potential deterioration.

2.3. Concrete

Concrete is defined as a "composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate; in hydraulic-cement concrete, the binder is formed from a mixture of hydraulic cement and water".[38] There are many factors that affect the performance of concrete, from the type of binder, the type, size and shape of the coarse and fine aggregates used, the mix ratio, the amount of water used in the mix, was the concrete mixed by hand or by machine, how the concrete was placed, whether any reinforcing was used, whether any admixtures were used, the design of the structure (as well as whether the concrete was designed appropriately for the application), and finally the prevailing climate conditions of the site. However, there has been over a century of continuous research into concrete since the last of the Totten fortifications were

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[36] Lawry, Nelson, (1991) " p. 13, and Beyer Blinder Belle, (2000)

[37] Twining, Capt. William Johnston, (1872) "Ventilation of Military Magazines" in *Printed Papers of the Essayons Club of the Corps of Engineers*, *Vol. I*, No. 22, April 29, 1872, Willets Point, New York, Battalion Press, 1879-1882

[38] ASTM C125, p. 3

completed, so while modern concrete specifications are far more advanced it should be stressed that some of the basic issues related to mix design have remained the same.

Concrete has good compressive strength, it did not require highly skilled labor to use, it could be poured into a number of forms, it possessed fire resistance, and, with the adoption of reinforcement, it possessed tensile strength allowing a variety of thinner, taller and more complicated forms in the early 20th century. However, each material or building system innovation did not equate to its immediate and wholesale adoption. For example, while portland cement began to be produced during the 1870s in the US, it would take 30 years for it to be accepted as equal in quality to imported portland cement. Similarly, early structural concrete was introduced in 1802, while early experiments in reinforced concrete were conducted between 1851 and 1871. However, it would take until the late 1890s/early 1900s before concrete would approach anything close to modern specifications and usage.[39] Therefore, there were a series of transformative steps leading from a simple mortar containing aggregate to a modern concrete technology, and the fortifications at Willets Point/Fort Totten are examples of these early developmental stages.

[39] Courland, Robert, (2011) *Concrete Planet: The Strange and Fascinating Story of the World's Most Common Man-Made Material*, New York, Prometheus, p. 208

3. The Fort at Willet's Point

3.1. Description of Willets Point

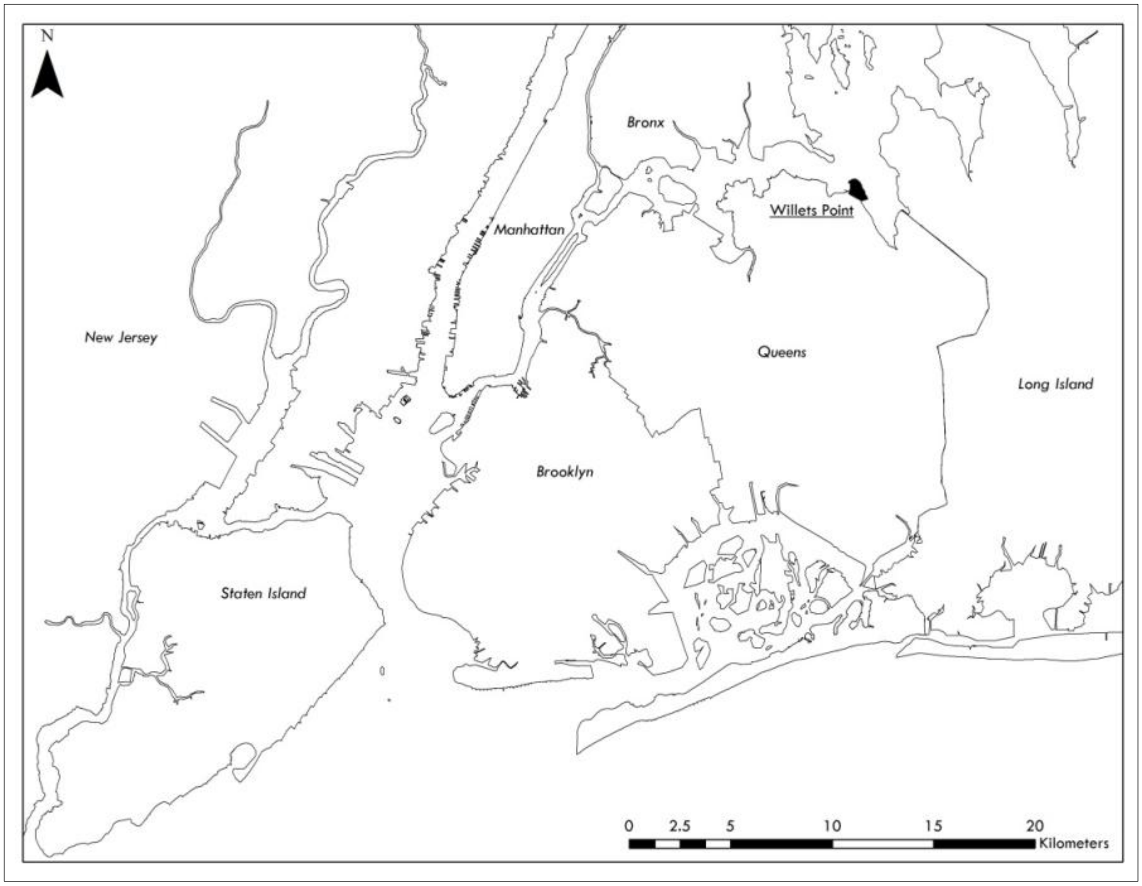

Figure 4: Map of New York City showing the location of Willets Point

Willets Point is a small promontory of land in Bayside, along the north-eastern coast of the Borough of Queens in New York City. Together with the Throgs Neck peninsula in the Bronx, to the north-west, Willett's Point guards the channel where Long Island Sound meets the East River. The site measures approximately 136 acres, with Little Bay located to the west of the promontory, and Little Neck Bay to the east.

3.2. Geology of the New York Area

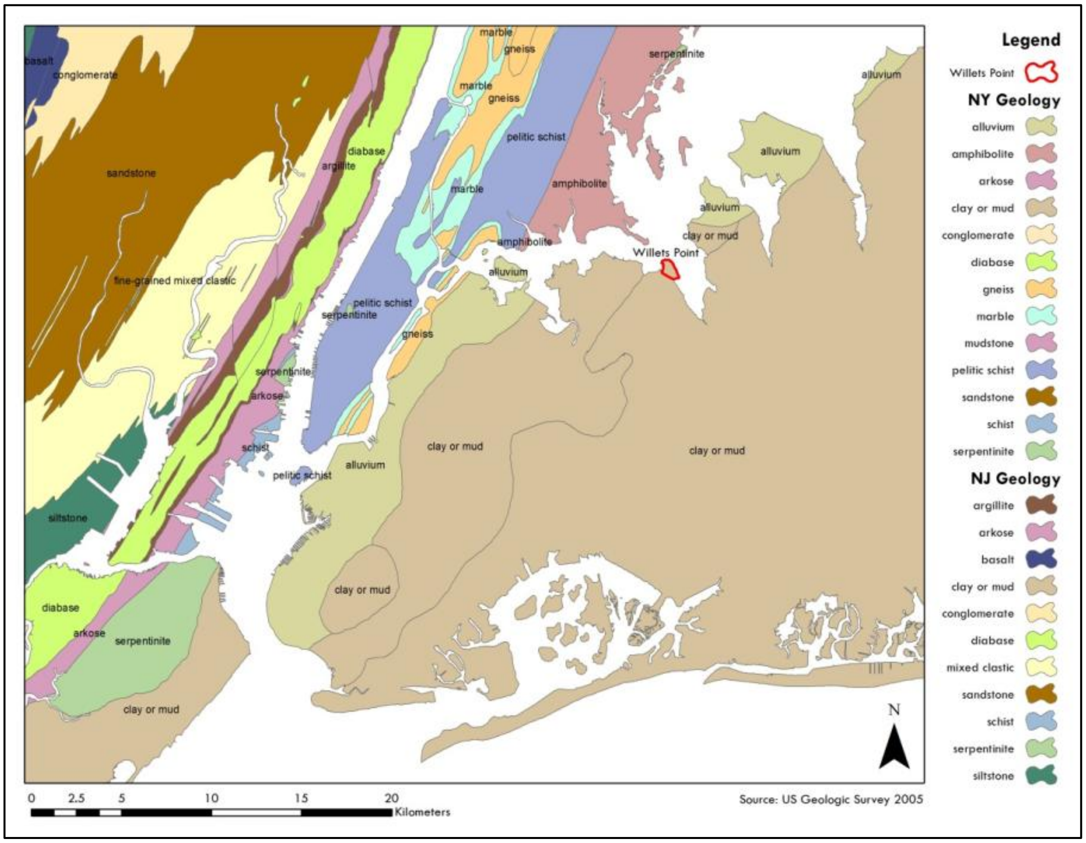

Figure 5: Basic Bedrock Geology of New York and New Jersey
(Based on GIS data provided by the U.S. Geological Survey, 2005)

The Willets Point peninsula, like much of Long Island, is located within the Upper Cretaceous Coastal Plain Deposits of the Monmouth Group/Matawan Group/Magothy Formation, which is composed of silty clay, glauconitic sandy clay, sand, and gravel. While sand and gravel would be useful in mixing concrete, there were no sources of building stone or large aggregate available on site, apart from scattered boulders left over from the last Ice Age. The bedrock of the Hartland formation lies far below the clay[40] and consequently any stone material would need to have been brought in from other areas. Across the channel in the Bronx and Manhattan, were sources of amphibolite, gneiss, marble and schist, and sources of diabase are found in New Jersey and New York. Indeed, the monumental granite

[40] Merguerian, Charles and Sanders, John E., (2010) *Trips on the Rocks: Guide 03: Geology of Manhattan and the Bronx, New York, New York*, Duke Geological Laboratory, p. 6

blocks used to build the Water Battery at Fort Totten were brought down by ship all the way from Maine.

3.3. Early History of Site

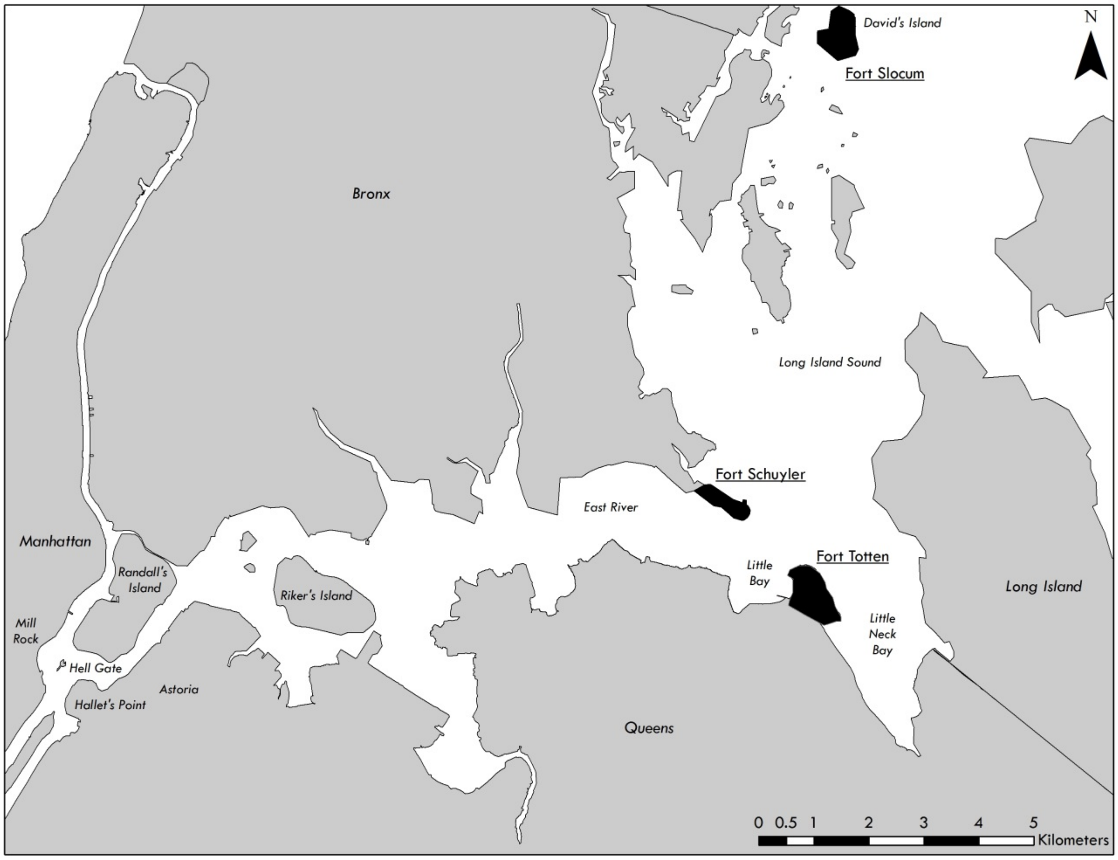

Figure 6: Fortifications guarding the eastern approach to New York City

The history of the Willet's Point has been ably covered in a number of works,[41] but to summarize, the earliest land records began in 1640, when the tract was ceded to a colonist by the native Matinecock tribe. The promontory has been renamed several times, often reflecting changes in ownership, as during the 17th and 18th centuries, it was called Thorne's Point (after William Thorne), during the 1780s the name was changed to Wilkin's Point (after

[41] Pearson, Marjorie, (1999) *Designation Report for the Fort Totten Historic District, Borough of Queens*, New York City Landmarks Preservation Commission, Beyer Blinder Belle, *Fort Totten Battery: Historic Preservation & Interpretive Plan.* Prepared for The State of New York Northeastern Queens Nature' and Historical Preserve Commission. April 2000, Chapter 2 & Gaines, William C., (1997) 'Fort Totten and the Coast Defenses of Eastern New York', *The Coast Defense Study Group Journal*, February 1997, p.42ff

one of the owner's William Wilkins) and then in 1829 it was changed to Willets Point (after another owner, Charles Willets). In 1857 the land was acquired by the Board of Engineers, although they had been interested in the site since the 1820s.

Figure 7: Aerial photo showing Willets Point, Queens in the foreground and Throgs Point, Bronx in the background (NARA, 1924 Army Air Service)

Gaines has perhaps written the most complete account of the early history of the fort at Willets Point/Fort Totten.[42] As early as 1820 the Board of Engineers concluded that a fort at Willets Point, together with a fort at Throgs Point, would effectively defend the head of Long Island Sound. However, work did not begin at Fort Schuyler at Throgs Neck in the

[42] Gaines, (1997)

Bronx until 1833.[43] Despite repeated petitions by the Board of Engineers in 1840, and the Chief of Engineers, Gen. J. G. Totten, in 1851, the fort at Willets Point was not begun until 1862.[44] The government's interest in the land was well known, and the delays in securing sufficient funds and a suitable engineer allowed rampant land speculation and profiteering by the time the land was finally purchased in 1857.[45]

Lt. William Petit Trowbridge, U.S. Engineer for New York was appointed superintendent of the project by Gen. J. G. Totten in 1861, but it was not until 1862 that surveys were begun and materials collected so that work could commence in 1863.

3.4. Defending New York City

Willets Point, along with Throgs Point across Long Island Sound in the Bronx, was a strategic position that guarded the eastern approach to New York Harbor, which is one of the great natural harbors along the north-east coast of America. The harbor has been central to the city since the Dutch and English colonies, even becoming the national capital of the new American Republic briefly in 1885. Along with Baltimore, Philadelphia, and Boston, New York was an important commercial center, but city was largely concentrated in a small area of Lower Manhattan below 14th Street. During the 19th century the population and economic importance of New York City exploded. The completion of the Erie Canal in 1824 linking New York with the Great Lakes, the waves of European immigration from the 1850s, the advent of fast trans-Atlantic steamships in the 1850s, the financial impact of the U.S. Civil War (1861-1865), and the completion of the Union-Pacific Railroad in 1869 all contributed to this economic and population expansion.[46]

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[43] Named after Revolutionary War hero and US Senator for New York, General Philip John Schuyler (1733-1804), Klawonn, Marion J., (1977) *Cradle of the Corps: A History of the New York District U.S. Army Corps of Engineers 1775-1975*, New York: USACE, p. 50

[44] Gaines, (1997) p. 43f The original price had doubled to $200,000.00

[45] Ibid. p. 44ff

[46] The population of New York City rose from 49,401 in 1790 to 2,507,414 in 1890, an increase of almost 5000%. U.S. Census data quoted in. Jackson, K. T. (ed.), (1995), *The Encyclopedia of New York City*, Yale

New York State was referred to as the 'Empire State' from the early 1800s and by 1866 New York City was "justly regarded at the Metropolitan City of the New World."[47] In 1865, William R. Martin went even further, "New York stands in relation with the whole country as its commercial and financial capital."[48] Indeed, Brig. Gen. Henry Abbott would state in 1887, "The supreme importance of New York, the commercial metropolis of our Atlantic seaboard, is unquestioned."[49] Therefore, as New York grew from a colonial entrepôt in the 17th century to a national resource by the 19th, there was an increasing need to protect it.

The majority of the pre-revolutionary fortifications in New York City centered on guarding the southern harbor approaches, since most of the city's population were concentrated in Lower Manhattan. However, the ease with which the British were able to invade and capture New York City from General George Washington in 1776 showed how ineffective its fortifications were. By comparison, the eastern approach to the city along the northern shore of Long Island was left relatively undefended, as the city relied on the natural defenses of the Hell Gate. This was a tortuous waterway at the confluence of the East River and the Harlem River, between Astoria in Queens, Randall's Island, and the Upper East Side in Manhattan. Partially or wholly submerged reefs, tidal movements, and swirling 8.6 knot (10 mph) currents all combined to make the passage of ships through the Hell Gate very dangerous, and on average 1000 vessels/year ran aground.[50]

In 1851 Gen. J. G. Totten, the Chief Engineer, published his *Report on the Subject of National Defences*, in which he divided the nation's existing fortifications into "three distinct epochs": the First System (1794-1807), the Second System (1808-1816) and the Third System (1817-1865).[51] This model set the tone for all future fortification research, although

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[47] Miller, J.D., (1865) Miller's New York as it is, or Stranger's guide-book to the cities of New York, Brooklyn, and adjacent places, New York, J. Miller, p. 20
[48] Martin, W. R., (1865), *The Growth of New York*, New York, George W. Wood, p. 15-16
[49] Abbot, Brig. Gen. H. L., (1888), Course of Lectures Upon the Defense of the Sea-Coast of the United States Delivered Before the U.S. Naval War College, November, 1887, New York, D. Van Nostrand, p.12
[50] Ibid., p. 69 and Abbott, Gen. H., (1879-1882) "Shock of the Explosion at Hallets Point" in *Printed Papers of the Essayons Club of the Corps of Engineers, Vol. II*, Battalion Press, Willets Point, New York, p.155-169, and Klawonn, (1977), p. 69-94
[51] Totten, Gen. Joseph G., (1851) *Report on the Subject of National Defences*, A. Boyd Hamilton, Washington DC, p.50

one should remember that this was an artificial and retroactive classification system that allowed Totten to categorize previous phases of fortification construction.

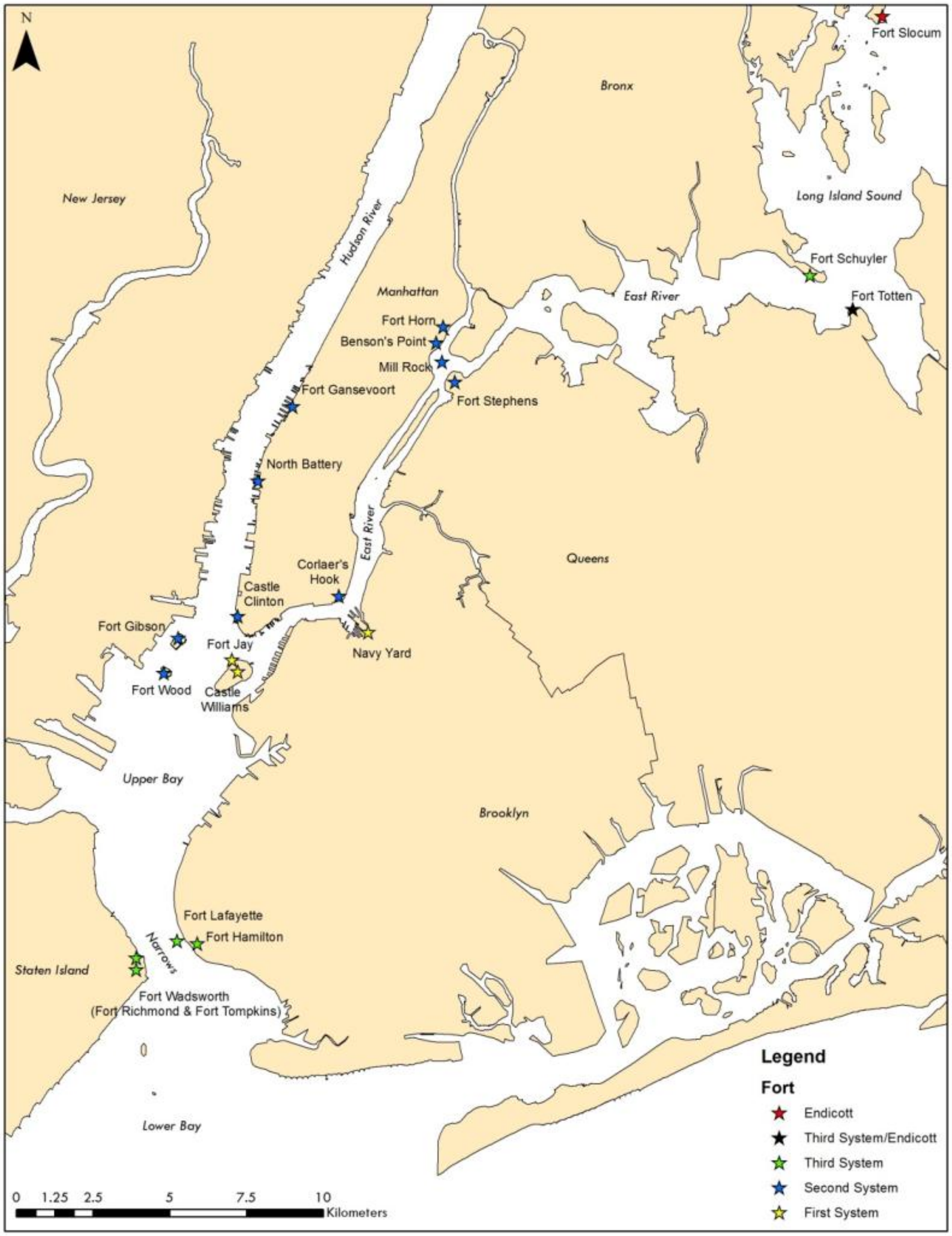

Figure 8: Fortifications in New York City, 1784-1900

The First System fortifications consisted of 22 small and temporary coastal fortifications possessing a basic design that incorporated open works, earthen parapets and an assortment of armaments.[52] They were not maintained and many fell into ruin, requiring substantial improvements by 1798.[53] Lewis has argued that this cannot be considered a true system as, "the nature of its components were neither uniform nor durable", while they had been designed and built by "individual engineers who had worked independently of each other."[54] In New York there was only one First System fortification, Fort Jay on Governor's Island, which guarded the inner Harbor formed by Staten Island, Manhattan and Long Island.[55]

The Second System of coastal fortification resulted from a damaging 1807 report on the state of the nation's coastal defenses, as well as continued friction between the US and Europe.[56] Led by the Superintendent of the Corps of Engineers, Lt. Col. Jonathan Williams, these fortifications were based on substantial masonry-built construction that incorporated a number of design innovations. These included cannons that could fire through embrasures or over parapets (*en barbette*), casemated batteries, and multiple tiers of firing platforms.[57] Lewis, however, noted that these fortifications were "marked by a dissimilarity among [their] elements…that was far more basic and evident than any common characteristic serving to distinguish them, as a group, from the products of earlier or later periods."[58] Indeed, Totten considered these defenses, "small and weak and being built for the sake of present economy, of cheap material, and workmanship, were very perishable."[59] In New York City, the majority of the Second System fortifications were concentrated around the inner harbor, but were extended to encompass the Narrows Channel between Staten Island and Brooklyn, in

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[52] Ibid.
[53] Ibid. p.143
[54] Lewis, Emanuel Raymond, (1970) *Seacoast Fortifications of the United States: An Introductory History*, Annapolis, MD: Naval Institute Press, p.37
[55] Ibid. p.148
[56] Dearborn, H. (1807), Letter from the Secretary of War, Enclosing His Report on "the State of the Fortifications of the Respective Ports and Harbours of the United States…" A. & G. Way, Washington D C and Klawonn, Marion J., (1977) p. 30
[57] Ibid. Many of these were drawn from the works of the late 18th century French military engineer, René de Montalembert, whose works Williams had translated.
[58] Lewis (1970), p.37
[59] Totten (1851), p.51

order to protect the city and the Brooklyn Navy Yard. However, there was a growing realization of the potential threat from the eastern entrance to New York Harbor. The Hell Gate was no longer secure as was once thought and Governor Tompkins, in his 1813 report to the legislature, would advocate for a defensive position to "guard against the approach of vessels from the Sound."[60]

Perhaps the greatest legacy of the War of 1812 for U.S. Coastal fortifications was in exposing their inadequacy, as the British easily invaded the Chesapeake and the Gulf Coast. The British victory at the Battle of Bladensburg in 1814, which led in the sack of the nation's capital, Washington DC, has been called "the greatest disgrace ever dealt to American arms"[61] and was a primary catalyst that led to the development of the Third System of fortifications.[62] The Third System was devised by the Board of Engineers for Fortifications, under the French military engineer, General Simon Bernard and, after 1838, by Lt. Col. J. G. Totten.[63]

There were numerous advances of fortification design during the Third System, including Totten's own experiments with lime and natural cement mortars at Fort Adams, Newport, RI.[64] Furthermore, Totten Embrasures, wall openings containing armored shutters through which cannons could fire, were developed between 1852 and 1855.[65] It is important to note that during this time armaments were also being improved, including new carriages and enormous smoothbore cast-iron Rodman cannons. On land, guns could be trained to fire on small areas of a fort, so repeated bombardments could easily reduce a curtain wall. Therefore, massive earthworks were built, which could both absorb cannon fire and any craters could easily be filled in. However, masonry coastal fortifications remained more

[60] Guernsey (1895) p. 159

[61] Howe, D. W. (2007), *What hath God wrought : the transformation of America, 1815-1848* , Oxford ; New York : Oxford University Press

[62] Uracius, Ken, "Natural Cement Revival", *Journal of ASTM International*, Vol. 4, No. 3. April 2007, pp. 3

[63] Ibid., p. 37ff. Due to the Totten's "singular influence on this generation of defenses and the continuity that he, far more than any other individual, provided for its realization, the Third System was often referred to by later engineers as the Totten System."

[64] Totten, Lt. Col. Joseph G., (1842) *Essays on hydraulic and common mortars and on limeburning…*, Wiley and Putnam, New York, p.227ff

[65] Abbot, Gen. H. (1887), *Course of Lectures Upon the Defence of the Sea-Coast of the United States*, New York, D. Van Nostrand, p. 139f. These would later be called 'Totten Embrasures.'

defensible, since cannon fire from the rolling deck of a warship could not attain the same levels of accuracy needed to effectively target a small area. This all changed with the advent of rifling.

Rifling referred to spiral grooves cast along the inside bore of a weapon, and imparted a stabilizing spin to the projectile thereby providing much greater range and accuracy. Rifling also facilitated the firing of an elongated shell, which allowed for a larger mass shell for the same diameter, which, therefore, would not increase the air resistance during flight. This, combined with newly armored warships that could better withstand cannon fire, made the expensive masonry built coastal fortifications of the Third System very vulnerable, as was seen during the US Civil War. As a result, a new fortification design was needed, built with new inexpensive materials. This led to the development of massive cast-in-place concrete batteries and magazines protected by massed earthen embankments.

3.5. The US Army Corps of Engineers at Willets Point

The history of the US Army Corp of Engineers has been covered expertly by Marion Klawon.[66] They were established in 1802 and stationed at the Military Academy in West Point, NY. Their role incorporated civil as well as military engineering work, and later ensured that the Hudson River and New York Harbor remained navigable.[67] Following the US Civil War (1861-1865) there was a wholesale reorganization of the Corps as Special Order No. 285 of the Adjutant General's Office established the Engineering Depot at Willets Point, where the hundreds of tons of engineering material and equipment left over from the war would be kept. The Engineer Battalion, commanded by Maj. Henry Larcom. Abbott, was assigned to maintain and guard this equipment.[68]

Furthermore, in 1866 the West Point Military Academy was restructured with a more general curriculum, so Abbott established the Engineering School of Application at Willets Point, which opened in 1867. The school’s purpose was to provide a two year post-graduate

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[66] Klawon, (1977), p. 24f
[67] Ibid., p. 63ff
[68] Gaines, (1997), p. 49

course on current engineering practices for Corps officers, as well as provide a research laboratory for their experiments.[69] By 1885, the School was expanded to cover subjects such as submarine mining, military photography, practical astronomy, military engineering, and civil engineering. With respect to the fortifications at Willets Point, the military and civil engineering courses included classes on modern seacoast defenses, as well as on producing and testing cements and concrete.[70]

In addition to the School, Major James Chatham Duane and Abbott established the Essayons Club, a group of officer engineers stationed at Willets Point, as well as a group of honorary members. The club was named after the motto of the Corps: "Essayons", French for "Let us try", and its aim was to present weekly papers during the winter months on various scientific and military topics for discussion and eventual publishing. Between January 1868 and 1882, fifty papers were presented and published, before the group finally disbanded in 1882.[71]

3.6. Third System Fortifications at Willets Point

The site selected for the first fortification by the Engineer-in-Charge, Lt. William Pettit Trowbridge, was the northern tip of the promontory at Willets Point. Trowbridge had a significant portion of the bluff overlooking the channel detonated and excavated in order to create a level area on which to begin construction of a pentagonal, multi-tiered, casemated fort composed of granite blocks quarried and shipped from Maine.

3.6.1. Granite Fort/Water Battery (1863-1867)

The original plans called for a three tiered casemated fort with eight feet thick walls, a barbette tier along the two shoreward facing sides, and a tower bastion at its apex. The three rear sides were planned as single tiered casemates surmounted with a barbette tier, which

[69] Person, (2012), p. 50
[70] Annual Report of the War Department for the Fiscal Year Ended June 30, 1897, Report of the Chief of Engineers Part 1, Washington, Government Printing Office, p. 563 (hereafter abbreviated to USACE)
[71] Abbot, Brig. Gen. Henry L., (1904) 'Early Days of the Engineering School of Application', *Occasional Papers of the Engineer School of Application, US Army, No. 14*, Washington Barracks, Washington DC, p. 8

extended into the bluff. Demi-bastions at each of the four rear corners would guard the flank. Trowbridge had 400 civilian laborers and craftsmen under his direction and work began in earnest in the summer of 1863.

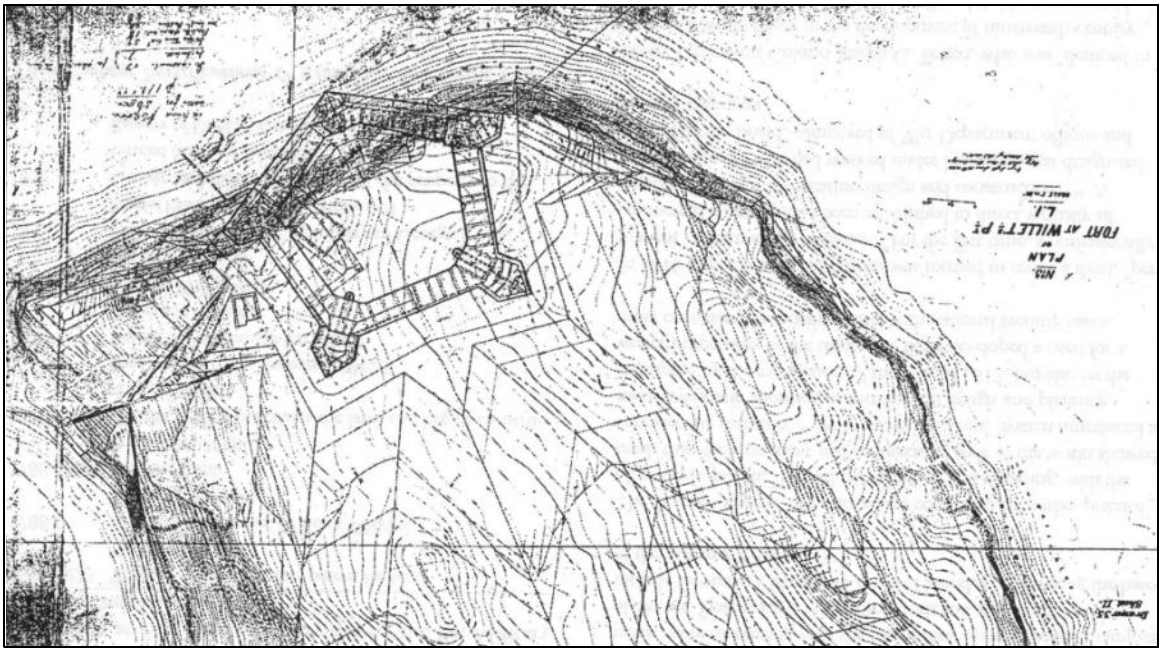

Figure 9: 'No. 3 Plan of Fort at Willet's Pt., L.I., June 25, 1863'
(NARA, RG 77, Drawer 35, Sheet 11)

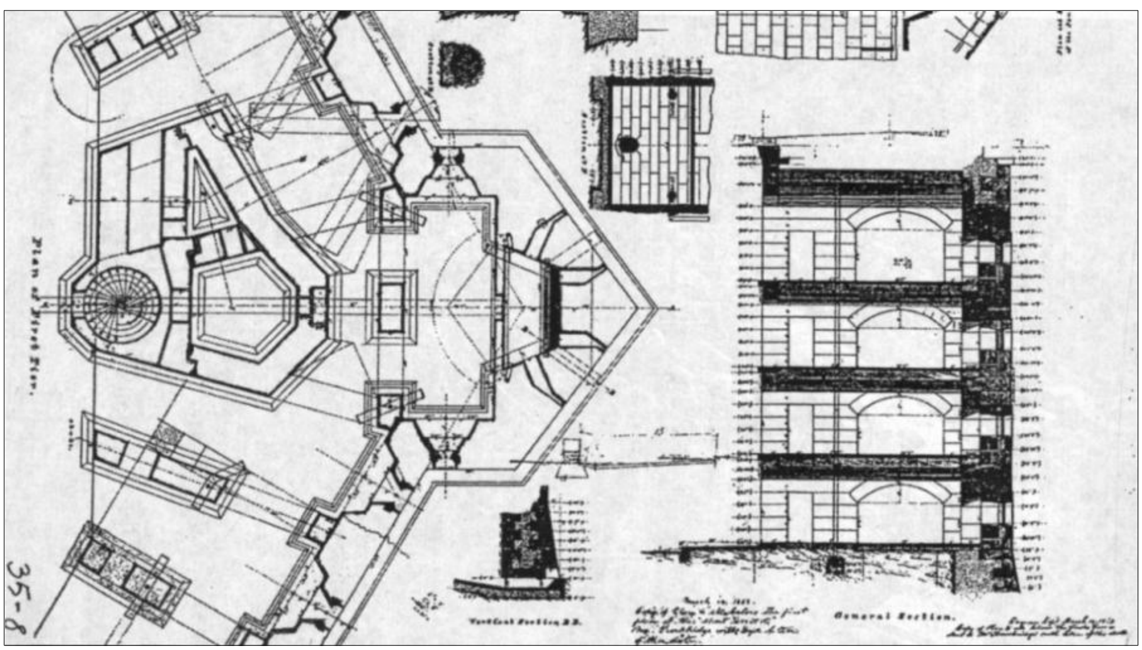

Figure 10: Detail of 'Fort at Willet's Point, May 20, 1864'
(NARA, RG 77, Drawer 35, Sheet 11)

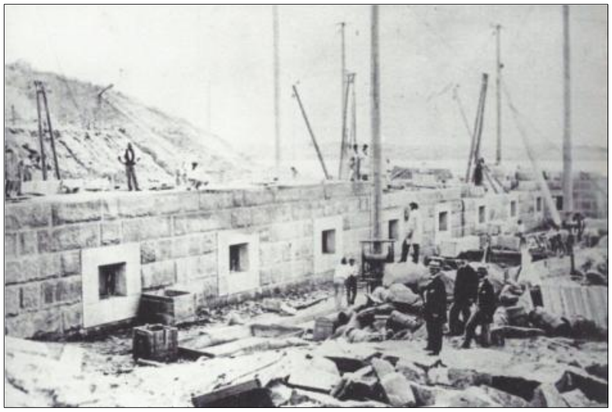

Figure 11: 'Fort at Willets Point, N.Y. View of Excavations and Embankments', ca. 1863 (NARA, RG 77 Drawer 35, Sheet 24)

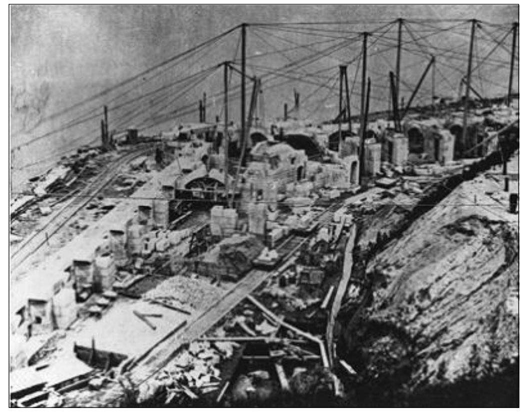

Figure 12: 'Fort at Willets Point, N.Y. View of the Work From the Hill Above', ca. 1863 (NARA, RG 77 Drawer 35, Sheet 21)

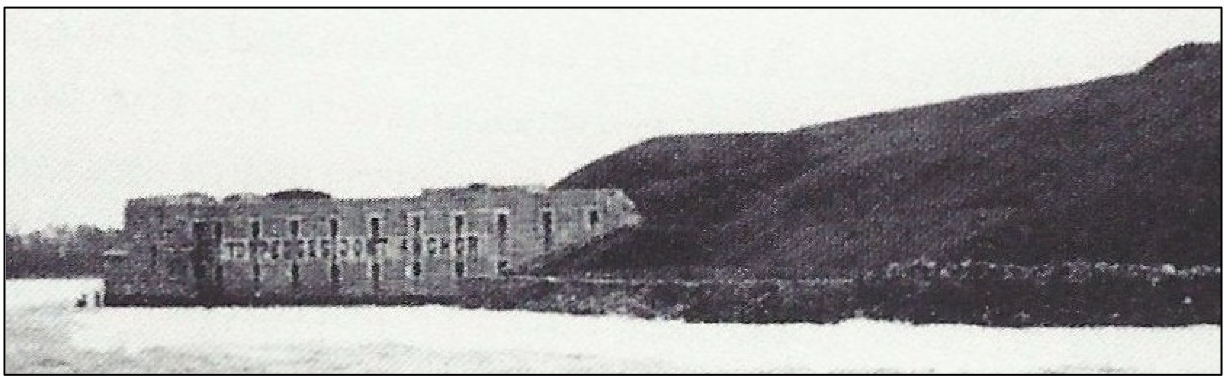

Figure 13: The Water Battery with the bluff line behind it. (NARA, 1900)

Figure 14: Upper Level of the Water Battery, Fort Totten (Mary Park, 2013)

Figure 15: Lower Casemates of the Water Battery (2013)

However, a year into the project, the design was amended to reduce the fortifications to a Water Battery in 1864, comprising the two tiers of the seaward walls that had already been constructed. A gorge wall was planned for the rear defenses, but only a month after this decision had been made, and after almost $950,000 had been spent, work was halted.[72] Work would recommence in the summer of 1865 under Major James Chatham Duane and several companies of engineers, following the demobilization and reassignment of the Army of the Potomac at the conclusion of the Civil War. Using these engineers Duane continued working on the Water Battery until he was replaced by Major Henry Abbot in 1968.[73] Work was halted again in 1869 and the two casemated tiers of the Water Battery remain incomplete to this day.

3.6.2. Failure of Masonry Fortifications at Willets Point

Figure 16: Damage caused by a rifled shell to the Water Battery, from left to right: the embrasure the shell punched through, the resulting damage on the far side of the bastion, and the metal remains of the shell embedded in the granite (2012)

In 1885, Lt. Eugene Griffin of the Corps of Engineers stated that, “The developments of our civil war, the broadside and turreted iron-clads and the long-range heavy ordnance, both smooth-bore and rifled, demonstrated this superiority beyond question, and marked the complete downfall of our third system of sea-coast defences.”[74] Indeed this was illustrated during a test of the defenses of the Water Battery, one of the last Third System forts to be built. While the walls were easily able to defend against a regular cannon ball fired from a warship, a carefully aimed single rifled shell from another vessel, tore through an armored Totten Embrasure located on the west face of the apex bastion and pulverized a section of the

[72] Gaines, (1997), p. 47-48
[73] Ibid, p. 48-50
[74] Griffin, Lt. Eugene., (1885), *Our Sea Coast Defences,* New York, C. P. Putnam’s Sons, p. 3

interior east wall. The damaged walls, along with fragments of the metal shell fused to the crushed granite blocks, are still visible today. Therefore new methods of construction and new materials were needed to build the next generation of US coastal fortifications. These began at Willets Point under the direction of the newly relocated US Corps of Engineers.

3.7. Post-Civil War Fortifications (1868-1876)

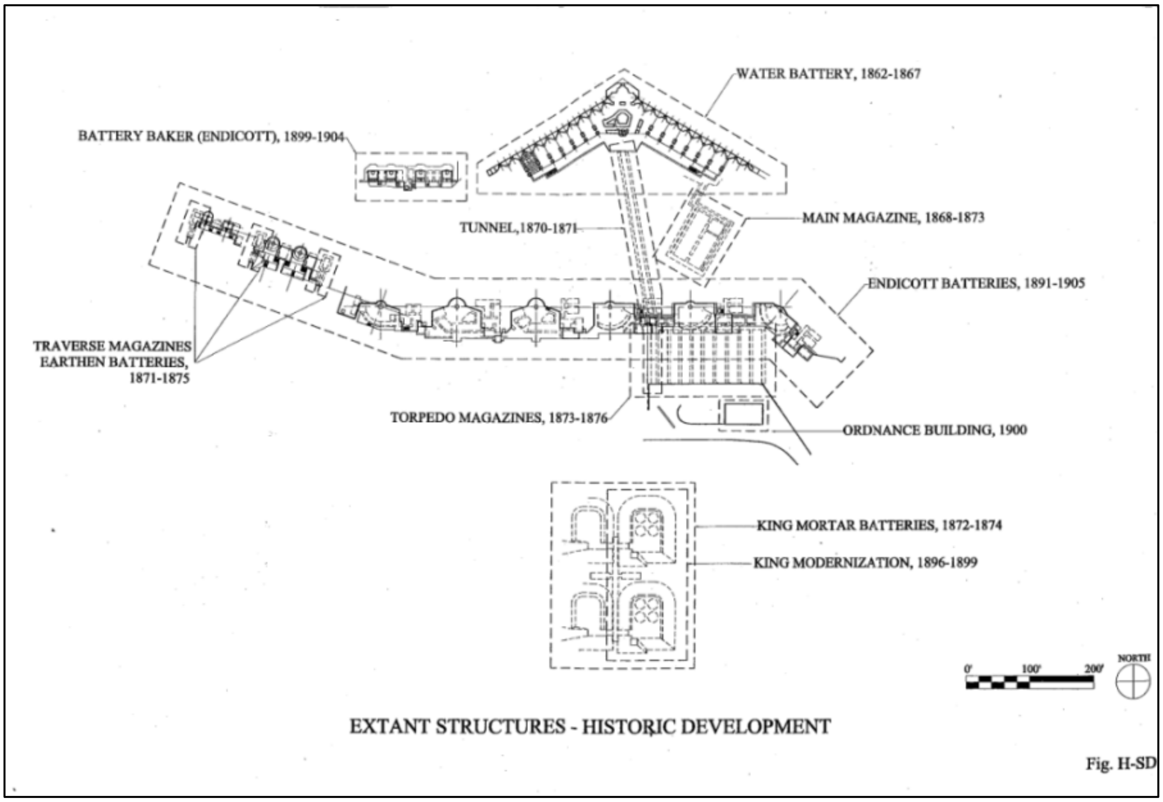

Figure 17: Layout of Extant Fortifications at Fort Totten (Beyer Blinder Belle, 2000, H-SD)

With the weaknesses of Third System exposed during the Civil War, the Corps of Engineers looked to new designs and different materials. Experiments were conducted with retrofitting existing masonry fortifications with iron armor cladding at Fort Monroe, VA and Fort Delaware, DE, but this option was deemed “inexpedient at present”.[75] Instead the Board of Engineers for Fortifications presented five recommendations to the Secretary of War and Congress on a coastal defense strategy.[76] The first recommendation was to prepare powerful

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[75] USACE Annual Report 1869, p. 5
[76] Ibid. p. 6

barbette batteries for the largest caliber guns, which would be protected by traverses and *parados*, and contain magazines and bomb proofs. Secondly, it was proposed to replace all existing coastal ordnance with depressed gun carriages. These would allow the guns to remain below battlements until they were released, spring up, and fire over the defenses, using the recoil action to push the gun back down below the parapet and remain hidden from view. Thirdly, the addition of mortar batteries was recommended, as these could fire projectiles over defenses in a parabolic arc which would fall directly onto the vulnerable wooden decks of enemy warships, thereby circumventing their heavily armored hulls. The fourth recommendation was to develop torpedoes (underwater mines) which could be used as inexpensive but potent accessory defenses in navigable waters. The final recommendation was the deployment of obstructions and floating batteries to protect the coast.

That same year, 1869, Willets Point was designated as the Torpedo Depot, while the Engineering Battalion, under Abbott, began constructing a series of concrete and earthwork batteries, magazines and mortars. This should also be seen in the context of Willets Point being the home of the Engineering School of Application and the Essayons Club, which sought to advance scientific knowledge through education and research.

One of the main challenges that Major Abbott and his engineers were faced with at Willets Point was how to incorporate these new ideas into site that already contained a partially-built masonry fort. As Trowbridge had already excavated a substantial area of the bluff immediately behind the Water Battery, Abbott decided to build two sets of magazines in this void: the Main Magazine and the Torpedo Magazines, as well as a Tunnel to connect the two resulting functional areas. After these were covered with earthworks, a series of earthen and concrete batteries were constructed along the bluff overlooking the channel. However, progress was slow due to the lack of appropriations. The Corps strenuously advocated in support of the project, citing the strategic importance of Willets Point, particular since the Corps in 1867 had begun the "operations for the removal of natural obstructions to navigation at Hell Gate, [which] render it even more important than heretofore that this channel of approach to New York City, and the Brooklyn navy yard, should be put in a proper state of defense."[77] Work on coastal defenses at Willets Point and elsewhere would continue slowly through to 1875, and the 1880 annual report noted that:

> *"much progress was accomplished in our earthen batteries, and various modifications were made in the plans of these batteries by which their strength was greatly increased, by adding to the thickness of parapets; by frequently interposing high and bonneted traverses between the guns to guard from enfilade fire and from splinters; by adding to the combined masonry and earth coverings of magazines; by increasing the heights of the parapets, and by introducing monolithic amasses of hydraulic cement concrete for the platforms of the guns in lieu of the granite blocks previously used for this purpose."* [78]

3.7.1. Main Magazine (1868-1873)

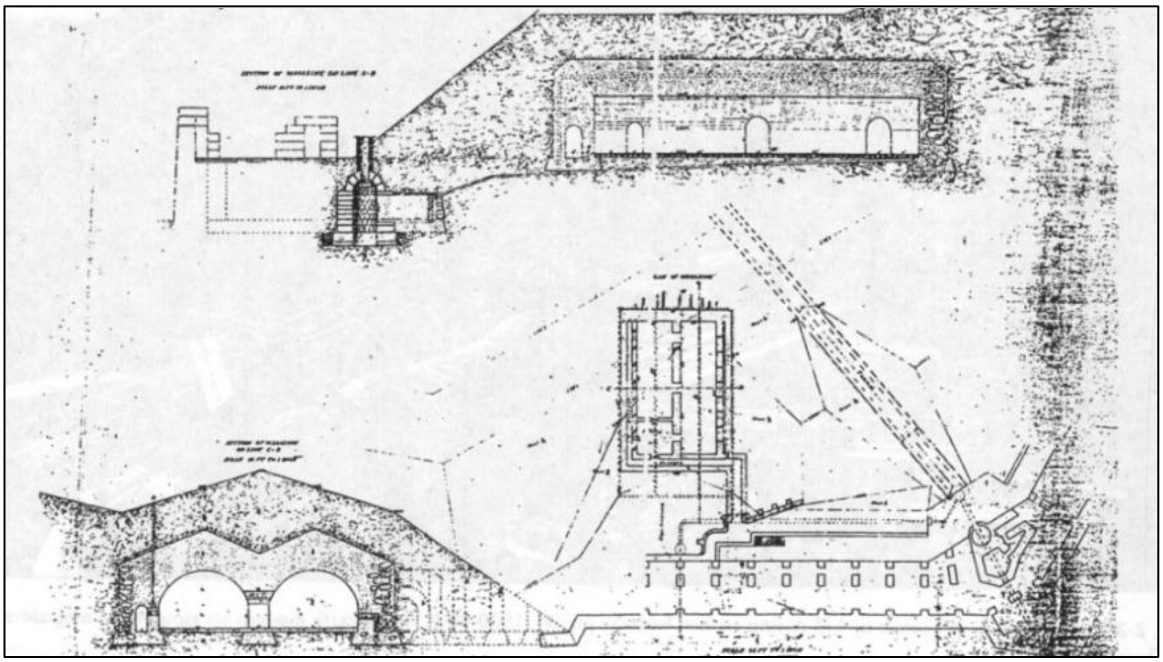

Figure 18: 'No. 3 Plan of Fort at Willet's Pt., L.I. June 25, 1863', Sections and Plan of the Main Magazine (NARA RG 77 Drawer 35 Sheet 11)

Located on the seaward side of the bluff and accessed via the second level of the Water Battery, work began on the Main Magazine in 1868, when its foundations were excavated. However, due to funding issues, work on the magazine was limited to preparing

[77] USACE Annual Report 1880, p. 16-17
[78] Ibid

the foundations in 1869 and laying the concrete foundations in 1870. The magazine was three quarters complete by 1871 and fully complete the following year. The covering of earth was finally added in 1874.[79]

Figure 19: Entrance to the Main Magazine (2012)

Figure 20: Entrance Tunnel Main Magazine (2012)

Figure 21: Smaller Powder Room, Main Magazine (2012)

The Main Magazine was a design that typified the Corps' fortifications built during the 1870s. As these magazines were built for the storage of ammunition and gunpowder in areas that were likely to receive enemy fire, they were designed with "massive walls and arched coverings, protected where exposed by earthen masks of great thickness and power of resistance."[80] The magazine measured 97 feet by 67 feet and comprised four distinct areas: an entrance tunnel, a filling room, and two powder magazines. The tunnel was eight feet wide and contained a barrel vaulted ceiling ten feet tall that led south into the hillside towards the magazine, before it turned east and wrapped around the east side of the magazine terminating into a dead end. The reason for this winding tunnel was to protect the powder rooms from the possibility of being hit from direct fire.

The filling room in the north east corner of the magazine opened into two gunpowder storage rooms, one 22 feet by 80 feet and one 22 feet by 58 feet. Each of the three rooms had

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[79] USACE Annual Report 1869, p. 11-12 and USACE Annual Report 1870, p. 17
[80] Twining, Capt. William J., (1872), "Ventilation of Military Magazines", *Printed Papers of the Essayons Club of the Corps of Engineers*, Vol. 2, No. XXII, Willets Point, NY, Battalion Press, p. 1

a 14 feet tall barrel vaulted ceiling and together they were built to hold 250,000 lbs. of powder.[81]

3.7.2. Tunnel (1870-

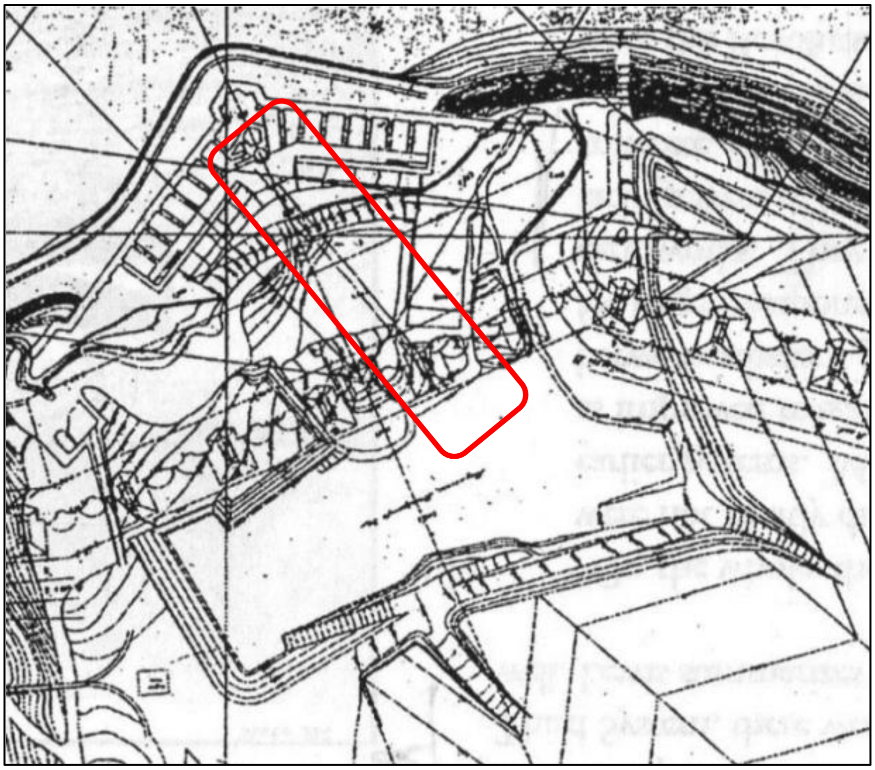

Figure 22: Detail of 'Plan of Willets Point, Eastern Entrance to N.Y. Harbor. Showing modifications proposed by the Board of Engineers for Fortifications, September 1869', proposed tunnel is outlined in red. (NARA RG 77 Drawer 35 Sheet 46)

When the Corps decided to fill in the excavated area behind the old fort, a means to link the Water Battery the rest of the Willets Point was required. Therefore, between 1870 and 1871, an underground concrete passageway was constructed, which was eight feet wide and 270 feet long, with a barrel vaulted ceiling ten feet tall. In 1874, the tunnel was extended by an additional 90 feet, and the whole tunnel possessed a one in nine slope. The walls were built three feet thick, increasing to four feet at the southern entrance near the Torpedo Magazines. The concrete floor of the tunnel incorporated rails with a 4 feet gauge track recessed into the floor to facilitate the transport of torpedoes from the magazines to the Water

[81] USACE Annual Report 1872, p. 13

Battery. The interior walls were finished with stucco, with historic and modern graffiti, including “Remember the Maine”.[82]

The northern entrance to the tunnel extended out from the earthen embankments, leaving it partially exposed. In addition, this arched entrance was decorated with a series of moldings topped with a keystone, all created with concrete formwork.

Figure 23: Tunnel interior, showing graffiti, and south entrance (2013)

Figure 24: North entrance of tunnel, showing decorative concrete moldings (2013)

3.7.3. Torpedo Magazines (1873-1876)

From 1869, the main focus of Willets Point was research and development into torpedoes, which were essentially underwater mines that could be raised from stationary moorings and remote detonated. These could be used to protect navigable waterways as a complementary defense to cannons fired from coastal batteries. At Willets Point, this led to the construction of a unique type of fortified structure. Nine cast-in-place concrete Torpedo Magazines were built in stages between 1873 and 1876, within the gap created by Trowbridge’s detonation of the bluff. Their design originated at Willets Point, which had been designated as the Torpedo School in 1869. After the foundations were prepared, the first

[82] This referred to the USS Maine, which exploded and sank in Havana harbor in Cuba under mysterious circumstances, and was one of the catalysts for the Spanish American War of 1898.

four casemated magazines were completed in 1873 next to the tunnel. This resulted in extending the tunnel by 90ft. These magazines were 14 feet wide, 84 feet long and contained a 14 feet tall barrel-vaulted ceiling. Three more magazines were completed in 1875 to the east of the original four using the same design, except these were 15 feet wide. The last two magazines were completed in 1876 at the end of the range, using the same design as the middle three. All magazines were waterproofed with an asphalt mastic and bluestone coping, while drains were placed in the valleys between the barrel vaults and in front of the magazines. Finally two feet of earth cover was added on top of the magazines.

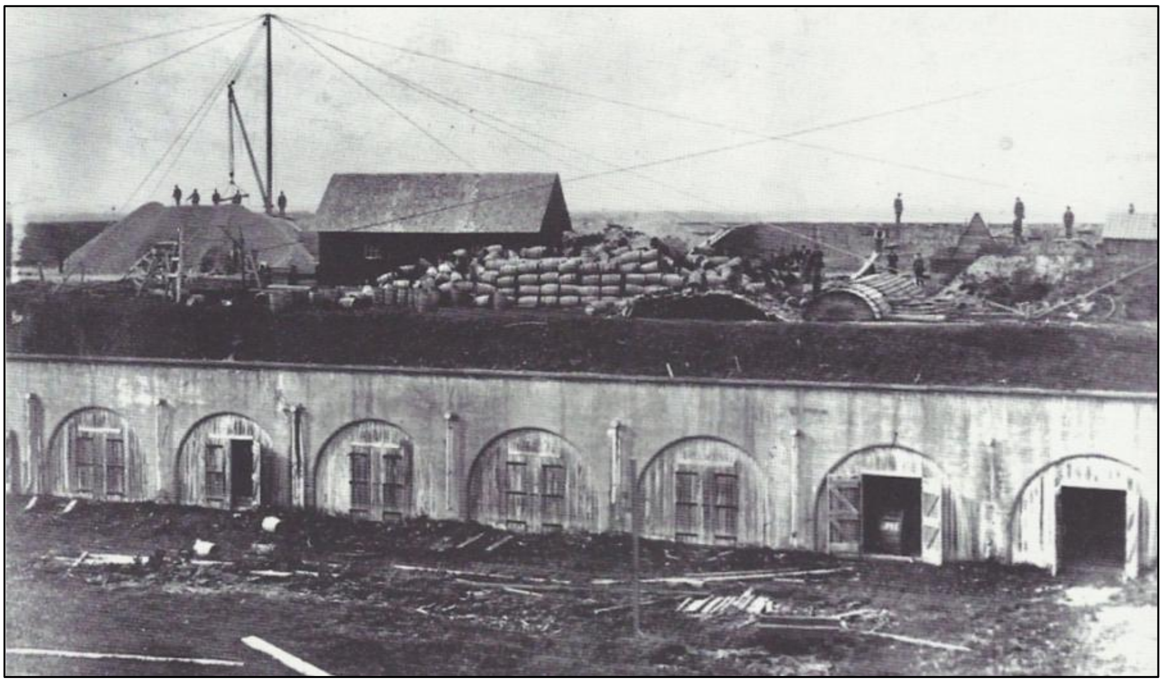

Figure 25: Torpedo Magazines, ca. 1880s (Fort Totten Museum Collection)

The semicircular entrances to each of the magazines were filled with a brick and wooden façade, containing a pair of heavy wooden doors. Additionally, rail tracks were added to link the magazines to the tunnel. At some point, several doorways were excavated to link some of the central magazines through their side wall, and one of these was left unfinished, but does allow a ‘window’ into the concrete used in its construction.

Figure 26: Torpedo Magazines, southern elevation (2013)

Figure 27: Torpedo Magazine Interior (2013)

Figure 28: Torpedo Magazine, showing two doorways cut into the side walls (2013)

Figure 29: Torpedo Magazine, showing a partially cut doorway in the sidewall (2013)

3.7.4. Earthen Batteries (1871-1875)

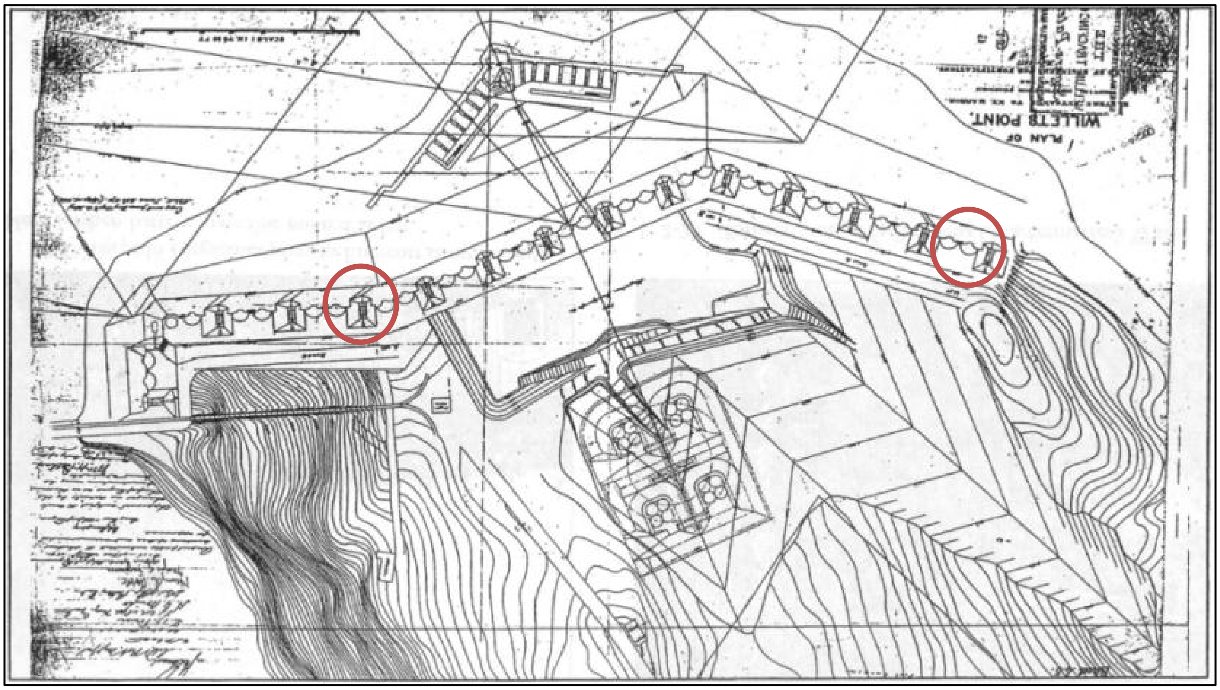

Figure 30: Detail of 'Plan of Willets Point, Eastern Entrance to N.Y. Harbor. Showing modifications proposed by the Board of Engineers for Fortifications, May 1871', The area circled on the left is the location of Battery Stuart, while the area on the right is the location of the exposed battery (NARA RG 77 Drawer 35 Sheet 48)

Along the top of the reconstituted bluff, the Corps built a series of four earthen batteries stretching along the bluff line behind the Water Battery, from Little Bay to the west through to Little Neck Bay to the east. Each battery was composed of a pair of barbette gun platforms that were separated by concrete service magazines, all of which were covered with earthwork traverses and *parados* to the rear. These were armed with twenty five heavy 15-inch Rodman guns and sixteen 23-inch mortars. From the western shore, Little Bay Battery was built between 1871 and 1873, which contained two guns and a traverse magazine. Next, running up the hill from the water was the West Battery, which was built between 1871 and 1874 for six guns and three service magazines. After the tunnel had been completed and the bluff rebuilt, the Middle Battery was begun in 1873 for ten 15-inch Rodman guns. Finally, running down the hill towards Little Neck Bay, the East Battery was constructed between 1873 and 1875 for seven 15-inch Rodmans.

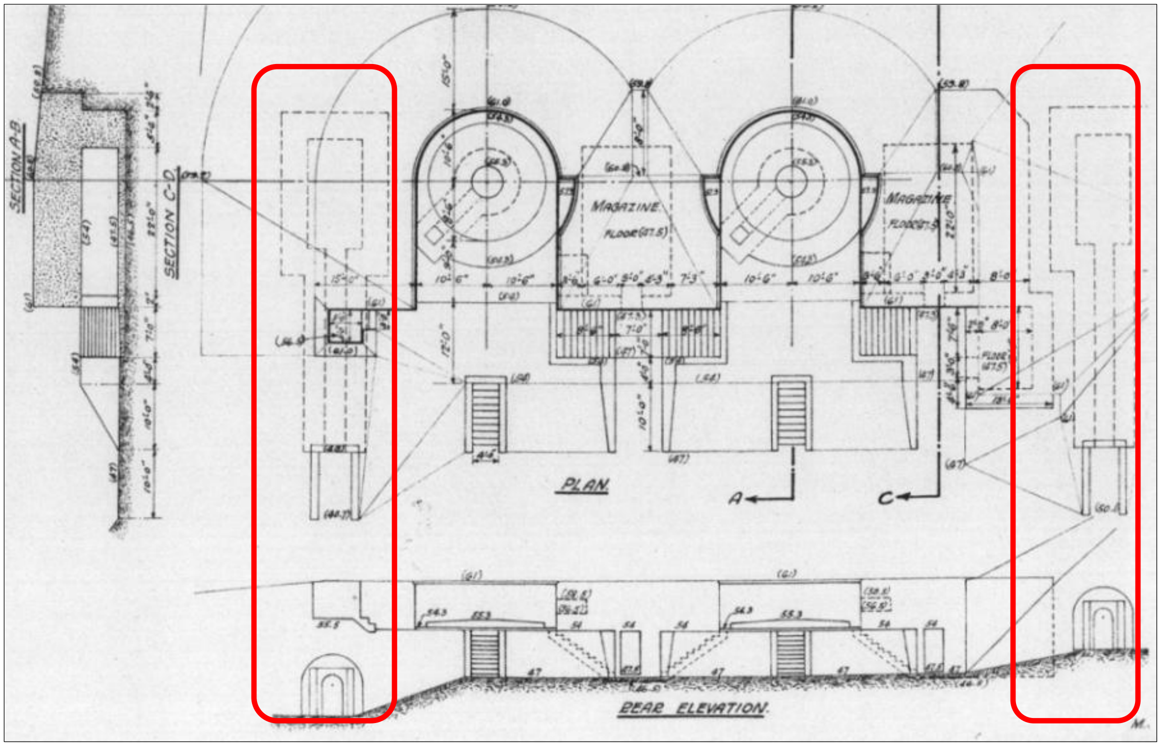

Figure 31: Plan, Elevation and Sections for Battery Stuart, Fort Totten showing the Remains of the Earlier 1870s Batteries (NARA 1920 Report of Completed Works)

Figure 32: Magazine entrance of the surviving 1870s Battery (2013)

Figure 33: Magazine interior of the surviving 1870s Battery (2013)

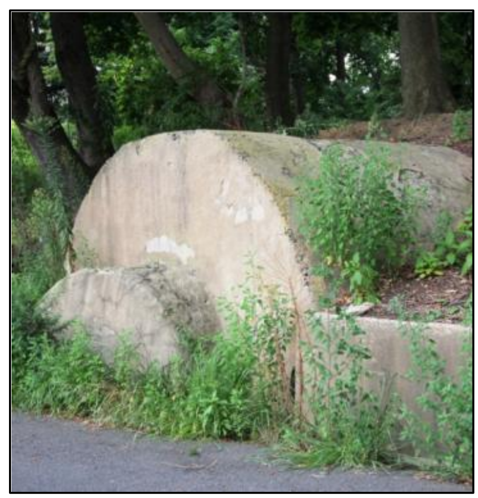

Figure 34: Magazine exterior, possibly from an 1870s Battery (2012)

Unfortunately, the majority of these fortifications were demolished by the Corps in the 1890s and replaced by a series of Endicott batteries. However, some of the concrete magazines have survived. Two were incorporated into Battery Stuart (built 1898-1900), while the rear of a magazine, possibly from the East Battery, is still visible (See Figures 31 to 34).

3.7.5. Mortar Battery (1872-1874)

The Mortar Battery, located behind the excavated area for the granite fort, was a new design devised by Maj. Henry Abbott, after which it was known as an 'Abbott Quad'. The battery consisted of four sets of four 13-inch mortars, each set massed within a single sunken rectangular concrete pit and an associated magazine and bombproof. The aim was to mass fire the mortars, with a shotgun-line effect. Excavations began in 1871, but when works were suspended in 1875, only one of the quad mortar pits had been completed. This battery was subsequently refurbished and renamed as Battery King during the Endicott period of the 1890s, before being covered with earth in the 1930s.

3.8. Endicott Period (1885-1905)

Following a decade long lack of investment, the America's coastal fortifications were in a deplorable state, which, according to the Corps of Engineers, seriously threatened the nation's security. Such arguments were made year after year in their annual reports to the Secretary of War, and were reiterated in the national press. Despite several military and government boards or committees that were convened to examine the matter, nothing much happened until March 1885.[83] The newly elected President, Grover Cleveland, created the 'Board on Fortifications or Other Defences', which was later referred to as the Endicott Board, named after its chairman, Secretary of War William Crowninshield Endicott.[84] The main aim of the Board was to study fortifications in order to make recommendations to the Government on the country's defenses. In January 1886, after less than a year, the Board's report was published, and included the reports from five sub-committees concerning contemporary arms and amour, underwater mines, foreign warships and ports, iron and steel industries, and floating batteries.

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[83] Fritz, Karl, (2010), "The Formation of the Endicott Board", *Coast Defense Journal*, Vol. 24, No. 4, November 2010, p. 4

[84] . The other members of the Board included Brig. Gen. S. V. Benet, Chief of Ordnance, Brig. Gen. John Newton, Chief Engineer, Lt. Col. Henry L. Abbot, Commander at Willets Point, Captain Charles S. Smith, Ordnance Department, Cmdr. William T. Sampson and Cmdr. Caspar F. Goodrich, US Navy, Mr. Joseph Morgan Jr., chief engineer of the Cambria Iron Works, PA, and Mr. Erastus Corning, president of the Rensselaer Iron and Steel Co., NY.

While the report has been called a “milestone” in US military history that essentially brought 20 years of reflection and experimentation to bear on recommendations that would affect policy for 30 years,[85] their findings were hardly revelatory. The tenets of Board’s recommendations, new guns, new fortifications, torpedoes, and floating batteries, could be read each year in the Chief of Engineer’s annual reports submitted since the late 1870s and in a number of occasional papers and reports submitted by members of the Corps.

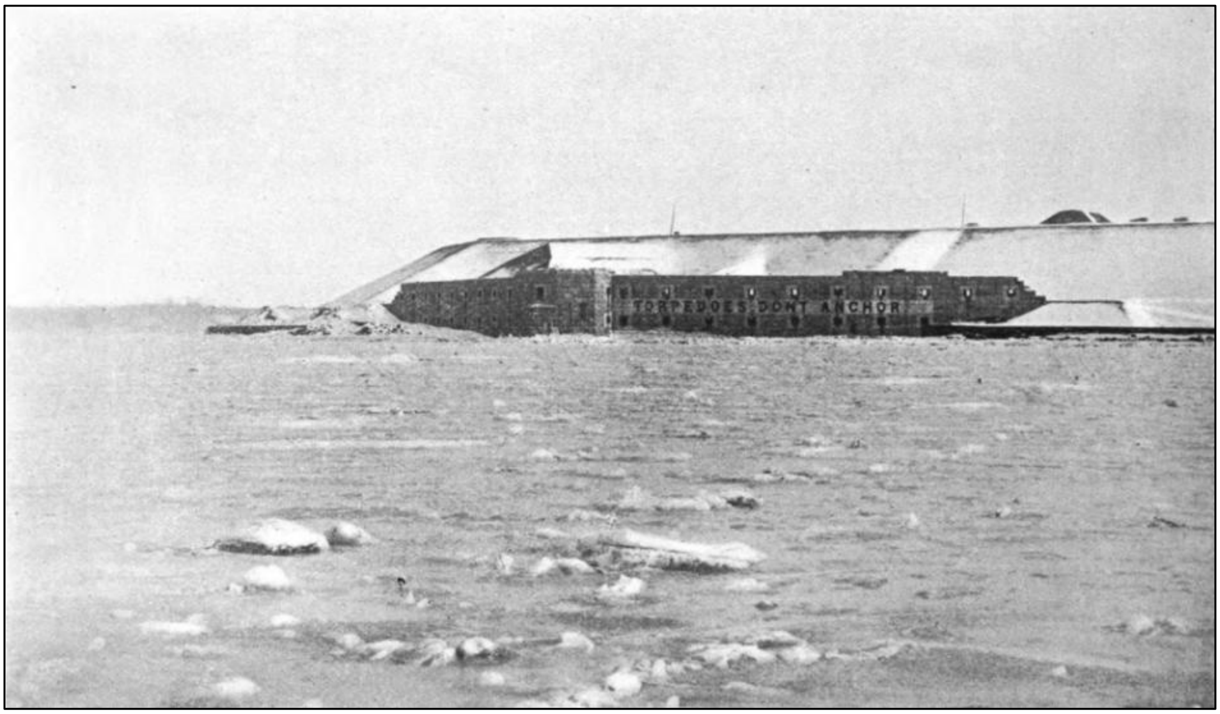

Figure 35: Water Battery and the reconstituted bluff behind shielding the Endicott Batteries (Abbott, 1904, p. 17)

However, the report did establish a defense plan for the Government and the Corps. It identified 27 US ports that urgently required new coastal defenses as well as a shortlist of ports where “fortifications or other defences are most urgently required,”[86] and New York was the top of both. Furthermore, the Board established what types of fortifications and defenses were needed at each site, as well as the industries that would be needed to help support these endeavors, namely steel and munitions. Moreover, the report placed a price tag

[85] Beyer Blinder Belle, 2000, 2.18
[86] Endicott, William C., (1886), *Report of the Board on Fortifications or Other Defences*, Washington, Government Printing Office, p. 8

on these works: $21,500,000 in appropriations in the first year, with $9,000,000 each year thereafter until the work was completed.[87] The high cost of these proposals inevitably led to several years of Congressional bickering, delaying any new appropriations until 1890, and even then, the first appropriation was only for $1,200,000, with subsequent annual appropriations of $500,000 until 1896, when they were increased significantly.[88] The projected works were spread out over a number of years, to make their high costs more palatable.

Figure 36: Detail of aerial photograph of Fort Totten (NARA, Aerial Photographs, July 1920)

However, such a delay was not altogether such a bad thing, since the Endicott Board had advocated a return to masonry fortifications clad in iron armor plate as well as using structural iron members and steel turrets. These, along with the proposed floating batteries were inevitably dropped, as they were considered too extravagant.[89] The delay also facilitated the change to the almost exclusive use of concrete in constructing the emplacements, traverses and magazines. Concrete was not only more economical than

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[87] Ibid. p. 29. By today's standards this would equate to $541,000,000 and $ 226,500,000, respectively.
[88] Winslow, (1920) p.15
[89] Kaufmann, J.E. and Kaufmann, H.W., (2004), *Fortress America: the forts that defended America, 1600 to the present*, Cambridge, MA, Da Capo, p.313

masonry construction, the properties of poured concrete forms would better suit the "more complicated program and configuration of interior spaces to service the larger more sophisticated guns."[90]

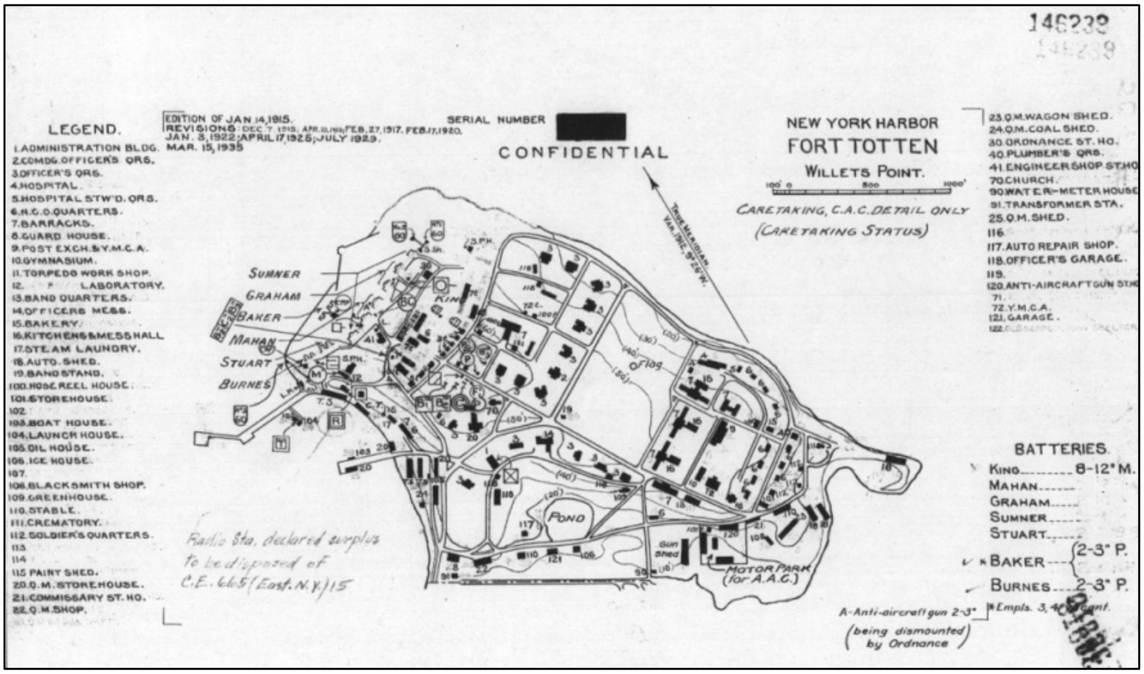

Figure 37: 'New York Harbor, Fort Totten, Willets Point', Plan (NARA, 1920, Report of Completed Works)

In addition, the American iron and steel industry was not yet prepared nor technologically advanced enough to make the cannon and structures proposed under the Endicott Board report. Indeed French steel was used to build some of the first ordnance in the early 1890s.[91] Indeed the Watervliet Arsenal, NY would not be ready to supply cannons until 1892. In the 1880s, the US steel industry was undergoing fundamental technological shift with research into steel, alloys, and mass production, so more time was needed to for the development and testing of disappearing carriages, more powerful guns, torpedoes, and armor shielding.[92]

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[90] Beyer Blinder Belle, 2000, 2.18
[91] Ibid. p. 314
[92] Beyer Blinder Belle, 2000, 2.17

3.9. Endicott Battery Typology

The Endicott batteries would exhibit a more standardized design and method of construction, which is evident at Willets Point and other sites. The basic design of the Endicott battery was a two story, roughly rectangular structure that comprised two basic functional areas: open deck gun emplacements above, and magazines for the storage of gun powder and arms below. Open platforms were adopted due to the enormous size of guns and carriages attained by 1880s, which were now designed to disappear behind high parapets. In addition, circular mounting pits were required to provide the depth needed to support the large heavy carriages and guns, as well as allow the guns to swivel. Covered stairs led from the back of the magazines up to the loading platforms of the gun emplacement.

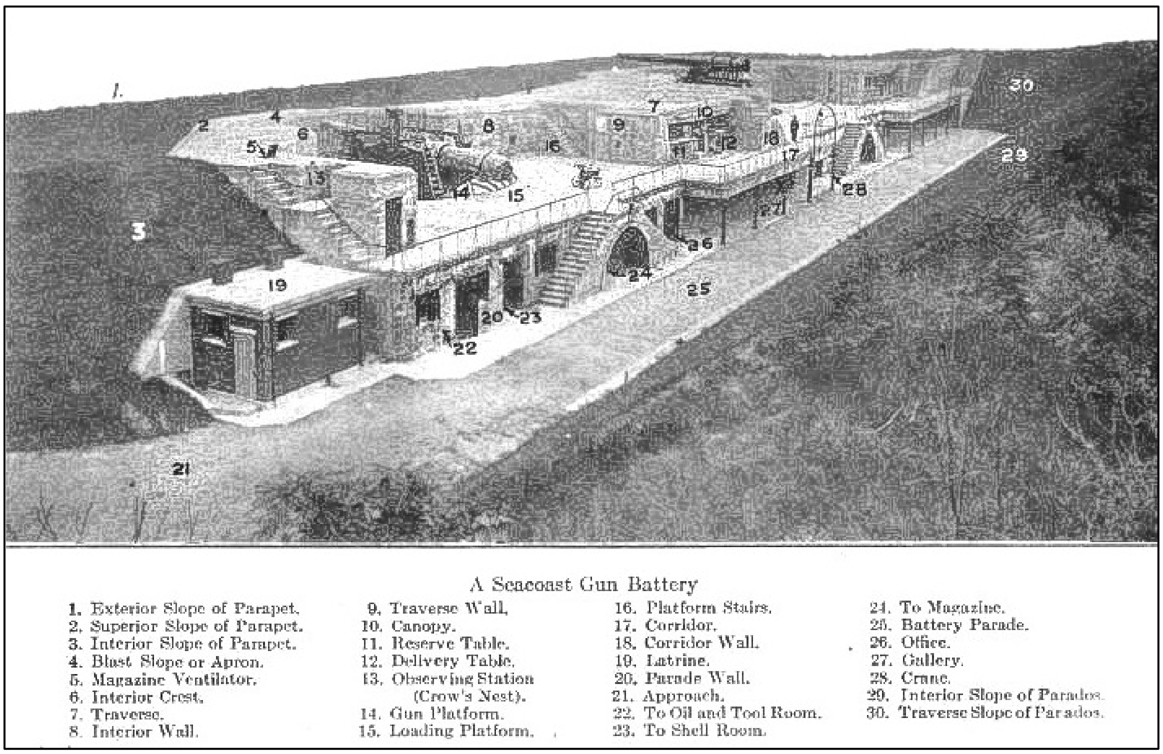

Figure 38: Anatomy of a Coastal Battery (Hines and Ward, 1910, frontispiece)

These batteries were built with concrete poured into wooden formwork creating solid mass forms, often with barrel vaulted ceilings, similar to the design of the 1870s batteries and magazines. In some early examples, the second floor platforms were built with exposed steel beams and concrete infill. After 1902, extensive additions to the Endicotts were built with true reinforced concrete, using twisted wrought iron rebar. In addition to the batteries and magazines, the Corps built observation towers and plotting rooms, as well as searchlights to help pinpoint the location of vessels travelling through the channel. Greater heights were required primarily due to the range of the heavier guns, which increased to ten miles.

3.10. Endicott Batteries at Willets Point

At Willets Point, six emplacements were built along the bluff, replacing the 1870s batteries, and were known as the Upper Endicotts (Batteries Sumner, Graham, and Mahan). Three additional batteries were built, two along the lower western slope (Batteries Burnes and Stuart) and one immediately to the west of the Water Battery (Battery Baker). Finally, the 1870s Mortar Battery was rebuilt and renamed Battery King.

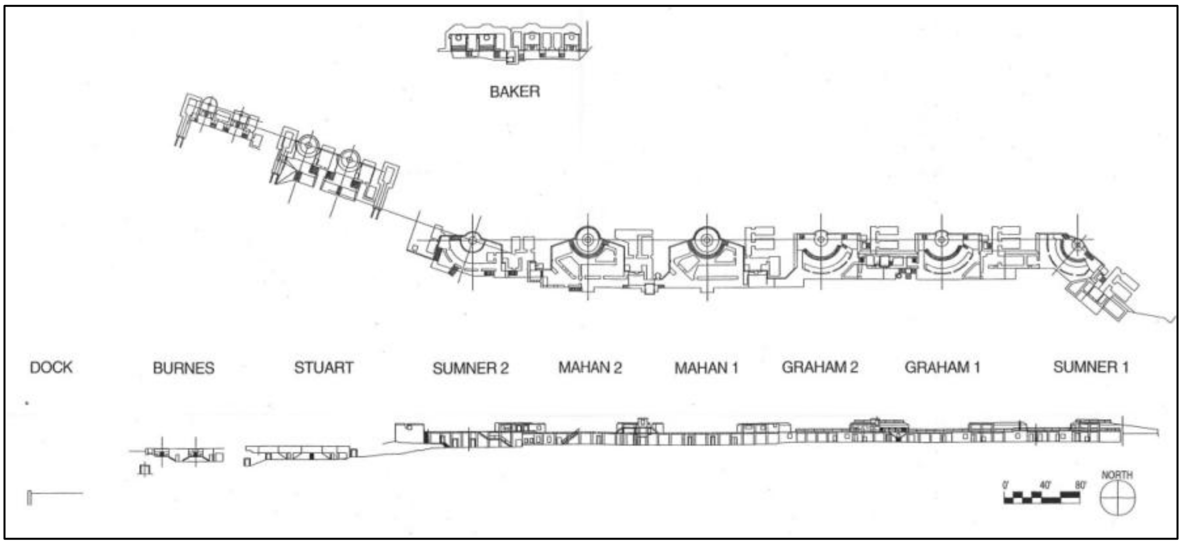

Figure 39: Plan and Elevations of the Endicott Batteries (Beyer Blinder Belle, 2000, 7-20)

The Upper Endicotts began with Battery Sumner 1 in 1891, Battery Graham 1 and 2 in 1892, Battery Sumner 2 in 1896, and Battery Mahan 1 and 2 in 1898. These designs were similar to the emplacements and magazines built during the 1870s with solid masses of cast-in-place concrete using natural cement, except for Batteries Mahan, Stuart, Baker, and Burnes, which were built using portland cement. From 1902-1905, all of the Upper Endicotts were extended to the south using reinforced portland cement concrete, creating additional ground level storage rooms, guard rooms, loading areas, and external staircases. Along the upper levels, the gun platforms were extended, while covered loading areas and additional range stations were added.

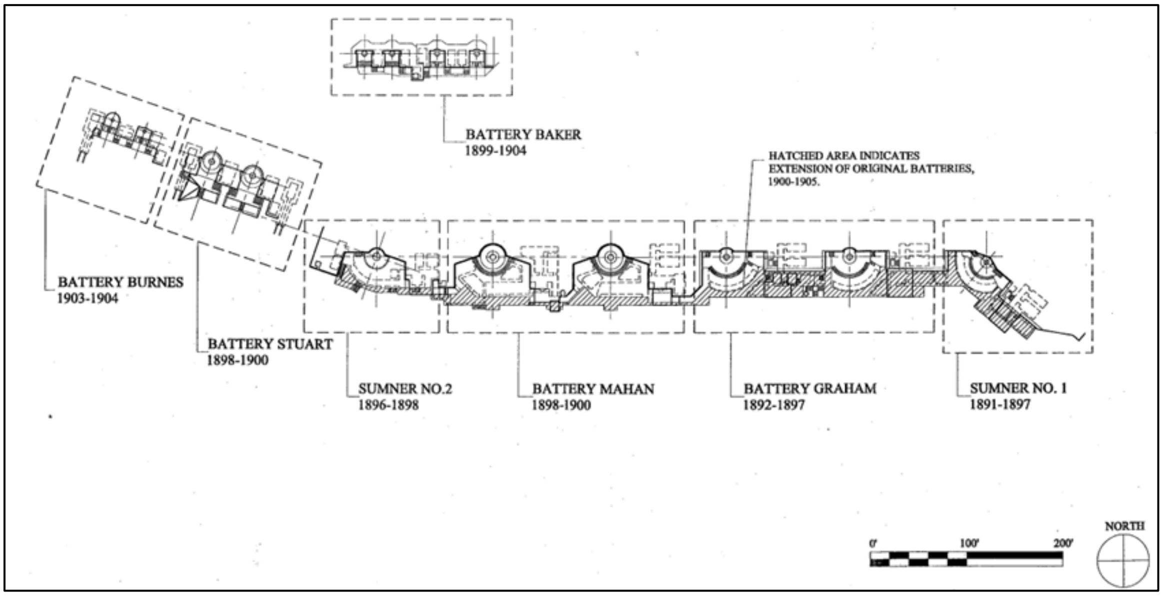

Figure 40: Development Phases of the Endicott Batteries, Hatched areas show 1902-1905 extensions to the south of the Upper Endicotts (Beyer Blinder Belle, 2000, H-EC)

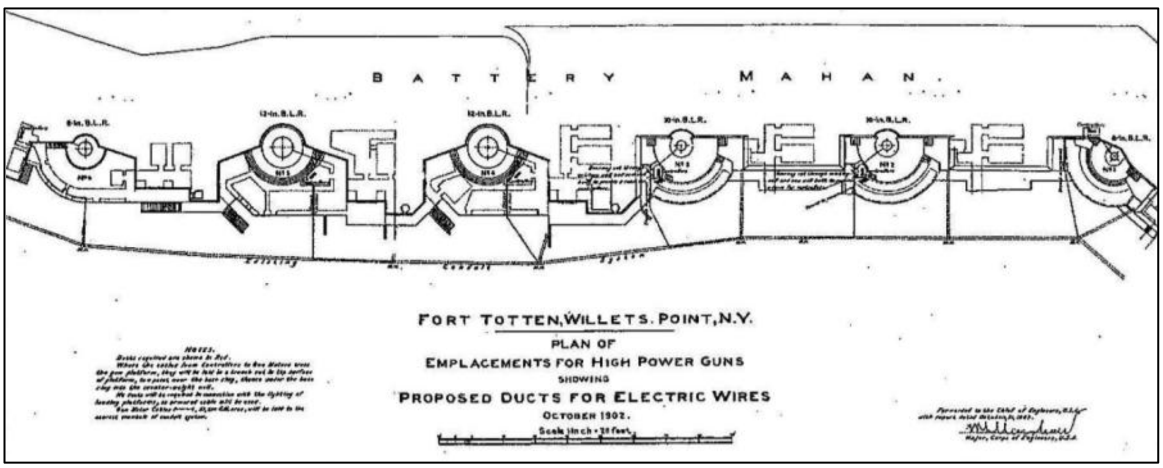

Figure 41: Details of 'Fort Totten, Willets Point, N.Y. Plan of Emplacements for High Power Guns Showing Proposed Ducts for Electric Wires. October 1902' Showing the Upper Endicotts before the southern extensions were built (NARA, RG 77, Drawer 35, Sheet 60a12)

3.10.1. Batteries Sumner 1 and 2 (1891-1898)

Originally called Emplacement No. 1, Battery Sumner 1 was built on the site of the 1870s East Battery, which had been demolished, and was built at an angle so that it faced Little Neck Bay rather than the channel. It was designed to mount an 8-inch M1888MI gun on a M1894 Buffington-Crozier disappearing gun carriage. In 1903 it was renamed after Jethro Sumner (1733-1785), a Brigadier General with the Continental Army from North Carolina.

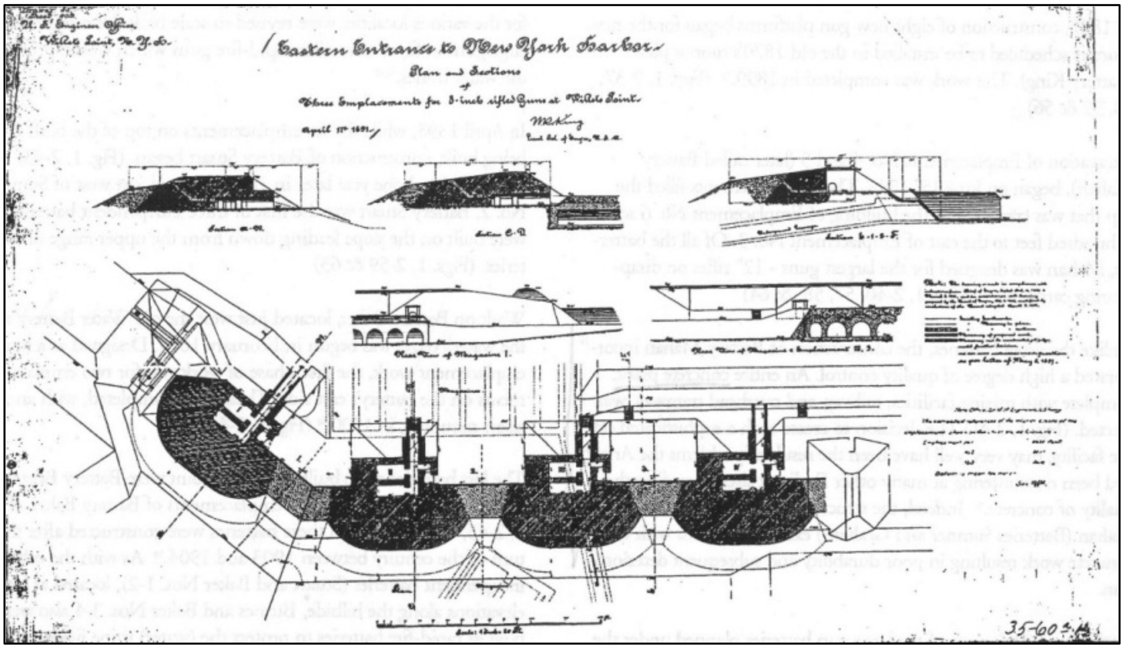

Figure 42: 'Eastern Entrance to New York Harbor - Plan and Sections of Three Emplacements for 8,inch Rifled Guns at Willets Point. April 17, I 891', showing the relationship between the early Endicotts and the 1870s work, Battery Sumner 1 is on the far left (NARA, RG 77, Drawer 35, Sheet 60al)

Battery Sumner 1 followed the standard Endicott design with a roughly semi-circular gun platform built of natural cement concrete, whose foundations were surrounded at the rear by a semi-circular brick wall. The ceiling extending from the emplacement foundations to the wall were built with rolled wrought iron beam supports with concrete infill. Two rectangular magazines with barrel-vaulted ceilings were built below and to the right of gun platform. Lt. Col. William R. King, the Commander of the Engineering Battalion, reported that, "work on one of three emplacements for 8-inch guns [Sumner 1] was well under way. The excavation for the magazine and its approaches has been made, and concrete is being put in at the rate of about 75 cubic yards, soon to be increase to 100 or more cubic yards, per day." [93] The magazine and part of the parapet wall were completed in 1892 and work on the gun emplacement continued from 1893 to 1896. However, the foundations for the gun emplacement settled unevenly, so they were loaded with 55 tons of granite and iron. The

[93] USACE Annual Report 1891, p. 7

problem was resolved in 1897, and work continued on the platform steps, the retaining walls, and the concrete floors, while the parapets were waterproofed with asphalt.[94]

3.10.2. Battery Graham (1892-1897)

Battery Graham (Emplacements 2 and 3), was a twin battery built between 1892 and 1897 for two 10-inch M1888 guns mounted on M1894 Buffington-Crozier disappearing gun carriages. These emplacements were renamed in 1903 after Lt. Col. William M. Graham of 11th US Infantry, who was killed in action on Sept 8, 1847 at the Battle of Molino del Rey during the Mexican-American War.

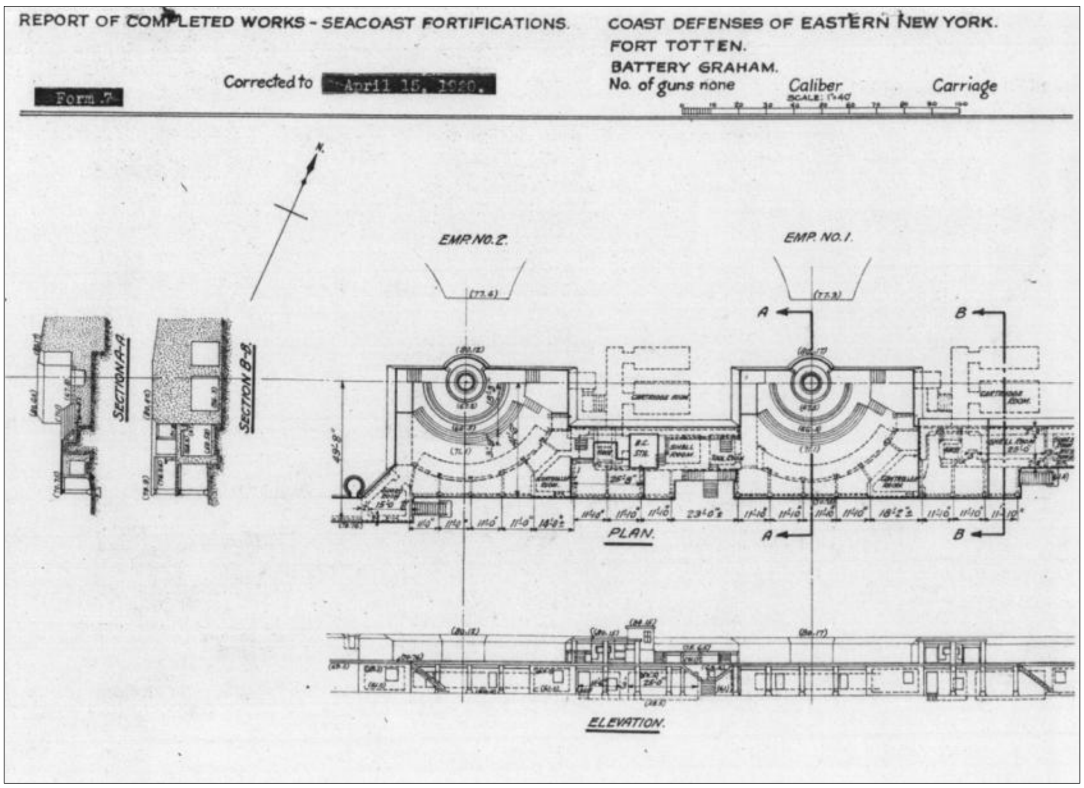

Figure 43: Plan, Elevation and Sections for Battery Graham, Fort Totten, built 1892-1897 (NARA, 1920, Report of Completed Works)

Work began on the emplacements and traverse magazines in 1892 using cast-in-place natural cement concrete, with Graham 1 completed in 1896 and Graham 2 in 1897,. The original designs for each battery were virtually identical, comprising the gun emplacement

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[94] USACE Annual Report, 1897, p. 612

with surrounding brick wall and two ground floor magazines, while stairs leading from the rear of the magazines led up to the gun platforms. From 1902 to 1905 the two batteries were extended to the south to widen the platforms, add loading rooms and exterior stairs for both batteries, along with a range-station for Graham 2.

3.10.3. Battery Mahan (1898-1900)

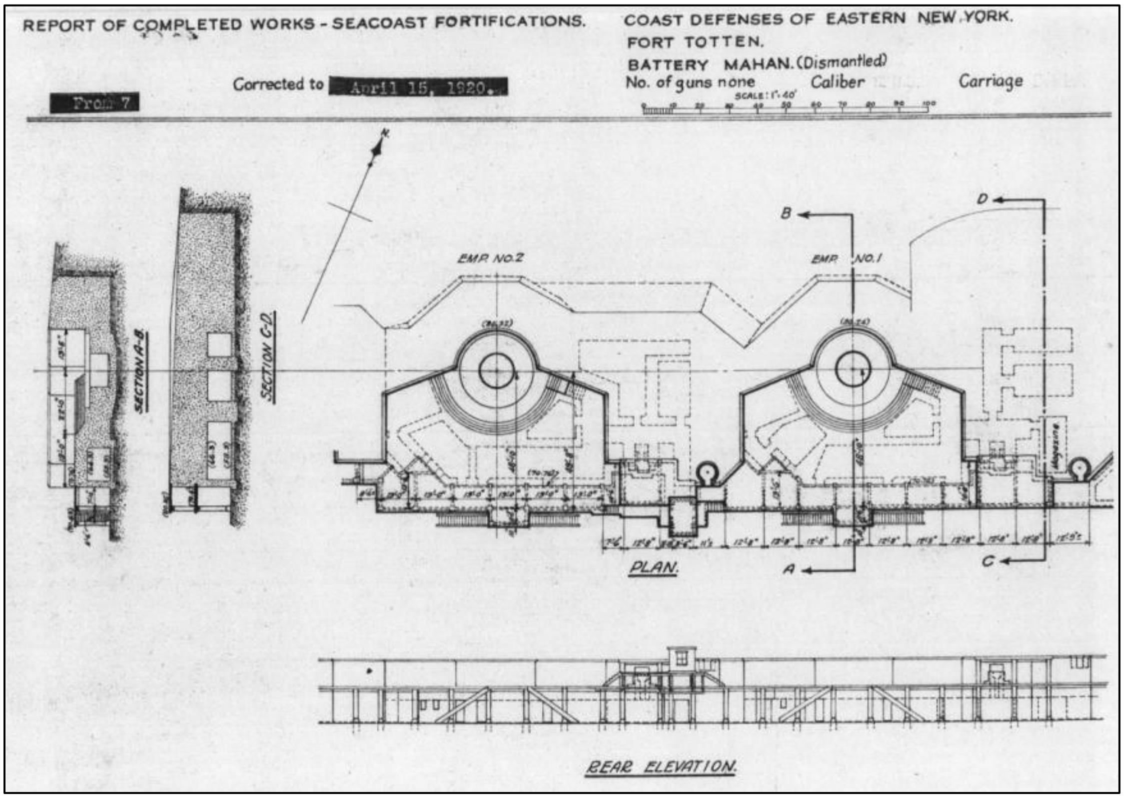

Figure 44: Plan, Elevation and Sections for Battery Mahan, Fort Totten, built 1898-1900 (NARA, 1920, Report of Completed Works)

Battery Mahan 1 and 2 (Emplacements 4 and 5), was a twin battery built between 1898 and 1901 for two 12-inch M1895 breech-loading rifles and mounted on M1897 disappearing carriages. These emplacements were renamed in 1900 after Dennis Hart Mahan (1802-1871), Professor of Civil and Military Engineering at the West Point US Military Academy for over 40 years.[95] Built on the site of the 1870s Middle Battery, excavations began in 1898 with the bulk of the work completed the following year. The roofs were

[95] Gaines, He also wrote several military engineering treatises, including, An Elementary Course on Military Engineering (1865) and Permanent Fortifications (1867)

waterproofed with Neuchatel Rock Asphalt, imported from Val de Travers, Switzerland, and the battery was completed in 1901.

Battery Mahan was unique amongst the Endicotts, as its construction incorporated a high degree of quality control utilizing a newly built concrete mixing plant. This change may have been attributed to problems with the quality of the concrete mixed for the earlier Endicotts, as Lawry believed. However, this was also the first time that a battery had been built out of portland cement concrete at Fort Totten. Furthermore, the design for Battery Mahan diverged from the design of the earlier batteries, as it possessed a crudely pentagonal shape for the gun platform along with multiple magazines built within the traverses and the emplacements. Finally, loading platforms were incorporated into the original batteries, and not the later extensions, as with the Batteries Sumner and Graham. The later extensions (1902-1905) simply incorporated widened platforms and a shared range-station.

3.10.4. Other Batteries

Four additional batteries were built at Willets Point. The 1870s unfinished Abbot Quad mortar battery was rebuilt beginning in 1892/3 with the excavation of 400 yds^3 of rock and 1,600 yds^3 of earth.[96] Work recommenced in 1897, as the two right hand mortar pits were rebuilt, and the two left hand pits remained as they were. The eight right hand mortar platforms were completed in 1898 and eight 12-inch M1890MI and M1890MII mortars on M1896 mortar carriages were mounted in 1900. The mortar battery was renamed in 1903 after Lt. Col. William R. King, former Commander of the Engineering Battalion between 1886 and 1895. In the 1930s the battery was buried with earth and the area became a sports field.

[96] USACE,(1892) p. 7

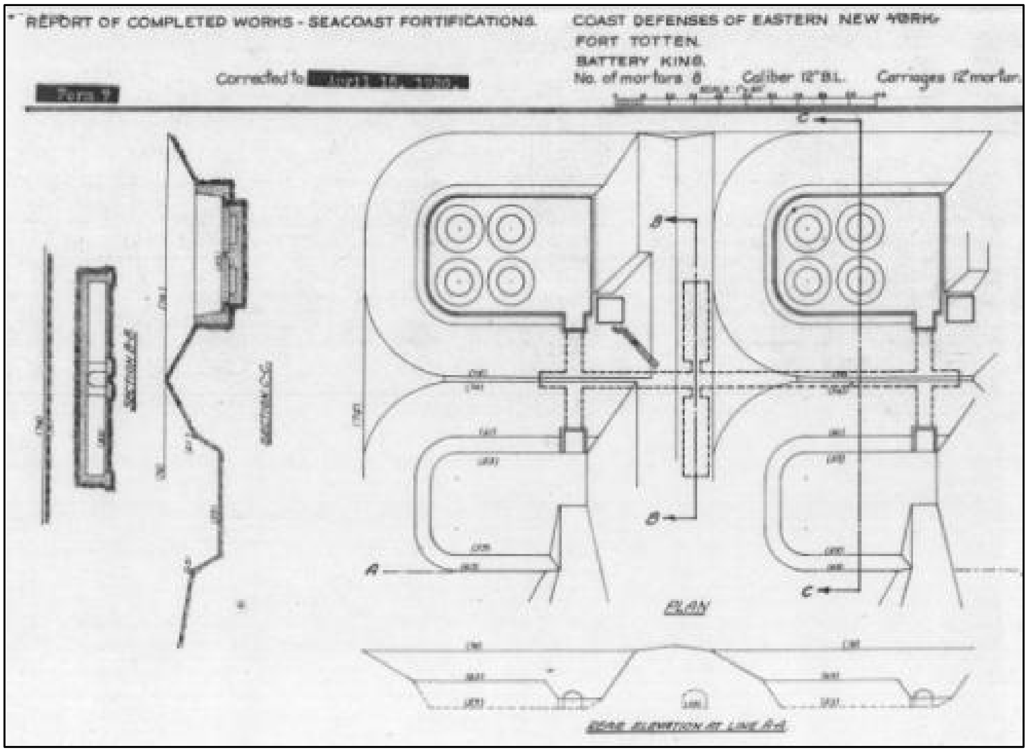

Figure 45: Plan and Sections of Battery King, upgraded 1896-1899 (NARA, 1920, Report of Completed Works)

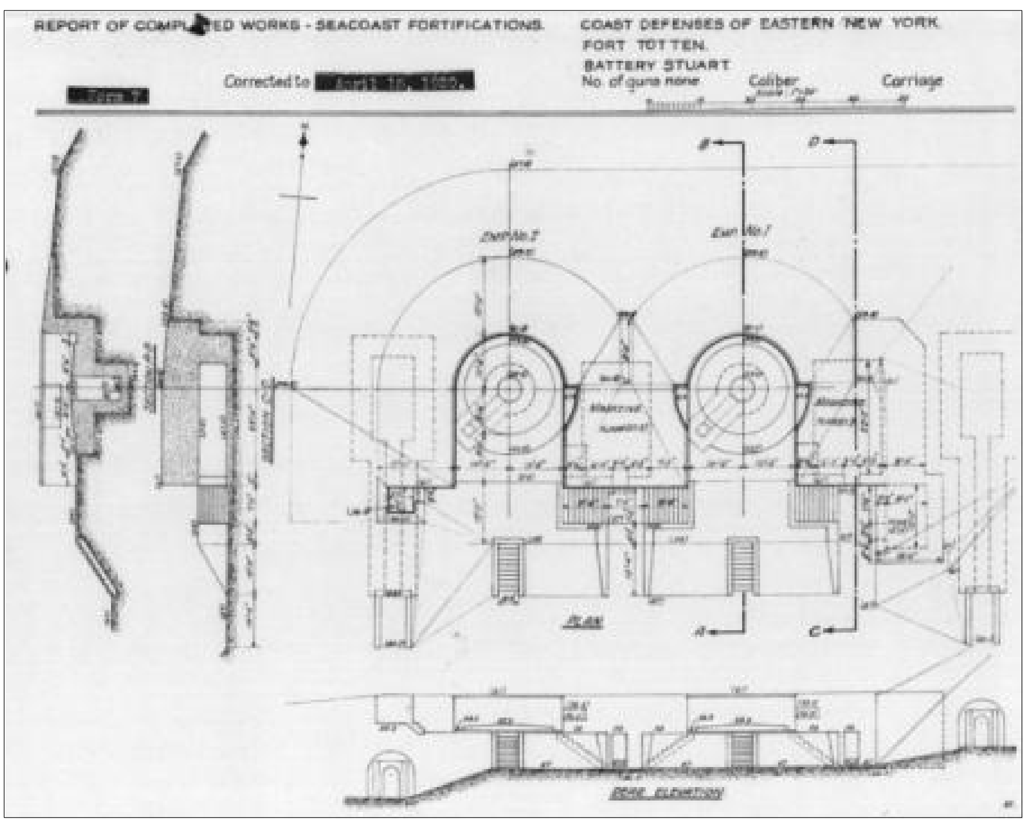

Figure 46: Plan, Sections and Elevation of Battery Stuart, built 1898-1900 (NARA, 1920, Report of Completed Works)

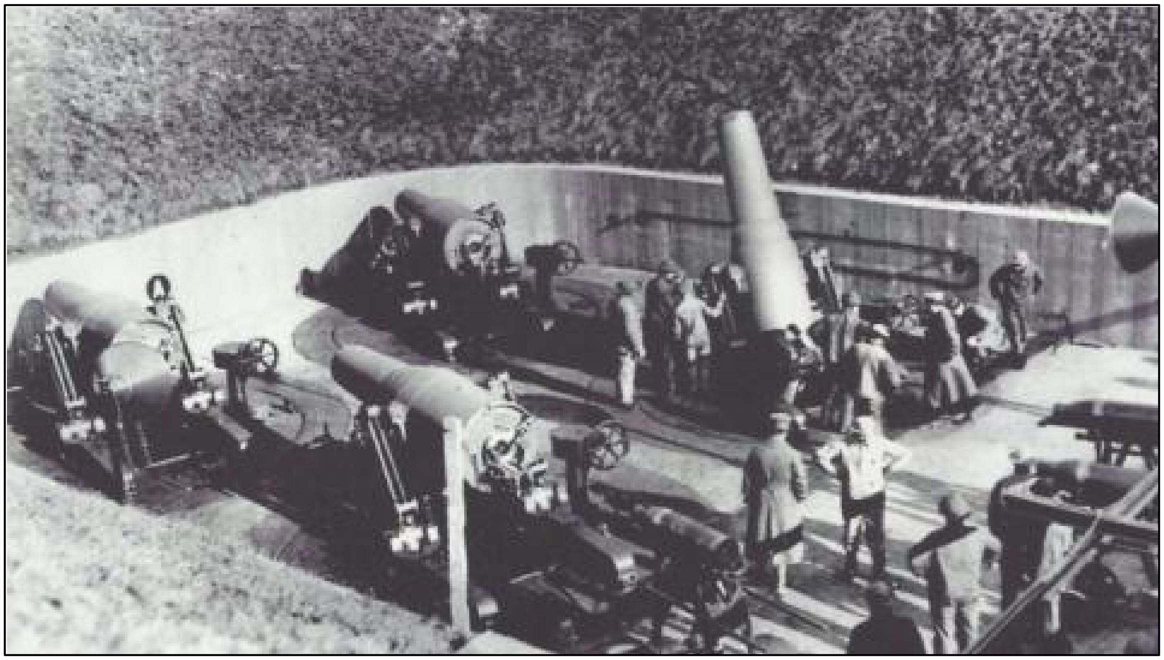

Figure 47: Battery King, showing one of the Abbot Quad mortar pits ca.1920 (Fort Totten Museum Collection)

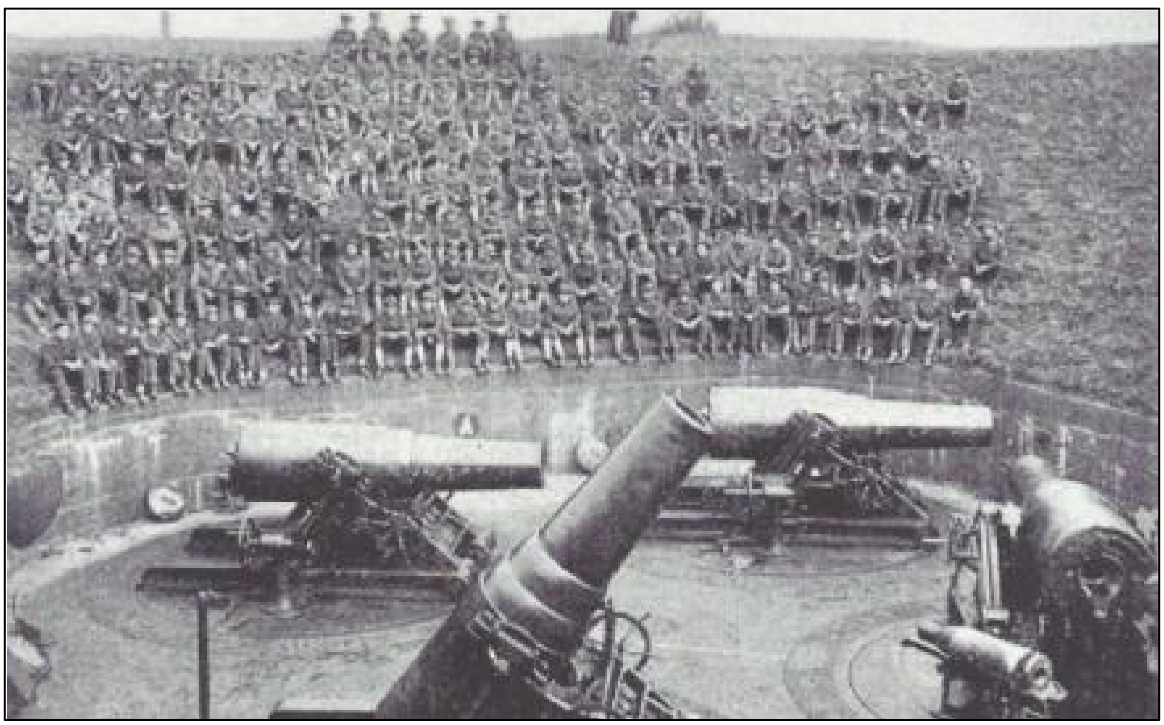

Figure 48: Battery King, showing one of the Abbot Quad mortar pits ca.1920 (Karl Schmidt Collection)

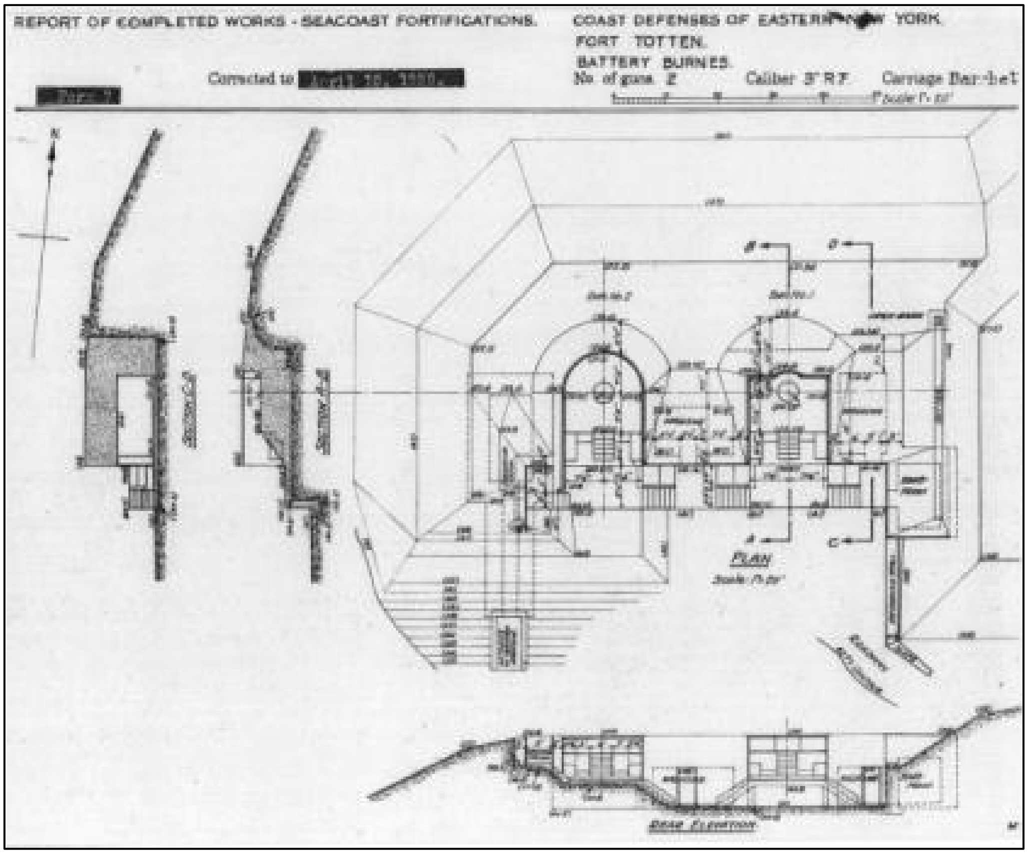

Figure 49: Plan and Sections of Battery Burnes, built 1903-1904 (NARA, 1920, Report of Completed Works)

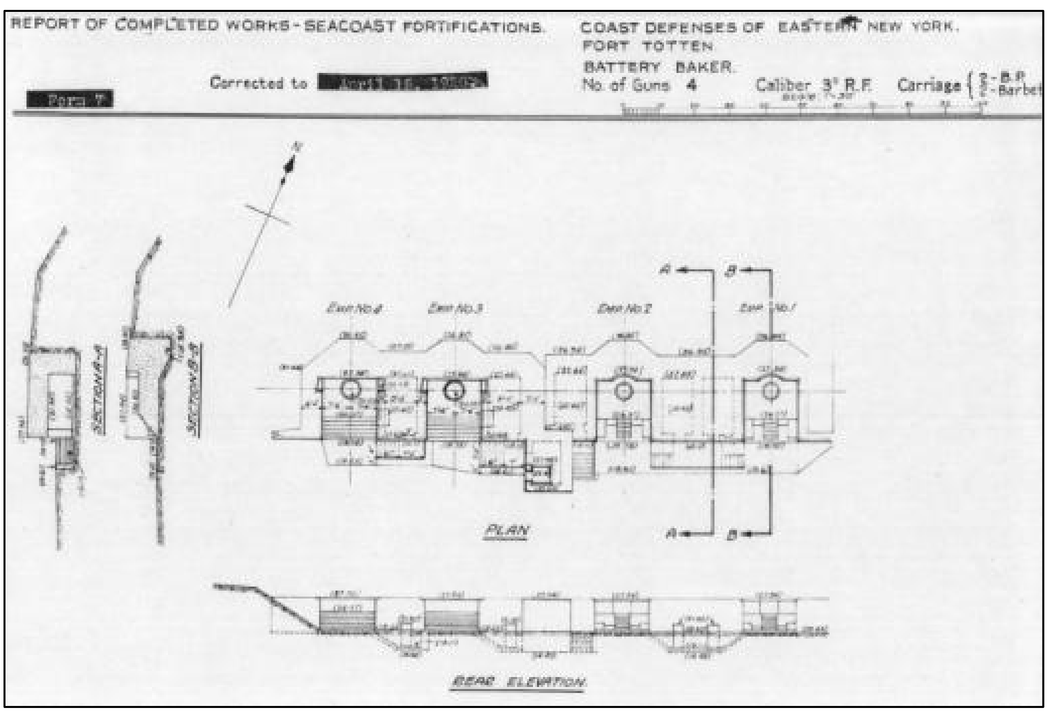

Figure 50: Plan, Sections and Elevation of Battery Baker, built 1899-1904 (NARA, 1920, Report of Completed Works)

Furthermore, three independent batteries armed with rapid-fire guns were built to guard the torpedo fields in the channel. The first of these, Battery Stuart, was begun in1898 and work was expedited due to the Spanish American War. This is perhaps why both batteries west of the Endicotts incorporated the existing magazines of the 1870s West Battery. Battery Stuart was armed with two 5-inch M1897 rapid fire guns mounted on M1986 balanced pillar mounts, and was renamed in 1903 after Capt. Sydney F. Stuart of the Ordnance Dept., who had been killed in 1899 during an explosion at the DuPont Powder Works in Wilmington, DE.

Immediately to the west of Battery Stuart, Battery Burnes was begun in 1903 to mount two M1902 3-inch guns on M1902 pedestal mounts and work was completed in 1905. It was named after 2nd Lt. Thomas Burnes, of the US 2nd Artillery, who died in 1865 from wounds received at the Battle of Hatchers Run, VA, during the US Civil War. The two raised emplacements were flanked by a 1870s subterranean magazine on the right and a newly built magazine on the right.

Finally a new battery was built to the west of the granite Water Battery in 1899, composed of two emplacements for a pair of M1898 Driggs-Seabury 3-inch guns on M1898 masking parapet carriages. A second set of two emplacements were then constructed in 1903/4 and armed with two M1902 3-inch guns on M1902 pedestal mounts. This battery was named after 1st Lt. William L. Baker, 4th Artillery, who was killed in action in 1862 at the Battle of Antietam during the US Civil War.

3.11. Later History of Willets Point/Fort Totten

On July 23, 1898 President William McKinley signed General Order No. 106 from the Adjutant General’s Office, which renamed the Fort at Willets Point as Fort Totten, in honor of Brigadier General Joseph G. Totten. Following the Spanish-American War in 1898, there was a significant reorganization of the Corps of Engineers. In 1901 the Engineer Depot was closed and the Engineer School was moved to Washington DC. The Corps was reorganized and the majority of engineering companies were deployed overseas to the newly acquired territories in the Philippines, leaving artillery companies in charge of the batteries. Finally in 1908, the Submarine Mining School was moved to Fort Monroe, VA.

Further advances in both naval technology and the advent of aircraft would make fixed coastal fortifications increasingly obsolete. Between 1917 and 1938, the various coastal batteries were disarmed to be replaced with anti-aircraft batteries in 1919. Indeed in 1922 the 62nd Artillery (Anti-Aircraft) Regiment was established at Fort Totten. In 1967, Fort Totten was placed on inactive status but in 1969 it served as the headquarters of the 77th Regional Support Command (RSC). The site has also been utilized by the US Coast Guard (1969), the US Department of Labor (1971), and the US Army Reserve (1983).[97] The Water Battery was designated as a New York City Landmark (LP-0826) in 1974, while a Historic District (LP-2040) was designated in 1999. In 2005, most of the site was acquired by the New York City Parks Department.

[97] Pearson, (1999) p. 15-16

4. Concrete Technology in Fortifications

A number of important treatises on the early experiments in mortars, cements and concretes were published in the 19th century, particularly by military engineers on both sides of the Atlantic.[98] There appears to have been a professional collegiality between the various engineering corps that included the sharing of published research. For example, based on the numerous references to their contemporaries, these engineers were reading each other's reports, and in some cases they were even translating them. This collegiality is perhaps epitomized by Lt. Sylvanus Thayer of the US Army Corps of Engineers, who from 1815-1817, toured the military and engineering schools of Europe. He returned with a collection of 1,000 volumes of technical books, which then became the Military Academy library at West Point, NY.[99] Their research was an ongoing process that continued throughout the 19th century and into the 20th, and consisted of trial and error experimentation, since most empirical data resulted from simple compressive and flexural loading tests. Furthermore, the majority of this research focused on newly cured cement or concrete, usually in the form of small cubes or prisms, and did not include tests on concrete structures that had been built decades ago. However, in 1863 the US Army Corps of Engineers declared that there was a "very great economic interest" in concrete, which "demands constant attention and study". Furthermore, they continued "The chemistry of mortar and its constituents, dry and in sea water, is far from complete, and is not likely soon to become so. The study of concrete working and its application must be perpetual."[100]

Masonry construction dominated fort building until the mid-19th century on both sides of the Atlantic, with concrete relegated to piers, docks, foundations, or 'waterproof' coatings for masonry structures. In 1835 an experimental casemate at the Woolwich Arsenal in London was built using Ranger's patent concrete, which contained feebly hydraulic Dorking

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[98] Vicat, Louis-Joseph, and Smith, Capt. J. T., (1837) *A practical and scientific treatise on calcareous mortars and cements, artificial and natural*, London, John Weale Architectural Library, Pasley, Col. Charles W. (1838) *Observations on Limes, Calcareous Cements, Mortar, Stuccos and Concretes, and … Cements*, London, John Weale Architectural Library, and Totten, Lt. Col. Joseph G., (1838) E*ssays on hydraulic and common mortars and on limeburning*, New York, Wiley and Putnam

[99] Klawonn, (1977) p. 51-53

[100] Hayes, E. B., (1863) *Engineer notes and queries; submitted to the officers of the U.S. Corps of Engineers*, New Haven, E. Hayes, p. 26-27

lime as a binder. Although it performed well against artillery fire, its slow rate of set was considered a liability.[101] The influential Maj. Gen. Charles W. Pasley of the Royal Engineers deemed concrete an unsuitable replacement for brick and stonework in the 1830s, as he was unable to produce concretes of sufficient strength. Pasley concluded that mixing too much sand with the cement would only cause it to weaken, so therefore concrete, with its mix of cement, sand, and aggregate, was inherently problematic. It would take several years of research in the late 1850s and early 1860s, notably from Capt. Henry Scott and Capt. Frances Fowke of the Royal Engineers, to successfully refute Pasley's bias against concrete.[102] It was not until 1865 when the first British fortification was built using significant portland cement construction at Newhaven, Sussex. As with most technological advances, it took time for concrete construction to be adopted, so it wasn't until the 1870s that this technology became standard in the UK.[103]

Across the Atlantic, in the maritime provinces of Canada during the mid-1860s things were quite different. The Royal Engineers were using natural cement concrete to build gun foundations, escarpment walls, galleries and expense magazines in Halifax at Fort Charlotte, Fort Ogilvie, and York Redoubt. As with the US, the cost of importing portland cement was one of the reasons for their use of locally produced natural cement. In addition, there were difficulties in keeping the costly imported cements dry, and there was a general lack of skilled labor for traditional masonry construction in the colonies. However, the experiment was successful and the Commanding Royal Engineer in Nova Scotia reported in 1866 that although he would have preferred traditional masonry construction, "for economy, dispatch and military labour the advantage of concrete is undoubted."[104]

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[101] Powter, Andrew, (1978) 'History, Deterioration, and Repair of Cement and Concrete in Nineteenth Century Fortification Constructed by the Royal Engineers", *Bulletin of the Association for Preservation Technology*, Vol. 10, No. 3, Department of Indian and Northern Affairs, Canada, p. 62
[102] Ibid. p. 63-65
[103] Ibid. p. 65 and Vincent, Elizabeth, (1993) *Substance and Practice: the Building Technology and the Royal Engineers in Canada*, Ottawa, Studies in Archaeology, Architecture and History, National Historic Sites, Parks Service, Environment Canada, p. 42-45
[104] Vincent, (1993), 42-43 and National Archives, RG8 C Series, Vol. 1587, pp. 159-162, *Lt. Col. F. C. Hassard to Commanding Royal Engineer, Canada*, 2 Feb 1866, enclosing reports on use of cement concrete at Halilfax.

4.1 Early American Concrete in Fortifications

In 1838, Lt. Col. Joseph Totten translated the work of the leading French Engineers, Treussart, Pitot, and Courtois, who defined concrete as the "mixing of small stones with hydraulic mortar", and who stated that the quality of the concrete depended principally on the mortar.[105] Indeed, early works on concrete treated the mortar and aggregate as two different constituents, rather than interdependent ingredients.

Totten had been conducting his own mortar experiments when building Ft. Adams in Newport, RI, and his published reports included a number of issues that formed the basis of the Corps of Engineers' early concrete technology. These included an appreciation of the relationship between void spaces, and the proportioning of stone fragments, sands and cements.[106] Furthermore, Totten, like Pasley, concluded that too much sand would weaken a mortar, while too much water would oversaturate the mix and create shrinkage problems.[107] Finally, Totten described two methods of placing concrete in molds: pouring a grout over aggregate or using a shovel to mix the aggregate with the mortar, and then hard ramming the mix to cause any excess water to rise to the top.[108]

The next major treatise was written by Lt. Col. Quincy Adams Gillmore of the Corps of Engineers, which was published in 1863 and reprinted many times. It was based on his experiences building the fortifications in New York Harbor during the years prior to the Civil War.[109] By the late 1850s, concrete technology had developed far enough for Gillmore to report on both advances in concrete theory and manufacturing. Although Gillmore included a report on how four men could laboriously hand mix concrete, he concluded that mixing concrete by machine was far more productive (producing up to 130 yds^3 in ten hours).[110] Similarly, breaking stone by machine was not only more efficient; it produced a better

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[105] Totten, (1838) p. 118
[106] Ibid. p. 243
[107] Ibid. p. 246
[108] Ibid.
[109] Gillmore, Lt. Col. Quincy Adams, (1886) *Practical Treatise on Limes, Historic Cements, and Mortars,* New York, D. Van Nostrand
[110] Ibid, p. 226-228. Gillmore also provided a detail methodology for mixing mortar and concrete at Forts Tompkins and Richmond on Staten Island and Fort Warren in Boston (p. 202-205), See Appendix 7.6

quality of concrete. Using stone crushers, it was possible to automatically separate the material into fine, medium and coarse stone, so that as it "packs closer" when mixed.[111] Gillmore also described the transport of concrete via wheelbarrow to the site to be emptied into wooden formwork. The concrete would then be rammed in place using wooden rods tipped in sheet iron in order to produce six to ten inch thick lifts.[112] Finally, Gillmore advised that an excess of water was better than a deficiency, especially for fresh ground cements. However, he did caution against adding too much water to aid its manipulation when being placed.[113] Additionally, as Eckel noted, natural cements could contain an excess of free lime, due to varying composition as well as relatively low, or variable, calcining temperatures.[114] Therefore, freshly prepared natural cement that contained an excess of free lime would have an increased water demand, which would cause the lime to slake as well as cause the cement to set hydraulically. Eckel reported that many manufacturers would try to "slake the free lime in some way" with the "ideal aimed at is to supply sufficient moisture to slake the free lime, but to leave the aluminates and silicates untouched."[115]

Throughout the 19th century, in the various treatises written by Totten, Gilmore, and Cummings, there were differing opinions over whether concrete should be mixed wet or dry. In 1920 Winslow highlighted the problem of too dry a concrete mix. In practice, Winslow argued, concrete was not rammed sufficiently to distribute the water throughout the mix. Additionally, Winslow warned that adding too much water to the mix would simply cause the water to puddle at the surface, making the concrete friable. Winslow concluded slightly ambivalently that, "the opinion of the engineering world is still divided as to what is the best amount of water to use in mixing concrete and as to the best method of placing it…"[116] Ira O. Baker, writing in 1909, was more pragmatic and suggested that, "the amount of water required to produce any particular plasticity varies so greatly with the proportions of the ingredients, the kind and fineness of the cement, the dampness of the sand, the kind of

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[111] Ibid. p. 245. Gillmore also mentioned a stone-crushing machine being used at the time in Central Park.
[112] Ibid. p. 229-230
[113] Ibid. p. 225
[114] Eckel, Edwin C., (1922) *Cements, Limes and Plasters: their materials, manufactures and properties*, New York, J. Wiley & Sons, p. 233ff
[115] Ibid. p. 234. This could be done through aeration, sprinkling, or steaming.
[116] Winslow, (1920), p. 53

aggregate, the amount of mixing, etc., that it is scarcely possible to give any valuable general data."[117] Baker went into great detail on the properties of both dry and wet concrete, which he described as "dry as damp earth" and "quaked like liver under moderate ramming", respectively.[118] He noticed that dry concrete set more quickly and gained greater initial strength than wet concrete, and that wet concrete contained a great number of invisible pores, while dry concrete contained a greater number of voids. These observations align well with what can be seen both under the microscope for the Fort Totten concrete samples, as well as the *in situ* structures.

4.2 Concrete Fortifications at Willets Point/Fort Totten

There are three main periods of concrete construction evident at Willets Point/Fort Totten: the coarse infill concrete used in the granite masonry Water Battery (1863-1860) at the end of the Third System, the large poured-in-place concrete vaulted forms of the fortifications built during the Post-Civil War (1867-1880) and the Endicott Period (1890-1905), where the large poured-in-place concrete construction technology transitioned into reinforced concrete construction. The Annual Reports of the Chief of Engineers did record the various fortifications projects constructed during these early periods, but these are laconic in the extreme. Furthermore there was a tendency for the reports on the fortifications built throughout New York Harbor to amalgamate the various projects, so that specific sites or fortifications were not distinguished.

By the late 1890s, Annual Reports of the Chief of Engineers often contained detailed building reports submitted by supervising engineers on the fortification construction projects. Unfortunately those submitted for the fortification projects built at Willets Point/Fort Totten remained mere summaries. This may be because that when supervising engineers working at other sites submitted their reports to the Corps headquarters at Willets Point, they needed to be as thorough as possible, whereas the Willets Point engineers might not feel the need to review and report on their own work to themselves. However, it was at Willets Point/Fort

[117] Baker, (1909) 169
[118] Baker, (1909) 167-169. It should be noted that these were very different standards than are used today and Baker's 'quaked like liver' would equate to a normal slump today.

Totten that these supervising engineers managing other sites had been trained, so there is a high degree of probability that their techniques were similar if not identical.

The cements types used in all the fortifications built at Willets Point/Fort Totten were listed in either the Annual Reports or the Reports of Completed Works of the Corps of Engineers. Rosendale natural cement was listed as being used in all construction up until 1897, including the Water Battery, the Main Magazine, the Tunnel, the Torpedo Magazines, the barbette batteries, and Batteries Sumner and Graham. From 1898, portland cement was used in the construction of Batteries Mahan, Stuart, Burnes, and Baker, along with the 1902-1905 extensions to the Upper Endicotts (Batteries Sumner, Graham, and Mahan). Unfortunately, these same records contained very little archival information on the brands of cement used when constructing the fortifications at Willets Point/Fort Totten, although there is more information for the other fortifications in the New York area. However, the general practice for the engineers was to choose the lowest bid.[119]

Elsewhere in New York Harbor, Gillmore described two concrete mixes used in the concrete construction of Forts Tompkins and Richmond on Staten Island between 1858 and 1862.[120] While both were made with an unnamed hydraulic cement, the concrete for the foundations was mixed with a 1:3:5 ratio of cement/sand/granite fragments, and each batch measured 21 ¾ yds^3. The concrete for the superstructures had a slightly different mix, with a richer 1:3:4 ratio that used 'broken stone' as a coarse aggregate. However, these were both quite lean mixes by the modern standard of a 1:2:3 ratio of cement/sand/stone.

Furthermore, in a later edition of his treatise, Gillmore added an appendix on the construction of the concrete magazines at Forts Tompkins and Richmond in 1870 and 1871, and listed the type of materials.[121] These included Rosendale natural cement from the Newark and Rosendale Cement Co. of Whiteport, NY. Gillmore rated this cement as above average, but also noted that, like other Rosendale natural cements, it was "subject to very considerable variations in quality from time to time, and often falls greatly below this test."

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[119] Cummings, (1898) p. 277 would decry this 'most pernicious system' as 'criminal folly'
[120] Ibid. p. 246
[121] Ibid. p.318-319

Portland cements from Stettin, Germany, Boulogne Sur-Mer, France, and London, England were also used, but in smaller quantities than the Rosendale cements, owing to their higher costs. The Annual Report for 1897 listed the bids of 'American Rosendale Cements' for the fortifications at Sandy Hook and at Long Island, which included the products of the Newark and Rosendale Lime and Cement Co., the New York and Rosendale Cement Co, and the Lawrenceville Cement Co.[122]

Baker stated that trap-rock, granite, syenite, diorite, gneiss, limestone, and some of the more compact sandstones made for good coarse aggregates in mixing concrete, while loose textured sandstones, shale and slates did not.[123] However, there was very little archival information found on the aggregate used in the concrete fortifications built at Willets Point. The 1870 Annual Report recorded the engineers, "gathering and breaking a supply of stone for concrete", while the 1872 Annual Report stated that the aggregate for Battery King had been prepared.[124] These reports did not mention whether this was done by hand or by machine, but considering that the Engineering Depot was located at Willets Point, and that all engineering equipment was stored there, the probability of crushing the aggregate by machine must be significant. As early as 1870, a crushing machine was employed by the Corps in preparing the aggregate used to build Forts Tompkins and Richmond on Staten Island, as Gillmore reported that ordinary aggregate was crushed into angular, irregular cubes that would pass a two inch screen, using a Blake's Stone Breaker.[125]

Information on the aggregate used at Fort Totten was limited to visual observations and the petrographic analysis of samples collected, which included evidence of granite, gneiss, and trap rock, but not of limestone, and this will be discussed further in Section 5. As with the cements used, more information was found for the other fortifications built in the New York area. Gillmore noted that at Forts Tompkins and Richmond coarse limestone aggregate, washed beach gravel, and pebbles, which ranged in size from peas to hen's eggs,

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[122] USACE Annual Reports, (1897) p. 617-618
[123] Baker, (1909), p. 100
[124] USACE Annual Report, (1870) p. 17 and USACE Annual Report, (1872) p. 10
[125] Gillmore, (1886), p. 317f

were used.[126] The 1897 Annual Report described the aggregates used during the construction of the fortifications at Sandy Hook and at Long Island, which were divided into building sand, small broken stone (granite, trap rock and limestone), large broken stone, and fine-crushed granite. While the names of the bidders were identified, unfortunately the provenance of the material was not.[127]

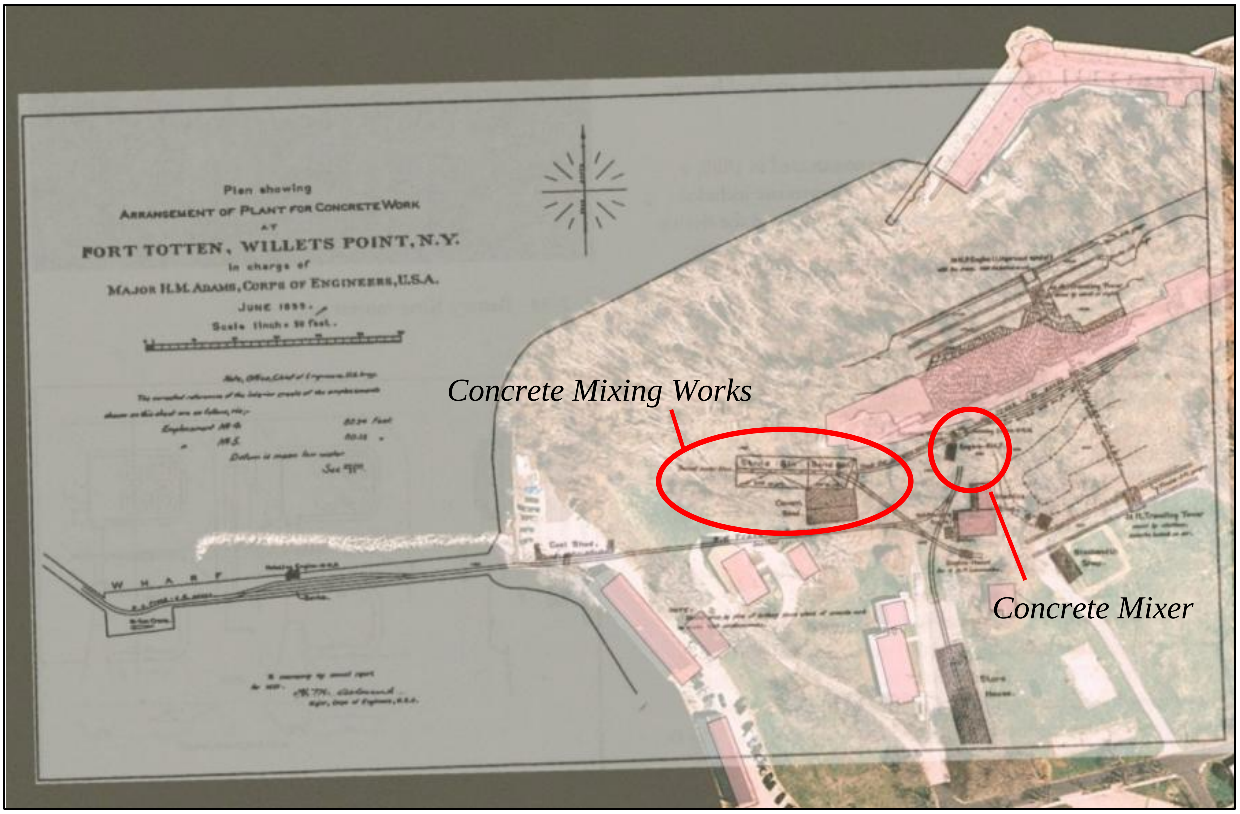

Figure 51: Plan showing arrangement of Plant for Concrete Work at Fort Totten, Willets Point, NY June 1899. Plan accompanying Annual Report of the Chief Engineer 1899 (NARA, RG77, Drawer 35, Sheet 60, georeferenced against the 2009 aerial photograph and buildings dataset, New York City Department of Buildings)

A plan for a ‘Plant for Concrete Work’ at Fort Totten was submitted with the 1899 Annual Report, which included a railway leading from the dock to the emplacements, separate stone and sand bins, and a cement shed. The materials were then conveyed to a concrete mixer near the site, so that the concrete could be placed in a timely manner. A concrete mixer had been employed at the site since at least 1896, since it was mentioned in

[126] Ibid.
[127] USACE Annual Reports, (1897) p. 617-618

the Annual Report for 1897. As this plant was built during the period when the fortifications were made from portland cement concrete, it has been interpreted as an attempt by the engineers to implement greater quality control in the mixing process.[128] However, this was only a temporary structure, since the area where these structures were located on the map, in front of Battery Stuart, were planted with trees by 1920.[129] Similar layouts and plant operations were also described at other fortification sites in the Annual Reports, including nearby Fort Davis in 1896.[130]

At this time the engineers were not only conducting cement and concrete testing at Willets Point/Fort Totten, but they were also conducting training in these methods as part of the Engineering School courses in military and civil engineering. Apparatus necessary for conducting tests of cement were procured on 18 July 1896 and in 1902 this equipment was transferred from Fort Totten to the Washington DC Barracks.[131] From the late 1890s, the annual reports discussed the military and civil engineering curriculum for building concrete foundations, fortifications, and river locks. These included courses on the preparation, composition, and use of concrete, the testing of hydraulic cement and concrete, both in the laboratory and the field, and finally the preparation of specifications for cements and concrete plants.[132]

Apart from the early coarse infill concrete used in the granite masonry Water Battery, the majority of the fortifications at Willets Point/Fort Totten were built using mass cast-in-place concrete poured and then rammed into wooden formwork, in lifts approximately six to ten inches high. Massive concrete structures possessed great compressive strength, but like all unreinforced concrete, they possessed poor tensile strength. Therefore all enclosed areas of these fortifications were constructed using barrel vaulted ceilings, which posed limitations on the width of these rooms. At Willets Point/Fort Totten, the largest of these were found in

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[128] Beyer Blinder Belle, (2000) p. 2.23
[129] Fort Totten, Aerial Photographs of New York Harbor, July 1920, 14 Photo Section, NARA. The precise location was confirmed by georeferencing 1899 map with various aerial photographs.
[130] USACE Annual Report for 1897, p. 585-586
[131] USACE Annual Report for 1897, p. 575, 578-579, the apparatus is not named but it cost $376.75. The 1902 Annual Report, p.820 stated that the value of this equipment was $700.00 and it weighed 825 lbs.
[132] USACE Annual Reports for, 1897, p. 563; 1898, p. 568; 1899, p. 656; 1900, p.1049

the Main Magazine, where the ceilings of the two main storage rooms spanned 22 feet. However, due to the nature of arched ceilings, in order to maximize vertical wall spaces before they began to curve, these rooms needed to be quite tall, and these were 14 feet. For the Tunnel and Torpedo Magazines, built in the same period, the same construction typology was followed. The surviving magazines of the 1870s barbette batteries also followed this tradition but their design on top the bluff did not allow for tall rooms, and consequently they are much narrower.

Figure 52: Construction of the batteries and magazines at Fort Totten, ca. 1890s, showing wooden formwork (Bayside Historical Society Collection)

In most cases, the wooden formwork erected by the engineers produced practical rectangular or curvilinear concrete structures, the most complicated of which were the barrel vaulted ceilings. In in the northern entrance to the Tunnel, however, the engineers allowed an aesthetic treatment, with decorated concrete moldings with keystone atop the center.

This type of mass concrete construction with barrel vaulted ceilings was continued for each of the Upper Endicotts, even though Batteries Sumner and Graham were built using natural cement concrete and Battery Mahan used portland cement concrete. This would indicate a very strong building tradition that continued for almost 30 years, perhaps longer if the massive masonry structures and vaulted casemates of the Water Battery are included. The only differences from the 1870s structures were the ceilings of the gun platforms, which extended out from the foundations of the gun emplacements, which were built with rolled wrought iron beams laid out in a radial pattern at two feet intervals with concrete fill. The ends of these beams were supported by a semicircular brick wall.

Figure 53: North entrance of tunnel, showing decorative concrete moldings and keystone (2012)

Figure 54: Battery Mahan 2 showing the later reinforced concrete extensions on the left and the cast-in-place mass concrete of the original traverses and magazines on the right (2013)

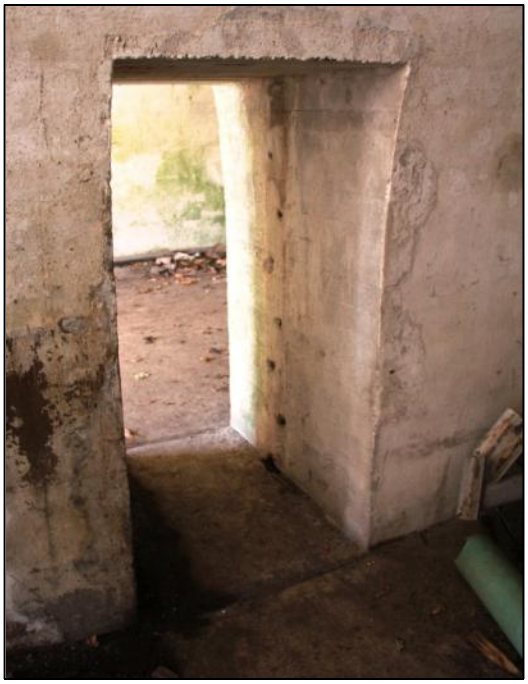

Figure 55:Torpedo Magazines, later doorway cut through the4 feet thick dividing walls showing the mass concrete construction (2013)

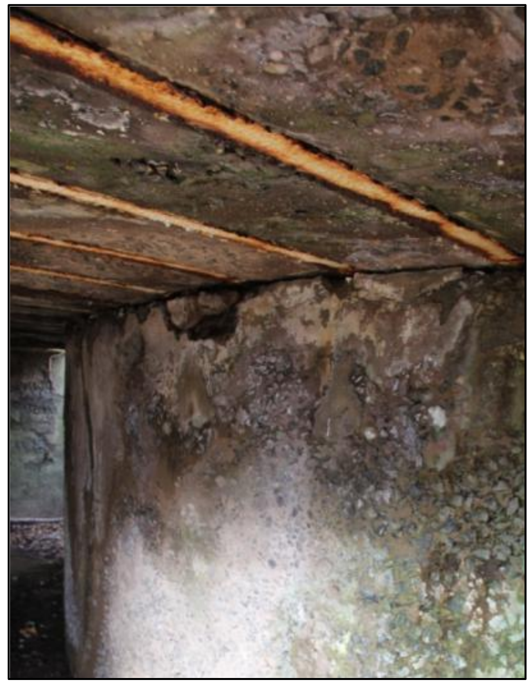

Figure 56: Battery Graham 1, ceiling showing rolled wrought iron beam and concrete infill ceiling surrounding the gun foundations.(2012)

Figure 57:Extension of Battery Sumner 1 showing the rolled steel I-beam supports (2013)

Figure 58: Battery Graham 1 showing the entrance to the original cast-in-place mass concrete magazines and the reinforced concrete columns and beams of the later extension (2012).

The main design change in concrete construction occurred at Fort Totten during 1902-1905, with the introduction of reinforced concrete when the southern extensions of the Upper Endicotts were built. With the added tensile strength of twisted wrought iron rods, it was possible to build much thinner structures using rectangular reinforced concrete beams and columns, along with flat ceilings. Indeed, this new design was well received and Winslow noted that the Annual Report of 1903 recommended this type of construction for all future emplacements.[133] In addition to using steel reinforced concrete, the engineers also utilized exposed rolled steel I-beams to support the second floors of the extension in Batteries Mahan 2 and Sumner 1.

4.3 Issues with Deterioration

In 1898, Congress passed the Preservation and Repair of Fortifications Act, in order to provide funds for the engineers to conduct much needed maintenance on the fortifications. This has been used to indicate that that there were serious material and structural problems with the earlier fortifications.[134] The 1899 Annual Report reported that, "Some difficulty has been experienced, particularly with the earlier batteries, from dampness in interior rooms and passageways, arising partly from infiltration and seepage and partly from condensation."[135] Furthermore, in 1903 a technical report on the problems and possible solutions for damp-proofing rooms in gun emplacements was submitted to the Chief of Engineers.[136]

Lawry had argued that the use of 'inferior' Rosendale cement in the construction of the early Endicott era fortifications caused many of them to be rebuilt or abandoned by the first decade of the 20th century.[137] In particular, he cited the rebuilding of Batteries Kellogg and Lincoln, both Abbot quad mortar batteries, at Fort Banks, Boston, MA. These were completed in Rosendale cement in 1896, and were rebuilt in 1912-1913 using portland cement. However, only a small area of the original concrete structures built with Rosendale

[133] Winslow (1920), p. 61
[134] Beyer Blinder Belle, 2000, 2.28
[135] USACE, (1899) p. 13-14
[136] USACE, (1903), Vol. 4, Appendix BBB, p. 2390-2396, written by Assistant Engineer G. W. Kuehnle and Superintendent John A. Yates, and submitted by M. W. L. Marshall
[137] Lawry, (1991), p. 11

cement were actually removed. Furthermore, these were parts of the original Abbott Quad that were rebuilt using a more practical design, which consisted of a larger platform containing only two mortars. While new shell rooms were added, the original magazines were left in place. This might indicate that the reason for the rebuild was design oriented, since the 1870s Abbot Quad design proved to be almost unworkable.[138] Lawry also cited problems with Battery Whitman/Cushing at Fort Andrews, Boston, MA (built 1898-1902 and remodeled 1909-1913) and Batteries Capron and Butler (built 1897-1898) at Fort Moultrie, Sullivan's Island, Charleston, SC, but again these were more of an issue with the Abbott Quad design.

One of the earliest modern examinations of concrete deterioration at a fortified site was conducted at Battery Decatur, Fort Washington, MD, in 1975 by James Madison Cutts, a consulting engineer.[139] These fortifications were begun in 1891 and completed in 1896 and over the succeeding 80 years, the massive concrete structures of the emplacement, traverses and magazines had been subject to "high stress due to temperature expansion and contraction." This caused the pargetting layer, or cement-stucco, to crack and spall due to water infiltration and freeze/thaw damage. Rosendale cement was used in the main fortifications, and Scott noted that this was a cheaper grade cement than portland cement. Therefore the more costly portland cement was limited to covering the exterior facing and apron slabs, which would be exposed to blast fire. Scott also reported that the cement was mixed with fine aggregate river sand, intermediate aggregate consisting of small rounded pebbles, and larger coarse aggregate of crushed gneiss.[140]

Scott argued that the "uncertainty and variability in [the] setting time of the Rosendale cement and the time required for each section to be set by manual labor using wheel barrows resulted in the layers hardening at different times, with the bonding of the layers of concrete not being as cohesive as originally desired."[141] Scott also acknowledged

[138] The batteries were simply too crowded for multiple gun crews to work in synchronicity, while the smoke resulting from each firing would settle in the sunken pit, thereby blinding the gun crews.
[139] Scott, Gary, (1978) "Historic Concrete Problems at Fort Washington, Maryland", *Bulletin of the Association for Preservation Technology*, Vol. 10, No. 2, U.S. National Park Service Issue pp.123-131
[140] Ibid. p. 126
[141] Ibid. p. 129

that the concrete quality could have been affected by the variable temperature during the placement of the concrete, the amount of water in the mix, the length of time between mixing and placement, and the heat produced by the setting process. These factors, Scott argued, produced a "sandy or powdery type of concrete," and that the horizontal lifts would harden before the next lift could be placed.[142] Without the benefit of any reinforcement, Scott noted, cold joints would form between the lifts, and these would be subject to water infiltration and the opening of the horizontal lift joints, which would result in lateral movement in the individual slabs. Finally, Scott reported that structural movement cracks occurred where structures of differing masses were joined.

However, it is significant that the military engineers blamed the deplorable state of these fortifications not on the type of cement used in their construction, but on the "insufficient appropriations during a long period of years" to conduct much needed maintenance.[143] Winslow noted that in the first concrete emplacements, "little care seems to have been taken in the mixing and ramming of the concrete" and that there was a tendency to "mix the concrete extremely dry" which, he argued, made the concrete "as porous as a sieve."[144] Dampness in magazines was a perennial problem and had been reported on at the Essayons Club in 1872 by Capt. William J. Twining.[145] Possible treatments included patching cracks in the concrete, adding a waterproofing mastic or asphaltic layer to the exteriors, adding liners to the interior walls, and promoting good ventilation. Furthermore, good drainage in an around these batteries was essential, and this was certainly built into the designs of the 1870s structures. Underground drainage systems were included in the Main Magazine, Tunnel and the Torpedo Magazines. In addition, the exteriors of each of these structures were coated with mastic before they were capped with earthen fill. For the Torpedo Magazines ceramic pipes were laid in the valleys formed by the vaulted roofs of each chamber, a system still in use today. Many of these treatments must have been successful since the Reports of Completed Works listed the conditions of all batteries as 'dry' in 1920.

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[142] Ibid.
[143] USACE, (1897) p. 8
[144] Winslow, (1920) p. 53-54
[145] Twining, (1872)

The only other contemporary report of deterioration at Willets Point/Fort Totten was the settlement of the gun foundations at Battery Sumner 1. In 1897 this problem was solved by adding 55 tons of weight to the foundations for several months in order to even out the displacement.[146] This was indicative of a major design problem with the Upper Endicotts, since they were built effectively on an area of earthen fill and unstable soil conditions.

In 2000, Beyer Blinder Belle conducted a comprehensive conditions assessment of Fort Totten, which is summarized below.[147] All the 1870s extant fortifications built with natural cement concrete were in reasonably good condition. The Main Magazine and the Tunnel were both relatively free of water, although stucco delamination in the Tunnel might be indicative of moisture penetration. Only the earliest four of the nine Torpedo magazines built had any reported problems. Water penetration and the general saturation of the vaulted ceiling in these four magazines could indicate a failure of the asphaltic waterproofing layer above. There was some structural cracking in the Main Magazine near the entranceway, which might be the result of settling or the lack of an expansion joint. Cracking near the uppermost part of the Tunnel, the later addition that adjoined the Torpedo Magazines, could represent a structural weakness. There was a substantial crack in the concrete façade between the first and second magazine near the tunnel entrance, which extends diagonally from the coping down to spring line of the arch, about three feet above grade.

Deterioration issues reported in the Endicotts were much more varied. There was pronounced horizontal cracking along the southern elevation of the six Upper Endicotts (Batteries Sumner, Graham and Mahan), approximately one to two feet below the second floor slab. Water running through these cracks has caused excessive water staining and salt deposition along the exterior walls. The concrete floor slabs at the open arcades and some of the poured concrete walls had also shifted. These symptoms were typical of problems caused by foundation settlement. Along parapets and traverses, there were a series of occasional diagonal cracks that are indicative of mass concrete poured without expansion joints. Horizontal cracking was noticeably more frequent and usually occurred at cold joints created

[146] USACE, (1897), p. 612
[147] Beyer Blinder Belle, (2000)

between the different concrete placements or lifts. In particular, the deterioration along the cold joints just below the tops of the parapet wall had received significant freeze/thaw damage. At Battery Mahan 1, this had caused a substantial failure in the portland cement concrete at the top right corner of the traverse. Finally, bituminous and asphaltic coatings, such as Neuchatel Rock Asphalt, were applied to most of the parapets and some of platforms as waterproofing, but only those on Battery Mahan have survived. This may be why the magazines in this battery were noticeably drier than in the conditions found in Batteries Sumner and Graham.

The 1902-1905 extensions to the Upper Endicotts, which were built with steel reinforced portland cement concrete, show significant surface deterioration. Water along with the salty air environment of this coastal site have penetrated the concrete and caused the reinforcing rods to rust, expand, and crack the concrete. Eventually this caused large pieces of concrete to fall off.

Since Fort Totten was made inactive in 1967, keeping invasive vegetation in check has been a significant concern, particularly for the Endicotts. The earthen ramparts were soon covered by a variety of trees and shrubs, as the aerial photographs attest, and many of these began to colonize the gun emplacements themselves, which would exacerbate any cracks in the structures. In 2012, during Hurricane Sandy, trees were knocked over into the Endicotts, causing further structural damage. Although the Parks Department quickly removed the fallen trees, their proximity to the fortifications is a growing concern. Furthermore, the foliage has become so dense that is it not possible to maintain the historic vistas of the channel and Long Island Sound from the Endicott batteries, while the structures are all but obscured from the landward side. Recent plantings of saplings in the area as part of New York City's 'MillionTreesNYC' project will no doubt compound both problems and this highlights the difficulty in balancing the historic and the natural environment in a public park setting. However, this also shows that some of the signs of deterioration may be recent and may have less to do with the concrete itself.

Figure 59: Battery Mahan 1, damage caused at the horizontal lifts (2013)

Figure 60: Freeze/thaw, calcite deposition and lateral movement of portland cement concrete in Battery Mahan 1 (2013)

Figure 61: Failure of the reinforced concrete at the extensions of Battery Sumner 1 (2012)

Figure 62: Bituminous coating at Battery Mahan 2 (2013)

Figure 63: Crack between Torpedo Magazines 1 and 2 (2012)

Figure 64:Horizontal cracking just below the second level at Battery Graham 1 with calcium deposits (2012)

Figure 65: Drainage at the Torpedo Magazine now covered by modern aluminium scuppers (2013)

Figure 66: Battery Mahan 1, showing trees colonizing the earthen ramparts in front of the blast apron (2012)

Figure 67: Base End Station on Battery Mahan 1, view of channel now obscured by trees and shrubs(2012)

Figure 68: Battery Sumner 1, showing encroachment of trees and shrubs(2012)

Figure 69: Battery Sumner 1, showing encroachment of trees and shrubs(2012)

Figure 70: Battery Mahan1 showing tree knocked over by Hurricane Sandy (2012)

Figure 71: Battery Stuart, showing encroachment of trees and shrubs (2012)

4.4 In-Situ Concrete

In certain structures, the interior of the concrete was exposed due to a failure of the surface coating or another type of deterioration. This provided an opportunity to make a gross visual inspection of the aggregate and the cement paste.

This was possible at the Water Battery (1862-67), which was only partially completed and therefore had large areas of exposed in-fill natural cement concrete. There was no evidence of any coating layer with the exposed crushed granite and rounded gravel coarse aggregate clearly visible. There were no apparent voids, suggesting that the concrete was well mixed with an adequate ratio of cement, sand and aggregate. Unlike the other concrete structures, this concrete was never meant to be seen, and so appeared quite basic, without any specific poured shape other than that of the surrounding granite blocks. However, the concrete appeared quite solid and dense, with minimal signs of deterioration, despite being completely exposed in a marine environment for over 145 years.

The Tunnel (1870-71) and the Torpedo Magazines (1873-76) were more complicated natural cement concrete structures. In several areas of the Tunnel, a stucco layer covering the walls had fallen away in places, exposing the concrete beneath. This concrete appeared well-graded with a good particle size distribution: a good mix of coarse and medium aggregates that were well coated with cement paste. However, in the Tunnel, fist-sized pieces of smooth rounded coarse aggregate up to six inches long were visible near the surface, along with smaller pieces of crushed coarse aggregate.

In several areas in the Torpedo Magazines, parts of the walls have been partially excavated, exposing the concrete beneath. Most of these areas were small and are located midway up the walls near the entrances, although their purpose was unclear. In Magazine 3, however a doorway was partially cut into the sideway to link through to Magazine 4. The concrete in these areas again showed good gradation with crushed coarse aggregate. Apart from visible areas of deterioration, the interior surfaces of these structures were in generally good condition and had been applied with a white coating.

Figure 72:Coarse infill concrete used at the Water Battery (1862-67)

Figure 73: Partially completed doorway cut through the sidewall at Torpedo Magazine 3 (1873-1876)

Figure 74: Exposed concrete north entrance of the Tunnel (1870-1871)

Figure 75: Exposed concrete showing large unbroken gravel aggregate in the Tunnel (1870-1871)

Figure 76: Coarse concrete foundations of Battery Graham 1 (1892-1897)

Figure 77: Battery Mahan 1 (1898-1900)

The foundations of the gun emplacements in Batteries Sumner 1 (1891-1897) and Graham 1 and 2 (1892-1897) were very different in appearance. The surface coatings had deteriorated exposing a natural cement concrete that appeared to have been made with a particularly lean mix, as the crushed coarse aggregate was not well coated with paste and voids were visible near the surface. However, this concrete does match Winslow's description of early concrete, as well as Gillmore's report of the concrete mix at the Staten Island fortifications in the 1870s. In other main areas of Batteries Sumner and Graham, the concrete appeared with much better gradation and paste coverage.

In Battery Mahan 1 (1898-1900), a significant portion of eastern corner of the upper traverse where it met the parapet has deteriorated significantly. A large area of the interior portland cement concrete has been exposed. The concrete appeared to contain moderately well graded crushed coarse aggregate with moderately good paste coverage. However, there was considerable water movement through the lift planes between each placement, which was readily apparent on rainy days. This movement of water also led to significant lateral movement of the upper placements, while considerable salt deposition emanated from these lift joints.

Concrete lifts were most visible in the upper traverses and the parapets, rather than the magazines of the Upper Endicotts. Furthermore, it was difficult to discern the concrete lifts in any of the 1870s concrete structures. This might indicate that the earlier fortifications were built in continuous concrete pours or that greater care was taken to ensure a good bonding between each lift. Baker noted that the "precautions must be taken to secure a good union between [each lift]" and that if the bottom layer was fully set a 1:1 or 1:2 cement mortar should be swept over the surface to facilitate a good bond with the next layer.[148] However, various stuccos and coatings had been applied to these magazines and enclosed structures, which would obscure these lift boundaries.

No metal reinforcement was observed in any of the concrete placed in the Water Battery, the Torpedo Magazines or in the Endicotts proper, excepting the rolled wrought iron beam and concrete infill used in the upper platform floors. True reinforced concrete was only observed in the southern extensions to the Endicott batteries, which were built between 1902-1905 using Ransome bars.

[148] Baker, (1909) p. 173

Figure 78: Battery Mahan 1 Upper, southern extension, showing reinforced concrete

Figure 79: Battery Sumner 1 Lower Core, southern extension, showing reinforced concrete

Figure 80: Sample from Battery Mahan 1 Lower, southern extension, showing an impression of a Ransome bar in the concrete

While examining the in-situ concrete can be informative, it is generally limited to macro observations of the fortification's surfaces. Samples were therefore collected to conduct a petrographic analysis of the interior areas of the concrete.

5. Petrography

In order to gain a better understanding of the concrete used in the construction of the Fort Totten fortifications, petrographic analysis was conducted. In addition to the macro analysis of the concrete structures summarized in section 4.4 above, the petrographic analysis included a visual and microscopic examination of the concrete hand and core samples collected, based on ASTM Standard C856. Thin sections produced from a selection of these samples were analyzed using polarized light microscopy. Furthermore, samples were treated with chemical reagents, to measure the pH of the concrete as an indicator of secondary carbonation.

5.1 Sample Collection

All necessary permissions from the New York City Department of Parks and Recreation were secured before sampling was conducted. Thirty samples of concrete were collected from the Upper Endicotts, Battery Stuart, and the Water Battery during a site visit on 20th December 2012, conducted with John Walsh from Highbridge Materials Consulting and Ken Uracius of Stone & Lime Imports, Inc. These structures all suffered from various states of deterioration, so that the samples were either loose or could be easily pried away using a rock hammer. These samples were generally hand sized, and those chosen measured at least two to four inches deep from the surface. Each sample was labeled, bagged, and taken to the Highbridge Lab in Pleasantville, NY for preparation. After a permit was issued by NYC Parks, nine concrete cores, four inches in diameter and between six and twelve inches long, were collected during a second site visit on 9th March 2013, from Torpedo Magazines 4 and 8, Battery Graham 1, Battery Sumner 1, and Battery Mahan 1. Ken Uracius from Stone & Lime Imports Inc. provided the core drill and supervised all the work (see Figures 81 and 82 below for sample locations). The samples were labeled, bagged and taken to the Highbridge Lab in Pleasantville, NY for preparation. The holes were subsequently filled with a proprietary Rosendale concrete blend supplied by Stone & Lime Imports Inc. Pieces of loose historic aggregate and stucco found on site that matched the existing surface features were then impressed into the wet concrete (See Appendix 7.2).

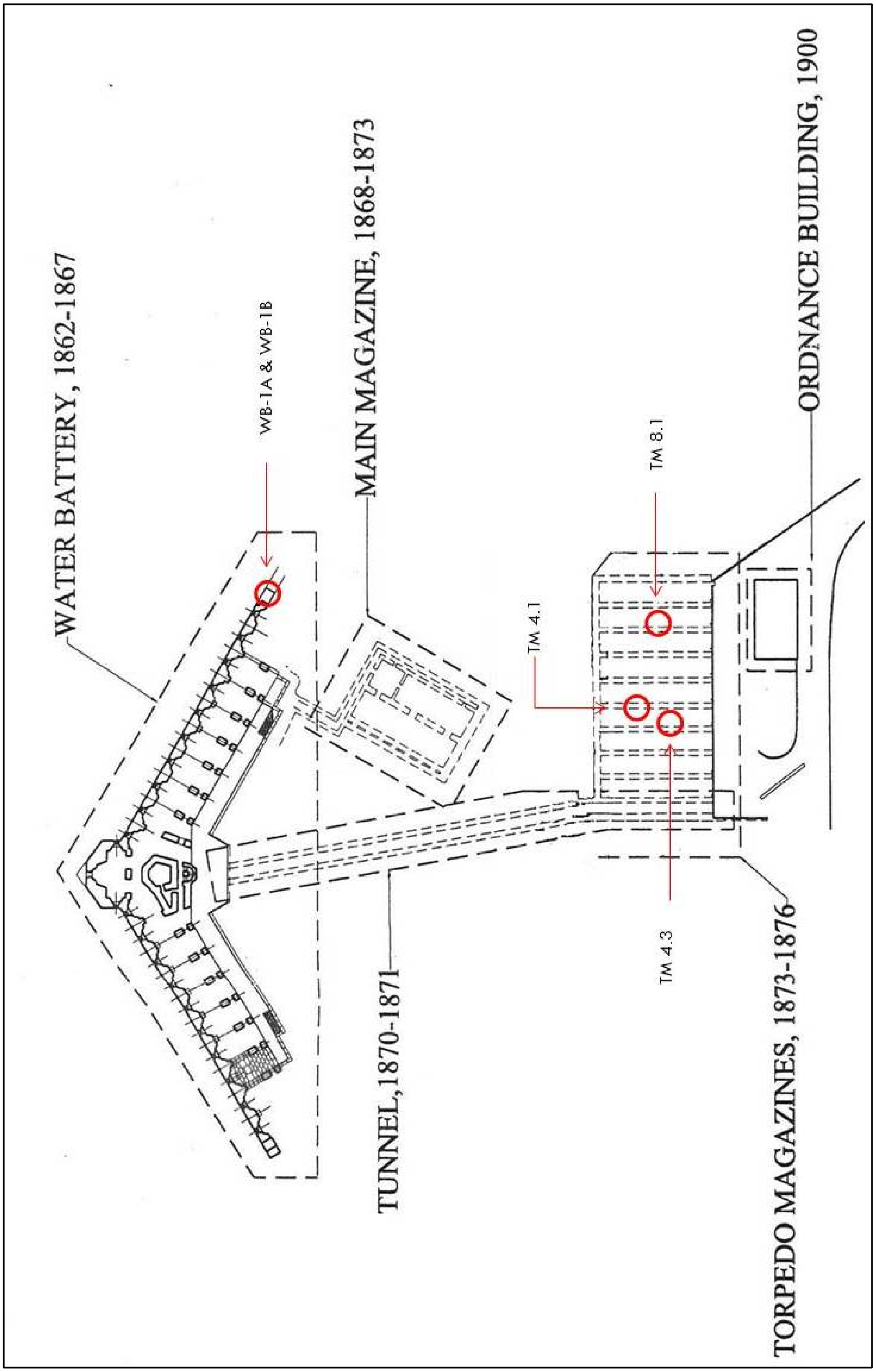

Figure 81: Map showing location of samples taken from the Water Battery and the Torpedo Magazines (Based on Beyer Blinder Belle, 2000, H-SD)

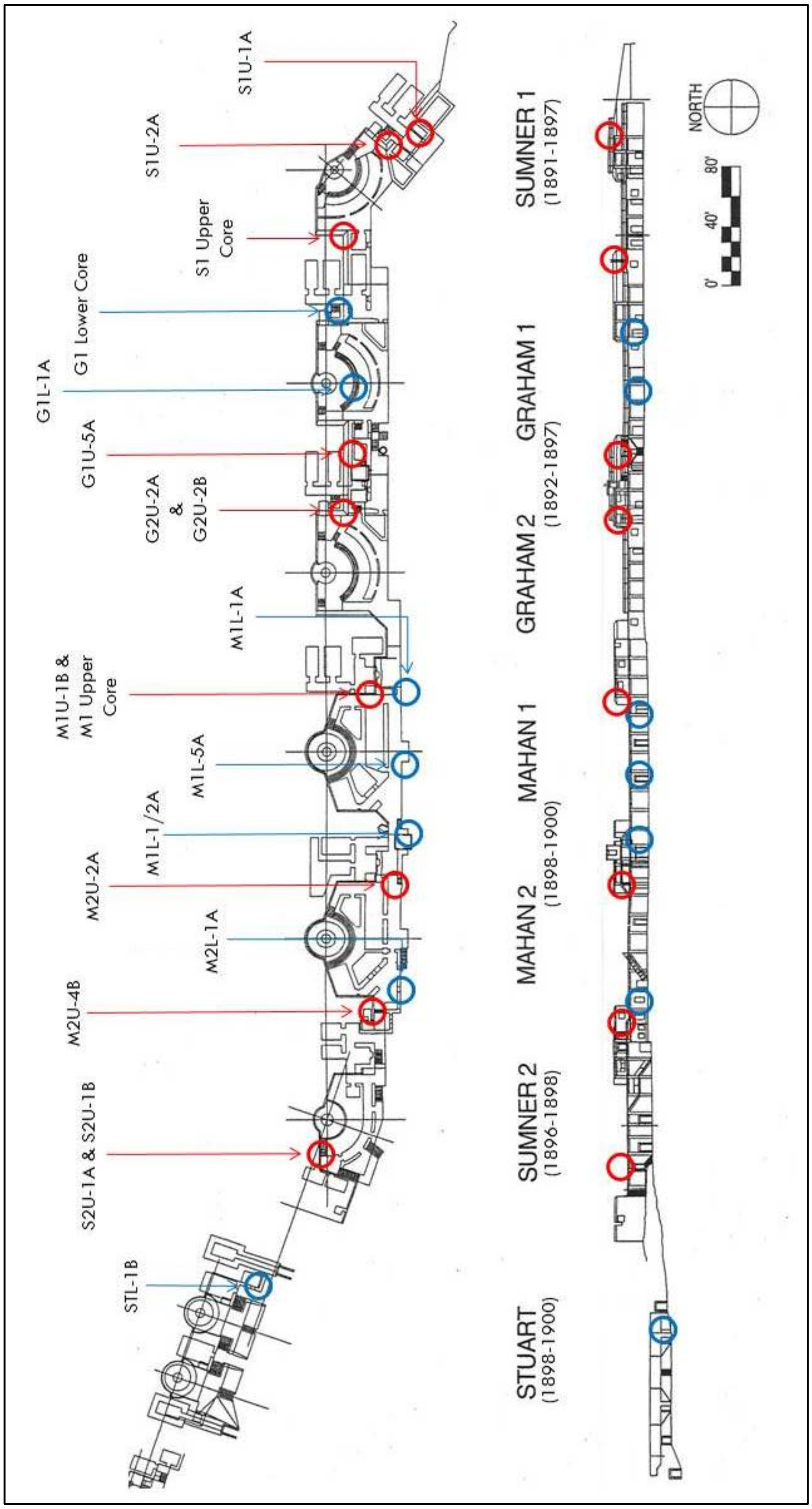

Figure 82: Map showing location of samples collection from the Endicott Batteries (Based on Beyer Blinder Belle, 2000, 7-20)

It should be noted that the collection of concrete samples from each construction phase of the Fort Totten fortifications represents only a small part of the thousands of cubic yards of concrete poured on site. Furthermore, since the Water Battery is a New York City Landmark and the site is part of a New York City Historic District, the invasive coring was kept to a practical minimum. Collecting loose hand samples was less invasive and covered a wider area than the coring method, but these comprised mainly surface concrete approximately two to four inches in thickness. Furthermore these loose samples had been exposed to the elements so that that secondary carbonation was more pronounced than the fresh cores that had been sealed within the concrete mass. Finally, due to budgetary constraints, only small areas of selective samples were chosen for thin sections to be analyzed using polarized light microscopy. While this was revealing, the information garnered was only a small snapshot of a much larger picture. Consequently, throughout the examination process, repeated site visits were made to Fort Totten to relate the micro-conditions of the thin section or hand sample to the macro conditions of the battery, magazine or emplacement.

5.2 Sample Preparation

In order to prevent contact with water, and preserve any unhydrated cement paste; concrete samples were cut into sections approximately ½ inch thick using a Covington Slab Saw lubricated with Rockhound mineral oil. The excess oil was rubbed off each section using PIG® Lite-Dri® Loose Absorbent recycled cellulose. Finally, to limit any carbonation of the binder, they were placed in airtight mylar sample bags and labeled with their provenance.

The cut sections of concrete were then examined to choose potential thin sections and the outlines of 27 x 46 mm and 2 x 3 inch slides were drawn on the sections using cardboard templates. Areas were chosen that contained a mixture of aggregate and paste, evidence of chemical boundaries, possible repairs, deterioration, or anything that seemed unusual or interesting. After reviewing the sections with the Senior Petrographer, John Walsh, several areas were selected and cut using small circular table saw lubricated with Rockhound mineral oil. The samples were again wiped using PIG® Lite-Dri® Loose Absorbent recycled cellulose, before they were photographed, labeled and bagged. Samples were sent to National

Petrographic Service Inc. in Houston, TX to prepare thin sections for petrographic analysis. From the loose hand samples, ten of the 27 x 46 mm and six of the 2 x 3 inch thin sections were prepared, while from the cores, five of the 27 x 46 mm and nine of the 2 x 3 inch thin sections were prepared (see Appendix 7.1 for a chart linking the on-site sample locations to the cut samples). Samples were prepared in thin section by impregnating them in a blue dyed epoxy and the samples were ground using oil to a thickness of 27 microns, before a cover slip was added.

5.3 Visual Appearance

Concrete samples collected from the fortifications and thin sections prepared from sampled collected were examined to assess a number of factors, which are summarized in Appendix 7.4. The first observation was the approximation of the gradation size number using the modern ASTM Standard C33 (see Appendix 7.5). This would provide a benchmark in describing the aggregate grading of the concrete sample, but it should be noted that this was an estimation of three dimensional concrete using two dimensional samples. Gradation is the particle size distribution of the aggregate and will affect the water demand of the concrete. This is a measure of the water required to produce a particular consistency of concrete and will therefore affect its workability and its durability. In modern terms the Portland Cement Associations (PCA) defined coarse aggregates as any particles greater than 0.19 inch (4.75 mm), but generally range between 3/8 and 1 ½ inches (9.5 mm to 37.5 mm). The PCA defined fine aggregates as natural sand or crushed stone with most particles passing through a 3/8 inch (9.5-mm) sieve.[149]

Well-graded aggregate was understood in the 19th century as being advantageous in the mixing of concrete, although only as less mortar was required.[150] Certainly, there were machines available to the Corps of Engineers to facilitate the grading of crushed aggregate (see Section 4.1 above). The gradation of the aggregates used in the concrete for the Endicott era fortifications (1891-1905) were estimated at size number five or six, meaning the largest

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149 http://www.cement.org/basics/concretebasics_aggregate.asp
150 Baker (1909), p. 133 and Noble Twelvetrees, W., (1920) *A Treatise on Reinforced Concrete, London*, Sir Isaac Pitman & Sons Ltd, p. 12

size of aggregate will pass through a 1 ½” and 1” screen, respectively. The samples from the foundations for the gun emplacement at Battery Graham 1 (1892-1897) were estimated at size number four, meaning the largest size of aggregate will pass through a 2” screen. The concrete used in the earlier fortifications, including the Water Battery (1862-67) and the Torpedo Magazines (1873-1876) generally contained were estimated at size number three, meaning the largest size of aggregate will pass through a 2 ½” screen.

Figure 83: Battery Mahan 1 Upper Core (1898-1900), note the lift line

Figure 84: Battery Sumner 1 Upper Core (1891-1897), note the lift line

Figure 85: Torpedo Magazine 8 Core (1875/6), note the large aggregate and surrounding voids

Figure 86: Torpedo Magazine 8 Core (1875/6), note the large aggregate and surrounding voids

However, one of the samples cores taken from Torpedo Magazine 8 (1875/76) was estimated at size number one, due to the presence of a single large piece of aggregate that could pass through a 4” screen. If this large aggregate piece was removed from the estimation then the gradation would be closer to a size 4, meaning the largest size of aggregate will pass through a 2” screen. This might then indicate that large pieces of aggregate were added to the concrete mix as it was being placed, in order to help fill out the immense area within the wooden formwork, rather than as an integral part of the original mix. Indeed, Maj. Maquay of the Royal Engineers noted in 1874 that for massive work, including foundations, abutments and revetments, small boulders and lumps of stone could be thrown in by hand with the concrete.[151]

Large void spaces were observed in the core samples removed from the Torpedo Magazines, especially from Magazine 8 (1875/76), which contained the largest single piece of aggregate collected. This could indicate that the concrete was poorly mixed, especially if it was hand-mixed, although this is unlikely since machine mixers were probably used. Indeed the coarse and fine aggregate particles were generally well coated with cement paste, which would indicate a well-mixed concrete. Such voids may also be indicative of poor placement and tamping of the concrete, which Winslow noted was common practice:

> *"In the first concrete emplacements built but little care seems to have been taken in the mixing and ramming of the concrete. It seems to have been thought at that time that about all that was needed was mass and that ramming was not very necessary to make the concrete strong. Occasionally the concrete was dumped in by the skipful, the surface being then tamped a little, but the effect of this tamping did not, of course, extend very far down into the mass. Sometimes it was customary to dump the skips while moving, which would thus scatter the cement considerably, and wherever the concrete fell it was tamped to some extent."*[152]

Given the quick setting nature of natural cement, usually within 15-30 minutes of mixing with water, any delay in placing the concrete containing large coarse aggregate along with poor tamping could easily lead to the production of large void spaces. Indeed, during the coring of two samples side by side in Torpedo Magazine 8, the water pumped in the second core hole, easily flowed out of the first, indicated that the void spaces were connected. However, these void spaces did not lead to excessive water infiltration in the Torpedo Magazines as leaks were only apparent in a few places in the first for magazines. This may be due to the effective waterproofing of structures, from the asphaltic coating on top and the stucco and limewash along the interior walls. In addition, secondary carbonation at the surface of the concrete may have also provided a denser, more water resistant paste.

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[151] Maquay, Maj. John, (1874) "Notes on Portland Cement Concrete", in *Professional Papers*, New Series, Vol. 22, Paper XIII , p. 141
[152] Winslow (1920), p. 53-54

Two cores were collected from Battery Sumner 1 (Core S1U.1, 1891-1897) and Battery Mahan 1 (Core M1U.A & C, 1898-1900) at the boundary of two concrete lifts. The boundary between the two lifts in the Sumner core was noticeable stronger than the boundary in the Mahan core, as the two pieces separated during sample preparation. In the Mahan core, the top lift contained predominantly large pieces of coarse aggregate, while the bottom section contained smaller pieces of coarse aggregate. It would be normal during the placement and the tamping of the concrete for the larger pieces of aggregate to settle to the bottom of the lift, leaving the smaller pieces near the top. However, there was little to distinguish the aggregate sizes between the lifts in the Sumner sample. This could indicate that the concrete mix was dry or had already begun to set when placed, and therefore the mix was less plastic which would limit any aggregate settlement.

Figure 87: Section of the Sumner 1 Core (1891-1897), showing a tight lift boundary

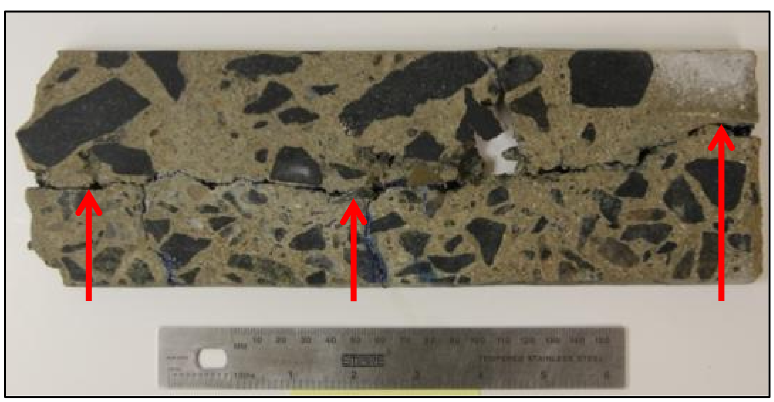

Figure 88: Section of the Mahan 1 Core (1898-1900), showing a large number of platy and crushed coarse aggregate

The shape and surface texture of aggregate was more likely to influence the properties of freshly mixed concrete rather than the properties of hardened concrete. However, this was not always fully understood in the 19th century as were the principles of gradation, which would determine how much cement paste was needed. Totten certainly reported on the relationship of void spaces and Baker reported that abundance of voids was directly related to how dry the mix was. However, irregular shaped, angular aggregate could increase the potential void content clashing with other irregular aggregate, creating spaces where the paste could not reach.

Baker reported that the sand used should be durable, sharp, coarse, and, most importantly, clean; gravel should be durable, clean and contain a variety of sizes; while broken stone should be durable and roughly cuboid.[153] As noted in section 5.3, aggregate is generally divided into coarse aggregate (stone and gravel) and fine aggregate (sand) and while their identification will be dealt with separately, the principles of shape and texture are applicable to both. Under current Portland Cement Association guidelines, concrete using aggregate that is rough in texture, angular, and elongated or 'platey' will require more water to produce a plastic or workable concrete than if smooth, rounded, and compact aggregate were used. Therefore, the cement content would need to be increased in order to maintain the required W/C ratio. Generally the coarse aggregate used the concrete sampled at Fort Totten was angular, indicating that it had been crushed. However, in the early natural cement concrete of the 1870s Torpedo Magazines and the Tunnel, significant amounts of large rounded gravel aggregate were visible.

Finally, samples of both the natural cement and portland cement concrete were broken and observed under a microscope in direct light. The texture of the natural cement concrete appeared 'waxy' when compared with the portland cement concrete under similar conditions. Drops of water were added to both samples to examine the absorption qualities. While each type exhibited similar moderate absorption rates, the water beaded slightly more on the portland cement concrete before it was absorbed.

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[153] Baker, (1909) p. 85-100

5.4 Chemical Testing for Secondary Carbonation

Cut samples of concrete were selected representing each of the batteries and magazines. Samples were brushed sparingly with Germann Instruments Rainbow Indicator and then with Fisher Chemical 1% Phenolphthalein, taking care not to mix the two applications. The testing indicated that the pH of the concrete was generally around 9-11 in the center and closer to 6-7 near the surface. The cause of this was the depletion of calcium hydroxide which has undergone conversion to calcium carbonate or carbonation, due to exposure to carbon dioxide dissolved in water. If the moisture content of the concrete is less than 40%, then the carbon dioxide cannot dissolve and no carbonation can occur. Conversely, a moisture content greater than 90% will prevent carbon dioxide from entering the concrete and carbonation will therefore not occur. This is a secondary process that happened over a period of time after the concrete had hydrated and set.

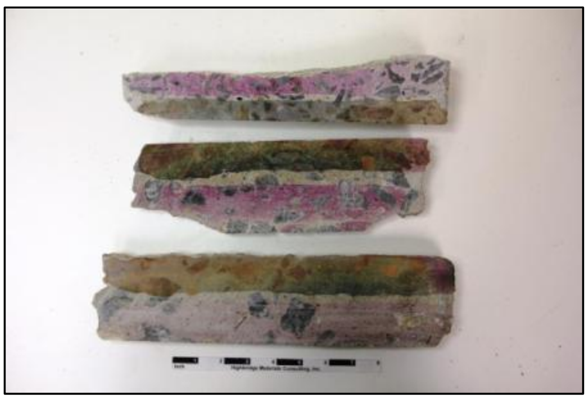

Figure 89: Carbonation testing, samples from top, Battery Mahan, Graham and Sumner

Figure 90: Carbonation testing, samples from top, Torpedo Magazine 4.3, 4.1 and 8

Carbonation can result in cracking when it occurs very deep within the concrete. At the surface carbonation can create a case hardened layer that may spall off due to expansive pressures that may develop from freezing moisture or salt deposition. In reinforced concrete, the passivation protection that occurs by coating the steel rebar in the alkaline cement paste will cease as the pH level drops. This is called depassivation and will lead to the rusting of the steel reinforcement and expansive pressures resulting in cracking of the concrete, which is readily apparent in the 1902-1905 Endicott extensions. However in many cases, carbonation will result in a decrease of the porosity of the paste, and increasing its strength, so one could argue that carbonation can be advantageous in non-reinforced concrete.

5.5 Polarized Light Microscopy

The thin sections were examined with a polarized light microscope under plane-polarized and cross-polarized light. This allowed the magnification of materials between 40x and 400x to aid in the textural analysis of the concrete thin section, including the identification and description of the aggregate, paste, and, as the samples were treated with epoxy, the pore structure, which may include air voids, capillary pores, aggregate pores, cracks, etc.

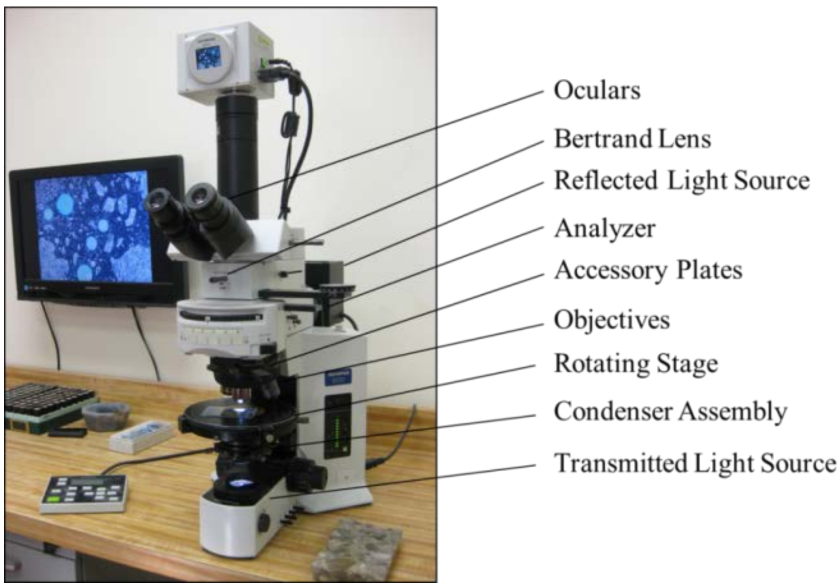

Figure 91: Petrographic microscope (courtesy of Highbridge Materials Testing)

5.5.1 Paste

The first step was to identify the binder in each of the samples collected. Portland cement may be identified by the presence of alite (C_3S) or belite (C_2S). Alite is only produced in clinkered cement kilned at temperatures above 1400ºC. Alite exhibits a high relief, it is colorless under plane-polarized light but under cross-polarized light its birefringence has a low first order gray interference color. Furthermore, hydration rims are common with alite, as a function of its water/cement ratio. Belite also exhibits a high relief, but it is colorless to amber under plane-polarized light and under cross-polarized light its birefringence has a mid-first order yellow interference color, while hydration rims are rare. Furthermore, belite has characteristic twin lamellae and a agglomerate (bunch of grapes) structure.

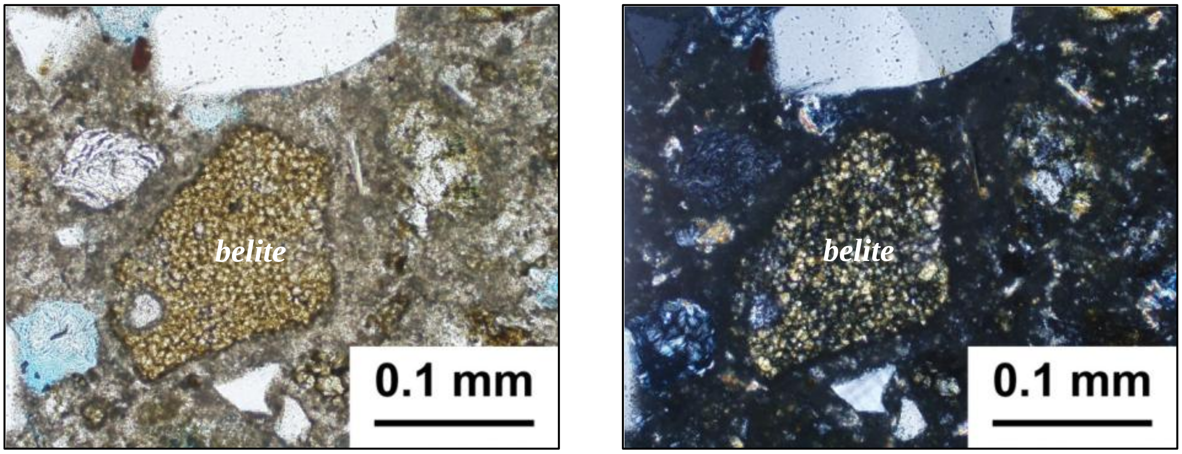

Figure 92: Belite, from portland cement (PC) stucco in sample G2U-2A (1892-1897), PPL (Left) and XPL (right)

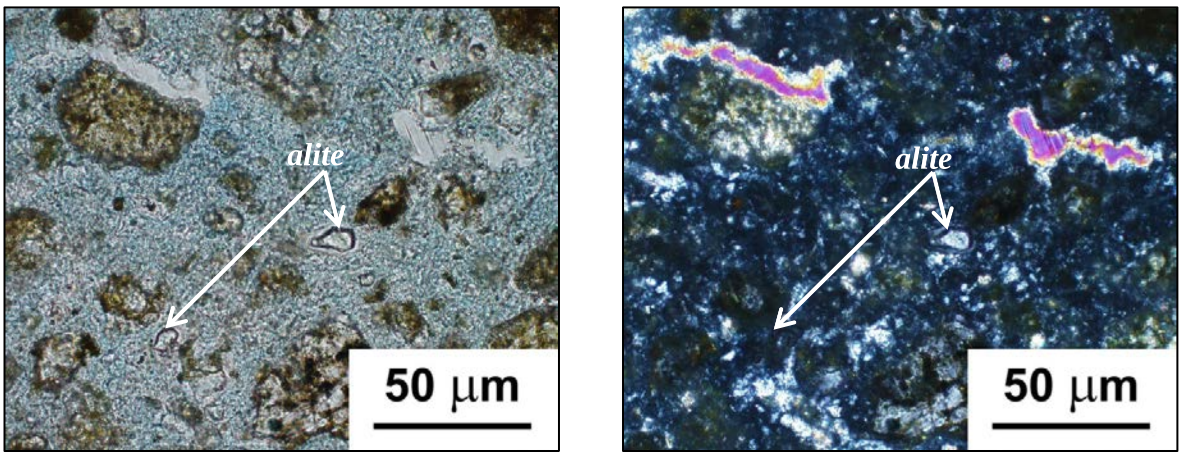

Figure 93: Alite, from PC sample M1L-1B (1898-1900), PPL (Left) and XPL (right)

Natural cement is kilned at temperatures high enough for calcination to take place but not high enough to clinker the limestone.[154] However, the specific kiln reactions and the full assemblage of mineral phases formed are currently unknown This is largely due to the relative lack of current research into natural cements compared with the large amount of work done on portland cements. However, Walsh has reported that it is possible to distinguish natural cements by identifying the residual textural characteristics of the original

[154] Normally calcination occurs around 800-900ºC, but 19^{th} century technology did not allow for precise temperature control and the historic literature generally referred by Gillmore, Cummings, and Eckel to firing the material to a 'red heat, as opposed to a higher 'white heat' normally reached to produce clinkered material in portland cements.

rock structure.[155] For Rosendale natural cements this is the dolomitic limestone of the Rondout formation and the residual mineralogy of dolostone is evidenced by rhombic crystals, a mid-first order interference with up to a creamy yellow birefringence of a carbonate, as well as an orange iron rich lining. Finally the natural cement grains are found amidst a brown clay mass.

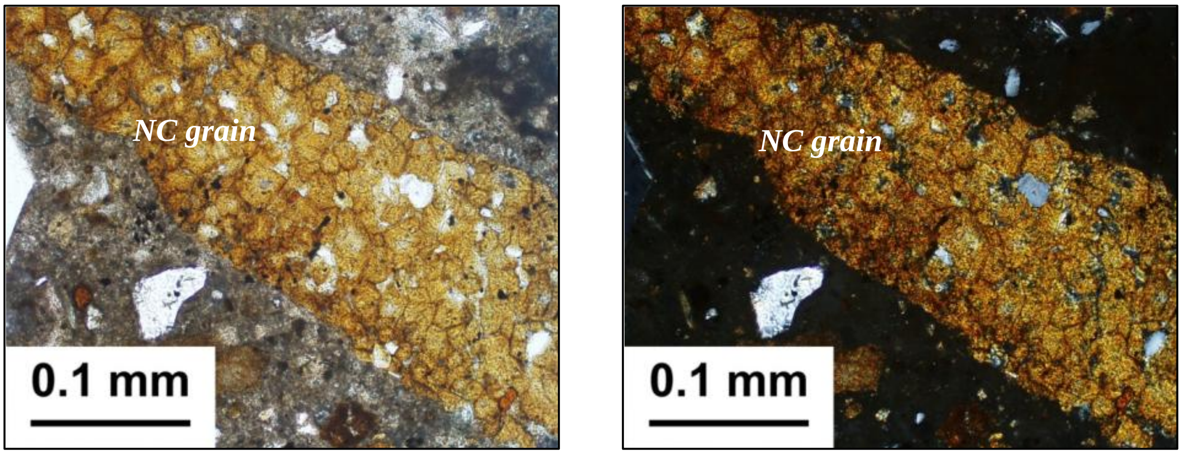

Figure 94: Natural cement grain, from natural cement (NC) sample G2U-2A (1892-1897), PPL (Left) and XPL (right)

The cements found in the samples collected at Fort Totten are detailed in Appendix 7.4. Generally these were identified from the presence of Rosendale natural cement grains in the natural cement concrete and the presence of belite and alite in the portland cement concrete. To summarize, the Water Battery (1862-1867), the Torpedo Magazines (1873-1876) and Early Endicotts (Batteries Sumner and Graham, 1891-1897) were built using natural cement concrete. However, the later Endicotts (Batteries Mahan and Stuart, 1898-1900) and the southern extensions of the Upper Endicotts (1903-1905) were all built with portland cement concrete. This information matches the historical and archival information found for the fortification. In both cases, for natural and portland cement, the cement grains are relatively large, which is indicative of a coarse grind.

Some natural cement concrete structures contained an area of portland cement, which may indicate a coating or a repair. This was observed in sample collected from an area along

[155] Walsh, John J., (2008) "Petrography: Distinguishing Natural Cement from Other Binders in Historical Masonry Construction Using Forensic Microscopy Techniques", *Journal of ASTM International*, Vol. 4, No. 1. January 2008, pp. 20-31

the back parapet wall of Battery Sumner 2 (S2U-1B, 1896-1898) where cracking between two natural cement concrete lifts had been repaired with portland cement.

A second sample from Battery Graham 2 (G2U-2A, 1892-1897), at the top corner of the parapet contained a fairly uniform surface coating of portland cement approximately one cm thick. This could indicate an attempt at waterproofing the parapet, but could also indicate an attempt to provide a hard surface around the blast apron of the emplacement. Winslow noted that, "In the older batteries where Rosendale cement was used it was practically impossible to make the concrete in front of the guns sufficiently strong to withstand the blast, and to overcome this weakness resort was occasionally had to substituting portland cement in this section of an emplacement."[156]

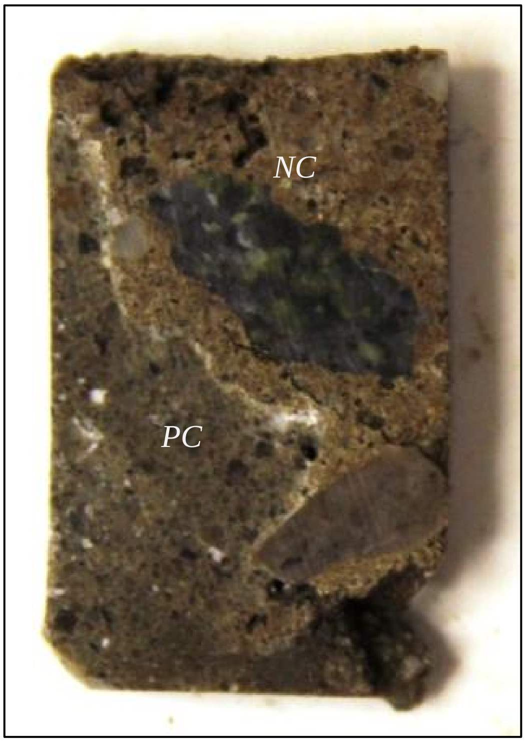

Figure 95: PC repair to NC sample S2U-1B (post 1900), 27 x 46 mm

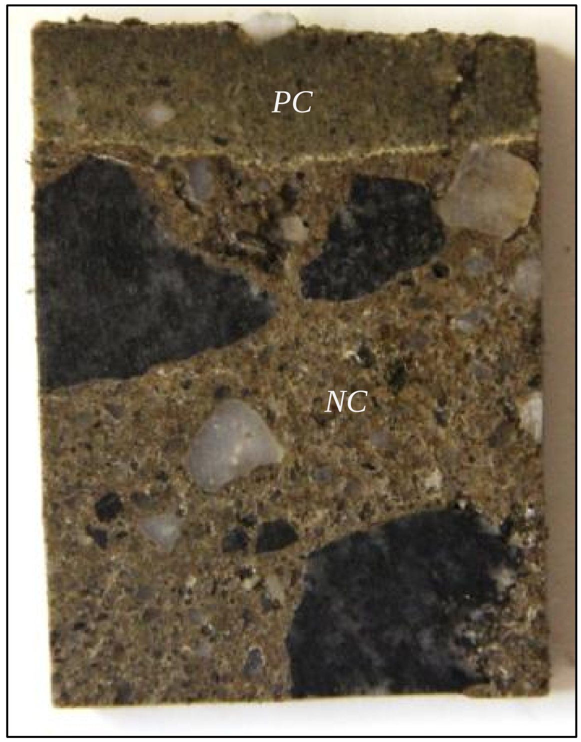

Figure 96: PC pargetting coating on NC sample G2U-2A (1892/98), 2 x 3 inch

[156] Winslow, (1920), p. 57

5.5.2 Coatings

In one of the samples (G1L-1A, 1892-1897) from the foundations of the gun emplacement in Battery Graham 1, a thin surface coat (0.15-0.5mm) contained a high number of ground slag inclusions. The slag particles were identified as having high relief, an irregular shape that looked like shattered glass containing bubbles, they possessed a reaction rim, and were isotropic under cross-polarized light. Slag cements were certainly known during the 19th century with ground blast furnace slag blended with hydrated lime. Eckel reported that slag cements were a medium cost, had a medium sand carrying capacity, a relatively long hardening time, and were fairly light in appearance.[157] However, as Baker noted, the slag would contain sulphides, which, on exposure to air, would convert to sulphates and expand, thereby causing damage to the concrete structure (although this was not evident in the sample). Baker therefore recommended that slag cement should be used in underwater concrete construction, or inside massive masonry or concrete construction that was constantly exposed to moisture.[158]

Figure 97: The gun emplacement foundations of Battery Graham 1 (1882-1897) with a slag cement coating

[157] Eckel, Edwin C., (1922) *Cements, Limes and Plasters: their materials, manufactures and properties*, New York, J. Wiley & Sons, p. 10ff
[158] Baker, Ira O., (1909, 10th edition) *A treatise on masonry construction*, New York, J. Wiley & Sons, p. 57

However, these slag particles were found in a surface coating on the foundations of the gun emplacements. Baker noted that there was a portland cement that used finely ground slag and hydrated lime (calcium hydroxide).[159] However, the residual slag particles would not be visible with this type of cement. The only cement binder that was observed in this sample appeared to be a fully-hydrated belite agglomerate, which would indicate portland cement, but this was not conclusive. However, granulated blast furnace slag, when crushed or milled to very fine cement-sized particles, possesses cementitious properties itself. However the rate of hydration for slag cements was minimal, so they required an activator, such as hydrated lime or by adding them to portland cement.[160] Another observation was that the shape and texture of the slag particles differed slightly from those found in most historic slag cements, which might be suggestive of a different metal smelting waste product.

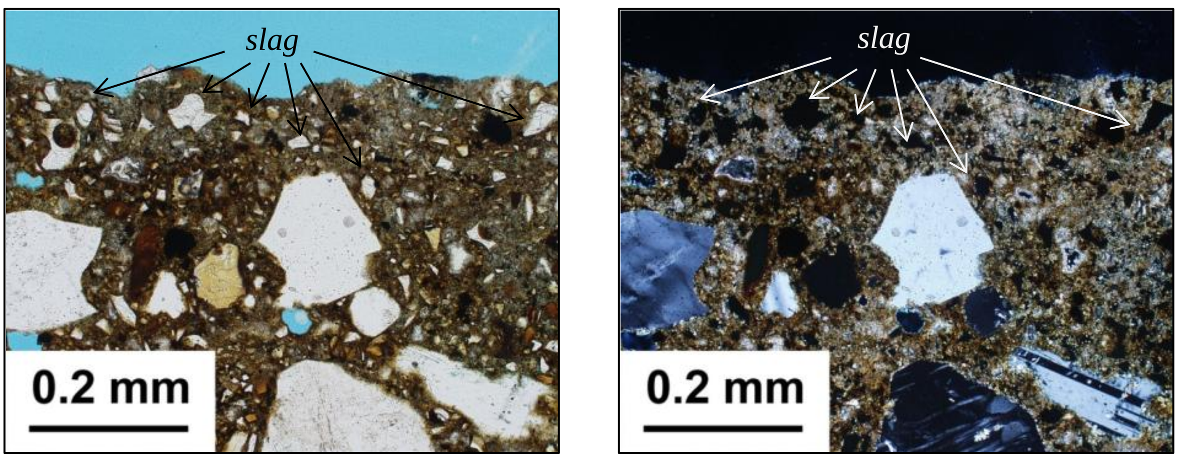

Figure 98: Ground slag inclusions, from NC sample G1L-1A (1892-97), PPL (Left) and XPL (right)

It is likely that this was a slag cement coating, since slag particles are only evident in the first few millimeters of the sample's surface. However, it is uncertain whether this was applied at the time of construction or sometime afterwards. The use of slag may have been an experiment by the Corps to produce a cementitious waterproof coating in a structure that had been built with very dry concrete that was to prove very porous. Otherwise, its presence could simply be accidental.

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[159] Ibid.
[160] ASTM C219, p. 3

All of the Torpedo Magazines had a white surface coating, which under polarized light microscopy has been identified as a limewash, which was made from slaked lime in water. When applied to the surface of the structure, the limewash will set as water evaporates and the calcium hydroxide will react with the carbon dioxide to produce calcium carbonate in the form of calcite. This process, known as carbonation, is lengthy and over time the limewash will harden and its opacity will increase. When examined under the polarized light microscope, the grains of lime appeared quite coarse. Since the 1960s lime has generally been ground fairly fine, so this coating of limewash appears to date from the first half of the 20th century, possibly from the first few decades, although further research is required.

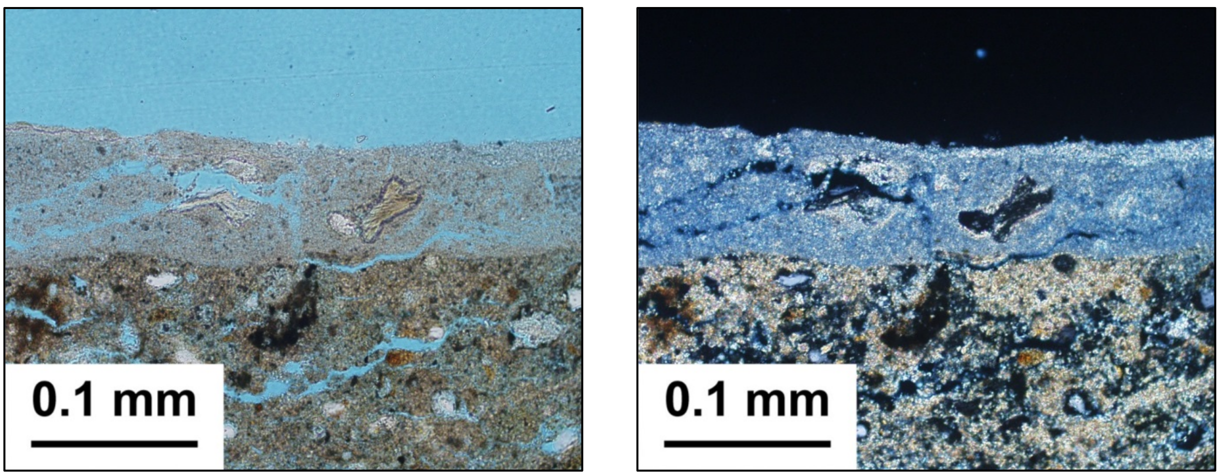


Figure 99: Limewash coating on natural cement concrete, from NC sample TM4.3A2 (1873/4)

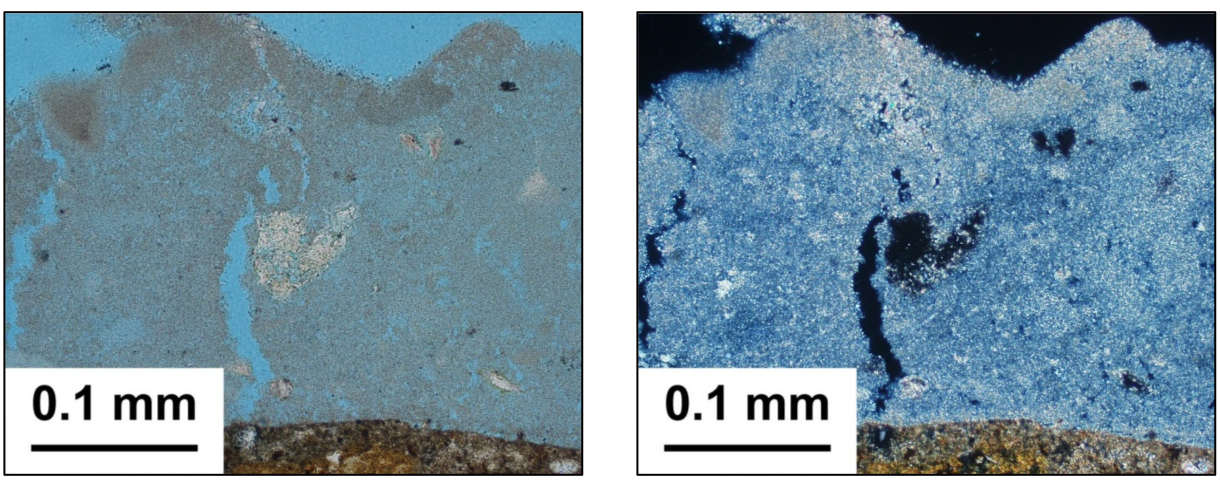


Figure 100: Limewash coating on natural cement concrete, from NC sample TM8.1 (1875/6)

5.5.3 Porosity

The water/cement (W/C) ratio is defined as "the ratio of the mass of water, exclusive only of that absorbed by the aggregates, to the mass of hydraulic cement in concrete, mortar, or grout, stated as a decimal."[161] This is relevant because excess mix water will lead to excess evaporable water, which will in turn lead to an increase in microporosity. However, adding water to the concrete mix will also improve its plasticity making the concrete more workable when placing it. Viewing the thin sections under the microscope, a low density paste, which is almost translucent and has a high microporosity, is indicative of a high W/C ratio. Conversely, a high density paste that is almost opaque and has a low microporosity is indicative of a low W/C ratio. In addition, as the W/C ratio increases, the amount of unhydrated cement grains decrease, as with an increasing amount of water they are converted to calcium hydroxide. A high W/C ratio means greater abundance of calcium hydroxide with coarser sizes and a less compact morphology. The cement grains do not preferentially convert to calcium hydroxide there is simply more pore water saturated with calcium hydroxide and this is the precipitate that forms, as the mix water evaporates.

Of the concrete samples examined in thin section, those based on portland cement had a moderate W/C ratio, which was more uniform throughout, particularly for the reinforced concrete used for the southern extensions of the Upper Endicotts. However, the natural cement concrete samples generally had a moderate to low W/C ration but were more variable both within and between samples. Indeed, from the difficulties in placing the 1870s concrete in Torpedo Magazine 8, as evidenced by the large void spaces, to the ease with which the larger pieces of coarse aggregate settled to the bottom of the lifts in Battery Mahan 1 (1898-1900), the samples of concrete examined showed a general increase in plasticity and workability, which matched this general increase in the W/C ratio.

Portland cement concrete replaced natural cement concrete at Fort Totten beginning with the construction of Battery Mahan in 1898, which was also around the time that the Engineers began using higher mixing standards and a concrete mixing works. This might

[161] ASTM C125, p.6

therefore explain the greater uniformity in the W/C ratios for the portland cement samples. Furthermore the higher W/C ratios for the portland cement concrete samples, particularly for the reinforced concrete might be explained by the desire to increase its workability and ensure good coverage in and around the reinforcing rods.

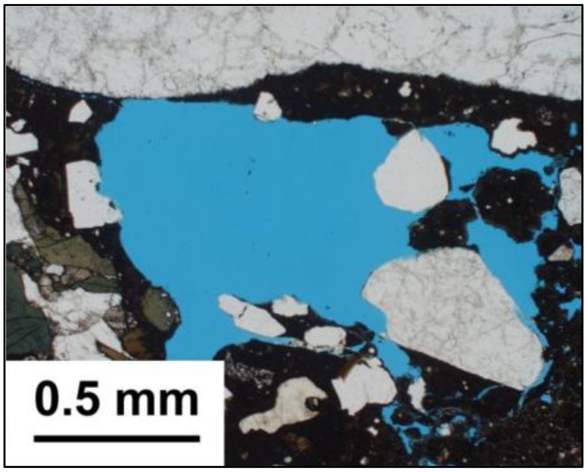


Figure 101:Irregular pores, from NC sample G2U-2A (1892-1897), PPL

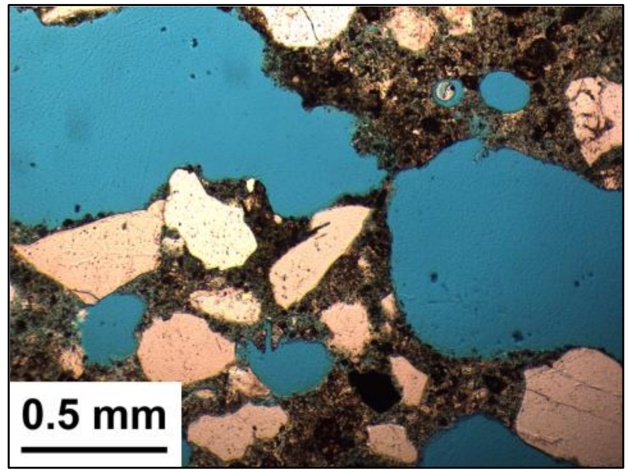
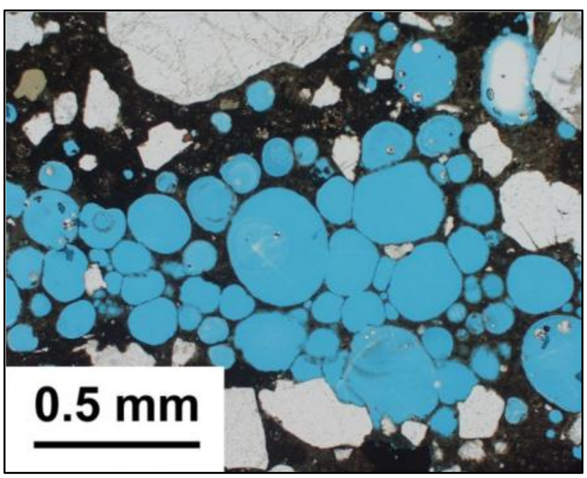


Figure 102: Irregular pores, from PC sample M1L-1/2A, (1898-1900) PPL

In addition to the microporosity, the abundance and shape of pores would also be affected by the viscosity of the cement paste in the concrete. A dense paste was more likely to trap air bubbles, while a less dense paste might allow the bubbles move up towards the surface and escape. The majority of the pores found in all the concrete samples were either spherical or sub spherical and most of the samples had a moderately low capillary porosity (see Appendix 7.4). Examining the thin sections, there were several samples that showed irregular shaped pores. However, apart from two natural cement concrete samples collected from Battery Graham (G1L-1A and G2U-2B, 1892-1897), the majority of these were found in the portland cement concrete at Battery Mahan, which also had a slightly higher capillary porosity. In sample of reinforced portland cement concrete from a lower pillar in Battery Mahan (M1L-1/2A, 1898-1900) where a high W/C ratio was observed, there were an unusually large number of irregularly shaped pores. Unfortunately, there was not enough time to prepare polished sections of concrete, thereby providing an intermediate level of examination.

Finally, clusters of pores were observed in two areas of a thin section prepared from a sample of reinforced portland cement concrete collected a window lintel in Battery Mahan (1903-1905). Unlike the other pores, these appeared to be entrained air bubbles. While entrainment was used as a method of reducing susceptibility in concrete to freeze/thaw damage from the 1930s onwards, it is unlikely that this was the intended purpose here, particularly since such clusters of bubbles were not seen in any of the other contemporary samples. It is more likely that these bubbles were inadvertently produced and could be explained by the accidental addition of organic matter during the concrete mixing process. Soap might have also produced these bubbles during the mixing process and Baker noted that soap was used to keep the wooden formwork from sticking to the concrete, while alum and soap were also used in concrete mixes as a waterproofing agent.[162] Another issue is that this sample had a moderate W/C ratio and, like other later portland concrete samples at Fort Totten, would have been relatively plastic when placed, so any bubbles should have easily escaped.



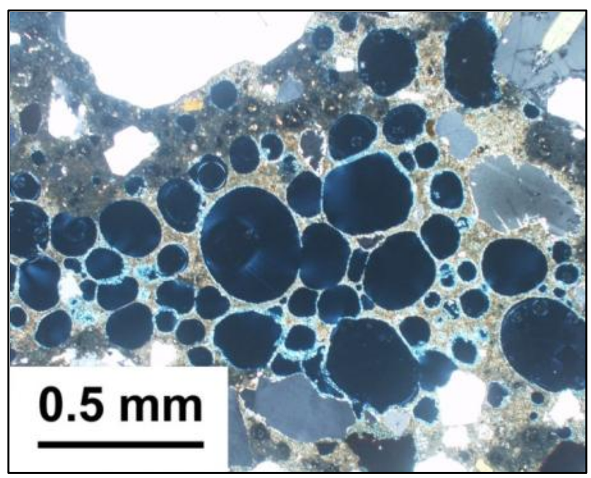


Figure 103: Entrained air, from PC sample M2L-1A (1903-1905), PPL (Left) and XPL (right)

[162] Baker, (1909), p. 173 & 186

5.5.4 Secondary Carbonation and Ettringite Formation

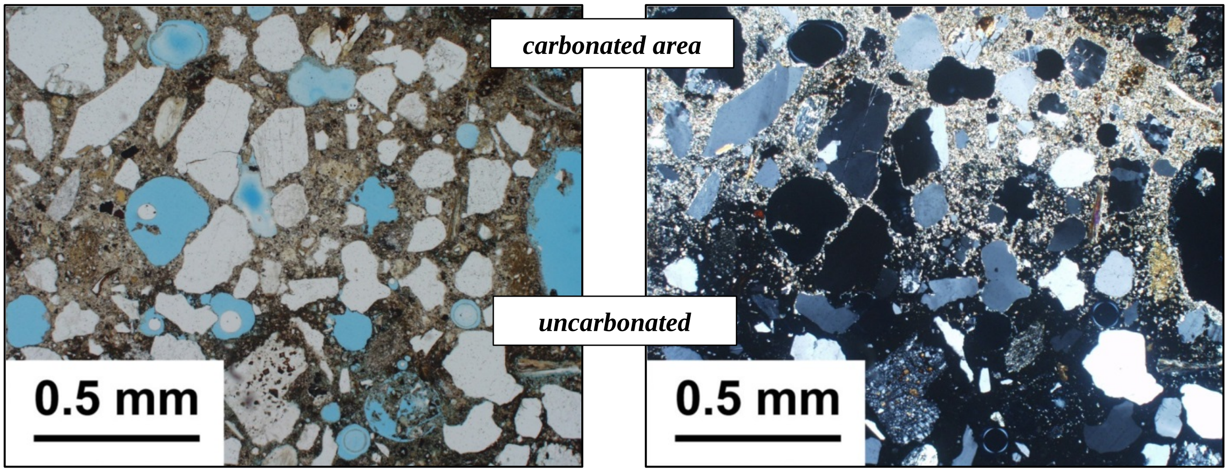


Figure 104: Area of carbonated paste, sample S1U-2A (1891/97), PPL (Left) and XPL (right)

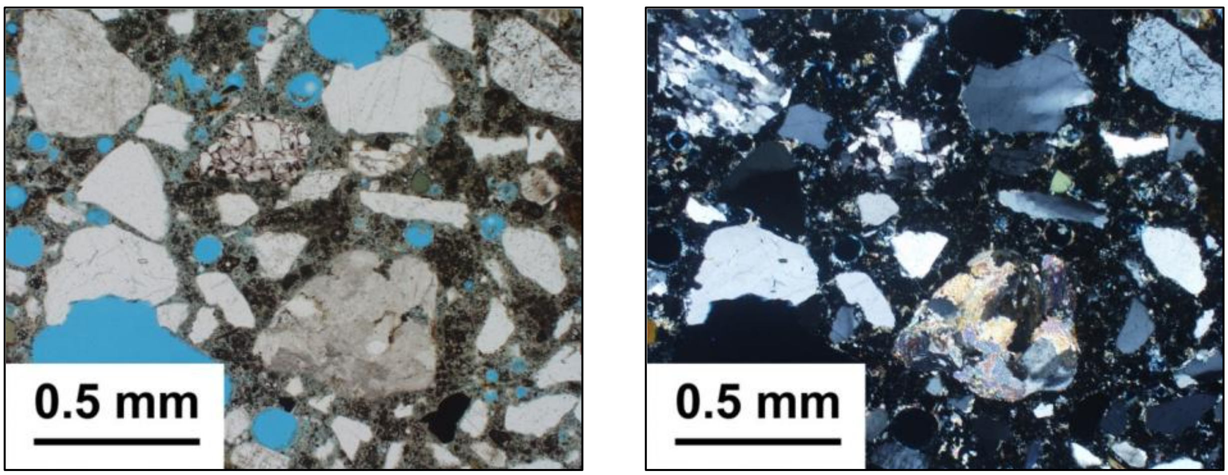


Figure 105: Area of uncarbonated paste, calcium hydroxide crystals appear as white flecks under XPL, Sample M1L-1A (1903-1905), PPL (Left) and XPL (right)

As noted in Section 5.4 above, secondary carbonation of the cement paste occurs when any unhydrated calcium hydroxide crystals have been converted to calcium carbonate due to exposure to carbon dioxide dissolved in water: a weak carbonic acid. This can easily be seen using polarized light microscopy. Under plane-polarized light uncarbonated paste appears thin and somewhat translucent, whereas under cross-polarized light the distinctively shaped calcium hydroxide crystals, whose birefringence possesses a high first order white interference color that stands out against the isotropic background of the thin epoxy impregnated paste. Under plane-polarized light the carbonated paste appears generally dense and dark, whereas under cross-polarized light the calcium carbonate is highly birefringent, with distinctive creamy 6th order interference colors. Again, the advantages and disadvantages of carbonation have been discussed in Section 5.4 above.

Beyond the carbonation boundary in many of these samples, ettringite was identified in pores or void spaces of the samples. Ettringite is a calcium-sulpho-aluminate-hydrate mineral formed by a reaction of calcium aluminate with calcium sulfate in the cement, whose crystals appear as radiating rosettes. No ettringite was found in the carbonated layer, as the pH has dropped below nine due to calcium hydroxide depletion, and ettringite breaks down at lower pH levels. Interestingly, ettringite even formed in the pores of pieces of loose-grained sandstone aggregate.

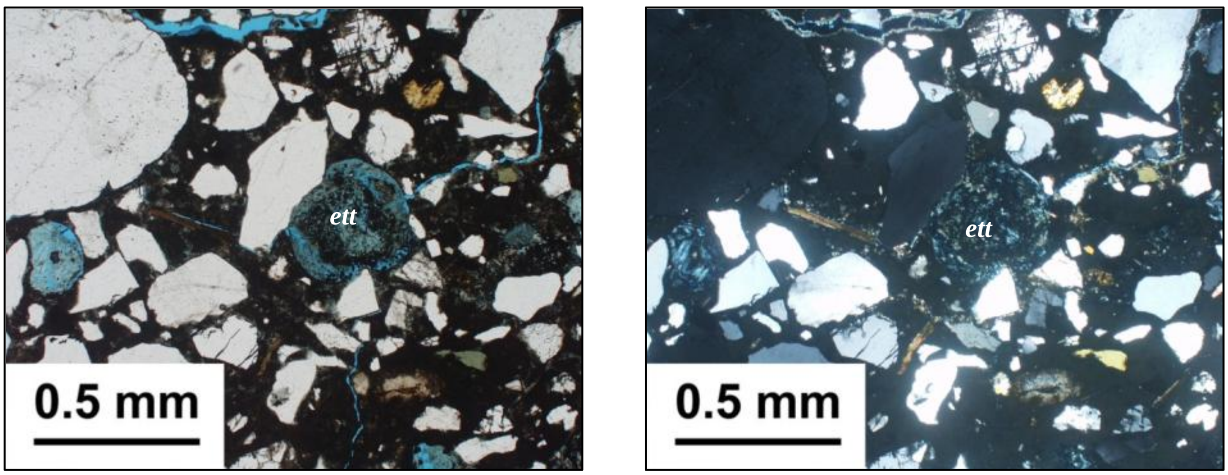


Figure 106: Ettringite (ett), from PC sample M1L-1A (1903-1905), PPL (Left) and XPL (right)

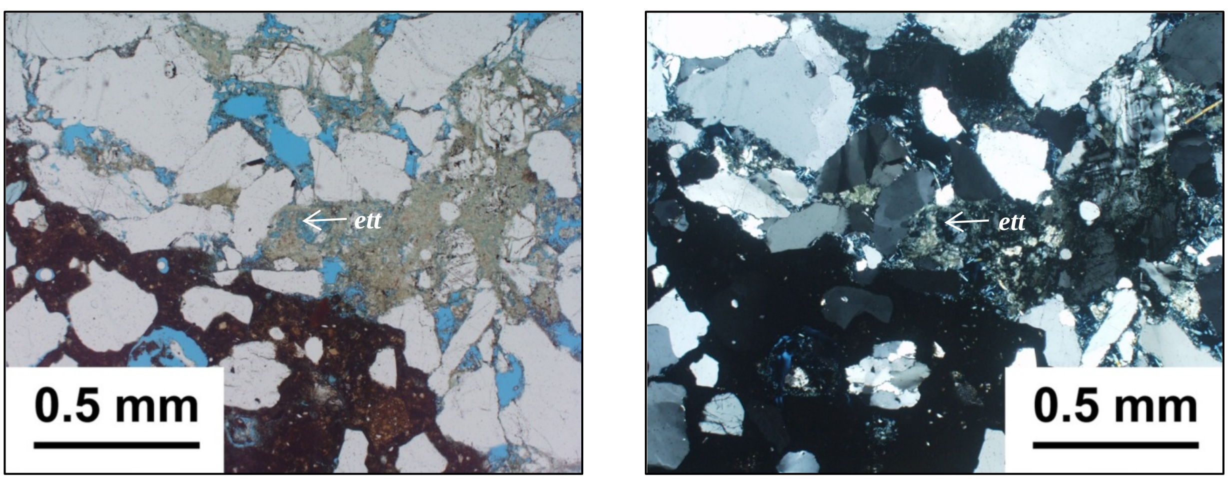


Figure 107: Ettringite (ett) in a loose grained sandstone, from NC sample TM4.3A1 (1873/4), PPL (Left) and XPL (right)

5.5.5 Coarse and Fine Aggregate

Using polarized light microscopy, it was possible to identify the aggregate used in the concrete, based on the diagnostic optical properties of the component minerals when viewed under a polarized light microscope and the rocks by the association and texture of these mineral grains. There was a variety of coarse aggregate types used in the concrete sampled at Fort Totten but there does seem to be a general pattern. The coarse aggregate identified in the samples taken from the infill concrete Water Battery (1863-1867), was generally strained quartz gravel and granite. This granite was almost certainly left over from the huge masonry blocks imported from Maine.

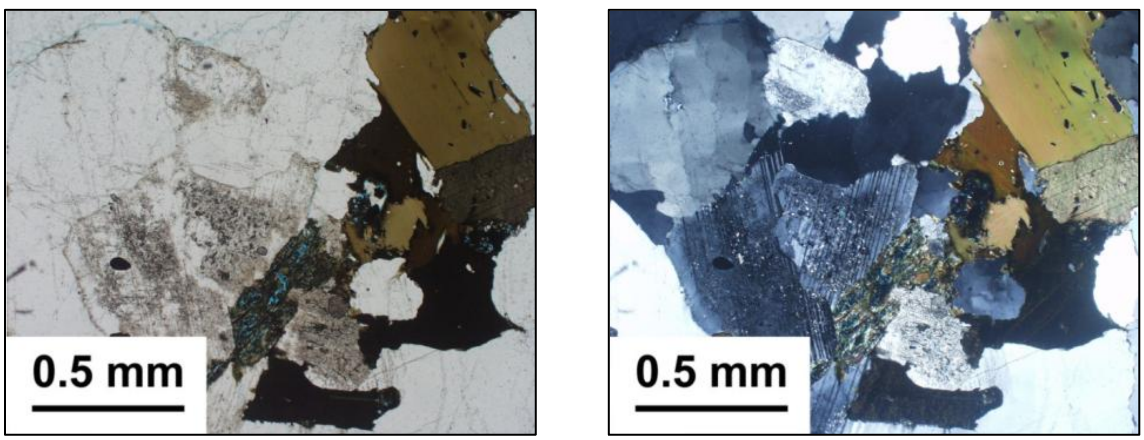


Figure 107: Granite aggregate, from NC sample WB-1A (1863-67), PPL (Left) and XPL (right)

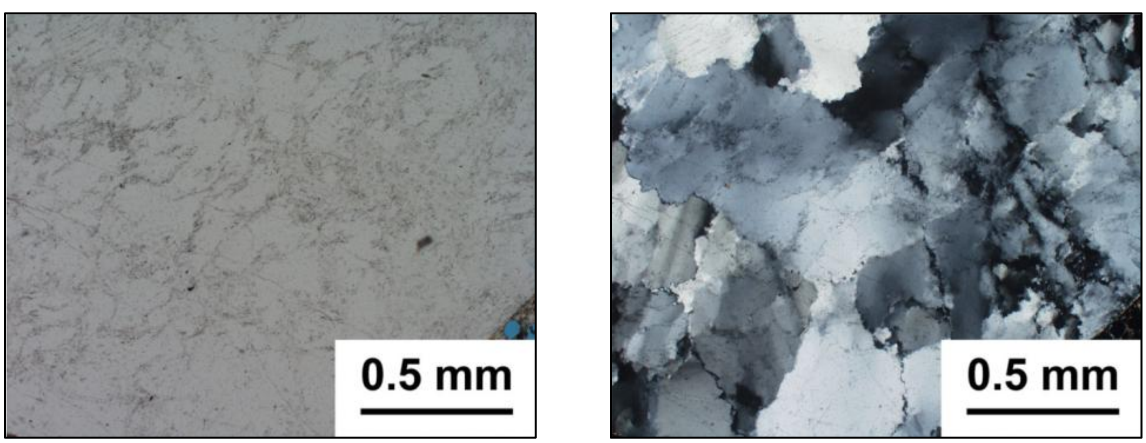


Figure 108: Strained quartz aggregate, from NC sample WB-1A (1863-67), PPL (Left) and XPL (right)

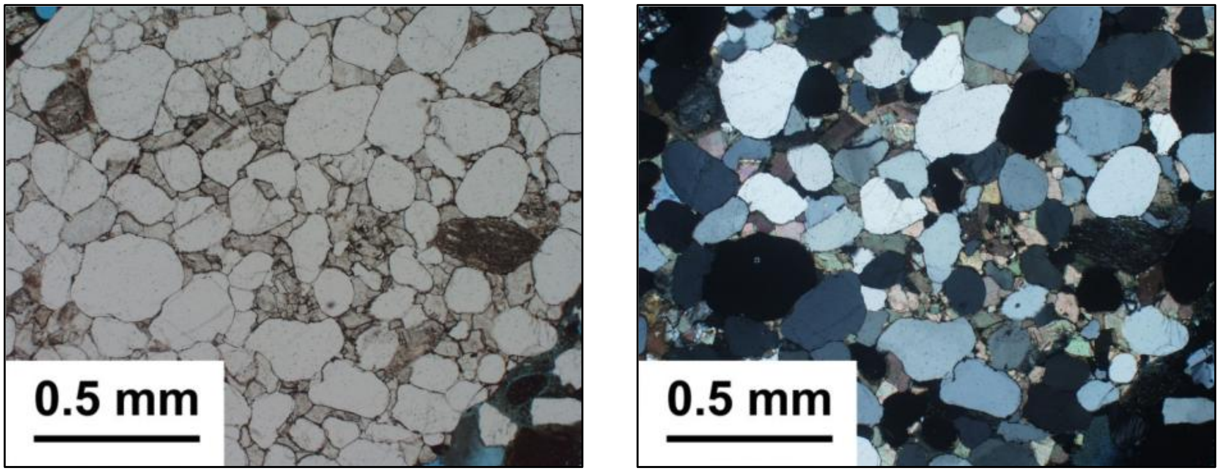


Figure 109: Calcite cemented sandstone aggregate, possible a Hudson Valley Bluestone, from NC sample TM.4.1B (1873-74) PPL (Left) and XPL (right)

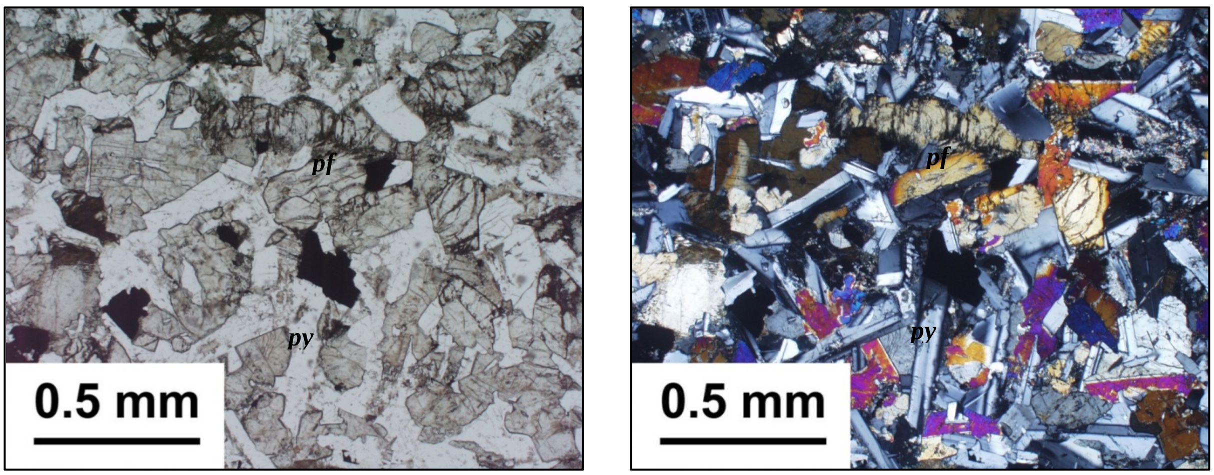


Figure 110: Diabase aggregate, from NC sample TM4.3B (1873/74), PPL (Left) and XPL (right), identified from the component plagioclase feldspar (pf) and pyroxene (py)

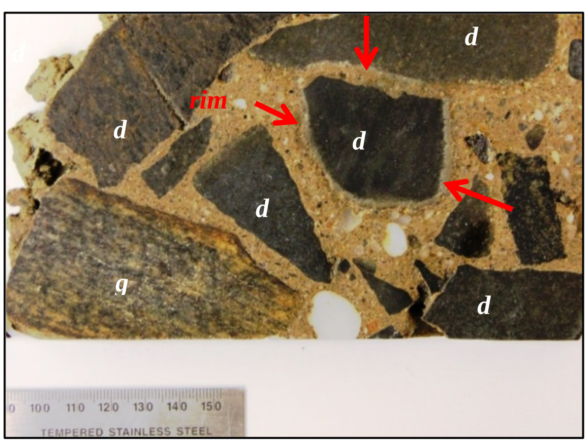


Figure 111: Aggregate used in the natural cement concrete collected from Torpedo Magazine 4 (1873/4), including diabase (d) and gneiss (g) as well as a reaction rim

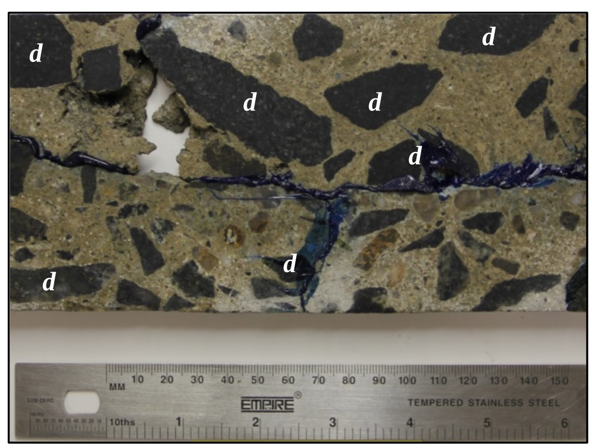


Figure 112: Diabase (d) aggregate used in the portland cement concrete collected from Battery Mahan Upper Core Sample (1898-1900)

The coarse aggregate identified in the samples taken from the Torpedo Magazines (1873-1875/6) included diabase, a foliated coarse-grained metamorphic rock, a fine grained sandstone, and quartz gravel. The lack of variety in the aggregate found in these structures, may indicate that it was imported from a single source

In one of the core samples from Torpedo Magazine 4, two thin sections contained rounded pieces of unbroken or partially broken diabase aggregate (TM4.3A2 and TM4.3B, 1873-4). Under the microscope, the first few millimeters of these pieces of aggregate appeared weathered.[163] This indicated that the diabase had been exposed to the elements for some time before being used as aggregate in the concrete mix. Unless it had been pre-wetted, such aggregate would have absorbed any surrounding water in the paste via capillary uptake. This is evident in the rim of surrounding the diabase which has a very granulated appearance. There is no evidence of any calcium hydroxide under cross-polarized light, nor does the paste appear carbonated. This indicates that that any mix water had been absorbed by the weathered aggregate, leaving the cement paste poorly hydrated. Therefore there was simply not enough paste to hold the matrix together. Indeed this can be seen as a greyish rim around the diabase in the hand section.

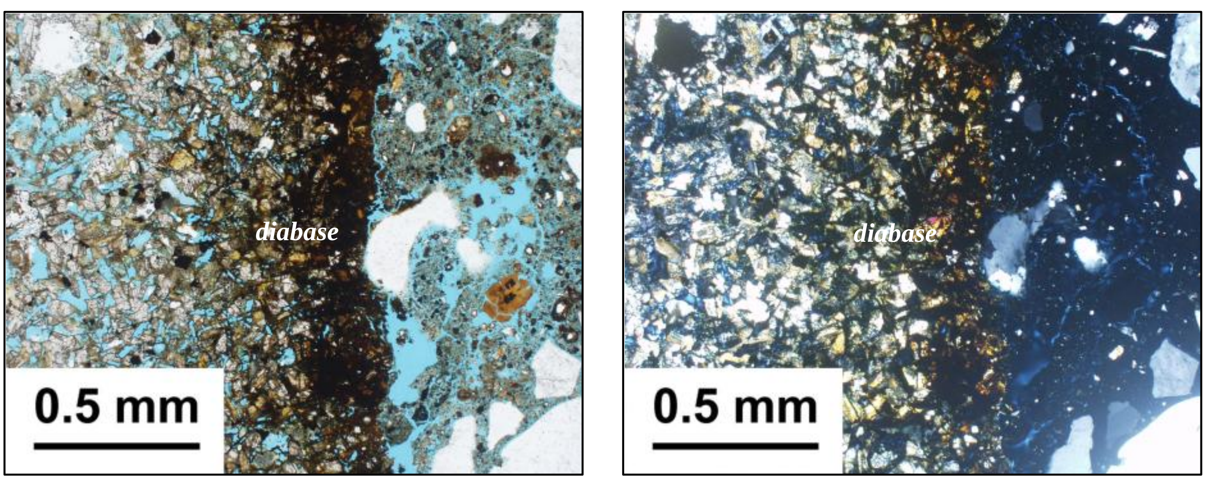


Figure 113: Weathered diabase aggregate from NC sample TM4.3A2 (1873/4), PPL (Left) and XPL (right)

[163] Inexplicably, it was the less reactive plagioclase feldspar (according to Bowen's Reaction Series) that had corroded away rather than the pyroxene.

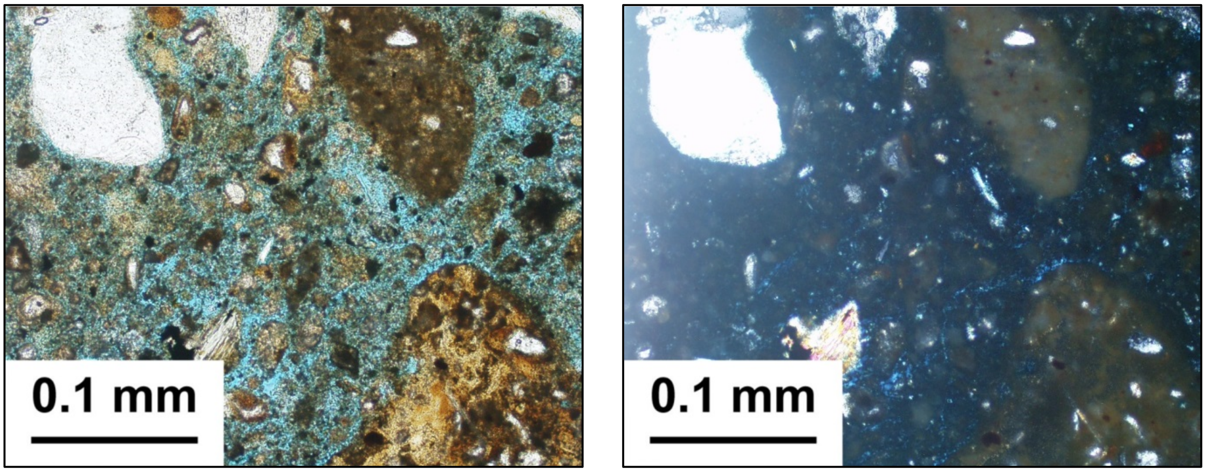


Figure 114: Rim of poorly hydrated cement paste around the diabase aggregate seen in Figs. 103 and 105. NC sample TM4.3A2 (1873/4), PPL (Left) and XPL (right)

If enough of these weathered pieces of aggregate were used, they could have made an already dry mix become a little drier and a little less workable. Furthermore, this weathered appearance, as well as the rounded largely unbroken shapes may indicate that the aggregate used in the 1870s concrete can from a natural gravel deposit.

The coarse aggregate identified in the samples taken from the Endicott Batteries (1891-1905) generally fall within two main types. In the natural cement concrete of Batteries Sumner and Graham (1891-1897), a foliated coarse-grained metamorphic rock was primarily used that was a variety of gneiss and schist, possibly from boulders found on site or possibly imported from the nearby Bronx. However, no diabase aggregate was identified in any of the concrete samples collected from these structures, but this changed with the later structures built with portland cement concrete. For Batteries Mahan and Stuart (1897-1903) along with the southern extensions to the Upper Endicotts (1902-1905) diabase was the predominant aggregate, although these were smaller, more angular, and 'platey' in appearance than those found in the Torpedo Magazines. This suggests that the diabase aggregate used in the portland cement concrete fortifications was crushed. It has already been mentioned that current PCA guidelines stated that such 'platey' aggregate will require more water in the concrete mix for it to have the same plasticity, compared with a mix using more rounded aggregate. Therefore it may not be a coincidence that the portland cement concrete samples examined form Fort Totten all had a higher W/C ratio than the natural cement concrete samples.

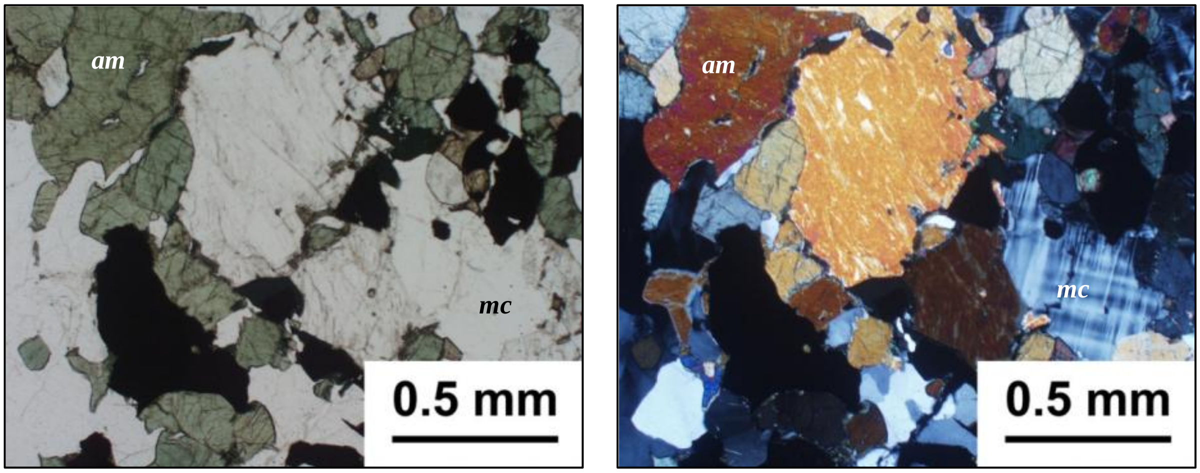


Figure 115: Gneiss aggregate, identified amphibole (am) and microcline (mc), from NC sample S2U-1A (1896-98), PPL (Left) and XPL (right)

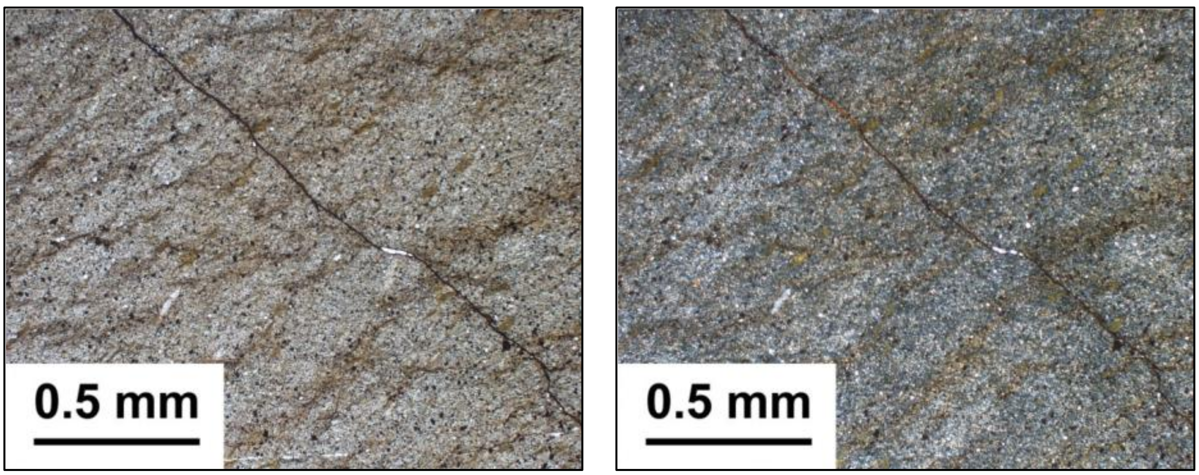


Figure 116: Siltstone aggregate, from NC sample G2U-2B (1892-1897), PPL (Left) and XPL (right)

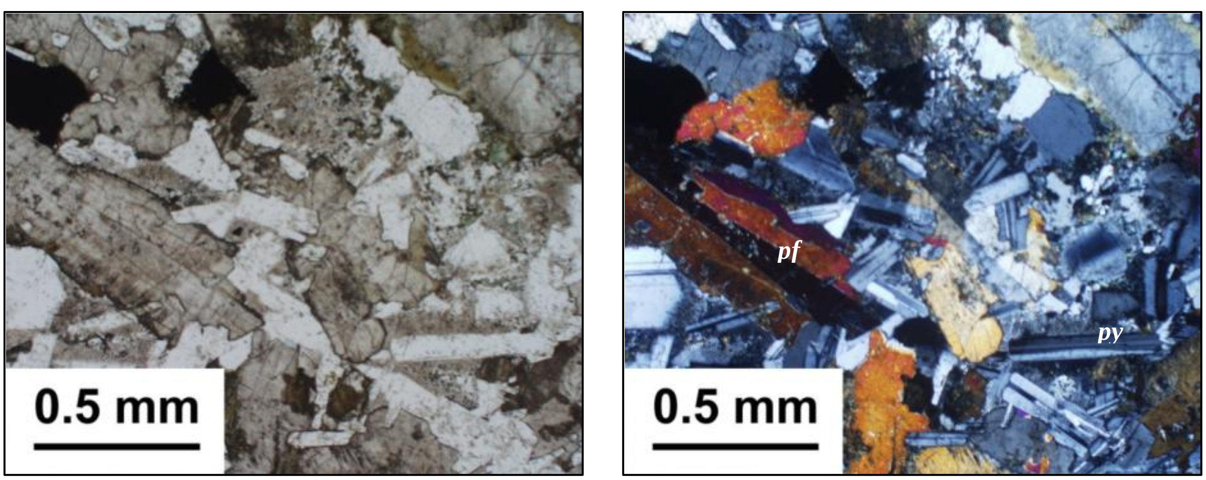


Figure 117: Diabase aggregate, from PC sample M2U-4B (1898-1900), PPL (Left) and XPL (right), identified from the component plagioclase feldspars (pf) and pyroxenes (py)

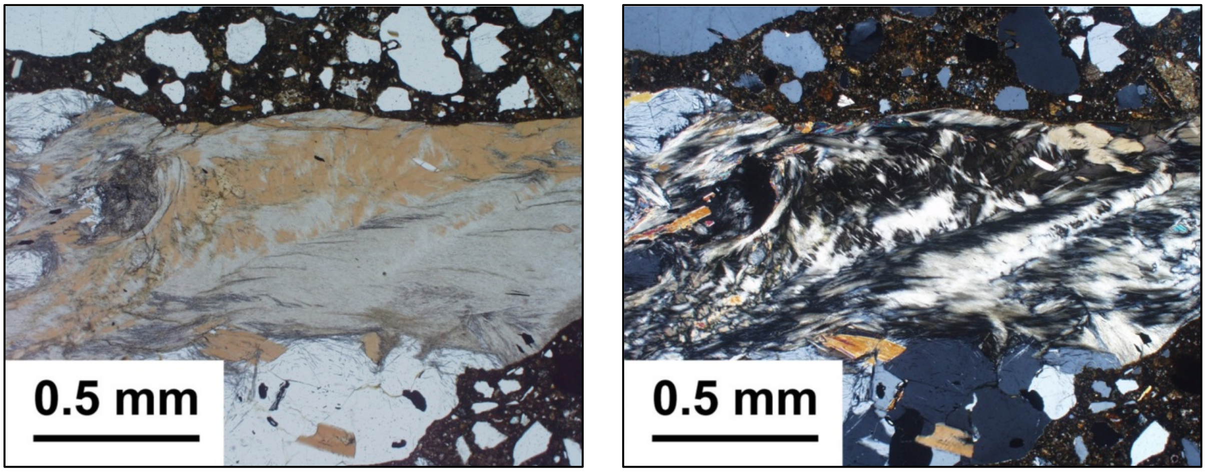


Figure 118: Piece of Sillimanite, probably from a schist aggregate, identified by its fibrous crystals, low birefringence, and yellow first order interference, from NC sample G1L-C2 (1892/98), PPL (Left) and XPL (right)

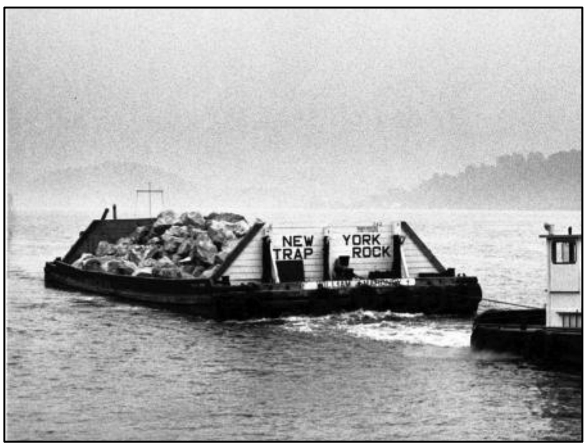


Figure 119: New York Trap Rock Co. barge, ca. 1950, (courtesy of the New York Public Library)

Figure 120: Steam shovel, Phoenix Sand and Gravel Company, Port Washington, N.Y., 1910 (courtesy of Port Washington Public Library)

The diabase aggregate almost certainly came from the nearby Palisades along the Hudson River in New Jersey and New York. Indeed diabase, or trap rock as it was more commonly known, was used extensively in concrete construction as aggregate in New York City from the late 19th century and into the 21st century.

Under the microscope it was possible to examine the fine aggregate or sands used in the concrete and, these were generally angular in appearance and were well coated with paste. Furthermore, the sand grains showed minimal point contact in two dimensions, although this could be different in three dimensions. The coarse and fine aggregate appeared to have been washed before it was mixed in the concrete, since there was a generally a minimal amount of very fine rock dust particles for the aggregates observed. Fine flakes of mica generated from schist aggregates were the most abundant, while there were minimal fines from the diabase aggregate visible. Additionally, while there was no obvious organic matter visible in the matrix, it would not be possible to observe any finer dispersed material or clays under the microscope.

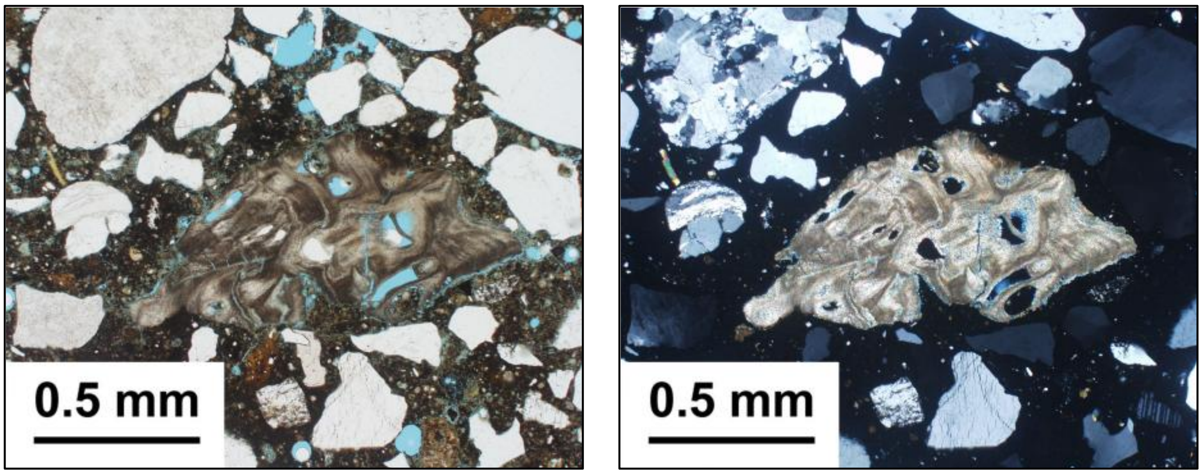


Figure 121: A fragment of shell, probably from a mollusk, from NC sample TM8.1 (1875/76), PPL (Left) and XPL (right)

There was little differentiation in the types fine aggregate used at Fort Totten, being primarily composed of quartz, with some grains of hematite, biotite, feldspar, schist, siltstone, garnet, staurolite, amphibole, tourmaline, zircon along with a general assemblage of phases typical of basement rock. Therefore it would be difficult to assign a particular source for the sand as the material is too common. Historically, much of the sand used in construction in New York came from the nearby Port Washington area of Long Island, although other sources were certainly available at the time. In addition, sand could also have been produced from blasting and crushing rock, which would appear sharper and more angular than natural beach sand that would have a more rounded, eroded appearance. In one of the samples (TM8.1) a shell fragment, possible from a mollusk, was found in the fine aggregate.

5.5.6 Deterioration

Generally, for concrete structures that are well over 100 years old, the concrete samples collected from Fort Totten were in pretty good shape, especially the fortifications built in the 1870s out of natural cement concrete. As detailed in Section 4.3 above, much of the noticeable deterioration could be linked to subsidence, a structural design flaw, expansive rusting of reinforcing rods, freeze/thaw damage, or a problem with the mix design.

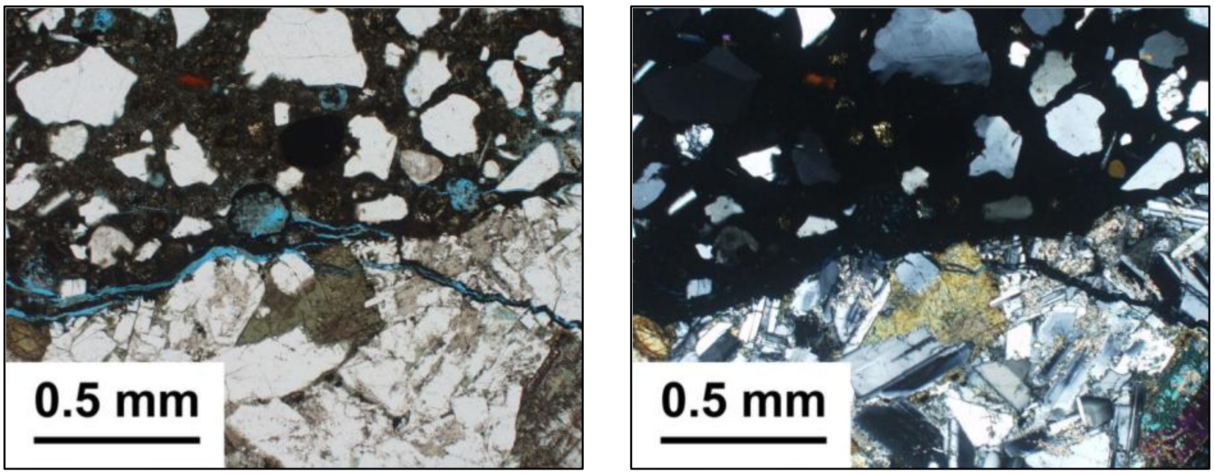


Figure 122: Tight pervasive parallel cracking indicative of freeze thaw damage, from PC sample M1L-1A (1903-1905), PPL (Left) and XPL (right)

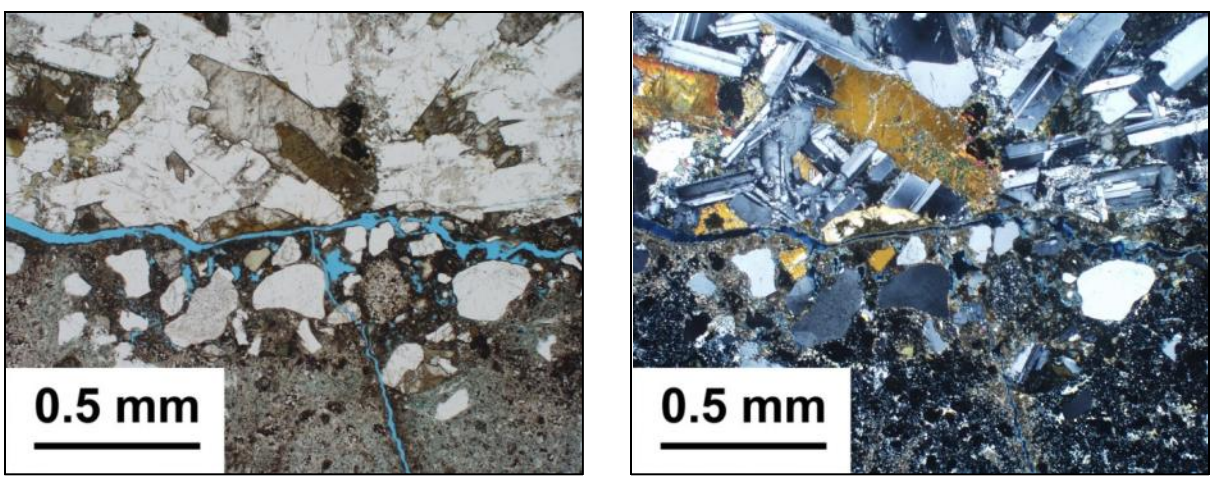


Figure 123:Cracking along the grain, from PC sample M2U-2A (1903-1905), PPL (Left) and XPL (right)

Of particular interest were the poured concrete lift boundaries that were captured in two core samples collected from Battery Sumner in natural cement (S1U-C2, 1891-97) and Battery Mahan in portland cement (M1U-CA, 1898-1900).[164] In the Battery Sumner sample, the lift boundary was quite tight compared to the lift boundary in the Battery Mahan sample, which separated during sample preparation, which suggests a difference in the mechanical bonding of the two concrete lifts. As noted in Section 4.3 above, this boundary was effectively a cold joint that was subject to water infiltration and the opening of the horizontal lift joints via frost wedging or changes in water pressure due to freeze/thaw. This could also result in lateral movement in the individual slabs as seen so spectacularly near the join between the parapet and traverse of the portland cement concrete built Battery Mahan 1 (1897-1900) discussed in Section 4.3.

Thin sections were prepared from both samples and were examined using polarized light microscopy. Both samples showed evidence of water movement along the lift boundary but with very different effects. In Battery Sumner (1891-1897), the lift boundary allowed water containing dissolved carbon dioxide to move through the natural cement concrete and create carbonated areas far deeper into the interior.

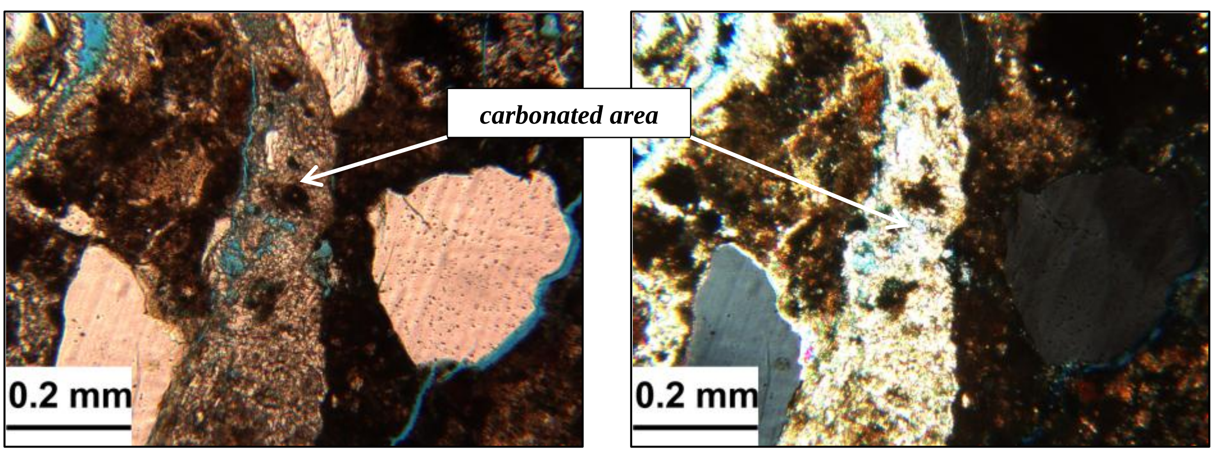


Figure 124: Lift Boundary from NC sample S1U-C2 (1891-97) showing areas of carbonation, PPL (Left) and XPL (right)

[164] Lift boundaries in natural cement concrete of the Torpedo Magazines were difficult to identify, as discussed above in Section 4.2

While calcium hydroxide is far more soluble, the Battery Sumner sample also contained evidence of calcium carbonate that had precipitated through the lift boundary. Where it recrystallized, it virtually replaced the cement paste that itself dissolved and mobilized elsewhere. The calcite crystals formed, enclosed and secured the sand grains, acting as a new binder in the concrete matrix. This could explain why the lift boundary was so strong.

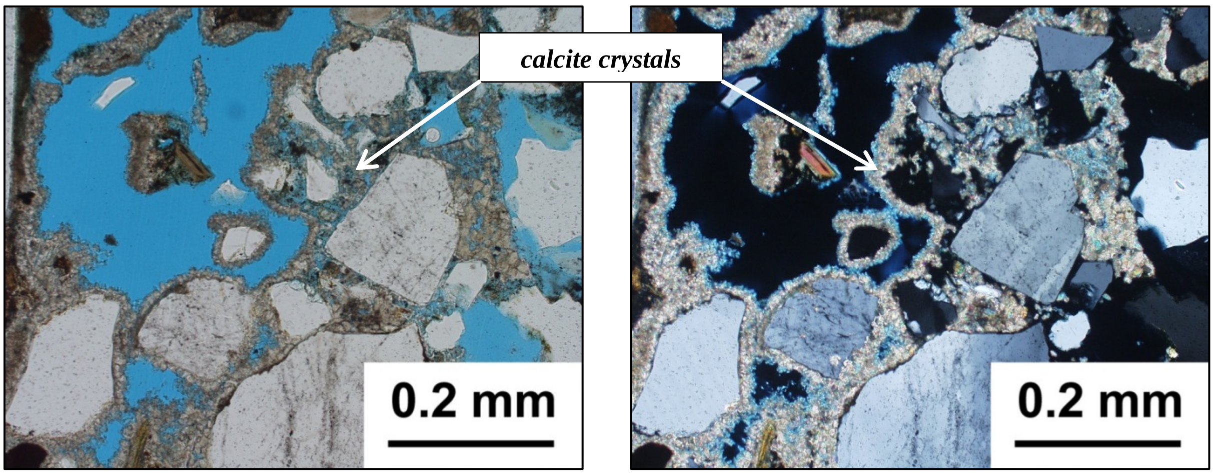


Figure 125: Precipitated calcite crystals along the lift boundary of NC sample S1UC.2 (1881-97), PPL (Left) and XPL (right)

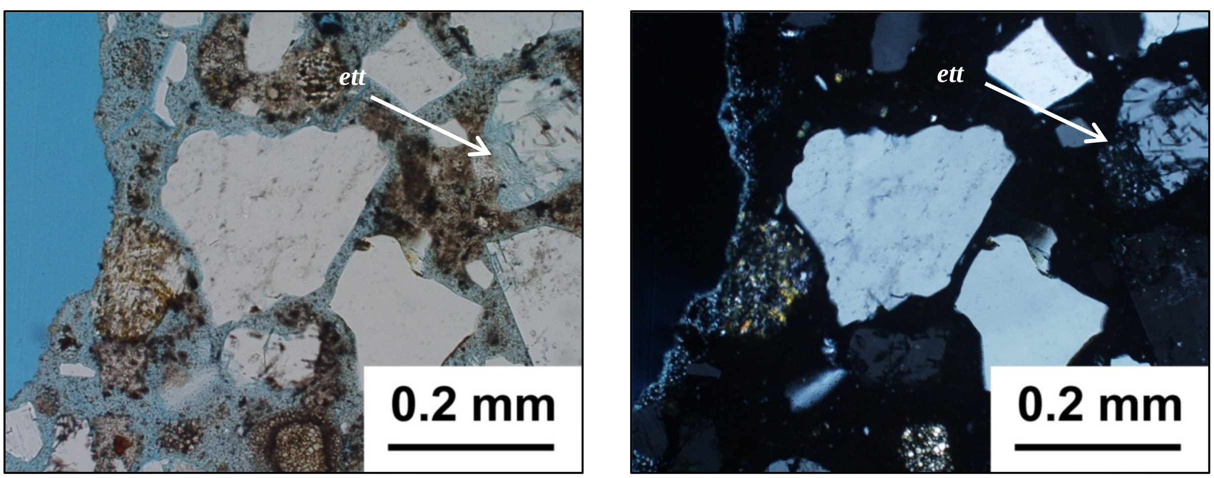


Figure 126: Depleted calcium hydroxide along the lift boundary of PC sample M1U.C (1898-1900), PPL (Left) and XPL (right)

In the Battery Mahan sample, however, the calcium hydroxide in the paste along the lift boundary had been depleted, but there was no evidence of any carbonation. Here the solubility of the calcium hydroxide had cause it to be leeched and mobilized into the cracks and voids to be precipitated as ettringite

Alkali Silica Reaction (ASR) is a reaction of the alkaline cement paste with the siliceous aggregate, converting it to a viscous alkali silicate gel. It is a very slow reaction and can take decades to manifest. If the gel comes into contact with water penetrating into the concrete, it will expand and cause cracking through the aggregate as well as the surround paste. While all silica will eventually react this way, some silica is more reactive than others, and the strained quartz river gravel in the New York area falls into the latter category. However, while this gravel is present in the concrete used at Fort Totten, there is very little evidence of ASR. Only one possible instance may have been found, although it was so small that its effect on the concrete as a whole was negligible. This was found in a sample of concrete from Battery Sumner which contained a portland cement repair in a natural cement concrete structure (S2U-1B, ca. 1897-1900). However, the ASR appears to have originated from a piece of aggregate within the natural cement concrete portion of the sample. Very little research has been completed on the effects of ASR on natural cement, so it is unknown whether it was ever a problem as has been documented with many early 20th century portland cement concrete structures.

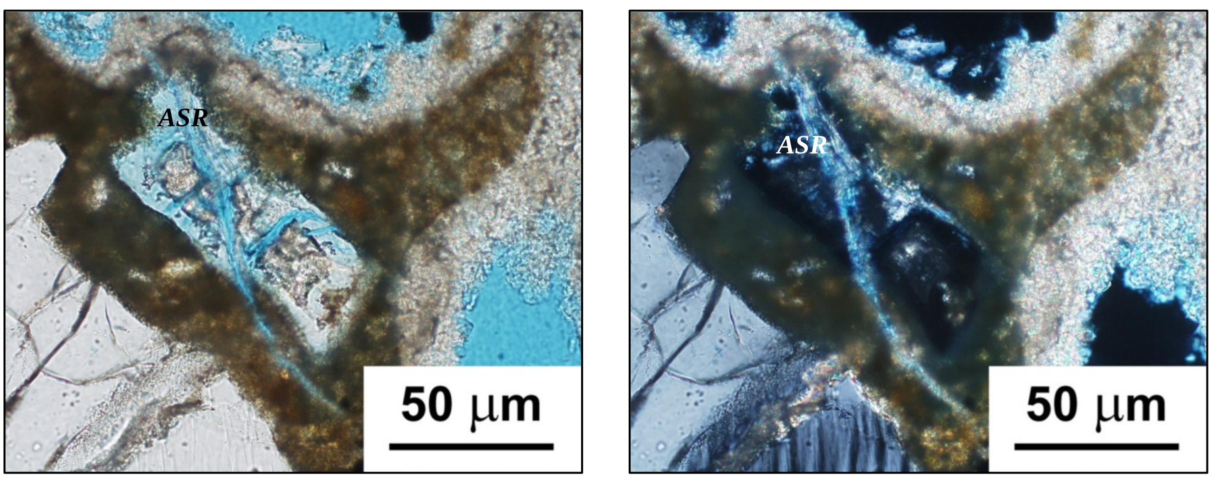


Figure 127: Possible ASR, from NC sample S2U-1B (1896-98), PPL (Left) and XPL (right)

In all of the samples examined under thin-section, there was no evidence of other deterioration issues, such as Alkai-Carbonate Reaction, although this is probably due to the lack of carbonate aggregate used in the concrete produced at Fort Totten.

6. Conclusions

The late 19th century witnessed a marketing battle between the American natural and portland cement manufacturers that at times was downright vicious. Certain contemporary writers incorporated a near evangelical fervor that seems strange by today's standards, but as several of these persons had a vested commercial interest in their preferred product, it was not surprising. For example, Uriah Cummings, a respected member of the US Army Corps of Engineers who had several decades of experience working with masonry and concrete construction, would write of natural cement:

> *"This is indeed a wonderful record, and it is but the culmination of four thousand years of successful usage of Rock cements. It is the refutation of all the baseless theories, false reasoning, and untenable analogies which have been evolved from the high short time tests of portland brands. This marvelous record is the final justification of American Rock cements, which, setting slowly at first, nevertheless, owing to their smooth and pasty consistency and greater volume per pound, attain in time a stone-like durability impossible to the brittle, quicksetting, and glassy portlands. The latter are an experiment begun seventy-three years ago, and the history of it is strewn with failures. The former have been made through centuries which disclose no recorded failure, and time but adds to the proof of merit. If long experience is to be a guide, the conclusion is irresistible that for substantially all the manifold purposes for which a cement is used, none has yet been produced equal to the AMERICAN ROCK CEMENTS."*[165]

However, this passage takes on a new meaning knowing Cummings also owned a natural cement plant in Akron, NY (the Cummings Cement Works). Furthermore, Cummings was writing at a time when the American natural cement industry was facing a serious and ultimately overwhelming challenge from domestically produced portland cement.

The rhetoric continued even after domestic portland cement came to dominate the US market. F. H. Doremus would write two articles in 1903 and 1904 on the decline and the 'decadence' of natural cement concrete:

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[165] Cummings, (1898) p. 299

“So it is that we see the sturdy old industry of natural cement making failing and dying, because like Antaeus, son of Earth, it has been compelled to wrestle for supremacy on a plane too far above its native level. And Portland, a Hercules born of man’s indomitable ingenuity, holds out to posterity benefits beyond all reckoning.”[166]

"The old order changeth, yielding to the new," and the once great commodity -a giant whose hand has held compact and firm the walls of sea and land for many a year-is doomed to downfall. And Portland, sprung from the ingenious mind of man-a Pallas fully armed, mighty, and responsive to the mystic call of a century that hints of signs and wonders-reigns in its stead.” [167]

However, natural cement was not without its benefits and in a 1941 *Popular Science* article, Walter Holbrook noted the greater durability of the older natural cement structures compared with those made with portland cement.[168] He cited a blended natural/portland cement mix developed by the engineer, Bertrand H. Wait that combined the durability of natural cement and the greater ultimate strength of portland cement that was used for road building. However this brief resurgence was fleeting and the natural cement industry stumbled on until the last Rosendale natural cement works closed in 1970.

In the last few decades, historic preservationists have shown a greater interest in using natural cement as replacement mortars for historic masonry construction. Furthermore, academic research into natural cement was rekindled and the first American Natural Cement Conference was held in Rosendale, NY in March, 2005. Two further conferences were held and ASTM compiled a journal of academic papers on natural cement in 2008. Across the Atlantic, the European Union has been funding the ROCEM Project (ROman CEMent to restore built heritage effectively) to address both the loss of contemporary technology and the

[166] Doremus, Frank H., (1903) ‘The Passing of Natural-Rock Cement’ in *The American Architect*, Vol. 79, No. 1422, March 28, 1903, p. 99-100
[167] Doremus, Frank H., (1904) ‘The Decline of Natural-Rock Cement’ in *Architects' and Builders' Magazine*, Vol. V, October 1903-1904, p. 151-153
[168] Holbrook, Walter, (1941) "Natural Cement Comes Back", in *Popular Science*, Vol. 139, No. 4, October 1941, p. 117-120

lack of suitable materials.[169] Therefore, the bias against natural cement is slowly being addressed and a greater appreciation of this much maligned material is being promoted.

This thesis has shown that there is no evidence to support the allegations of Lawry and Winslow that there was an inherent defect in the natural cement concrete used by the US Army Corps of Engineers to build their fortifications in the late 19th century. Indeed it is difficult to compare the two types cement concrete used in the various structures built at Fort Totten between 1863 and 1905, since concrete technology was constantly evolving. It was not until the early 20th century that the Corps had finally developed a concrete mix that would be recognizable by modern standards. However, by that time, the Corps was no longer using natural cement at Fort Totten, having switched to portland cement in 1898 to build Batteries Mahan, Stuart, Baker, and Burnes.

The first natural cement concrete mixes used at the Water Battery at Fort Totten were little more than coarse infill concrete without any of the sophistication shown in the later structures. However, the Water Battery was primarily a masonry structure and the concrete was only used to fill in cavities between the granite stones. This natural cement concrete served its limited purpose well for 150 years, and what it may have lacked in complexity it made up in tenacity and durability.

The 1870s natural cement concrete structures of the Main Magazine, the Tunnel, the Torpedo Magazines, along with the remaining barbette-battery magazines were a significant development in concrete construction technology. Their design was certainly inspired by masonry construction, largely because these were the types of structural forms that the engineers knew how to build. However, masonry structures were now redundant in the face of advances in armament, and so the Corps experimented with purpose-built poured-in-place structures out of a material that they only had a basic understanding of, but which had already been used in the UK and Canada with great promise. Their concrete mixes were generally dry by modern standards; they had moderate plasticity; and could include overly large pieces of weathered aggregate. While we can easily criticize these early concrete mix

[169] Hughes, David, Swann, Simon, and Gardner, Alan (2007b) "Part Two: Stucco and Decorative Elements, a Conservation Strategy", *Journal of Architectural Conservation*, Nov., v.13, n.3, p.41-58

designs, it should be remembered that in 1870, the Corps had no real specifications to draw on and the ASTM standard was decades away from being written. It is easy to imagine the engineers working at Fort Totten tinkering with their mix designs and noting what batches were particularly effective. While they were certainly at the forefront of military research and development, with the Engineering School of Application and the Essayons Club at Fort Totten, they were not conducting scientific concrete testing. This remained the purview of the Watertown Arsenal in Boston, MA, whose research would lay the foundations of ASTM.

By the Endicott period (1891-1900), the design of the concrete fortifications grew more sophisticated. These structures included more complex exterior and interior shapes that were also more open and exposed to the elements than the covered magazines and tunnels built in the 1870s. There was also a similar development in the natural cement concrete used in their construction. The large voids and large coarse aggregate observed in the concrete mixes used for the Torpedo Magazines are not evident in the concrete samples collected from Batteries Sumner and Graham. Furthermore, the mix design had improved with a better aggregate gradation and a slightly improved water/cement ratio, although by modern standards it would still be considered a dry mix.

By the time the Corps switched to portland cement concrete construction with Battery Mahan in 1898, the water/cement ratio had improved further, as seen from the polarized light microscopy, but this was still not a wet mix by modern standards. Arguably, however, it was this particular structure that experienced the greatest deterioration out of any of the concrete fortifications built at Fort Totten. At Battery Mahan the cold joints created by the different placements of concrete did not adhere as well as those in the other structures, which resulted in a greater degree of water infiltration along these lift boundaries. This caused significant calcite deposition, surface spalling, lateral movement of concrete slabs, and frost jacking. This was especially pronounced in the upper east corner of the traverse in Battery Mahan 1. Perhaps this may be attributed to the engineer's uncertainty in using the portland cement, and these problems are not as evident in Batteries Mahan 2, Stuart, Baker, or Burnes.

The development and use of reinforced concrete at Fort Totten in the early 20th century was almost symbolic. Doremus alluded to the main reason for the decline of the natural cement industry, which was that it could not cope with the needs of the 'Concrete

Steel Age'. The natural cement concrete used at Fort Totten was not workable enough to be poured around the reinforcement to create the slender structures characteristic of reinforced concrete. Furthermore, the strength achieved in 28 days by portland cement was one third of the time required by natural cement concrete for the same rating, so portland cement structures could be built much more quickly.

On the whole, the natural cement concrete fortifications at Fort Totten have performed admirably, and in many respects better than the portland cement concrete fortifications. Much of the deterioration has less to do with the type of cement used in the concrete, and more to do with the prevailing site conditions, the encroachment of vegetation and a general lack of maintenance since the closure of the army base in 1967. Indeed maintenance was listed as a primary problem by the Corps as far back as the 1890s. However, the design of the fortifications were also important, and the natural cement concrete was particularly suitable to the subterranean poured-in-place concrete structures of the 1870s as these are arguably in the best condition although they were built with relatively unsophisticated concrete mixes.

The deterioration experienced in the Endicotts was more pronounced but these fortifications had more complicated and open designs, and were far more exposed to the coastal environment of Willets Point. Furthermore, it should be noted that the Corp had far greater experience working with natural cement concrete than with portland cement concrete. Consequently, it is perhaps not surprising that there were some initial problems with their first portland cement concrete battery, but these seem to have been dealt with their subsequent portland cement concrete fortifications. In all, the concrete used by the Corps at Fort Totten, and elsewhere, generally exhibited a high degree of competency for the materials that were available as well as their understanding of concrete technology.

6.1 Further Research

At the start of this project I was told that I would not be able to complete everything that I had proposed. Even after paring down my original objectives, the majority of my work provoked additional avenues of future research. There is much more to learn from these types of early concrete structures, to see how well they have fared, since most modern construction is only expected to last for a generation before it is torn down and a new structure is built. One area of future research would be to examine the permeability of the concrete used to build the fortifications at Fort Totten. It would be interesting to see whether water is directed along specific boundaries, such as the cold joints between concrete lifts, or whether it was able to leech through to adjacent areas and saturate them. Furthermore, would it be possible to test for differences in deterioration caused by frost wedging or changes in water pressure in the concrete mass caused by freeze/thaw?

Further research could also incorporate all extant concrete structures built during the 1870s, including the Main Magazine, the Tunnel and the remaining magazines of the barbette-batteries. It would be interesting to chart the technological development of natural cement concrete from 1869-1876, examining changes in the mix along with differences in deterioration between the massive subterranean structures and the smaller magazines built on top of the bluff in a more exposed area.

Further archival research could be conducted on the different brands of cement or the suppliers of the aggregate used in the construction of the concrete fortifications at Fort Totten. This may lie in the financial records of the Corps of Engineers. Related to this would be a more detailed geological analysis of Willets Point, to see if there were any exposed areas of bedrock, as there were at Throgs Point across the channel.

A final avenue of research could include the documentation of the historic graffiti along the Tunnel. This could be done using a high resolution 3D laser scan of the walls and then analyzing the carvings in the stucco to discern one set of graffito from the other. These then could be studied and transcribed to see if they could be linked to any of the personnel stationed on the site.

7. Appendices

7.1 Sampling

Note: Those highlighted in red measure 2 x 3 inches, and those highlighted in blue measure 27 x 46 mm.

Water Battery				 WB-1A	 WB-1B
Sumner 1 (Upper)				 S1U-2A	
Sumner 1 (Upper)				 S1U-1A	
Sumner 2 (Upper)				 S2U-1A	 S2U-1B
Graham 1 (Upper)				 G1U-5A	
Graham 1 (Lower)				 G1L-1A	
Graham 2 (Upper)				 G2U-2A	 G2U-2B
Mahan 1 (Upper)				 M1U-1B	

Mahan 1 (Lower)				 M1L-1A
Mahan 1 Lower				 M1L-5A
Mahan 1 Lower				 M1L-1/2A
Mahan 2 (Upper)				 M2U-2A
Mahan 2 (Upper)				 M2U-4B
Mahan 2 (Lower)				 M2L-1A
Stuart (Lower)				 STL-1B
Torpedo Magazine 4				 Core TM.4.1.A  Core TM.4.1.B  Core TM.4.1.C
Torpedo Magazine 4				 Core TM.4.3.A1  Core TM.4.3.A2  Core TM.4.3.B

Torpedo Magazine 8						
				Core TM.8.1		
Graham 1 Lower Core						
				Core G1L 1	Core G1L 2	
Mahan 1 Upper Core						
				Core M1U.A	Core M1U.B	Core M1U.C
Sumner 1 Upper Core						
				Core S1U.1	Core S1U.2	

7.2 Core Hole Remediation

Graham 1 Lower

Sumner 1 Upper

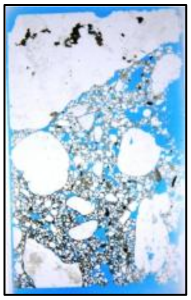
Mahan 1 Upper

Torpedo Magazine 4

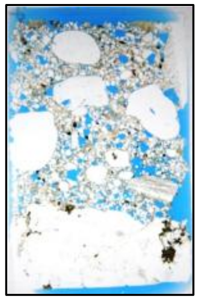
Torpedo Magazine 8

7.3 Thin Sections

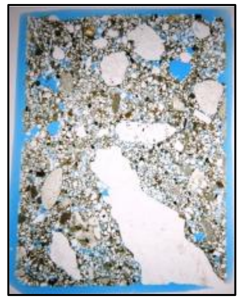
Thin sections photographed on a light box, please note the all images are oriented with exterior face pointing upwards.



WB-1A (27 x 46 mm)



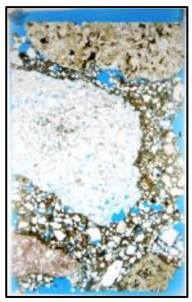
WB-1B (27 x 46 mm)



TM4.1.A (2 x 3 inch)

TM4.1.B (2 x 3 inch)

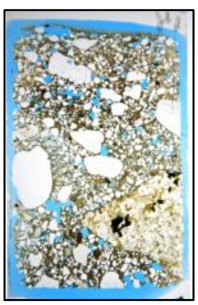
TM4.3.A2 (27 x 46 mm)



TM4.3.A1 (2 x 3 inch)

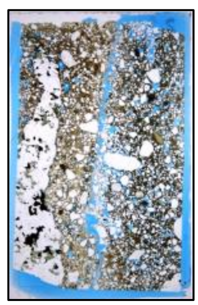
TM4.3.A2 (2 x 3 inch)

TM4.3.B (2 x 3 inch)

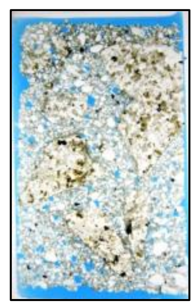


TM8.1A (27 x 46 mm)

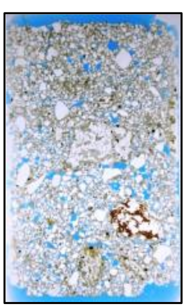
S1U.C1 (2 x 3 inch)



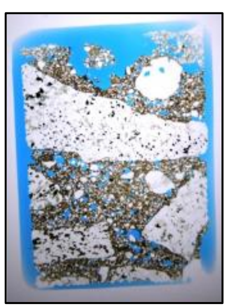
S1U.C2 (27 x 46 mm)



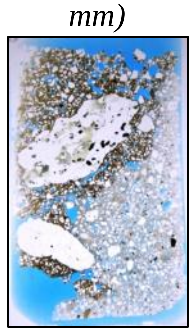
S1U-1A (27 x 46 mm)



S1U-2A (27 x 46 mm)

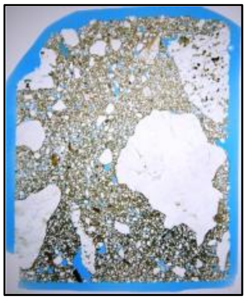


S2U-1A (2 x 3 inch)

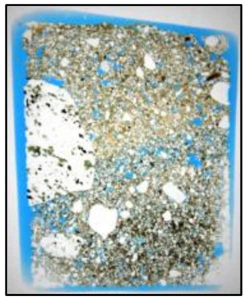


S2U-1B (27 x 46 mm)

G1L-C1 (2 x 3 inch)



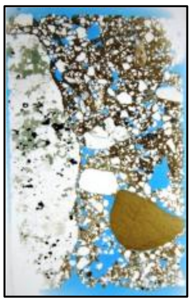
G1L-C2 (2 x 3 inch)



G1L-1A (2 x 3 inch)

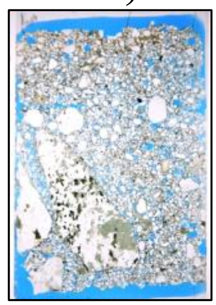
G1U-5A (27 x 46 mm)

G2U-2A (2 x 3 inch)

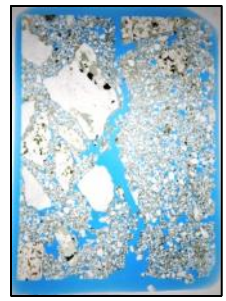


G2U-2B (27 x 46 mm)

M1U.C1 (2 x 3 inch)



M1U.C2 (27 x 46 mm)



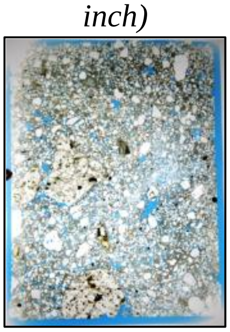
M1U.C3(2 x 3 inch)

M1L-1/2A (2 x 3 inch)

M1L-1A (2 x 3 inch)

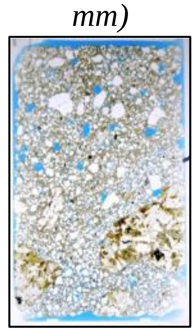
M1L-5A (27 x 46 mm)

M1U-1B (2 x 3 inch)



M2L-1A (2 x 3 inch)

M2U-2A (2 x 3 inch)



M2U-4B (27 x 46 mm)

STL-1B (27 x 46 mm)

7.4 Thin Sections Analysis Summary

Sample	Sample Type	Thin Section	Location	Date of Construction	Gradation Size No.	Binder	Coarse aggregate	Fine Aggregate	Deterioration	Porosity	Paste	Voids & Cracks
TM4.1.A	Core	large	side wall	1873	3	NC	shist/gneiss, diabase	quartz, hematite, shist, biotite, sandstone	None	Moderately low capillary porosity	moderately dense, some vacant paste, moderate to low W/C ratio, secondary carbonation near surface	no major voids/cracks
TM4.1.B	Core	large	side wall	1873	3	NC	shist/gneiss, diabase	quartz, hematite, shist, biotite	None	Moderately low capillary porosity	moderately dense, some vacant paste, moderate to low W/C ratio, secondary carbonation near surface	no major voids/cracks
TM4.1.C	Core	small	side wall	1873	3	NC	shist/gneiss, diabase	quartz, hematite, shist, biotite	None	Moderately low capillary porosity	moderately dense, some vacant paste, moderate to low W/C ratio, secondary carbonation near surface	no major voids/cracks
TM4.3 A1	Core	large	side wall	1873	3	NC	shist/gneiss, diabase	quartz, hematite, shist, biotite	cracking around void space	Moderately low capillary porosity	moderately dense, some vacant paste, moderate to low W/C ratio, secondary carbonation near surface	some voids
TM4.3 A2	Core	small	side wall	1873	3	NC	shist/gneiss, diabase	quartz, hematite, shist, biotite	cracking around void space	Moderately low capillary porosity	moderately dense, some vacant paste, moderate to low W/C ratio, secondary carbonation near surface	some voids
TM4.3 B	Core	small	side wall	1873	3	NC	shist/gneiss, diabase	quartz, hematite, shist, biotite	cracking around void space	Moderately low capillary porosity	moderately dense, some vacant paste, moderate to low W/C ratio, secondary carbonation near surface	some voids
TM8.1	Core	small	side wall	1875/76	1	NC	shist/gneiss, diabase	quartz, hematite, shist, biotite, shell	cracking around void space	Moderately low capillary porosity	moderately dense, not much vacant paste, moderate to low W/C ratio, secondary carbonation near surface	major voids
S1U.C1	Core	large	upper front traverse	1891-1897	5	NC	shist/gneiss	quartz, hematite, shist, biotite	None	Moderately low capillary porosity	moderately dense, not much vacant paste, moderate W/C ratio, secondary carbonation near surface	cold joint
S1U.C2	Core	small	upper front traverse	1891-1897	5	NC	shist/gneiss	quartz, hematite, shist, biotite	None	Moderately low capillary porosity	moderately dense, not much vacant paste, moderate W/C ratio, secondary carbonation near surface	cold joint
S1U-1A	Loose	small	top cap of parapet corner of traverse	1891-1897	6	PC	shist/gneiss	quartz, hematite, shist, biotite	None	Moderately low capillary porosity	moderately dense, not much vacant paste, moderate W/C ratio, secondary carbonation near surface	no major voids/cracks
S1U-2A	Loose	small	reinforced concrete beam of extension	1902-1905	6	PC	shist/gneiss	quartz, hematite, shist, biotite, silliminite	None	Moderately low capillary porosity	moderately dense, not much vacant paste, moderate W/C ratio, secondary carbonation near surface	no major voids/cracks
S2U-1A	Loose	large	back wall of parapet, area of repairs	1896-1898 (poss later patch)	6	NC	shist/gneiss	quartz, hematite, amphibole	minor cracking around coarse aggregate, filled in with CaCO3	Moderately low capillary porosity	moderatelly dense paste, moderately low W/C ratio	no major voids/cracks
S2U-1B	Loose	small	back wall of parapet, area of repairs	1896-1898 (poss later patch)	6	NC/PC	shist/gneiss	quartz, feldspar, siltstone, garnet	Aggregate cracking/crushing. some evidence of ASR, evidence of freeze/thaw, filled in with CaCO3	Moderately low capillary porosity	Possible PC repair to NC emplacement, ettringite formation at carbonation boundary, moderate low W/C ratio for NC, moderate W/C ratio for PC	no major voids/cracks

Sample	Sample Type	Thin Section	Location	Date of Construction	Gradation Size No.	Binder	Coarse aggregate	Fine Aggregate	Deterioration	Porosity	Paste	Voids & Cracks
G1L.C1	Core	large	lower side traverse stairwell	1892-1897	4	NC	shist/gneiss	quartz, hematite, amphibole	None	Moderately low capillary porosity, irregular pores	Moderately high dense paste, not much vacant paste, moderate low W/C ratio	no major voids/cracks
G1L.C2	Core	large	lower side traverse stairwell	1892-1897	4	NC	shist/gneiss	quartz, hematite, amphibole	None	Moderately low capillary porosity, irregular pores	Moderately high dense paste, not much vacant paste, moderate low W/C ratio	no major voids/cracks
G1L-1A	Loose	large	Gun Emp Foundations	1892-1897	6	NC	shist/gneiss	quartz, hematite, amphibole	None	Moderate high capillary porosity, medium sized irregular pores	Slag inclusion layer on surface (unlikely to be steel slag), ettringite formation at carbonation boundary, moderate low W/C ratio, moderate dense paste, some weak areas	no major voids/cracks in thin section, poor cement coverage in situ
G1U-5A	Loose	small	steps/platfor m	1902-1905	5	NC	Diabase/quartz	quartz, hematite, amphibole, garnet, siltstone, feldspar	None	Moderately low capillary porosity, irregular pores	Moderately high dense paste, not much vacant paste, moderate low W/C ratio	no major voids/cracks
G2U-2A	Loose	large	top cap of parapet corner of traverse	1892-1897	6	NC/PC	shist/gneiss	quartz, hematite, garnet, feldspar, biotite	None	Moderately low capillary porosity, irregular pores	thick layer of PC at surface (blast apron/waterproofing?), moderate W/C ratio, moderately dense paste	no major voids/cracks
G2U-2B	Loose	small	top cap of parapet corner of traverse	1892-1897	6	NC	shist/gneiss/silt stone	quartz, hematite, garnet, feldspar, biotite	minor cracking around coarse aggregate, filled in with CaCO3	Moderately capillary porosity, some irregular pores, lots of pores	secondary carbonation at top and bottom, moderate high W/C ratio	no major voids/cracks
M1U.C1	Core	large	upper side traverse	1898-1900	5	PC	Diabase	quartz, hematite, amphibole	None	Moderate capillary porosity, irregular and spherical pores of moderate abundance	well carbonated surface layer, ettringite near carbonated layer	cold joint
M1U.C2	Core	small	upper side traverse	1898-1900	5	PC	Diabase	quartz, hematite, amphibole	None	Moderate capillary porosity, irregular and spherical pores of moderate abundance	well carbonated surface layer, ettringite near carbonated layer	no major voids/cracks
M1U.C3	Core	large	upper side traverse	1898-1900	5	PC	Diabase	quartz, hematite, amphibole	None	Moderate capillary porosity, irregular and spherical pores of moderate abundance	well carbonated surface layer, ettringite near carbonated layer	cold joint
M1L-1A	Loose	large	Support column of reinforced concrete	1902-1905	6	PC	Diabase	quartz, hematite, amphibole	evidence of freeze/thaw, filled in with CaCO3	Moderate capillary porosity, some irregular pores, lots of spherical pores	moderate W/C ratio, ettrigingite formation at carbonation layer with silica condensed gel, moderately dense paste	no major voids/cracks
M1L-1/2A	Loose	large	Support column of reinforced concrete	1902-1905	6	PC	Diabase	quartz, hematite, amphibole	none	Moderate capillary porosity, some irregular pores, lots of pores	secondary carbonation at top and bottom, moderate W/C ratio, moderately dense paste	no major voids/cracks
M1L-5A	Loose	small	Support column of reinforced concrete	1902-1905	6	PC	Diabase	quartz, hematite, amphibole	minor cracking around and through coarse aggregate, filled in with CaCO3	Moderate capillary porosity, some irregular pores, lots of pores	secondary carbonation at top and bottom, moderate W/C ratio, Ettringite formation at carbonation boundary, moderately dense paste	no major voids/cracks

Sample	Sample Type	Thin Section	Location	Date of Construction	Gradation Size No.	Binder	Coarse aggregate	Fine Aggregate	Deterioration	Porosity	Paste	Voids & Cracks
M1U-1B	Loose	large	top cap of parapet corner of traverse	1898-1900	5	PC	Diabase	quartz, hematite, amphibole	minor cracking around and through coarse aggregate, filled in with CaCO3	Moderate capillary porosity, large irregular pores of moderate abundance	secondary carbonation at top and bottom, moderate W/C ratio, moderately dense paste	no major voids/cracks
M2L-1A	Loose	large	Window lintel	1902-1905	5	PC	Diabase	quartz, hematite, amphibole	None	Moderate capillary porosity, evidence of flocculation/entrainment	moderate to good paste density	no major voids/cracks
M2U-2A	Loose	large	reinforced concrete beam of extension	1902-1905	6	PC	Diabase	quartz, hematite, amphibole	minor cracking around and through coarse aggregate, filled in with CaCO3	Moderate capillary porosity, irregular and spherical pores of moderate abundance	top coating of almost neat PC (repair job?)	no major voids/cracks
M2U-4B	Loose	large	Interior room in traverse	1898-1900	6	PC	Diabase	quartz, hematite, amphibole	None	Moderate capillary porosity, irregular and spherical pores of moderate abundance	well carbonated surface layer, ettringite near carbonated layer	no major voids/cracks
STL-1B	Loose	Small	exterior corner of emplacement	1898-1900	6	PC	Diabase/siltstone	quartz, hematite, amphibole, feldspar	moderate cracking along grains	Moderate capillary porosity, irregular and spherical pores of moderate abundance	carbonated layers at surface and along cracking	no major voids/cracks
WB1A	Loose	Small	beton	1863/4	3	NC	Granite/strained quartzite gravel	quartz, hematitie, amphibole, garnet	None	large pore spaces, moderate capillary porosity	moderate W/C ratio	no major voids/cracks
WB1B	Loose	Small	beton	1863/4	3	NC	Granite/strained quartzite gravel	quartz, hematitie, amphibole, garnet	None	large pore spaces, moderate capillary porosity	moderate W/C ratio	no major voids/cracks

7.5 ASTM C33 Table 3: Gradation Requirements for Coarse Aggregates

TABLE 3 Grading Requirements for Coarse Aggregates

Size Number	Nominal Size (Sieves with Square Openings)	Amounts Finer than Each Laboratory Sieve (Square-Openings), Mass Percent													
		100 mm (4 in.)	90 mm (3½ in.)	75 mm (3 in.)	63 mm (2½ in.)	50 mm (2 in.)	37.5 mm (1½ in.)	25.0 mm (1 in.)	19.0 mm (¾ in.)	12.5 mm (½ in.)	9.5 mm (⅜ in.)	4.75 mm (No. 4)	2.36 mm (No. 8)	1.18 mm (No. 16)	300 µm (No.50)
1	90 to 37.5 mm (3½ to 1½ in.)	100	90 to 100	...	25 to 60	...	0 to 15	...	0 to 5	...	...	...	...	...	...
2	63 to 37.5 mm (2½ to 1½ in.)	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...	...
3	50 to 25.0 mm (2 to 1 in.)	...	...	...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	...	...
357	50 to 4.75 mm (2 in. to No. 4)	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	...	0 to 5	...	...	...
4	37.5 to 19.0 mm (1½ to ¾ in.)	...	...	...	...	100	90 to 100	20 to 55	0 to 15	...	0 to 5	...	...	...	...
467	37.5 to 4.75 mm (1½ in. to No. 4)	...	...	...	...	100	95 to 100	...	35 to 70	...	10 to 30	0 to 5	...	...	...
5	25.0 to 12.5 mm (1 to ½ in.)	...	...	...	...	...	100	90 to 100	20 to 55	0 to 10	0 to 5	...	...	...	...
56	25.0 to 9.5 mm (1 to ⅜ in.)	...	...	...	...	...	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	...	...	...
57	25.0 to 4.75 mm (1 in. to No. 4)	...	...	...	...	...	100	95 to 100	...	25 to 60	...	0 to 10	0 to 5	...	...
6	19.0 to 9.5 mm (¾ to ⅜ in.)	...	...	...	...	...	...	100	90 to 100	20 to 55	0 to 15	0 to 5	...	...	...
67	19.0 to 4.75 mm (¾ in. to No. 4)	...	...	...	...	...	...	100	90 to 100	...	20 to 55	0 to 10	0 to 5	...	...
7	12.5 to 4.75 mm (½ in. to No. 4)	...	...	...	...	...	...	...	100	90 to 100	40 to 70	0 to 15	0 to 5	...	...
8	9.5 to 2.36 mm (⅜ in. to No. 8)	...	...	...	...	...	...	...	...	100	85 to 100	10 to 30	0 to 10	0 to 5	...
89	9.5 to 1.18 mm (⅜ in. to No. 16)	...	...	...	...	...	...	...	...	100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5
9[A]	4.75 to 1.18 mm (No. 4 to No. 16)	...	...	...	...	...	...	...	...	...	100	85 to 100	10 to 40	0 to 10	0 to 5

[A] Size number 9 aggregate is defined in Terminology C125 as a fine aggregate. It is included as a coarse aggregate when it is combined with a size number 8 material to create a size number 89, which is a coarse aggregate as defined by Terminology C125.

7.6 Mixing Concrete at Fort Tompkins and Fort Richmond, Staten Island and Fort Warren in Boston, 1870 and 1871

Excerpt from Lt. Col. Q. A. Gillmore (1886) *Practical Treatise on Limes, Historic Cements, and Mortars*, New York, D. Van Nostrand, p. 226-228, containing a detailed methodology for mixing mortar and concrete at Forts Tompkins and Richmond on Staten Island and Fort Warren in Boston (p. 202-205).Lt. Wright in Boston reported:

“The concrete was prepared by: first spreading out the gravel on a platform of rough boards, in a layer from eight to twelve inches thick, the smaller pebbles at the bottom and the larger on the top, and afterwards spreading the mortar over it as uniformly as possible. The materials were then mixed by four men, two with shovels and two with hoes, the former facing each other, and always working from the outside of the heap to the center, then stepping back ; and recommencing in the same way, and thus continuing the operation until the whole mass was turned. The men with hoes worked, each in conjunction with a shoveller, and were required to rub well into the mortar, each shovelful, as it was turned and spread, or rather scattered on the platform by a jerking motion. The heap was turned over a second time in the same manner, but in the opposite direction, and the ingredients were thus thoroughly incorporated, the surface of every pebble being well covered with mortar. Two turnings usually sufficed to make the mixture complete, and the resulting mass of concrete was then ready for transportation to the foundation. The success of the operation, however, depends entirely upon the proper management of the hoe and shovel, and though this may be easily learned by the laborer, yet he seldom acquires it without the particular attention of the overseer."

Aggregate	granular material, such as sand, gravel, crushed stone, or iron blast-furnace slag, used with a cementing medium to form hydraulic-cement concrete or mortar.
Apron (Apron Slab)	1. Reinforced concrete or metal portion of superior slope of a parapet and the interior slope of as mortar pit designed to protect against blast. aka Blast Slope 2. That portion of the superior slope of a parapet and the interior slope of a pit designed to protect against blast
Barracks	A building to house troops
Barbette	A mound of earth or a platform on which guns are mounted to fire over a parapet.
Barrel	A unit of measure for cement, sand or aggregate. 1 barrel equals 3.8 ft^3
Battery	1. The entire structure erected for the emplacing, protection and service of one or more guns or mortars, together with the guns and mortars so protected. The guns of a battery are the same size and power, and are grouped with the object of concentrating their fire on a single target and of their being commanded directly by a single individual. Normally a battery of the primary armament consists of two guns or two pits of mortars. Under exceptional circumstances a single gun with its fire-control service may constitute a battery. In the case of intermediate and secondary armament a battery may consist of any number of guns assigned to it. 2. The entire structure erected for the emplacing, protection and service of one or more cannon.
Battery Parade	The place in the rear of the emplacements where the detachments form
Bastion	An angular structure projecting outward from the curtain wall of an artillery fortification
Bomb-proof	A term applied to military structures of such immense thickness and strength that shells cannot penetrate them
Beton	Concrete made in the French fashion
Caponiers	A covered walkway or counterscarp bastion
Casemate	An obsolete bombproof chamber, usually of masonry, in which cannon were placed to be fired through embrasures or portholes; or one capable of being used as a magazine.

Concrete	A composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate; in hydraulic-cement concrete, the binder is formed from a mixture of hydraulic cement and water.”
Counter Scarp	The opposite wall or side to a Scarp.
Emplacement	An opening with sides flaring outward in a wall or parapet of a fortification usually for allowing the firing of cannon.
Enfilade Fire	Fire which rakes a fighting line, the gun being on the prolongation of the line. In naval or fortress engagements fire delivered on the stern or bow of a ship so that the projectiles rake the whole length of the deck.
Gallery	Any passage covered overhead and at the sides.
Glacis	In field fortification a mound of earth which inclines from the front of the ditch toward the foreground, thus forcing the assailant to fully exposure to the fire from the parapet before reaching the ditch.
Gneiss	Durable metamorphic rock
Granolithic topping	Durable cement composed of cement and fine aggregate, usually granite that is used for paving or topping.
Gravel	Natural coarse aggregate sourced from unconsolidated deposits.
Hydraulic cement	Cement that sets through hydration rather than carbonation.
Laitance	An accumulation of fine particles on the surface of fresh concrete due to an upward movement of water
Lifts	A horizontal placement of concrete, usually between 6 and 12 inches in thickness.
Magazine	1. In a literal sense any place where stores are kept; as a military expression a magazine signifies rooms and galleries for the storage of powder, primers, fuses, etc. Magazines are classified as peace magazines and storage magazines. 2. The rooms and galleries for the storage of ammunition.
Mortar	A cannon employed to throw projectiles at high angles of elevation.
Natural cement	A hydraulic cement produced by calcining a naturally occurring argillaceous limestone at a temperature below the sintering point and then grinding to a fine powder
Parados	1. Earthworks in rear of a battery for protection against fire from the rear. It may have interior, superior, exterior and traverse slopes. 2. A structure in rear of the battery for protection against fire from the rear. It may have an interior, superior and exterior slope.

Parapet	1. That part of a battery, composed of earth, timber, stone, metal, etc, which give protection to the armament and personnel from front fire. 2. That part of the battery which gives protection to the armament and personnel from front file.
Pargetting	A decorative plastering applied to building walls.
Portland cement	A hydraulic cement produced by pulverizing clinker, consisting essentially of crystalline hydraulic calcium silicates, and usually containing one or more of the following: water, calcium sulfate, up to 5 % limestone, and processing additions
Render	A first thin coat of plaster applied to a surface
Revetment	A sloped structure formed to secure an area from artillery, bombing, or stored explosives
Rosendale cement	A natural cement produced from the Rondout Formation in Ulster County, NY
Salient angle	An interior angle of a polygon that is less than 180 degrees
Scarp	In field fortification the wall of the ditch adjacent to the parapet. It is always made at as large an angle as the nature of the soil will permit, the design being to offer the greatest possible obstacle to the assailant. The opposite wall or side is called the Counter-Scarp.
Spalling	A type of weathering which occurs in porous building materials, where dissolved salt or water is carried through the material and crystallizes or freezes near the surface as the water evaporates. As the salt or ice crystals expand this builds up shear stresses which break away spall from the surface.
Tier	A row or level of a structure, typically one of a series of rows placed one above the other
Traverse	1. In fortification, the structure perpendicular or oblique to the parapet wall, protecting the armament and personnel from flank fire. In gunnery, a term used to indicate the horizontal travel of the piece either to the right or left. 2. The structure perpendicular or oblique to the parapet wall, protecting the armament and personnel from flank fire.
Traverse magazine	A magazine built in a traverse
Vault	A roof in the form of an arch or a series of arches
Voussoirs	A wedge-shaped or tapered stone used to construct an arch.
Water/cement ratio	the ratio of the mass of water, exclusive only of that absorbed by the aggregates, to the mass of hydraulic cement in concrete, mortar, or grout, stated as a decimal.

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