Characterization of Historic Mortar:

Tucker Free Library
31 Western Avenue
Henniker, NH 03242

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Cover Photo: "Tucker Free Library", July 20, 2018, Tucker Free Library, Henniker, NH, accessed November 19, 2021, http://www.tuckerfreelibrary.org/wppg_photogallery/wppg_photo_details/?gallery_id=9&image_id=5608.

Section 1.0: Purpose Statement

The purpose of a basic acid digestion mortar analysis is to determine the approximate proportions of three principal components of historic mortars—aggregate, binder, and fines. Certain additives may also be detected via this method, but their proportions may not be accurately determined. A basic mortar analysis is primarily used to help ascertain general details about composition of a mortar for the purpose of recreating a historic blend or as a prelude to further instrumental analysis. Thus, this test is most useful for identifying whether cement, lime, and sand are present and in what quantities. Acid digestion can be an important part in developing plans for repairing and maintaining historic structures. For further information on methodology, please see Section 4.0.

However, while this test protocol is useful for distinguishing general characteristics associated with different binders, it is important to note that the test is subjective, based on the interpretation of data and physical properties, rather than unequivocal. Interpretation relies not only on the data produced while testing, but also on observed physical characteristics such as color, texture, hardness, cohesiveness, and visual properties of aggregate. Additional clarification on specific properties or additives of a mortar, such as additional pigments, modifying additives, cement type, or mineralogy, would require further instrumental analysis (X-Ray Diffraction, SEM-XEDS, petrography, and other tests) which can be arranged at a client's request for fees to be determined on a case-by-case basis. It is important to note that testing cannot determine several other important factors in mortar which are difficult or impossible to accurately ascertain, including original water mix, mixing and pointing method, rate of drying, or original condition/origin of aggregate.

Lime*Works*.us personnel conduct these analyses with care to produce accurate results to the greatest degree possible. However, it is up to the client to confer with owners, conservators, masons, and/or installers to determine material appropriateness, installation methods, and performance testing of recommended products beyond data provided by the manufacturer. Lime*Works*.us staff will use information gathered during this test to recommend a compatible material from our products and any additional steps or services if necessary or requested. These recommendations can be found in Section 3.0.

Section 1.1: Background

Two samples were submitted to Lime*Works*.us by Graham Pendlebury of Pendlebury Masonry. The samples were extracted from the Tucker Free Library in Henniker, NH. Both samples were extracted on October 19, 2021 from near the entrance to the structure on the north elevation with one sample from the brick joints, and the other from the limestone joints. Documents accompanying the sample indicate a joint size of 1/4" to 3/8".

The Tucker Free Library was built in 1904 and based on a variation of an 1884 pattern by architect Henry Martyn Francis, a noted designed of several other historic New England libraries. Built in Classical Revival style out of brick and granite with limestone detailing, the symmetrical T-shaped building was constructed following a generous donation by George Tucker, a former Henniker resident who maintained a love for his hometown and with no other heirs, left a substantial portion of his estate to the people of Henniker for the erection of a town library. After surveying other libraries of the region, the board of trustees for the new library employed the firm of H.M. Francis and Sons to design the structure, with the building contract awarded to Nashua Granite Co.

The library underwent many modifications over the years including two substantial expansions in 1969 and 1991, and at least one repointing campaign in 1989. Since the early 2000s, the library has undergone several additional restoration and refit campaigns, which continue to this day. While the building is not listed on the National Register of Historic Places, it was listed in the New Hampshire State Register of Historic Places in 2015.[1]

1 Lynn M. Piotrowicz and Anthony Mento A, Tucker Free Library Historic Building Report, report, SMP Architecture, Inc., August 11, 2020, accessed November 18, 2021, http://www.tuckerfreelibrary.org/library-stories-pictures/

Section 1.2: Executive Summary

Because of the amount of samples submitted, the full details of this report are lengthy. As such, this executive summary section has been prepared in order to summarize the relevant conclusions and recommendations. Reading the full detailed report is highly recommended to understand these conclusions and recommendations to ensure accuracy and agreement with the goals of the project before proceeding.

In this section, "Test Results" summarizes the data from the mortar analysis, "Mix Recommendations" summarizes the kind of mix the client should look for in a replacement mortar, and "Lime*Works*.us Products" lists the products available through Lime*Works*.us that meet or are analog to the recommendations. Mixes and products are to be considered substitutes for the historic mortar. If the historic mortar needs to be precisely replicated, additional testing according to ASTM C1324 would be required. It is the responsibility of the client to read this report in its entirety and, in consultation with stakeholders or other authorities, determine the suitability of recommended products. Color recommendations are based on submitted samples and may not reflect weathering conditions or variation present on the building. Mock ups are recommended to determine color suitability.

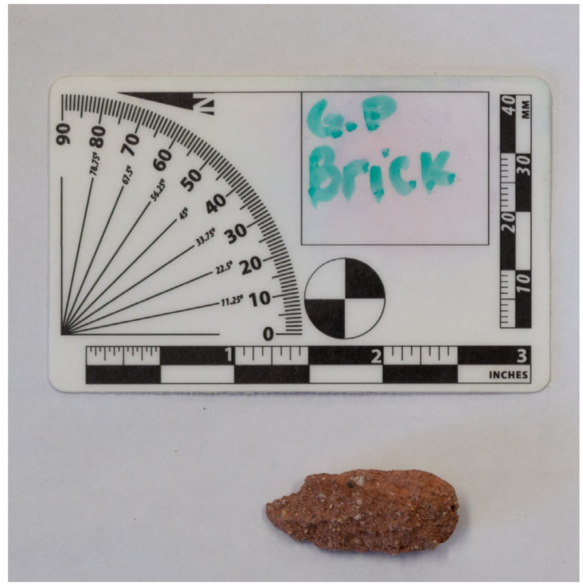
The two samples provided by the client were identified by their extraction locations as follows:

1. Brick: Taken from brick joints on the north elevation near the entrance
2. Limestone: Taken from limestone joints on the north elevation near the entrance

	Test Result	Mix Recommendation	Lime*Works*.us Products
Brick Sample	2 parts binder (cement and lime) to 5 parts fine aggregate by weight, with pigmentation added for color.	1 part NHL 3.5 to 2.5 parts fine aggregate with a majority of particles distributed on a bell-shaped curve from the #30 to #100 sieves. Pigment either with aggregate or UV and alkali stable pigment.	Ecologic Mortar SCG(F) Custom Simulation
Limestone Sample	Test inconclusive due to multiple phases of pointing present in submitted samples. However, oldest mortar is likely similar to Brick Sample, while newer mortar appears similar to a modern Type S.	Composition to match Brick Sample, color to match weathered face of Limestone Sample. 1 part NHL 3.5 to 2.5 parts fine aggregate with a majority of particles distributed on a bell-shaped curve from the #30 to #100 sieves. Pigment either with aggregate or UV and alkali stable pigment.	Ecologic Mortar SCG(F) in color blend 60% Non-Pigmented / 40% DGM Gray

Section 2.0a: Analytical Summary (Brick)

The reactive and physical characteristics of this mortar sample suggest it contains a binder based on a lime mixed with fine sand in a ratio of 2 part binder (cement and lime) and 5 parts fine aggregate by weight with pigmentation for color. This conclusion was based on the following observations:



Photograph of the weathered face of the bulk sample before digestion (fluorescent light, color corrected).

Sample Composition:

$CaCO_3$	~13.982%
$CaMg(CO_3)_2$	~5.725%
Solubles	~8.075%
Aggregate	~66.528%
Fines	~5.690%

Sample Observations:

- ***Layering:*** No layering was observed.
- ***Color:*** The weathered face of the bulk sample corresponded to 10R 5/6 *red*.
- ***Hardness:*** The sample was cohesive and hard with a Mohs rating of 9, requiring excessive force to pulverize with a mortar and pestle. This is consistent with a cement-containing mortar.
- ***Reactivity:*** The sample reacted vigorously with amble effervescence when exposed to a 14% dilution of hydrochloric acid. Mortars with high cement content tend to react less vigorously than mortars high in lime. Limes high in dolomite ($CaMg(CO_3)_2$) will have a secondary reaction after the primary calcium carbonate reaction ($CaCO_3$). Calcium carbonate, such as that found in lime mortars and calcareous aggregates, evolves a large amount of CO_2 when exposed to acid, while pure cement-based mortars release very little during acid digestion. This sample's reaction is consistent with a cement-lime mortar where lime is the dominant binder portion.
- ***Solubles*:** The moderate amount of solubles and high hardness suggest the presence of a cement but not as the sole binder. Products in cement are acid soluble but do not evolve CO_2 and so a mortar with low carbonate but high solubles indicates the probable presence of a cement. This sample is consistent with a cement-lime mortar.
- ***Aggregate:*** Aggregates extracted from the mortar were various shades of light red with an overall average color of 10R 7/3 *pale red*. The surviving aggregate fell just outside the modern mortar aggregate grading standards found in ASTM C144. Overall, this aggregate can be characterized as dull and fine. For more information on extracted aggregates please see Section 2.1.
- ***Fines:*** Fines extracted from the mortar were an average color of 10R 5/6 *red*. The fines appear to be a pigment added to give color to the mortar, though this test cannot fully characterize what kind of pigment was used.
- ***Other Notes:*** While the results of this test indicate the probable presence of cement, they cannot objectively conclude what kind of cement is present. While Portland cement is the most common kind of cement used during the period, natural cement was still available and used especially in New England. A test according to ASTM C1324 would be required to further characterize or confirm the components of this mortar.

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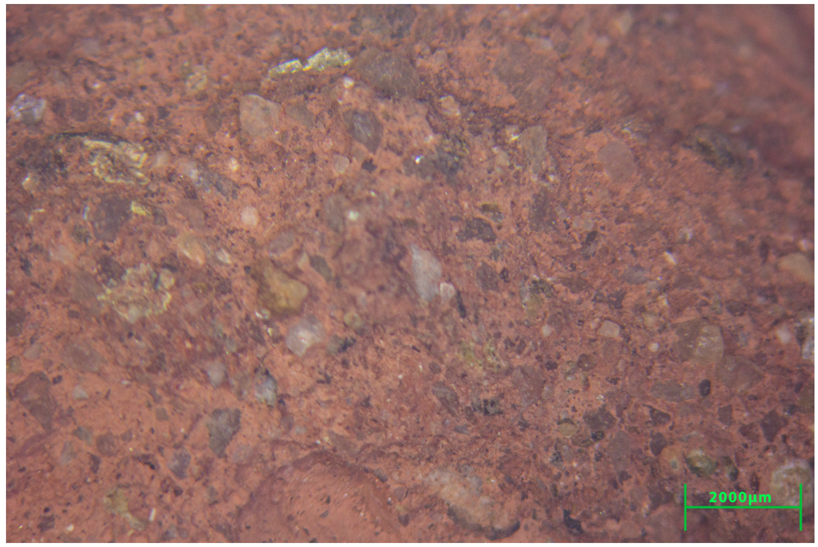
Section 2.1a: Characterization of Extracted Aggregate (Brick)

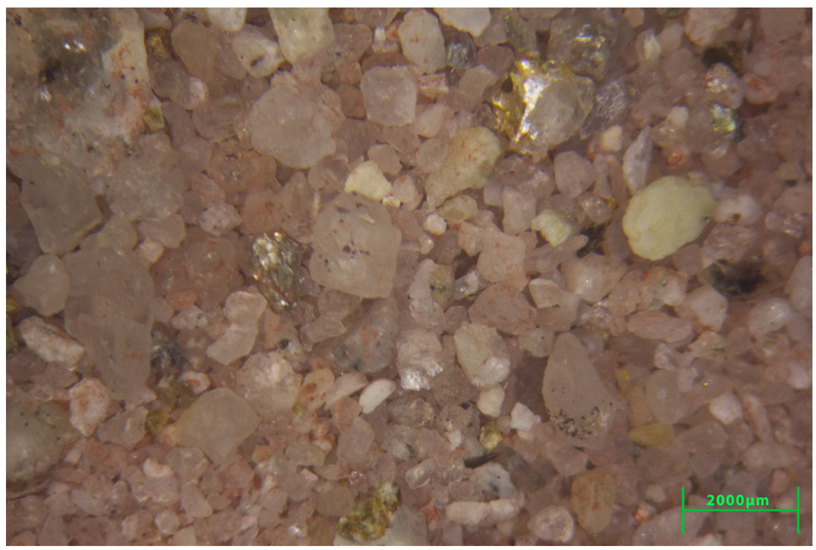
Because aggregate is an important portion of mortar, helping not only to determine material performance, but also in simulating historic color and texture, this mortar analysis includes a careful examination of aggregates extracted following the acid digestion of the sample. Analysis included a visual analysis and evaluation of particle size. This data can be used to both simulate a historic mortar and/or assess the potential properties imparted by an aggregate blend. It is important to note that certain portions potentially present in aggregate (such as crushed limestone, marble, and certain silicas) are fully or partially soluble in acid. These are included within a broad category of "solubles." Solubles would require further instrumental analysis to accurately characterize.

Individual grains of sand varied slightly in color but were consistently shades of *pale red*, with an overall average of 10R 7/3 *pale red*.

The aggregate particles varied widely in shape from very elongate to equant in sphericity, but had dull angularity ranging from subangular to rounded in roundness. Particles were captured on a bell-shaped range from the #8 to #200 sieves, with the most material on the #50 sieve. The fineness modulus of this aggregate was 1.822, indicating a moderately fine sand. The sand fell just outside ASTM C144's specifications for a coarse masonry sand, but this is not necessarily a problem for smaller joints. For detailed definitions of these terms, please see section 5.0.



Photomicrograph of the weathered face of the bulk sample before digestion (incident daylight-balanced light, 10x magnification).



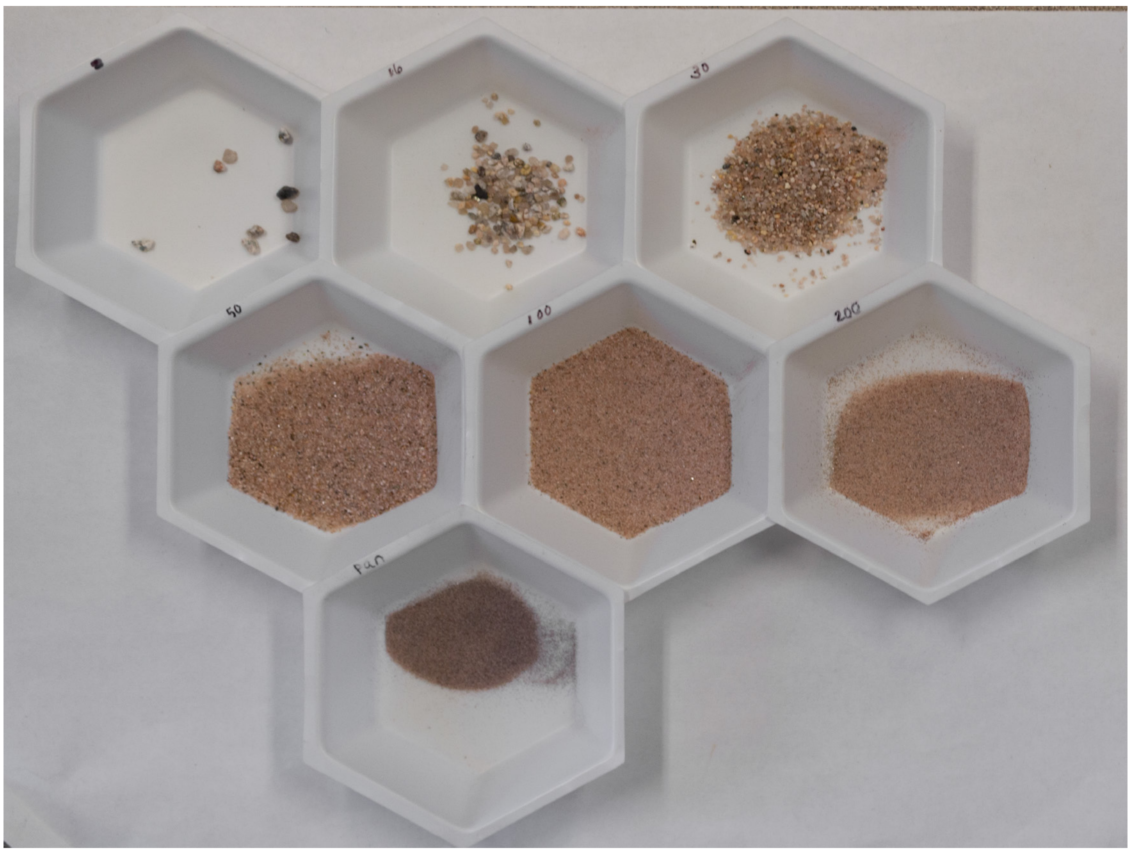
Photomicrograph of the extracted aggregate before sieving (incident daylight-balanced light, 10x magnification).

A substantial amount of fine red material was captured from the aggregate during cleaning. This material appears to be an unidentified pigment. While the exact kind of pigment cannot be identified by this test, the use of pigment to color mortars is consistent with building practices of the time.

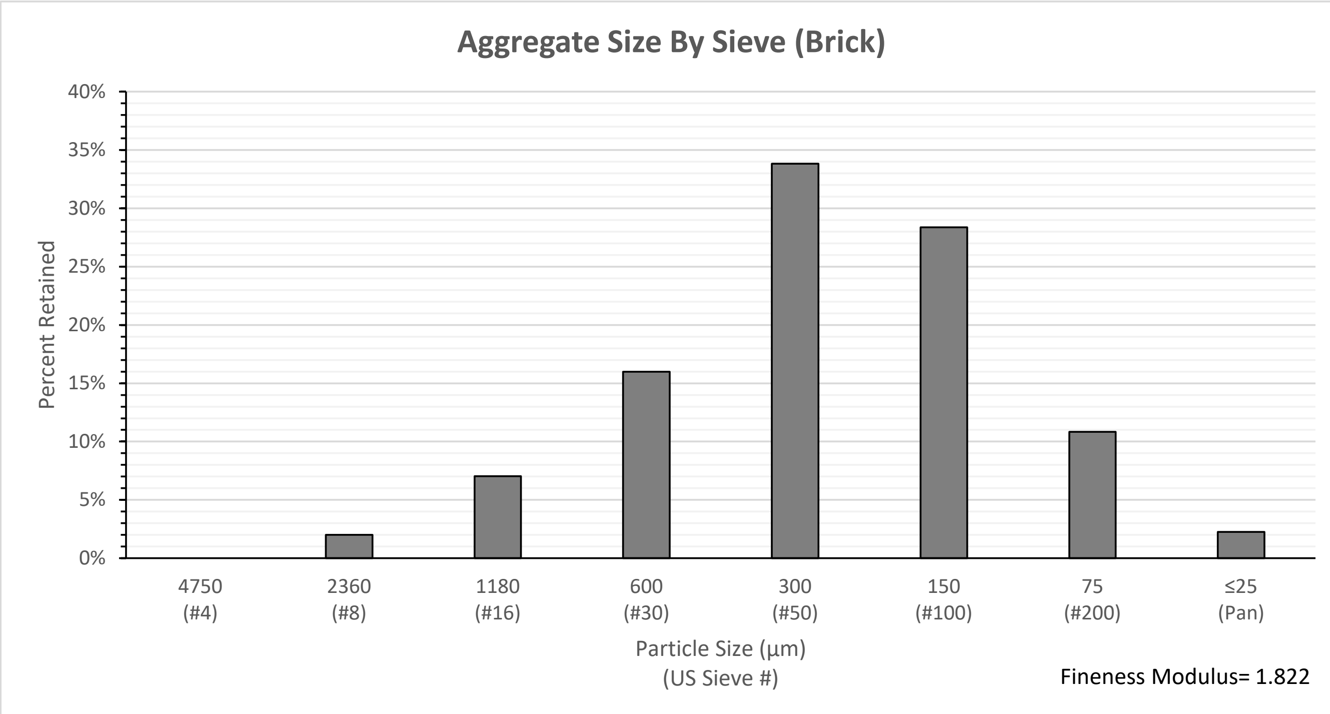
Extracted aggregates were sieved according to ASTM C136. Material was passed through a US Standard Sieve Stack (as governed in ASTM E11) and material retained on each mesh was recorded by weight and expressed as a percentage of the whole to determine approximate grading of the aggregate. Results are as follows:

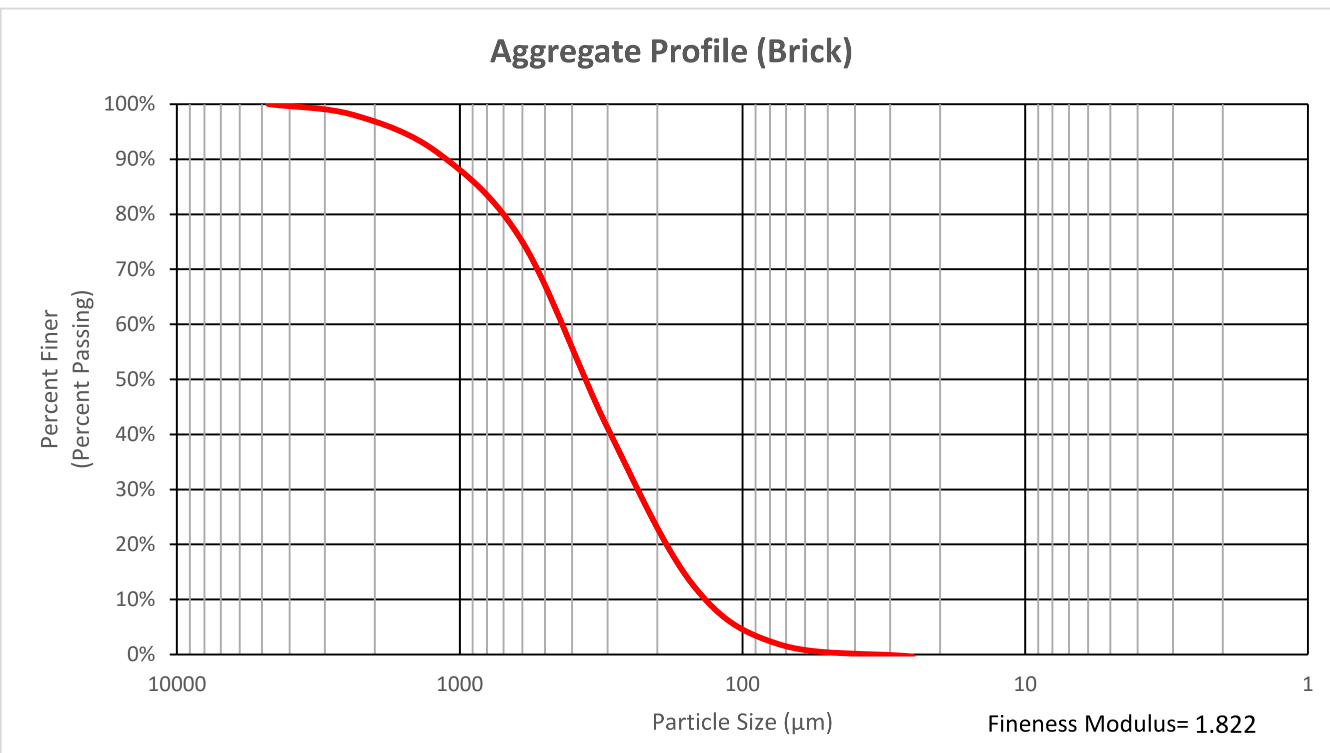
Aggregate Grading:

Sieve Number	#4	#8	#16	#30	#50	#100	#200	Pan
Screen Size	4750μm	2360μm	1180μm	600μm	300μm	150μm	75μm	≥25μm
Aggregate Retained	0.000%	2.017%	7.024%	15.994%	33.832%	28.373%	10.848%	2.260%



Washed and sieved sands sorted according to sieve size (color corrected fluorescent light)





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Section 2.0b: Analytical Summary (Limestone)

The reactive and physical characteristics of this mortar sample could not be accurately determined due to the presence of multiple phases of mortar in the samples. However, it appears to be a modern Portland and lime mortar with coarse sand over top of an older lime or lime-cement mortar. This conclusion was based on the following observations:

Photograph of the weathered face of the bulk sample before digestion (fluorescent light, color corrected).

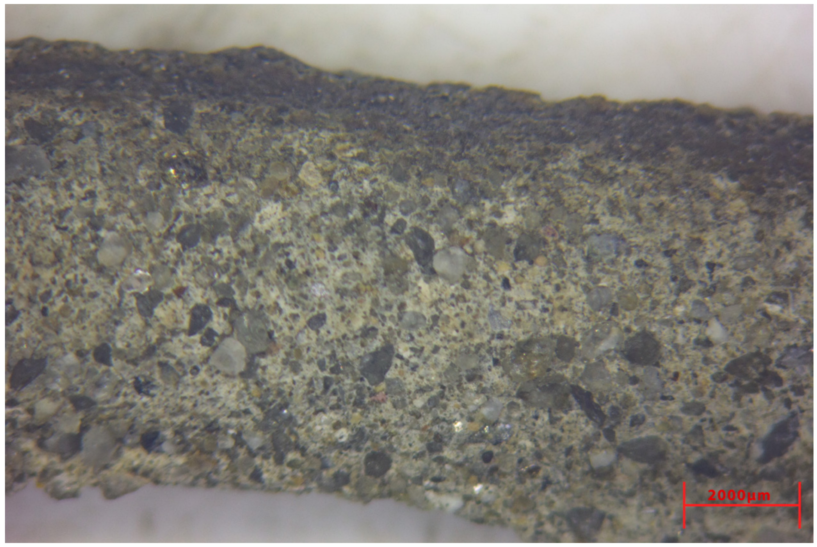
Sample Composition:

$CaCO_3$	~17.057%
$CaMg(CO_3)_2$	~5.725%
Solubles	~21.684%
Aggregate	~34.447%
Fines	~21.088%

Sample Observations:

- ***Layering:*** Samples showed evidence of at least two pointing campaigns, with a denser harder mortar near the surface and a softer lighter mortar behind. The layers could not be separated easily, leading to problematic testing conditions.
- ***Color:*** The weathered face of the bulk sample corresponded to 2.5Y 6/2 *light brownish gray*.
- ***Hardness:*** The surface mortar was hard and dense with a Mohs rating of 8.5, while the back mortar was softer with a Mohs of 5. The overall sample required moderate force to crush with a mortar and pestle. Both samples are consistent with cement-lime mixes of various proportions and vintages.
- ***Reactivity:*** The sample had a very short, but initially vigorous reaction when exposed to a 14% dilution of hydrochloric acid. Mortars with high cement content tend to react less vigorously than mortars high in lime. Limes high in dolomite ($CaMg(CO_3)_2$) will have a secondary reaction after the primary calcium carbonate reaction ($CaCO_3$). Calcium carbonate, such as that found in lime mortars and calcareous aggregates, evolves a large amount of CO_2 when exposed to acid, while pure cement-based mortars release very little during acid digestion. This sample's reaction is consistent with a cement-lime mortar.
- ***Solubles*:** The high amount of solubles compared to the amount of carbonates in this mortar suggests a cement-lime binder. Products in cement are acid soluble but do not evolve CO_2 and so a mortar with low carbonate but high solubles indicates the probable presence of a cement. This sample is consistent with a cement-lime mortar.
- ***Aggregate:*** Aggregates extracted from the mortar were various shades of light gray to white with an overall average color of 10YR 8/1 *white*. The surviving aggregate mostly fell inside the modern mortar aggregate grading standards found in ASTM C144. Overall, this aggregate can be characterized as dull and somewhat coarse. For more information on extracted aggregates please see Section 2.1.
- ***Fines:*** Fines extracted from the mortar were an average color of 5Y 8/2 *pale yellow*. This mortar was very unclean with over 21% fines. The reason for such a large amount of fines is unclear, but may indicate an unwashed sand was used in one of the pointing campaigns.0
- ***Other Notes:*** Because of a multitude of factors including inconclusive results and products not able to be identified by this testing regimen, this mortar is a good candidate for further testing according to ASTM C1324.

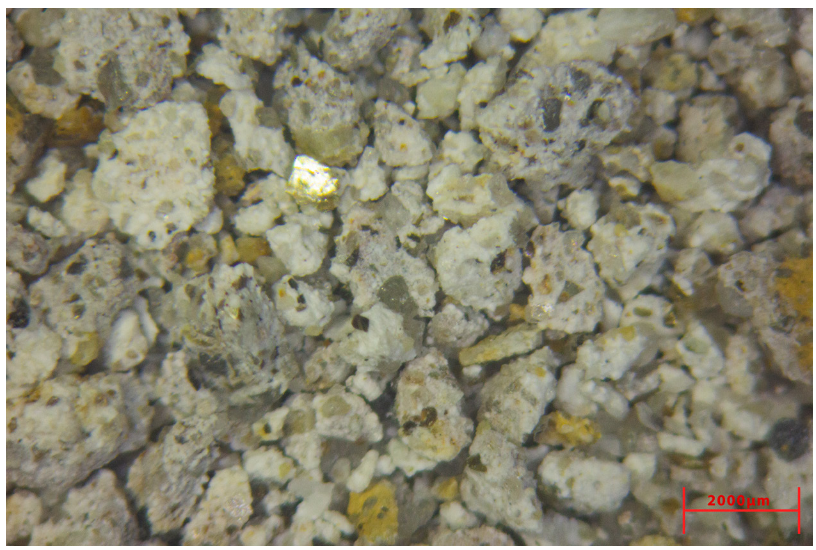
Section 2.1b: Characterization of Extracted Aggregate (Limestone)



Photomicrograph of the weathered face of the bulk sample before digestion (incident daylight-balanced light, 10x magnification).

Because aggregate is an important portion of mortar, helping not only to determine material performance, but also in simulating historic color and texture, this mortar analysis includes a careful examination of aggregates extracted following the acid digestion of the sample. Analysis included a visual analysis and evaluation of particle size. This data can be used to both simulate a historic mortar and/or assess the potential properties imparted by an aggregate blend. It is important to note that certain portions potentially present in aggregate (such as crushed limestone, marble, and certain silicas) are fully or partially soluble in acid. These are included within a broad category of "solubles." Solubles would require further instrumental analysis to accurately characterize.

The individual color of grains could not be fully determined due to undigested binder skewing sieves lighter and grayer in virtually every sieve. However, with the binder included, average particles tended towards light gray to white with an overall average of 10YR 8/1 *white*.



Photomicrograph of the extracted aggregate before sieving, note the abundant undigested binder clumps (incident daylight-balanced light, 10x magnification).

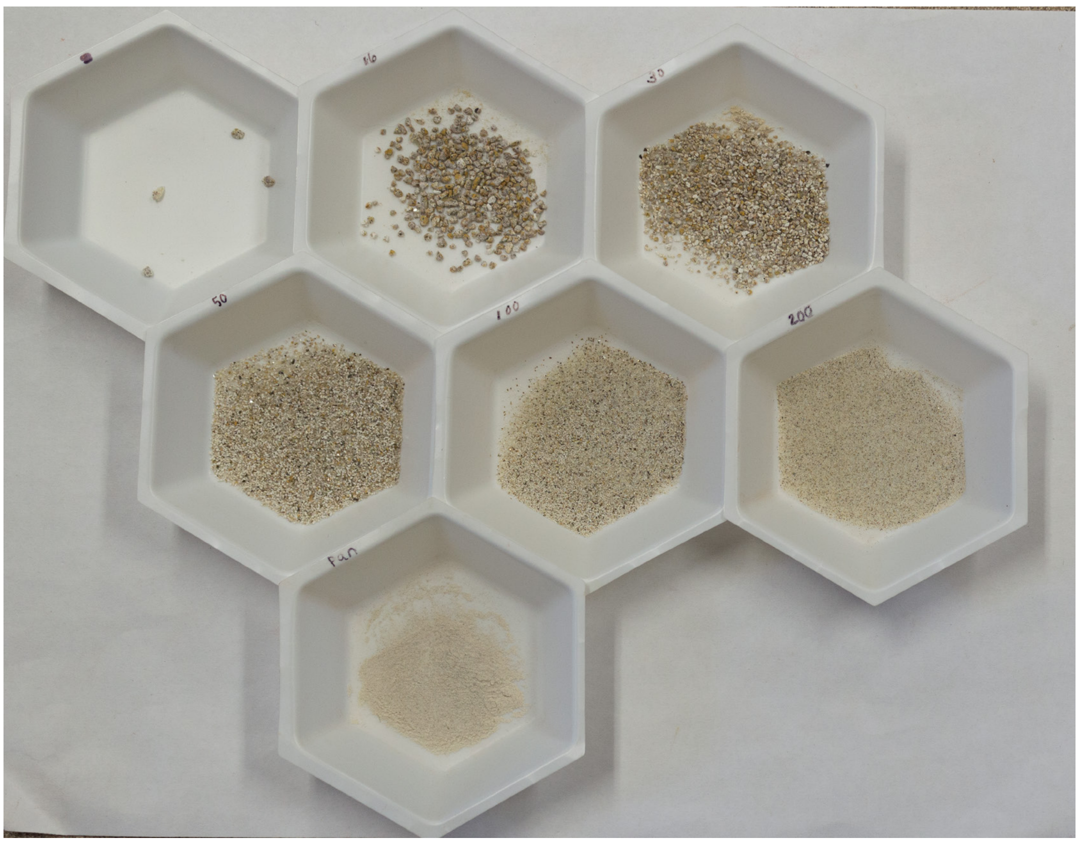
The aggregate particles varied widely in shape from very elongate to equant in sphericity, but had relatively dull angularity ranging from subangular to subrounded in roundness. Undigested binder portions were observed in sieves #8 through #100, making the aggregate appear less graded and more coarse than it probably was in reality. With binder clumps included, there was a nearly even spread across the #16 to #100 sieves with a minority of particles on the #200. The fineness modulus of this aggregate was 1.938, indicating a moderately coarse sand. The sand fell mostly inside ASTM C144's specifications for a coarse masonry sand, but probably would have been much finder had binder clumps not been present. For detailed definitions of these terms, please see section 5.0.

In addition, small piece of shell were observed in most sieves. These shell portions probably came from the older likely lime-based mortar that was clinging to the rear of the harder likely Portland-based mortar, or may be natural portions of the aggregate. Because of the undigested binder and multiple pointing phases, this mortar is a good candidate for further testing according to ASTM C1324.

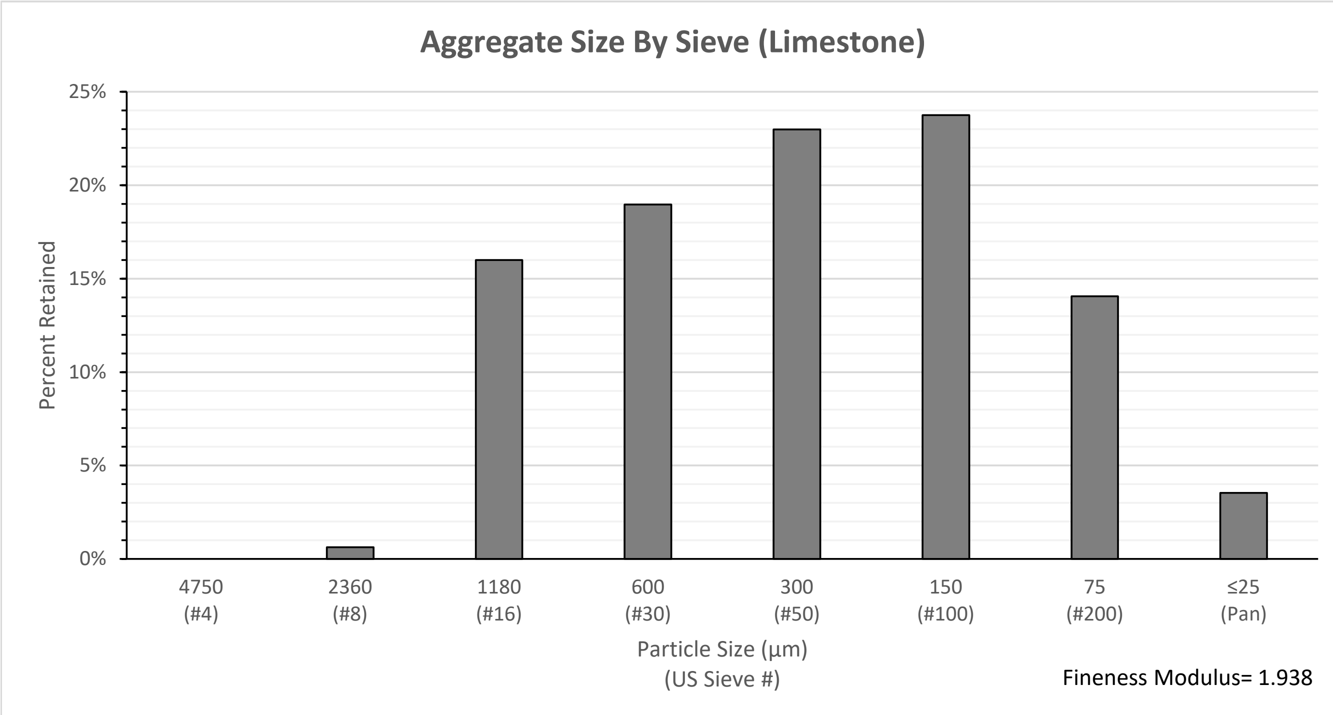
Extracted aggregates were sieved according to ASTM C136. Material was passed through a US Standard Sieve Stack (as governed in ASTM E11) and material retained on each mesh was recorded by weight and expressed as a percentage of the whole to determine approximate grading of the aggregate. Results are as follows:

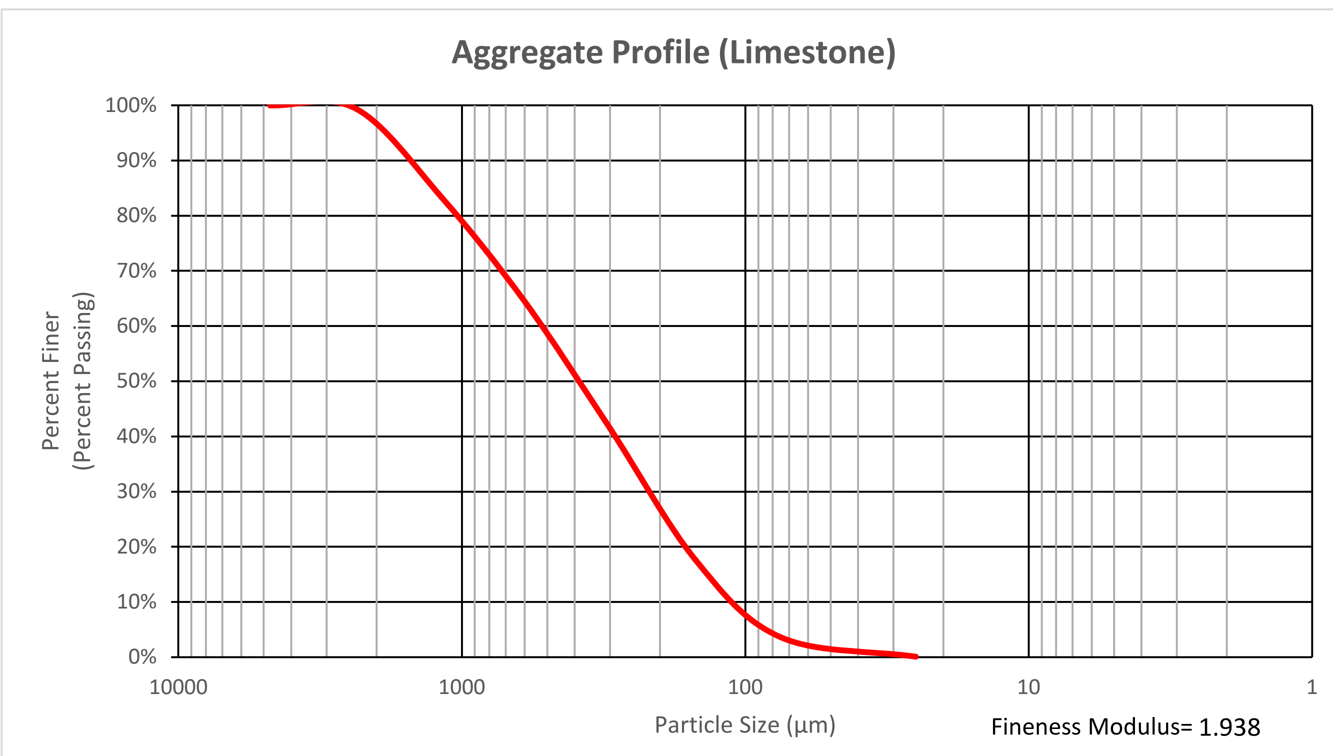
Aggregate Grading:

Sieve Number	#4	#8	#16	#30	#50	#100	#200	Pan
Screen Size	4750µm	2360µm	1180µm	600µm	300µm	150µm	75µm	≥25µm
Aggregate Retained	0.000%	0.623%	15.997%	18.975%	22.992%	23.753%	14.058%	3.532%



Washed and sieved sands sorted according to sieve size (color corrected fluorescent light)


Aggregate Size By Sieve (Limestone)
Percent Retained
25%
20%
15%
10%
5%
0%
4750 (#4)
2360 (#8)
1180 (#16)
600 (#30)
300 (#50)
150 (#100)
75 (#200)
≤25 (Pan)
Particle Size (µm)
(US Sieve #)
Fineness Modulus= 1.938


Aggregate Profile (Limestone)
Percent Finer
(Percent Passing)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
10000
1000
100
10
1
Particle Size (µm)
Fineness Modulus= 1.938

Section 3.0: Product Recommendations

The Secretary of the Interiors' *Standards for the Treatment of Historic Properties* recommends replacing a historic mortar with one similar to or less dense than the original for restoration and rehabilitation projects. However, the standards acknowledge that changes in material preparation, new understanding of material properties, and weathering over time may necessitate a mix different than the original.[1] These standards were taken into account in the following recommendations. All mortar selections should conform to ASTM C1713, with pointing practices conforming to ASTM E2260.

1) Brick Sample

The composition and properties of the Brick Sample are consistent with early 20th century cement-lime mortars and the color is in keeping with the original pinkish-red colored mortar noted to have been used on the building.[2]

By the early 1900s when this building was constructed, both Portland and natural cements were in use along side lime and cement-lime mixes were increasingly common.[3] However, the exact blends of cement were not necessarily standardized to the extent they are today. Likewise, the historic production of cement was not equivalent to the more refined and automated processes of modern production, resulting in cements that varied widely in strength and density compared to modern cements. Because of this, a mortar based on Natural Hydraulic Lime 3.5 (NHL 3.5) is a good alternative as the production of modern NHL results in a modern more similar to historic Portland-lime mortars than modern Portland-lime mortars of similar proportions to the historic blends.

NHL is a traditional building material which offers certain advantages over non-hydraulic lime materials, lime-Portland hybrids, and cement-based materials. Whereas materials based on slaked lime putty or dolomitic lime cure with a process of carbonation over extended periods of time, NHL achieves a cure time more quickly through hydration. Additionally, materials based on St. Astier® NHLs are typically more durable and easier to use than those based on non-hydraulic limes, yet more flexible, vapor-permeable, and sulfate resistant than lime-cement hybrids, different NHL brands, or other cementitious materials.

Given the 1/4-3/8" average joint size indicated by the client, fine sand where a majority of particles are distributed on a bell-shaped curve from the #30-#100 sieves is recommended. If using an NHL, sand should be mixed in a ratio of 1 part lime to 2.5 parts sand. The sand should be dry, clean, sharp, and contain a mixture of particle sizes and shapes to best optimize the mortar properties. Color matching can be achieved either through the use of colored aggregates or by using an alkali-stable, UV-stable dry powdered pigment.

Lime*Works*.us does not have a stock mortar or blend of stock mortars that mimics the appearance of the weathered face of the tested sample. Were a pre-mixed mortar desired, a **Custom Simulation** would be required.

***

2) Limestone Sample

Because multiple phases of mortar were present in the submitted sample, the overall testing of this sample is inconclusive. However, based upon what data could be collected, the current pointing mortar which represents the weathered face of the submitted sample is likely a modern Portland-lime mortar similar to a Type S, a kind of mix available during the 1989 repointing campaign noted in the historic structure report,[4] but generally a mix that could have been used anytime from the mid-20th century onward. The deeper mortar is likely a Portland-lime mix similar if not identical to the Brick sample above (without pigment) plausibly consistent with available mixes during the early 20th century.

1 United States, Department of the Interior, National Park Service Technical Preservation Services, The Secretary of the Interior's Standard for the Treatment of Historic Properties, ed. Anne E. Grimmer, 2017, (accessed November 4, 2020, https://www.nps.gov/tps/standards/treatment-guidelines-2017.pdf), 84.

2 Piotrowicz and Mento A, Tucker Free Library Historic Building Report, 27.

3 E. W. Lazell, *Hydrated Lime* (Pittsburgh, PA: Jackson-Remlinger PTG., 1915), 56.

4 Piotrowicz and Mento A, Tucker Free Library Historic Building Report, 8

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Based on available information, replacement mortars for the Limestone Sample should follow the recommendations of the Brick Sample, with color recommendations following the look of the later face mortar. Changes to this recommendation may be appropriate or required if further testing according to ASTM C1324 is conducted.

From the Lime*Works*.us product line, a blend of **Ecologic Mortar SCG(F) in color 60% Non-Pigmented / 40% DGM Gray** closely mimics the look of the Limestone Sample's weathered face while meeting the recommendations for the mix design presented in the Brick Sample discussion above.

Please Note: While analysis suggests the recommended mortar is an appropriate substitution for the historic mortar, if the mortar needs to be *recreated* and not simply *substituted*, additional analysis will be required to better understand the specific aggregates, binders, or other material in the sample. Product recommendations are provided as a good faith courtesy and are not warranties or guarantees. It is the responsibility of the client and any relevant stakeholders to determine final product suitability and selection. Please speak to a Lime*Works*.us representative to discuss timetables, pricing, and additional testing options if any additional services or products are necessary.

Limestone Sample's face compared to the rough side of a cured tile of Ecologic Mortar in 60% Non-Pigmented / 40% DGM Gray (color corrected fluorescent light).

Section 4.0: Testing Methodology

Testing is completed by an architectural conservator specializing in masonry and with sufficient education and experience to meet the American Institute for Conservation's qualifications for a conservator and bound by the AIC's Code of Ethics; or an experienced lab technician under the observation and review of an architectural conservator. Reports are written by the same and reviewed according to Lime*Works*.us strict quality control standards. All testing is performed in a laboratory conditioned to ASTM C511 specifications for a mortar mixing room.

The approximate composition of the material was determined by referencing the Jedrzejewska analytical method with a calcimeter and techniques conforming to the specifications outlined in ASTM D4373.[1] This technique essentially breaks down a sample into constituent parts and provides data on the nature of the binder by gauging the extent of its reaction with hydrochloric acid (HCl). As HCl dissolves bicarbonates of calcium carbonate ($CaCO_3$) and magnesium calcium dicarbonate ($CaMg(CO_3)_2$) compounds found in lime and (to a lesser extent) cement binders, carbon dioxide (CO_2) is produced. While not absolute and open to a degree of interpretation, by using standard gas/temperature/pressure laws, it is possible to calculate approximate amounts of carbon dioxide released during the acid digestion of the sample providing a reasonable estimation of the amount of carbonates present in the binder of the sample. Data obtained during experimentation was compared with published experimental standards based on known mixes to arrive at conclusions about the composition of all samples.[2] This method has its limits, as it can only give an approximation which can be skewed in the presence of certain additives like gypsum, and cannot differentiate between calcium-carbonate and magnesium-carbonate. Aggregates made of acid soluble material such as shells, marble, or limestone may also not be adequately characterized. A certain amount of error can be introduced by the process of crushing the sample for acid digestion, especially in mortars that require a great deal of force to pulverize.

Insoluble portions of the aggregate were retained and washed, while fine particulates of the material were captured in 20-25µm filter paper and retained. The aggregate was dried and weighed, and evaluated according to particulate size with a Standard U.S. Sieve Stack corresponding to ASTM E11 as outlined in ASTM C136. Sorted aggregate was then examined microscopically for particle sphericity, roundness, color, sorting, and other physical properties. Fine particulates, once filtered, were dried, weighed, and examined visually and microscopically. Color classification is performed using the Munsell Color System in accordance with ASTM D1535.

All microscopic examination was conducted using a Nikon SMZ-2T trinocular reflected light microscope, illuminated by an AmScope 312W-2GOP LED daylight-balanced illuminator. Photographs of samples were captured using a Canon EOS T5 DSLR camera with a special lens designed to make use of the microscope's trinocular bay. All photographs were then color corrected using Adobe Photoshop.

The degree of testing discussed herein is sufficient to establish a basic understanding about the composition of the materials supplied to our laboratory. That said, gravimetric analysis and tests which utilize acid digestion constitute an inexact science, relying substantially on the experience and interpretation of the analyst as well as comparison with materials with known composition. As such, this report should not be interpreted as providing absolute objective composition data on the material. Petrographic analysis including examination of thin sections in transmitted polarizing light and/or elemental analysis would be required to identify mineral phases which are specific to different types of cementing material and to unequivocally quantify the amount of lime and/or cement present. If analysis in accordance with testing procedures described in ASTM C1324 is desired, micro-chemical characterizations may be expanded upon with elemental analysis using techniques such as X-Ray Diffraction (XRD), petrography, and/or physical characterizations of thin sections using transmitted and polarized light microscopy.

1 Hanna Jedrzejewska, "Old Mortars in Poland: A New Method of Investigation," Studies in Conservation 5, no. 4 (November 1960): , doi:10.2307/1505237.

2 James Christopher Frey, *Exterior Stuccoes as an Interpretive and Conservation Asset: The Aiken-Rhett House*, Charleston, SC, Master's thesis, University of Pennsylvania, 1997 (Philadelphia, PA: University of Pennsylvania, 1997); John Stewart and James Moore, "Chemical Techniques of Historic Mortar Analysis," Bulletin of the Association for Preservation Technology, Vol. 14, No. 1 (Washington: APT, 1982), 11-16.

Section 5.0: Definitions[1]

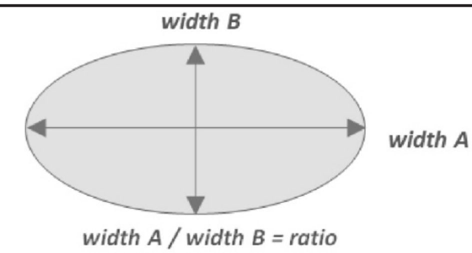
- **Grading:** Grading is a measurement of how well distributed particulate sizes are within the aggregate of a sample. A sample with a broad, even distribution of grains from small to large is considered well-graded. Grading of materials helps predict certain properties of a mortar, such as shrinkage, porosity, permeability, and curing behavior. Appropriate grading for modern mortars is governed by ASTM C144, but historic mortars will vary widely from modern specifications. Typically, modern mortar sands will have a fineness modulus between 2.1 and 3.2, with smaller numbers indicating a finer sand and larger a coarser sand.

- **Hardness:** Hardness is a subjective measurement of how difficult the mortar is to snap or pulverize. Hardness can also be characterized using the Mohs Hardness Scale, which is a qualitative scale ranking an objects hardness by its resistance to being scratched by harder objects. For example, a sample with a Mohs rating of 5 will be scratched by (but cannot scratch) a 6, while being able to scratch (but not be scratched) by a 4. The Mohs Scale is based on a comparison to the hardness of known minerals.

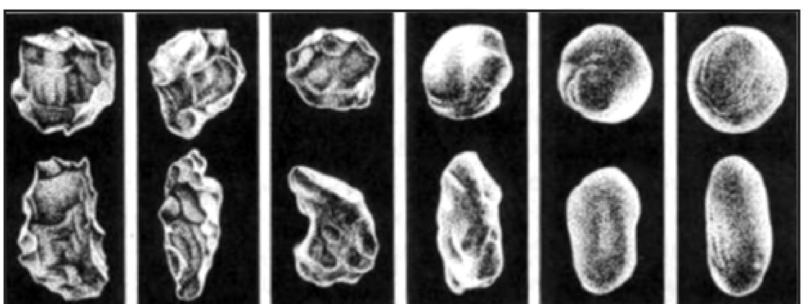
Hardness	1	2	3	4	5	6	7	8	9	10
Mineral	Talc	Gypsum	Calcite	Fluorite	Apatite	Feldspar	Quartz	Topaz	Corun-dum	Dia-mond

- **Sphericity:** Sphericity compares the size of individual particles to how close they approach a perfect sphere. Samples very close to a sphere are said to be "very equant," while samples that are more distant from spherical are said to be "very elongate."

RATIO	DESCRIPTION
under 0.60	Very Elongate
0.60 to 0.63	Elongate
0.63 to 0.66	Subelongate
0.66 to 0.69	Intermediate
0.69 to 0.72	Subequant
0.72 to 0.75	Equant
over 0.75	Very Equant



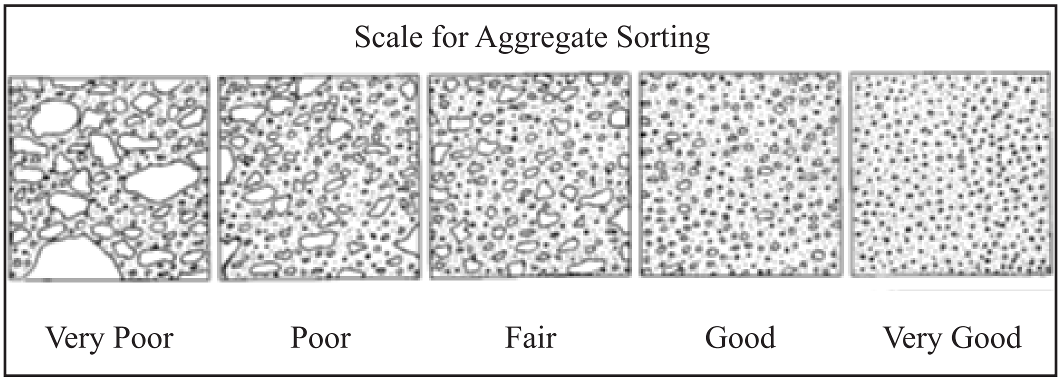
- **Roundness:** Roundness is an observation of the sharpness of the edges and corners of a particle. A particle that is significantly worn by abrasion to the point that it appears smooth is considered *well-rounded*, while a particle that appears cleaved with very sharp edges and little abrasion is considered *very angular*.



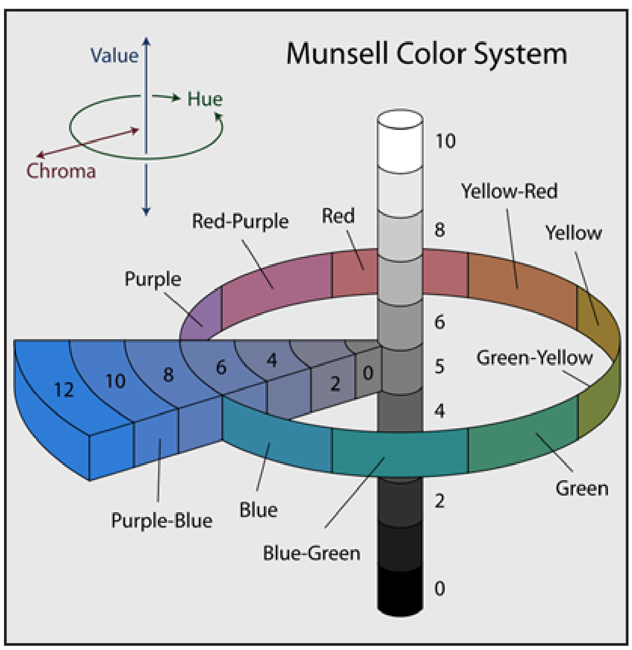
Very Angular | Angular | Subangular | Subrounded | Rounded | Well Rounded

1 Definitions and figures adapted from "Characterization of Granular Samples by Sieve Analysis," Graduate Department of Historic Preservation, HSPV 555, Spring 2016 (Philadelphia: University of Pennsylvania, 2016).

- **Sorting:** Sorting is a description of the degree of distribution of particles of varying size and shape within an individual sample. Samples that are *well-sorted* have nearly homogeneous size and shape distribution, while those that are *poorly sorted* have heterogeneous size and shape distribution.



- **Color:** Because color is subjective, the Munsell Color System attempts to classify the visual experience of color into perceived attributes of hue, lightness, and chroma. These values only apply to opaque samples that are viewed by individuals with healthy color vision in daylight conditions. This method provides a simple, more cost effective alternative to analytical procedures such as spectrophotometry. Munsell notations are given a number-letter-number combination in the form number-letter-slash-number representing Munsell hue (H), Munsell value (V), and Munsell chroma (C). A Munsell color guide also assigns each value an official name. Color classification using the Munsell Color System is performed in accordance to the procedures outlined in ASTM D1535.



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