Stucco Analysis Report

Denver and Rio Grande Depot

21 North Rio Grande Avenue, Montrose, CO

Prepared for
LimeWorks.us

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LIME001

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Cover Image

The Denver and Rio Grande Depot. Image downloaded August, 12, 2019.
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Respectfully submitted,

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1. Introduction

On June 26, 2019, Highbridge received a stucco sample from Mr. Anthony Hita of LimeWorks.us. The sample is reported to have been recovered from the exterior south wall of the Denver and Rio Grande Depot, a building in Montrose, CO constructed ca. 1912. At the client's request, a compositional analysis is performed only on the finish coat of the three-coat exterior plaster assembly. The testing includes petrographic examination and chemical analysis in order to identify constituents, estimate proportions, and assess overall condition. An acid digestion to extract an aggregate sample for description and gradation is also included.

2. Methods of Examination

The petrographic examination is conducted in accordance with the standard practices contained within ASTM C1324-15. Data collection is performed or supervised by a degreed geologist who by nature of their education is qualified to operate the analytical equipment employed. Analysis and interpretation is performed or directed by a supervising petrographer who satisfies the qualifications as specified in Section 4 of ASTM C856-18a.

Chemical analysis is performed in general accordance with the procedures outlined in ASTM C1324-15. Water, carbon dioxide, and aggregate weight percentages are determined gravimetrically. Oxide weight percentages are determined by inductively coupled plasma - optical emission spectroscopy (ICP-OES). While ASTM classifies C1324 as a test method, it is intended to serve as a guideline for qualified practitioners with ample experience in the various materials under consideration. Section 10.2 indicates the need for discretion on the part of the laboratory to ensure that methods are tailored to specific mortar compositions. As such, Highbridge chooses specific digestion methods, supplementary tests, instrumentation protocols, and mathematical models to best characterize each individual mortar under consideration. Many of these are proprietary methods that have been researched internally.

The following personnel contributed to the examination:

Technician:	M. Pattie
Analysts:	J. Negron
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Chemist:	H. Hartshorn
Petrographer:	J. Walsh

3. Executive Summary

This report presents the results of a compositional and condition analysis on an exterior stucco from a ca. 1912 construction. Only the finish coat is the subject of the examination. The material is identified as a roughcast mixture thrown to thicknesses ranging from 1/16" to 3/4". The textural relief of the roughcast is dominated by the 3/8" sizes of the gravel. The laboratory removed an orange-toned coating to reveal a weathered surface that now exhibits some aggregate exposure. The background color is a neutral gray. Partially exposed gravel grains have a moderately dark purplish color palette and these contrast against the cement paste. Exposed sand also produces some texture and color variation but this is less noticeable from a distance.

The stucco contains ordinary gray portland cement and no other binder additives. The fine aggregate is a somewhat fine-grained and moderately sharp-textured natural sand. The coarse aggregate is a natural volcanic gravel. The binder to sand ratio is estimated at approximately 1 : 1.8 by volume and the gravel is estimated to represent approximately 40% of the total aggregate content (i.e., two-thirds the total sand weight). The mix water content was relatively low as expected for a roughcast plaster. The material was well mixed and compacted. However, it appears that some early evaporation has left the finish coat more permeable than it might have been otherwise. Still, the cement is adequately cured and the product is reasonably hard. Though physical properties were not determined, the finish is estimated to have qualities similar to those of a modern Type F or possibly Type FL plaster.

There is no evidence for any significant service distress. Though volcanic grains in the gravel have a potential susceptibility to alkali-silica reaction, there is no evidence for any having occurred. The finish coat is fully carbonated. It is not known if the scratch coat is similarly carbonated. However, there is no obvious corrosion in the embedded expanded metal lath.

4. Petrographic Findings and Discussion

4.1 - Materials

The finish coat is a roughcast meaning that a gravel was incorporated into a standard stucco mixture to provide a coarse texture to the final finish. The coarser aggregate addition in this sample is a natural volcanic gravel. This material represents approximately 40% of the total aggregate extracted through acid digestion. The volcanics are intermediate types including porphyritic andesite and possibly some basaltic andesite. Most of the groundmass is aphanitic and no glass is positively identified. There is some minor local porosity, usually within feldspar grains. However, none of the pore space appears interconnected. There are minor occurrences of felsite and spherulitic material that could be more alkali-silica reactive. However, there is no evidence for any incipient reaction. From a physical perspective, the gravel is considered hard and inelastic. Technically, the grain types may be moderately susceptible to alkali-aggregate reactivity. However, there is probably a much lower risk in this application.

The gravel extracted through acid digestion is opaque and variegated in appearance. Purplish shades predominate including dark purplish gray, burgundy, dark red, mauve, and pale purplish gray. There are also lesser to minor pale greens and light yellowish grays. The purplish grains provide most of the visual contrast on the stucco surface, at least once the surface paint or coating is removed. The gravel particles are mostly rounded to subrounded in shape. Any angularity noted in the recovered sample is an artifact of the saw-cuts necessary to reduce the sample. Aspect ratios are equant to slightly oblate. Some slightly prolate grains are minor. The visual appearance of the stucco is strongly influenced by gravel particles in the 3/8" size range. However, the actual gradation lies between the 1/2" and No. 8 sieves with the peak between the 3/8" and No. 4 mesh. Additionally, the amount retained on the 3/8", while 25% of the gravel weight, is closer in size to 3/8" than 1/2". Details of the gradation profile are presented in Section 6.

The fine aggregate is a natural granitic sand consisting of quartz and alkali feldspar. There is a minor accessory assemblage including biotite, magnetite/ilmenite, amphibole, and sphene. No clay coatings or friable materials are identified and the sand is considered hard, non-porous, and durable for use in cementitious mixtures. The sand extracted through acid digestion is semi-translucent to semi-opaque with a light brownish gray color overall (Munsell code approximately 1.5Y 7/1.5). White feldspar particles create a distinctive speckling on the weathered surface of the stucco finish. This is much more obvious on the stucco face than it is in the extracted sand. The sand is moderately sharp-textured with equidimensional particles that are subangular in shape on average. The recovered aggregate was graded through a standard sieve stack and results are presented in Section 6. The nominal top size is at the No. 16 sieve though most sand passes this mesh. There is a strong peak abundance between the No. 30 and No. 50 sieves with almost 60% retained within this interval. Finally, there is a modest fines content. If treated as a base coat material in a more modern stucco, the particle size distribution would be tighter and finer than permissible under the current standard (ASTM C897-15). However, finish coat sands are permitted to deviate from these standards in order to achieve particular textural effects.

The binder consists of ordinary gray portland cement. No lime-based additions or supplementary cementitious materials are present. The construction also predates the masonry cements and plastic cements that became available after ca. 1925. As expected, constituents that would be identified in these prepackaged mixtures are absent from the examined sample. The cured binder is homogeneously developed with a moderately high capillary porosity and a distinctively microgranular texture. There is a very high abundance of residual unhydrated portland cement grains. These appear as coarse-grained calcium silicate agglomerates with interstitial iron-bearing ferrite. The ferrite identifies the cement as a gray variety and this is also shown by a chemically measured SiO_2/Fe_2O_3 ratio of 8.2. In fact, it was possible to estimate the original chemical composition of the binder and the resulting estimate is consistent with the major element chemistry of ordinary gray portland cement (Table 5.2). The unhydrated cement grains are found in diameters up to and just retained on the No. 100 sieve. This coarser grind is consistent with cements produced within the first two of decades of the twentieth century. As such, it is almost certain that the finish coat is original to the ca. 1912 construction.

4.2 - Component Proportions

Chemical analysis was used to estimate the mix proportions of the finish layer and these results are presented in Section 5. It is useful to consider the material as a mortar to which a gravel component is added. When considered this way, the cement to sand ratio is estimated at approximately 1 : 1.8 by volume. Though prepared ca. 1912, the stucco design is more consistent with modern standards and can be compared to ASTM C926-19a, the standard specification for portland cement-based plaster. In this case, the binder to sand ratio is considered appropriate for a finish coat stucco. The author did not have an opportunity to analyze the base coats, but a superficial scan suggests that the mortar portions of the mixtures are all similar in composition. For the base coats, the absence of lime would be permissible, though a greater sand content would be needed to classify as a Type C mix appropriate for use over low-absorption substrates. On the other hand, finish coats should generally have anywhere from 0.75 to 2 parts lime for every part of cement. Still, more cement-rich mixtures are more desirable for all types of dash finishes such as the one examined for this report. If designed today, a Type F finish coat mixture would typically be chosen. Given the expected lower strength of an early twentieth century cement relative to modern portland cements, the physical properties of the original mix are probably closer to the ideal Type F mixture even if the proportions are not.

Estimating the gravel content is not as straightforward. The roughcast mixture is essentially a fine concrete. As such, a significantly larger sample would have been required to provide an accurate estimate of the composition. Nevertheless, approximately 160 grams of the finish coat was dissolved in acid to release the aggregate. Fortunately, the sand and gravel exhibit virtually no overlap in sizes. It was possible to cleanly separate the two components on either side of the No. 8 sieve. The strongly bimodal distribution is visually obvious in Figure 4 and graphically depicted in the gradation chart presented in Section 6. After separating, the gravel is determined to represent approximately 40% of the total aggregate weight. If a quasi-replication of the finish coat is a goal of this analysis, this rough estimate can be used as a starting point once an appropriate aggregate source is identified. Of course, it is always critical for exposed aggregate finishes to be fine-tuned through a mock-up process as small differences are easily registered visually.

4.3 - Original Preparation and Placement

The scope of the analysis was limited to the finish coat, and a broader evaluation of the entire assembly was excluded. Nevertheless, passing commentary may be made regarding the plaster cross section. Notes from the initial visual analysis are offered in Appendix I. The stucco is essentially a three-coat, portland cement-based exterior plaster reinforced with expanded metal lath. Scratch and brown coats are just less than 1/2" in thickness each. The entire assembly is well compacted and all lifts are thoroughly bonded to one another.

The finish coat is a roughcast plaster meaning that all components were blended together first, and then thrown onto the wall as a single mixture. The sand and cement were certainly well blended and there are no sand streaks or significant binder lumps identified petrographically. Based on the area examined, the gravel addition also appears to have been evenly incorporated. There are no gaps or clusters of the stone observed along the presentation face of the stucco.

The original finish coat mixture was prepared to a relatively stiff consistency with a modest mix water content. The mixture would have needed to have been somewhat workable, but tight enough to resist sagging when thrown to thicknesses of at least 3/4". The lower mix water content is evident in the microstructure of the hydrated cement paste. The hydration was adequate and there was sufficient development of hydrated cement paste to create a cohesive product. Still, there is a very high abundance of unhydrated cement particles. In part, this is due to the lower mix water content. However, the microgranular texture of the binder suggests that there was also some early evaporation of the mix water. The curing is not as thorough as it could have been, and interstitial space between unhydrated cement particles is responsible for a moderately high liquid water permeability.

4.4 - Finish Qualities

The sample was received with a soft orange-toned coating thinly applied over the finish. It is not within the scope of the laboratory to determine whether this finish was original to the installation. For the sake of argument, it is assumed that the finish was applied at a later date. The original stucco finish would have had the coarse, clumpy texture apparent now. However, the aggregate grains would have been coated with a thin layer of cement paste and the entire surface would have been a uniform gray color. This assumes that the surface was left alone after dashing and there was no subsequent brushing or scrubbing of the green stucco. Whatever the case, the aggregates would have become partly exposed after a relatively short time as a result of the cement paste weathering. This may have been more prevalent in areas with greater exposure to rain or running water.

Before destroying the sample for analysis, the laboratory scrubbed the soft coating off under running water. This revealed a surface that may reflect an early appearance of the stucco if not the original one. Though the portland cement paste has carbonated, it has not developed the rich orange discoloration rind that is often observed in older products. Instead, the matrix retains a neutral gray color. Where the gravel is exposed, there is a contrasting appearance due to the darker purplish shades of the volcanic grains. As opposed to a pebble dash where gravel grains would be in close contact, the contrasting exposed gravel particles are sporadically distributed about one to three grain widths apart. Finally, sand grains are also exposed along the stucco face. From a distance, these contribute only to the overall texture of the stucco, especially under oblique lighting conditions. Up close, there is a distinctive white speckling due to the relatively high content of opaque alkali feldspar grains.

4.5 - Condition and Service Performance

As discussed earlier, the finish coat is moderately hard and cohesive as expected for the pure portland cement composition. However, some inhibition of curing has left the layer more permeable than might otherwise be the case for the design. It should also be expected that portland cements from the early twentieth century would exhibit lower compressive strengths than similar products manufactured today. Taken together, the hardened properties of the finish coat are probably closer to that of a modern Type F or even a Type FL mixture as specified by ASTM C926-19a.

Despite any deficiencies in the curing, the finish layer appears sound. There is no macroscopic or microscopic cracking identified. No deleterious mineralizations are noted in air-voids or along exposed surfaces. None of the constituents exhibit evidence for unsound behaviors while in service. The only secondary service effect identified is a thorough carbonation of the cement paste. This is a normal consequence of long-term curing that was likely accelerated by the higher permeability. Carbonation does not pose any significant threat to the stucco mixture itself. However, the pH reduction that accompanies carbonation can result in the depassivation of any embedded steel. This in turn can leave the steel vulnerable to corrosion. It was not noted whether the carbonation extended to the scratch coat. However, no corrosion product or evidence of expansion is noted in the embedded expanded metal lath.

4.6 - Final Comments

The nature of the identified aggregates warrant some discussion of alkali-silica reaction (ASR). ASR is a reaction that occurs between alkaline cement paste and disordered forms of silica in certain types of aggregate. The reaction produces a hygroscopic gel that swells when moisture is absorbed. If the reaction becomes advanced, the expansion produced by the moisture-induced swelling is often sufficient to produce significant visible cracking.

In general, volcanic rocks tend to be more susceptible to ASR, though varieties with intermediate silica content such as andesite are often less reactive. Whatever the case, there is absolutely no evidence for ASR in this particular sample. Even if the andesite was potentially reactive, the pH reduction produced by the carbonation reaction would have likely obviated any future reaction. With that said, the author is generally less concerned with the use of potentially reactive stone in thin and exposed applications such as exterior stucco. Carbonation and the leaching of surface alkalis through rainwater are likely to mitigate any reactivity. Still, it is suspected that the client may wish to replicate the appearance of the gravel. Most rocks within this color palette tend to have a higher susceptibility to ASR. There are more formal tests that can be used to assess this potential in sources without an established history. Results of these tests are often available from aggregate suppliers that provide products for concrete or masonry. As the risk is relatively low, the client may reasonably decide that durability testing is not necessary. However, the author recommends choosing aggregates from products marketed to the construction industry. Landscaping aggregates or hobby aggregates are more likely to contain deleterious materials. Furthermore, the author would caution against the more reactive rhyolites, though these often exhibit a similar color palette as the andesites used in this stucco. If landscaping aggregates or rhyolites are the only available options, then further testing would be prudent.

5. Chemical Analysis

Table 5.1: Chemical Analysis Results

Sample ID	**Stucco finish**
Component (wgt. %)	
SiO_2	5.64
CaO	16.15
MgO	0.27
Al_2O_3	1.57
Fe_2O_3	0.69
Insoluble residue	67.58
LOI to 110°C	1.04
LOI 110°C-550°C	4.18
LOI 550°C-950°C	4.45
Measured Totals	**101.56**

Table 5.2: Estimated Original Cement Chemistry

The binder consists only of portland cement with no other additives. As such, the cement chemistry is estimated from the total chemical analysis present in Table 5.1. The five major oxides in the binder are normalized to a 95% weight yield. The 5% is reserved for unmeasured constituents such as sulfite, alkalis, and trace elements. The estimated chemistry is consistent with an ordinary gray portland cement and there is no indication of unsoundness (e.g., excessively high magnesium).

Sample ID	**Stucco finish**
Component (wgt. %)	
SiO_2	22.0
CaO	63.1
MgO	1.1
Al_2O_3	6.1
Fe_2O_3	2.7
Other	5.0
SiO_2/Fe_2O_3 ratio	8.2

Table 5.3: Calculated Components

Sample ID	**Stucco finish**
Component	
Portland cement (wgt. %)	27
Lime expressed as dry hydrate (wgt. %)	Not detected
Masonry or plastic cements (wgt. %)	Not detected
Pigment (wgt. %)	Not detected
Sand (wgt. %)	43
Gravel (wgt. %)	30
Cement : sand ratio (by volume)	1 : 1.8

Notes:

1. Portland cement is calculated from the five measured oxides assuming these represent 95% of the total dry cement weight. The total aggregate is calculated from the chemically measured acid-insoluble residue reported in Table 5.1. The proportion of sand and gravel is determined from the acid digestion process. Based on this analysis, the sand represents 58.8% of the total recovered aggregate. The insoluble residue is partitioned accordingly. All material weights are normalized to 100% and are reported on a dry weight basis. Given the sample size, it is impracticable to calculate the volume proportion of the gravel component. Instead, volumetric proportions are given for the mortar fraction. These are calculated from assumed bulk densities of 94 lbs./ft.^{3} and 80 lbs./ft.^{3}, respectively.

6. Aggregate Sieve Analysis

Aggregate analysis was performed by digesting a subsample of the finish coat in an acid sufficient to dissolve the binder. The fines are examined petrographically to ensure that all recovered material represents sand rather than undigested binder components. In this case, most of the material passing a No. 325 sieve is determined to represent hydrous silica residues from the incongruent dissolution of the cementitious binder. This material is discarded and not included in the calculations below. The loss of small amounts of silt along with this discarded binder residue is considered a negligible error.

An analysis of the recovered aggregate under magnification indicates that all of the gravel is coarser than a No. 4 sieve and all of the sand is finer than a No. 8 sieve. As such, these two components are readily distinguished through sieving, and the gradation profiles for each material are provided separately in the following tables.

In order to subsample the roughcast finish, it was necessary to slice perpendicularly into the stucco. This produced thinner pieces from which the finish could be cleanly sectioned from the brown coat using a masonry saw. Every attempt was made to choose cuts to go between the gravel aggregate. However, some of the gravel was necessarily sliced during this preparation. As such, the reported gradation may be slightly finer than the original. This is probably a negligible error. Similarly, the cut gravel pieces will seem more sharp-textured than is actually the case.

Qualitative descriptions of the sand are given in the discussions above, and the recovered samples are returned to the client. The sample size is significantly smaller than would be required to perform a sieve analysis on fresh aggregate materials as per ASTM C136, and some small errors should be expected.

Table 6.1: Acid Digestion Data (Gravel)

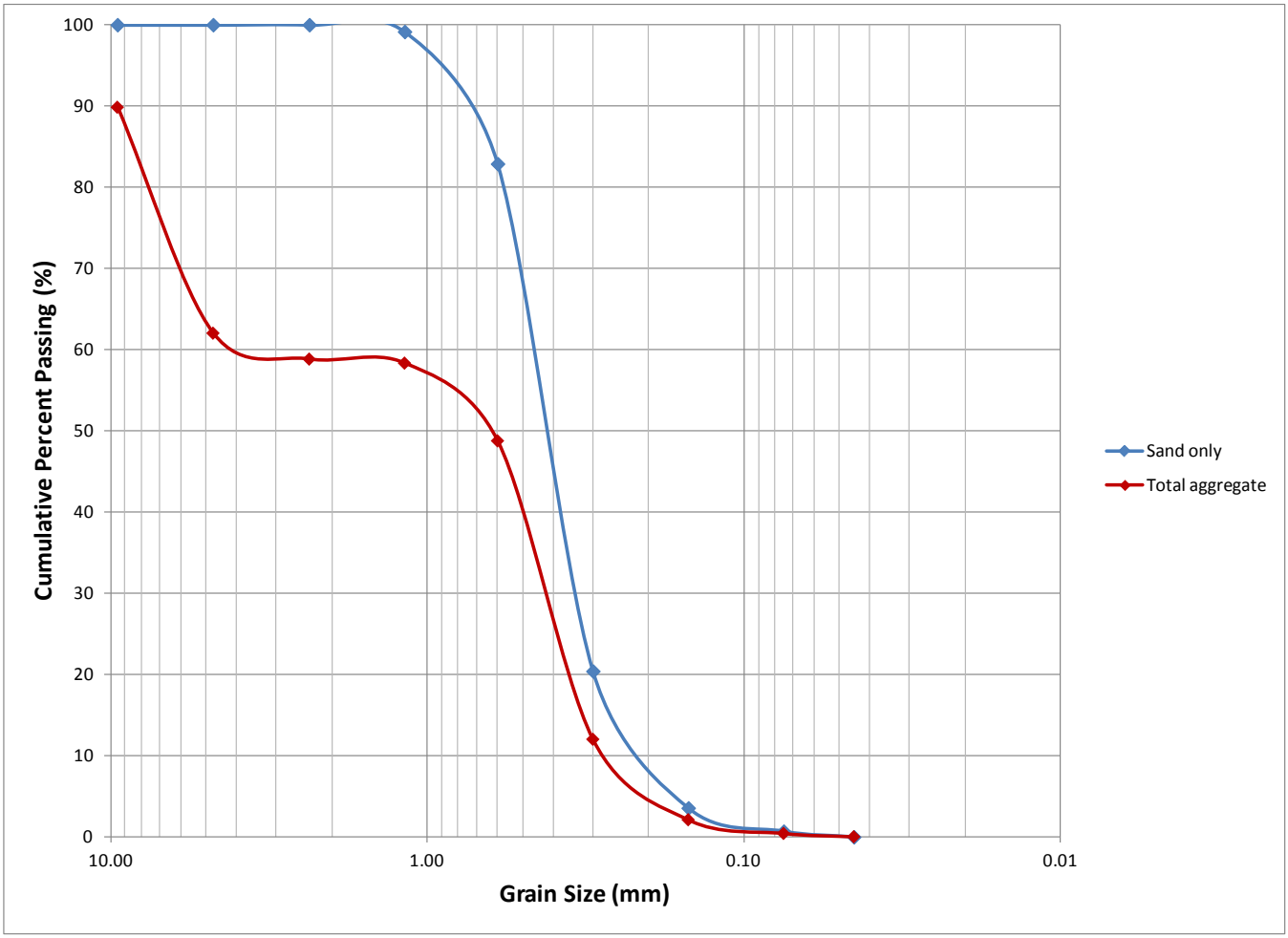
	Retention (g)	Cumulative passing (%)	Cumulative retained (%)
3/8"	10.76	75.3	24.7
No. 4	29.42	7.8	92.2
No. 8	3.38	0.0	100.0
No. 16	0.00	0.0	100.0

Table 6.2: Acid Digestion Data (Sand)

	Retention (g)	Cumulative passing (%)	Cumulative retained (%)
No. 4	0.00	100.0	0.0
No. 8	0.00	100.0	0.0
No. 16	0.52	99.2	0.8
No. 30	10.12	82.9	17.1
No. 50	38.86	20.4	79.6
No. 100	10.48	3.6	96.4
No. 200	1.78	0.7	99.3
Pan	0.44	0.0	100.0
Fineness Modulus			**1.94**

Chart 6.1: Aggregate Sieve Analysis

The following chart presents particle size distribution curves for the extracted sand samples. The chart plots the data from Tables 6.1 and 6.2. The blue curve includes only the sand while the red curve plots the total aggregate.



Appendix I: Visual Description of Samples as Received

Sample ID	Stucco
Dimensions and details	The provided sample consists of one full depth stucco panel sawn to an area of approximately 6.5" x 4.5". The thickness is irregular due to the roughcast finish but ranges anywhere from about 1" to 1.75". The scratch and brown coats are both just less than 1/2" each. The finish coat ranges in thickness from about 1/16" to 3/4".
Inner surface	The scratch coat is mostly well compacted against (presumably) a wood lath substrate. The represented lath width is approximately 1.5". The material behind the lath is uncertain but the scratch coat is compacted against another surface that is wavy planar and approximately 1/4" to 3/8" behind the lath.
Stucco body	The scratch coat is well-keyed into the expanded metal lath reinforcement. The brown coat and finish coat are both bonded and well-consolidated along apparently planar surfaces. There is no obvious visual evidence for troweling or scratching in cross section.
Outer surface (before cleaning)	The surface of the roughcast finish is craggy and lumpy. The texture has a very high surface relief. Much of the texture is created by pebbles at approximately 3/8" diameter. However, the pebbles are often thinly coated with mortar. The entire surface has a thin, orange-toned coating or paint.
Outer surface (after cleaning)	The finished surface was cleaned under running water with a nylon scrub brush to observe the appearance below the paint. The original finish would probably have only shown paste only, that is to say; a sandy, lumpy texture with a medium greenish gray color. However, assuming the plaster was originally uncoated, some type of aggregate exposure would have followed in a few years, probably more so in areas of direct runoff or water flow. At the present time, the pebbles present sporadic dark spots within the 3/8" size range. The most contrasting are the dark red to dark purplish gray grains. There is also a modest sand exposure that produces a semi-opaque white speckle at approximately the No. 50 sieve size. This is due to the high content of alkali feldspar in the sand.
Appearance	All coats have a similar appearance. On fresh exposure, the color is a medium greenish gray (Munsell code approximately 5Y 5.5/1) though the scratch coat may be a little lighter. The luster on fresh fracture is moderately subvitreous translucent.
Hardness/ friability	The matrix in all layers is hard, indurate, and nonfriable.
Absorptivity	Absorptivity seems to be somewhat variable. Most freshly exposed surfaces are slowly absorptive. Some areas of the scratch and brown coats are more absorptive. After cutting in oil, the entire plaster became saturated and the oil could not be wicked out.
Reinforcement	The stucco contains an expanded metal lath. The lath is well encased in stucco mixture and there is no significant corrosion product observed.
Other details	No cracks, efflorescence, or mineral deposits are visible in hand sample.

Appendix II: Photographs and Photomicrographs

Microscopic examination is performed on an Olympus BX-51 polarized/reflected light microscope and a Bausch and Lomb Stereozoom 7 stereoscopic microscope. Both microscopes are fitted with an Olympus DP-11 digital camera. The stereoscopic microscope is used for simple magnification. Sample types examined under this microscope include fractured surfaces, fine constituents extracted through chemical or physical means, or honed or polished cross sections. The polarized light microscope (PLM) magnifies but also employs principals of optical crystallography. The most common sample preparation for the PLM is the petrographic thin section. For this preparation, cross-sectioned samples are mounted to glass slides and are milled to a thickness sufficient to allow light to be transmitted through the material. These are usually prepared without water and with minimal heat to avoid altering minerals that are water or temperature-sensitive. In many cases, the samples are impregnated with a low-viscosity, blue-dyed epoxy. When so treated, blue areas represent some type of void space (e.g., air-voids, capillary pores, cracks, etc.). The polarized light photomicrographs are taken using a variety of optical settings chosen to best demonstrate the feature(s) of interest. These are distinguished as follows:

Plane polarized light (abbreviated as PPL)

This method uses the refractive power of different constituents to produce an artificial sense of surface relief. Otherwise, the method is the closest to a simple magnification of the material. The setting is often used to demonstrate granular relationships or microstructure. Pore spaces and cracks are observable with this setting if the blue-dyed epoxy is used.

Conoscopic polarized light (abbreviated as CPL)

In this setting, the transmitted light is condensed just before passing through the thin section. The method tends to bring colors or finer particulates into higher contrast at the expense of image sharpness. The setting is often used to image grain boundary failures in dimension stone, pigment particulates in binders, or gel phases in the micropores of cement pastes.

Cross polarized light (abbreviated as XPL)

The setting places the thin section between two pieces of polarizing film oriented at 90° to one another. In isotropic materials (e.g., glasses, simple salts), all light is absorbed and the materials appear black. In anisotropic crystals, two light rays traveling at different speeds are produced within the thin section and these offset waves interfere at the upper polarizing film. The interference produces a color that can be used to calculate properties of the crystal structure and aid in identification of mineral species. In essence, the colors are artificial. It should be noted that color is a function of orientation and color differences do not necessarily indicate material differences.

Compensator plates

When in XPL mode, full-wave or quarter-wave compensator plates may be inserted into the light path to add or subtract interference. Technically, these methods are used to calculate properties of the crystal structure. However, they can also be used to alter the image appearance to help improve contrast between different constituents. They can also reveal preferred orientations in some materials (e.g., oriented residual crystallinity in fired ceramics).

Scale bars are included with all photomicrographs. In higher magnification images, the µm symbol represents microns. One micron is equal to 0.001 millimeter.

Figure 1: Photographs of the stucco sample received by Highbridge for examination. (Upper left) The outer face is shown as received. Note there is a soft, orange-toned coating covering most of the finish coat. (Upper right) The outer surface is shown after the laboratory scrubbed off the coating to reveal a weathered face with partially exposed aggregates. (Lower) The inner surface is shown. There are complete impressions of wood lath and another surface behind the lath.

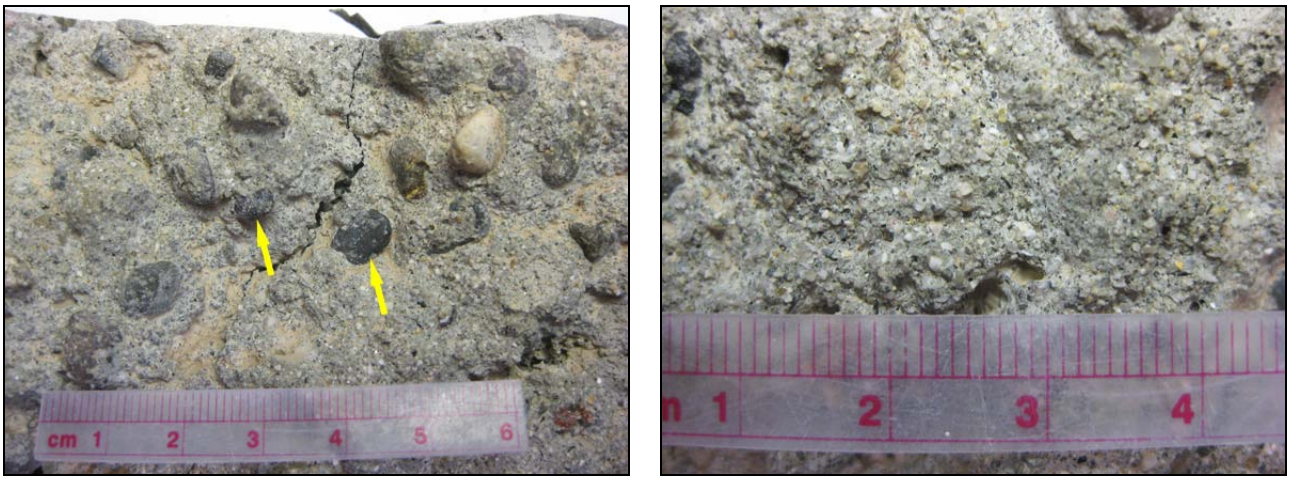


Figure 2: Photographs illustrating the visual qualities of the outer surface after removal of the coating. (Left) The arrows indicate purplish grains of andesitic gravel. (Right) Exposed sand creates a gritty surface texture. Opaque alkali feldspar grains contribute to the white speckling.

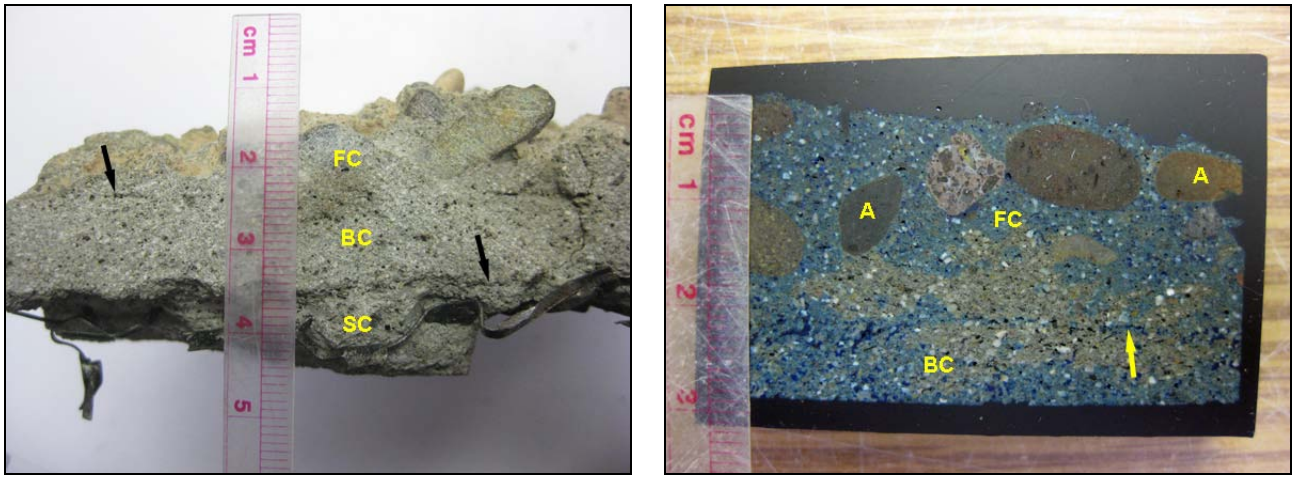


Figure 3: Photographs illustrating the stucco in cross section. The sawn edge as received is shown at left. The arrows indicate the contact surfaces between the scratch coat (SC), brown coat (BC), and finish coat (FC). A honed thin section billet is shown at right. This needed to be used for the honed section as the remainder of the material was consumed for the chemical analysis and acid digestion. The blue color is due to the absorption of blue-dyed epoxy used in the sample preparation. In this case, the arrow indicates the contact between brown coat and finish coat. The size and distribution of the gravel aggregate (A) can be viewed.

Figure 4: Photographs of the aggregate extracted through acid digestion. (Upper left) The gravel addition is shown. The volcanic particles are mostly rounded to subrounded in shape with aspects that range from equant to slightly oblate. (Upper right) The sand addition is shown. The sand is mostly uniform and light brownish gray in color. (Lower) The total aggregate is shown after gradation through a standard sieve stack. Note the distinctly bimodal distribution with a trough at around the No. 8 sieve that divides the gravel and the sand.

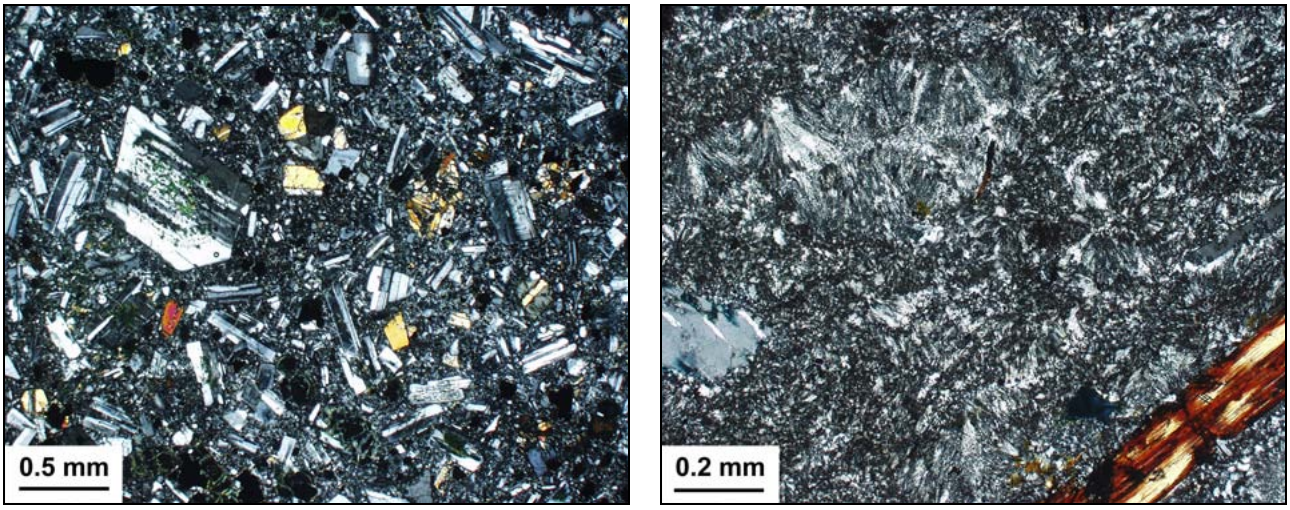


Figure 5: XPL photomicrographs illustrating some characteristics of the volcanic gravel. A typical andesite particle is shown at left. The white and gray particles are plagioclase feldspar. The yellow and red grains are pyroxenes. These phenocrysts are set in a fine-grained but mostly non-glassy groundmass. The image at right is a higher magnification image of the groundmass in another particle. This exhibits a spherulitic texture that could cause the grain to be more susceptible to alkali-silica reaction. Nevertheless, no evidence for even an incipient reaction is identified in the sample.

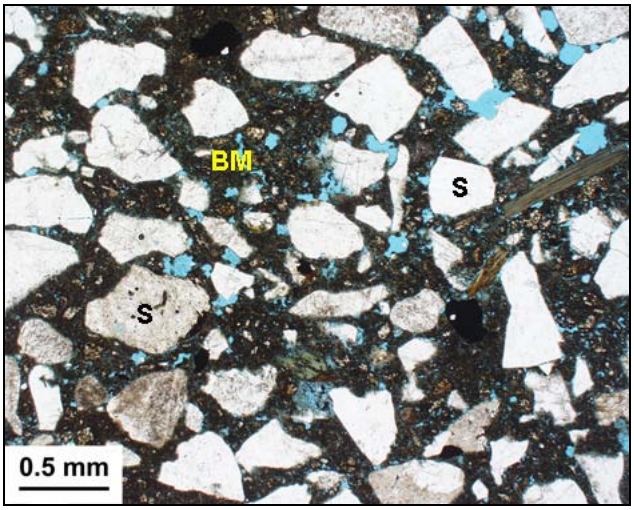


Figure 6: PPL photomicrograph illustrating the overall microtexture of the stucco finish layer. Sand grains (S) are evenly distributed and are not too closely packed. Sufficient binder matrix (BM) coats the sand grains to produce a well consolidated mass. Air-voids and other pores appear blue due to the absorption of the dyed epoxy used in the sample preparation. Note that the voids are not excessive.

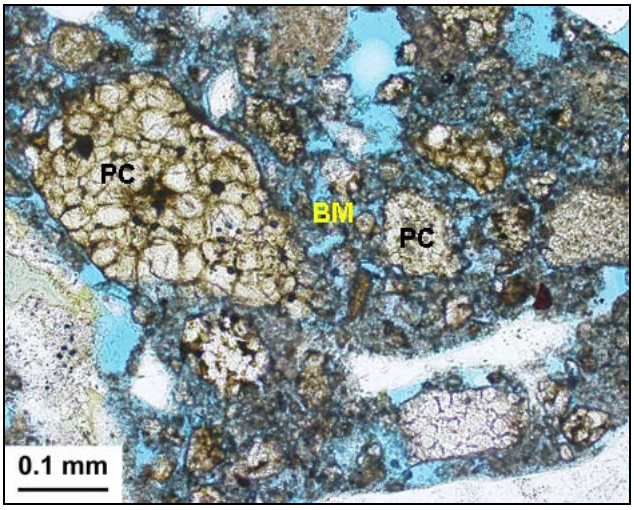


Figure 7: PPL photomicrograph illustrating the nature of the binder and its hydration characteristics. The only binder identified is a gray portland cement. Residual portland cement grains (PC) are highly abundant due in part to a lower original mix water content and in part to early evaporation of the mix water. The microtexture of the cement is consistent with the ca. 1912 construction date. While the binder matrix is adequately formed (BM), there is a distinctive microgranular quality and a high microporosity evidenced by the absorption of the dyed epoxy. Though relatively hard, the matrix is permeable.

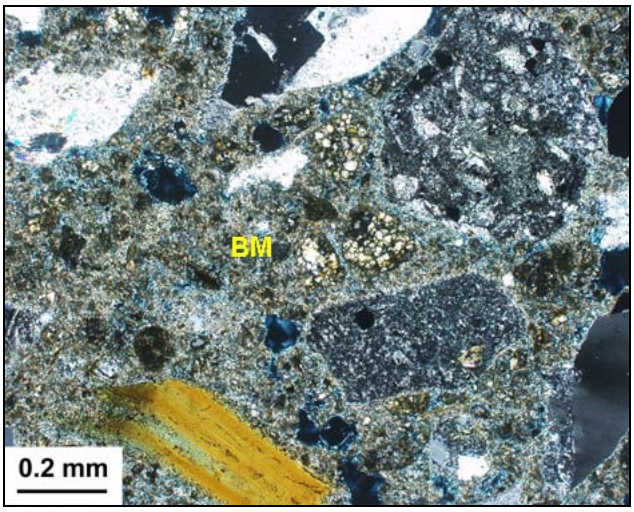


Figure 8: XPL photomicrograph. The golden color of the binder matrix (BM) indicates that it is fully carbonated. This is the only significant effect of service identified petrographically.