

MARBLE CONSOLIDATION TESTING



THE GRANT MEMORIAL

Prepared for the

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NATIONAL PARK SERVICE

National Capital Parks- Central

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MCC MATERIALS, INC.

P.O. BOX 6, COLEBROOK, CT 06021



IRVING SLAVID
PROF. NORMAN R. WEISS

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I. The Monument

The Grant Memorial, Washington, DC, is located at the east end of the Mall, at the foot of Capitol Hill. The history of its conception and creation is well documented in a rare commemorative volume (The Grant Memorial in Washington) published in 1924, found by us in the collections of Butler Library, Columbia University.¹ The site, defined as “Union Square” in a Senate Report dated January 15, 1902, was laid out by a committee composed of Daniel Burnham, F.L. Olmsted, Jr., Charles McKim and Augustus St. Gaudens,² but no monument was envisioned for this location.

The Grant Memorial Commission, created by the Hepburn Act in 1901, issued a program for a design competition on April 10 of that same year, and received submissions from 23 sculptors. The program identified two possible sites, both near the White House. Selection of the team of Henry Merwin Shrady (sculptor) and Edward Pearce Casey (architect) was made on February 4, 1903, and a contract signed on August 10. It was not until 1905-06 that the “Union Square” site was chosen for the Memorial and approved by Congress on June 30, 1906.

¹The Grant Memorial in Washington (J.W. Bryan, ed.). Washington: Government Printing Office, 1924.

²Concklin, E.F., “The Grant Memorial in its relation to the plan of the city of Washington,” in The Grant Memorial..., op. cit., pp. 27-32.

Excavation for foundations began October 7, 1907. It was originally anticipated that construction would take about 5 years. Stonework was completed in January of 1909, but the production of the bronzes, among the largest in the world, demanded considerably more time. Installation of the final piece, the equestrian Grant, was in October and November of 1920.³ The dedication ceremony was on April 27, 1922, the 100th anniversary of General Grant's birth, and 15 days after the death of the sculptor Shrady.

Edward Casey's design was executed in white marble, a fitting selection as his father was responsible (as Chief of Engineers, United States Army) for the completion of the Washington Monument two decades earlier. Casey's own essay in The Grant Memorial... tells us that:

All of the stonework of the memorial is white marble, furnished by the Vermont Marble Co., and presents a rubbed finish.

The platform is covered with blocks of marble, which, on either side of the main pedestal, surround panels paved with 12-inch square tile, 2 inches thick, of brown Tennessee marble from Knoxville.⁴

Casey mentions no particular marble name or quarry location; this issue will be discussed further below. Of note in the 1924 book are the full page photographic illustrations, showing the Memorial as it looked immediately following the dedication. Several of these photographs show distinct patterns of staining, presumably the early stages of the situation that is seen today. This is most especially true for the bases of the four lions, which were the first bronzes installed, in late January of 1909.⁵

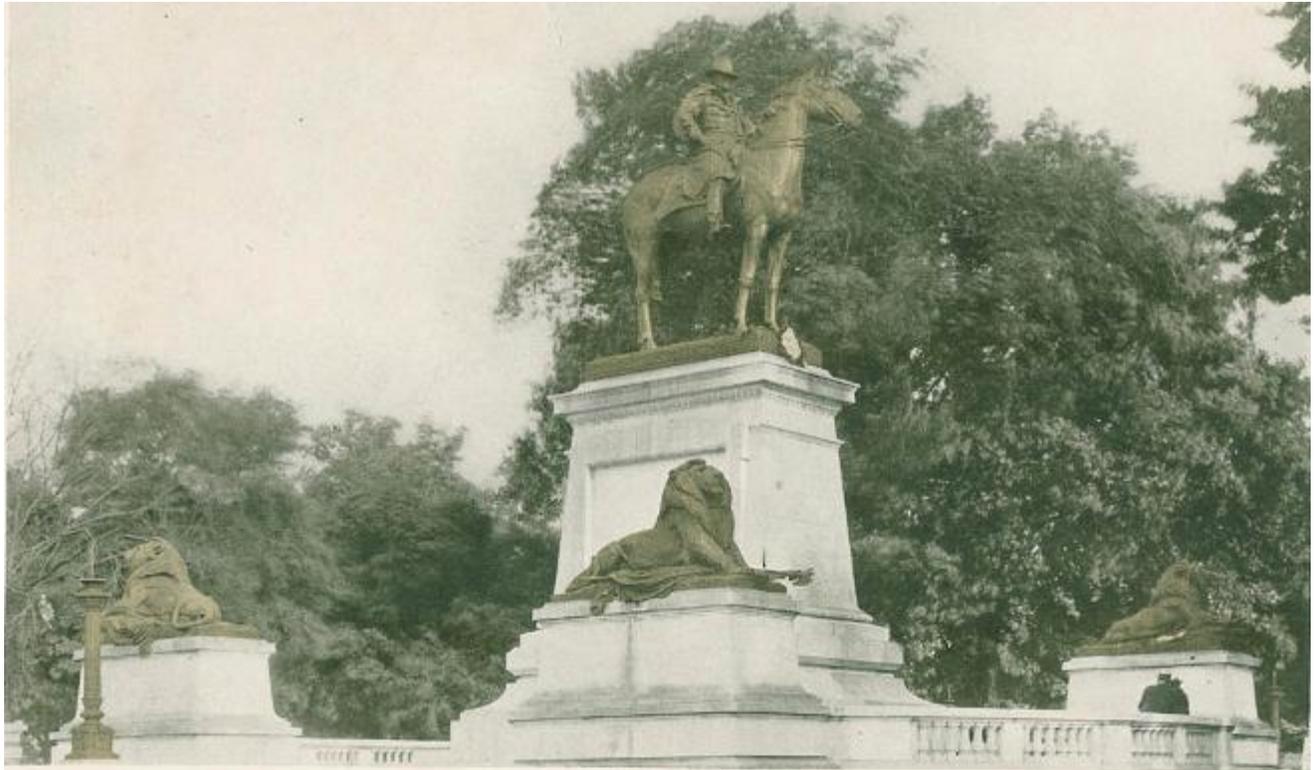
The staining of the marble of the Grant Memorial is the subject of some discussion in a 1953 National Bureau of Standards publication by Daniel W. Kessler and Ross E. Anderson.⁶ There are two accompanying photographs of the Memorial, including a close-up of a corner of the base of the Cavalry group, showing "badly cracked marble". They write that:

³Bryan, James William, "The Grant Memorial," in The Grant Memorial..., op. cit., pp. 17-26; see also pp. 53-54 in Fallows, Samuel, "The Grant Memorial Commission," in The Grant Memorial..., op. cit.

⁴Casey, Edward P., "The Architecture and Sculpture of the Grant Memorial," in The Grant Memorial..., op. cit., pp. 41-48, this text on p. 44.

⁵Bryan, James William, op. cit., p. 26; see also Fallows, Samuel, op. cit., p. 54.

⁶Kessler, Daniel W. and Ross E. Anderson, "Influence of the wash from bronze on the weathering of marble," NBS Building Materials and Structures Report 137, 1-11 (1953).



THE CENTRAL PEDESTAL OF THE GRANT MEMORIAL

Towering 44 feet above the ground, this statue of General Grant, two and one-half times life size, is the largest equestrian statue in the world. Mounted on the central pedestal and guarded at each of the four corners by a bronze lion, it forms the central portion and main theme of the Memorial

Illustration from The Grant Memorial in Washington 1924

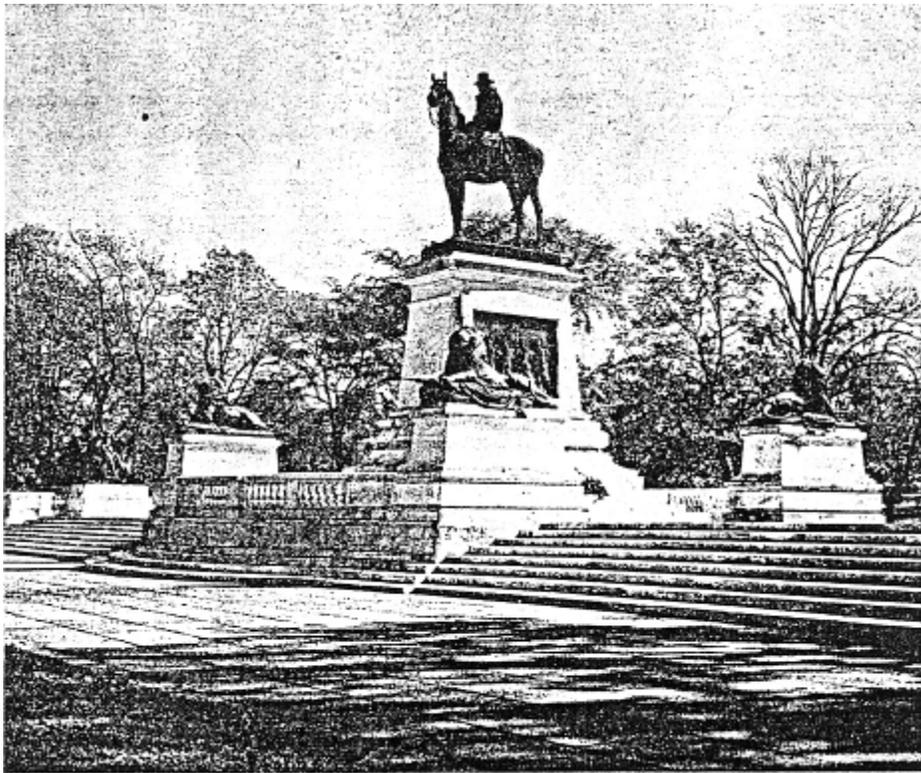


FIGURE 1. Grant Monument, Washington, D. C., from the southwest showing all but one of the bronze groups and the supporting marble.

“Several blocks have prominent brown stains, accompanied by cracking of the marble. The worst condition is shown in figure 3, but many blocks appear to be in good condition. The corner block under the south group is projecting considerably over the edge of the block below. This is believed to indicate that the injured block has undergone a swelling action.

This same marble was used in the American Red Cross Building on Seventeenth Street. Two bronze lampposts are attached to the marble cheek walls at the main entrance. One block in the north cheek wall is showing a condition of incipient cracking similar to the more advanced stage shown in figure 3.”⁷



FIGURE 3. Block of badly cracked marble under the north statuary group of the Grant Monument showing the worst condition in this structure.

Illustrations from Kessler and Anderson 1953 Figures 1 and 3

⁷Ibid.,p.7.

II. Vermont Marble

By the turn of the century, Vermont was producing more than 3 times as much marble as any other state in the nation. Writing in his Report of the State Geologist... in 1914, George Perkins stated that:

...now nearly all of the finished marble of Vermont is controlled by the Vermont Marble Company and the Green Mountain Marble Company....⁸

The Vermont Marble Company was chartered in 1880. In 1914, Perkins reported that it employed over 4,000 people and operated 25 mills, producing about 1 million cubic feet of marble for sale annually.

The mills were “fed” by 75 quarries, most of them in the marble district that lies west of the Green Mountains, in Bennington, Rutland and Addison Counties. Most of the commercial production in this part of the state is calcite marble, only occasionally interbedded with small lenses of dolomite. Despite the overall chemical similarity of most Vermont marbles, the range of colors, textures and figures that was available for architects and sculptors was enormous. In a discussion of the West Rutland quarries, Perkins commented that:

The number of varieties here and to some extent elsewhere in the state is considerable. ...suffice it so say here that nearly, or quite, one hundred distinctly unlike varieties can be obtained in the state, though some of these are seldom quarried and the Vermont Marble Company write [sic] that ‘We produce nearly fifty different varieties of marble, all of which, generally speaking, can be supplied at comparatively short notice.’⁹

Casey’s choice of Vermont for the Grant Memorial--rather than the Maryland marble used for the Washington Monument--may have been in response to the enormous marketing power of the Vermont Marble Company. In turn, it seems that the scientific professionals serving the marble industry helped promote him as a designer. Of the numerous

⁸Perkins, G.H., “History of the Vermont marble industry,” in Perkins, George H. Report of the State Geologist on the Mineral Industries and Geology of Vermont, 1913-1914. Burlington: Free Press Printing Company, 1914, pp. 161-223; this text on p. 165.

⁹Ibid., p. 167.

photographic plates that illustrate both Perkins' and T. Nelson Dale's texts in the 1914 Report..., only one building exterior is shown--Casey's Memorial Continental (DAR) Hall, "with columns of calcite marble from South Dorset".¹⁰ His marble interiors for the Congressional Library are also noted by both authors.

But Casey turned to a different marble for the Grant Memorial, apparently seeking a finer-grained material. Although the identification of white marbles is exceedingly difficult, our experimental program (see "Pre-treatment Study", below) seems to have provided two useful pieces of evidence. First, this stone is of remarkably fine texture. Second, it is mineralogically very pure. Taken together, these observations strongly suggest that the Grant Memorial was constructed of a marble called "Second statuary Rutland," quarried near West Rutland, in Rutland County. An 1897 analysis by W.C. Day reported the calcium carbonate content of this stone as 99.15%.¹¹

Second statuary Rutland was an extremely costly material, presumably because the beds are very thin. Dale reported that the cost per cubic foot, in 1910, was \$ 11.50. For comparison, white marble from South Dorset cost only \$ 2.00 per cubic foot. South Dorset was used for the construction of Carrere and Hastings' New York Public Library, and for Casey's Memorial Continental Hall. These prices were "f.o.b. at the nearest railroad for blocks of ordinary sizes in the rough."¹²

III. Pre-treatment Study

A stone sample for analysis and testing was taken from the Memorial late last year, and shipped to MCC Materials' Connecticut laboratory. It was received on November 24, 1998. It is a large fragment of a baluster (lacking the uppermost portion), measuring 16½" in height. The 7¼" square base is 2½" high. The thickest part of the turned portion of the baluster is (similarly) 7¼" in diameter.

¹⁰Plate XI, following p. 88, Dale, T. Nelson, "The commercial marbles of western Vermont," in Perkins, George H., op. cit., pp. 1-160.

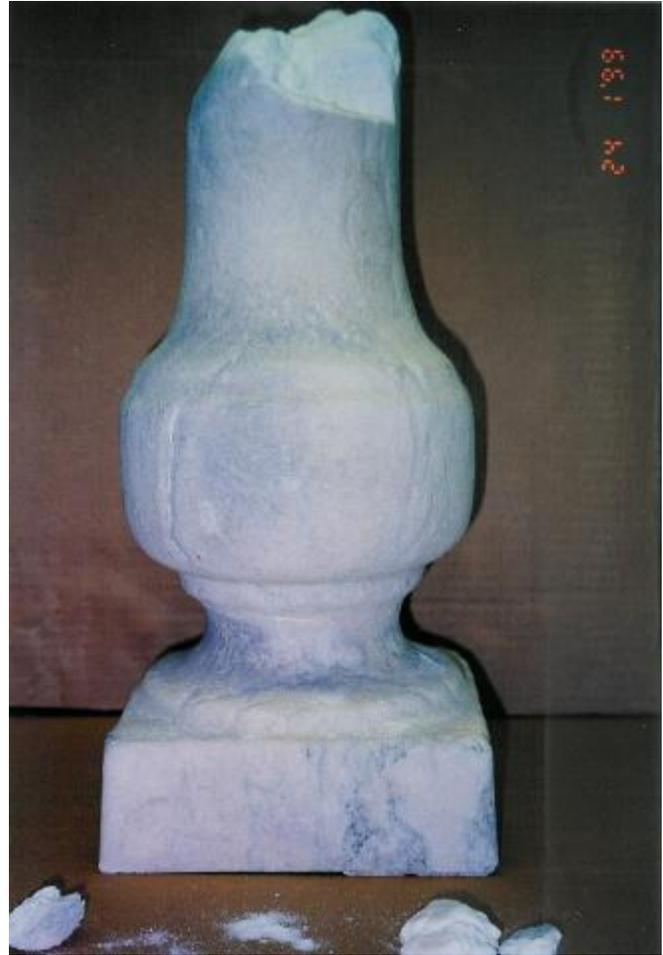
¹¹Day, W.C., in Eighteenth Annual Report..., U.S. Geological Survey, Part 5. Washington: Government Printing Office, 1897, p. 985 (reprinted in Dale).

¹²Dale, T. Nelson, op. cit., p. 145.

The entire fragment is heavily weathered and discolored. The upper one-third was fragile, with the topmost portion exhibiting extreme “sugaring” and losses. A considerable amount--550 grams--of loose debris was able to be collected. This material was run through a set of U.S. Standard Series sieves using a Tyler Ro-Tap shaker (Model B, Tyler Industrial Products, Mentor, OH). Separated into individual size fractions, the rock particles were examined under a Nikon SMZ-1 stereobinocular microscope at 7 to 30X magnification.

Virtually all particles passing a 100 screen (.15 mm or less) were single crystals of remarkable transparency; 88% of these were larger than .07 mm. Many of the smallest of those in the 50/100 fraction were also single crystals, but some in that size range (.15 to .30 mm) or larger were rock fragments. Average grain diameter was thus estimated at .10 to .25 mm. This can be classified by Dale’s 1914 system as Grade 3 (“Fine”), which includes one of the finest statuary grades of marble quarried in western Vermont.¹²

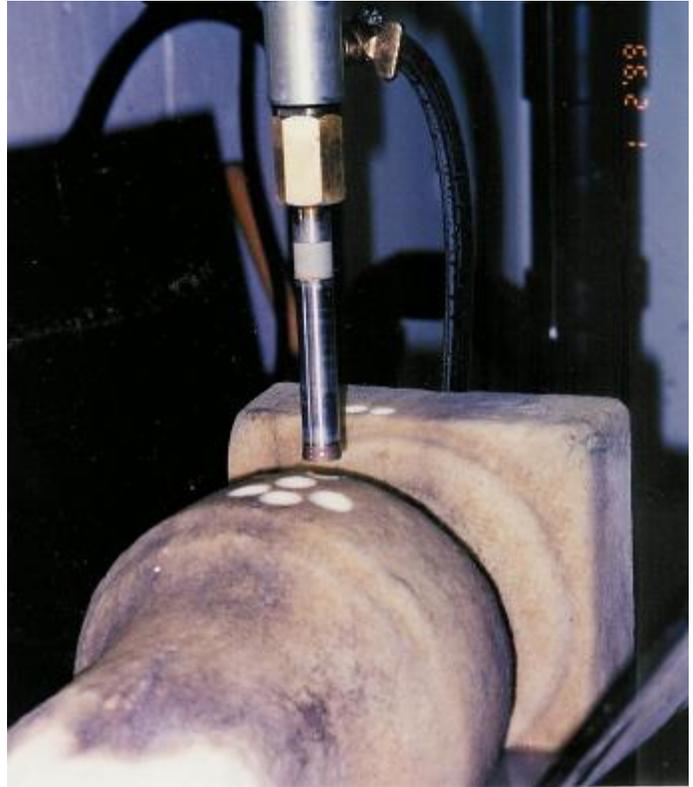
A small amount of loose rock material was pulverized and digested with aqueous oxalic acid, precipitating the calcium ion as calcium oxalate. The acidified supernatant liquid was tested for magnesium ion with 0.1% (w/v) Magneson reagent (4-(p-nitrophenylazo) resorcinol) in 0.25M NaOH. One drop of the reagent is followed by 5 drops of 6M NaOH. The violet color, a negative test result, identifies the rock as a calcite marble, typical of the white marbles of western Vermont.



**The baluster fragment as received
in MCCM Laboratory**

¹²Ibid., pp. 43-47.

Coring of the base and the lower turned portion ("center") of the baluster was done with a standard 14" Delta bench-top drill press operating at 460 rpm (Delta Industrial Machinery Corp., Pittsburgh, PA). Our press is fitted with a 4" long by 14 mm. ID impregnated core drill by Lunzer Diamond Associates (Saddle Brook, NJ), attached via a water swivel chuck that permits bit cooling and flushing of cutting debris. Coring by this method yielded approximately 70 "mini-cores," each 13.7 mm. in diameter, typically 20 to 65 mm. in length.



Drilling of cores from the center of the baluster



Cores taken from the base of the baluster

Two of these cores were shipped by us to Dr. Allan S. Gilbert of Fordham University, for petrographic examination. (Preparation of thin sections parallel to the core axis was done by Mrs. Donna Organist, of Newark, DE.) Examination under the polarized light microscope revealed the high mineralogical purity of the rock, with a calcite content described by Dr. Gilbert as “well over 99%”. He states that the “average crystal diameter is quite small...”, with clear grain boundaries, confirming the findings of our screening experiments. He reports that 85% of the grains were smaller than .30mm. Concerning the slightly weathered surface of each core, he notes from the thin sections that:

Some crystals revealed incipient dissolution at the surface, indicated by erosive flattening or attrition at their outer boundaries, but some pitting was also observable, due either to complete dissolution or popping out of individual surface grains.¹⁴

Three cores from the baluster base were utilized to determine specific gravity and % absorption, as per ASTM C 97. The cores were dried under an infrared heat lamp for 24 hours, then air dried for several weeks, and weighed on an A&D HR-120 electronic balance (A&D Engineering, Inc., Milpitas, CA) to the nearest 0.1 mg. Apparent volume was computed for each core from measurements taken with a digital micrometer (Mitutoyo SC-6”), and the specific gravity computed. The mean value for the three cores is 2.642 g/cm³. This is in compliance with the physical requirements for exterior marble as stated in ASTM C 503-67, that is, a minimum specific gravity of 2.60 for calcite marble.¹⁵

These weighed cores were then submerged in distilled water at room temperature (20-22 °C) for 48 hours, to determine % absorption.. They were re-weighed at the end of the soaking period; the difference between the wet and dry weights (the quantity of water absorbed) is divided by the dry weight, and this value multiplied by 10² to convert to percentage. The mean value for the three cores is 0.40%. The C 503 requirement is a maximum of 0.75%.¹⁶

¹⁴Gilbert, Allan S., “Petrographic report to MCC Materials, Inc. on marble cores from the Grant Memorial, Washington, D.C.,” dated April 16, 1999, 1 p.

¹⁵The C 503 physical requirements for exterior marble are summarized in Table C.5., in “Appendix C: Stone Specifications (ASTM),” in Winkler, E.M. Stone in Architecture: Properties, Durability. Berlin: Springer-Verlag, 1994, p. 294.

¹⁶Ibid., p. 294.

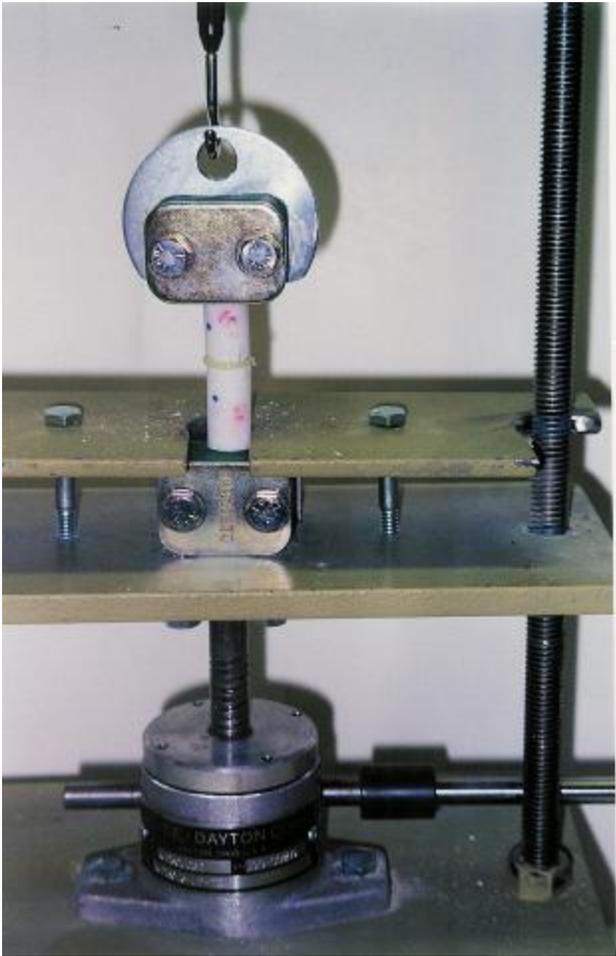
The majority of the longer cores were utilized in the design of a novel experiment to determine the cohesive strength of the weathered surface. For control (unweathered) data, five cores from the baluster base were tested in direct tension, using a modification of ASTM D 2936-95, eliminating the gluing of end caps, and instead securing the specimen with plastic pipe clamps.¹⁷ These cores ranged from 62 to 73 mm. in length. Measurement of the applied tensile load was with an Imada PS 100 Mechanical Force Gauge (0.5 lb. resolution, Imada, Inc., Northbrook, IL), on a custom-built test stand. The five specimens averaged 21.0 ± 3.7 lbs. of load at failure.



Surface-coupled cores secured with pipe clamps

Cores from the base and center of the baluster were then examined visually. If the weathered surfaces were largely intact (that is, they survived the coring process), pairs of cores were precisely aligned and adhered--surface to surface--with Abocast 8101-5, a two-part thixotropic epoxy adhesive (Abatron, Inc., Kenosha, WI). Each surface-coupled pair was then tested in tension to assess surface soundness. "Breaks" within 3 mm. of the glue line were considered to provide useful data. The average tensile force to cause failure in the base specimens was 7.7 ± 1.2 lbs. The more fragile center specimens failed at 4.4 ± 0.8 lbs.

¹⁷"Standard test method for direct tensile strength of intact rock core specimens (Designation: D 2936-95)," in Vol. 04.08, Annual Book of ASTM Standards. Philadelphia: American Society for Testing and Materials, 1996.



Coupled cores mounted on test stand



Testing surface-coupled cores in tensile failure

IV. Experimental Treatment

The chemical treatment of building stone has made enormous advances since the first American patent for masonry preservation was granted to J.C. Coombe in 1863.¹⁸ Methods based on paraffin, linseed oil and tung oil were especially popular at the turn of the century. They were tried on our most problematic stones--brownstones and crystalline marbles--with relatively little long-term success. By the early 1970's, there were numerous publications describing the experimental treatment of marble with epoxies and with barium hydroxide, but little or none of this laboratory research seems to have been able to be translated into successful field practice.¹⁹

Much of the current work with masonry consolidants in this country is with ethyl silicate formulations introduced from Germany by ProSoCo., Inc. and marketed as Conservare OH and H. They were first used on American buildings in the period 1985-88, and continue to be enormously important for the treatment of sandstone.²⁰ Unfortunately, the results achieved for sandstone have not been equaled for carbonate rocks. In fact, carbonate minerals have recently been shown to be anti-catalytic to the formation of silicate polymers from ethyl silicate monomer.²¹

Ethyl silicate treatment of marbles is occasionally successful, most especially when there is a considerable quantity of non-carbonate secondary minerals present. This is certainly not the case for the marble of the Grant Memorial. Concerning a gray marble quarried in the New York City area, Jerome et al. have recently written that:

¹⁸Coombe, J.C., "Improvement in indurating and preserving stone, cements, wood, etc., U.S. Patent No. 38,287, April 28, 1863.

¹⁹For a review of this subject, see Weiss, Norman R., "Chemical treatments for masonry: an American history," APT Bulletin, XXVI (4), 9-16 (1995).

²⁰Interest increased with the publication of the first testing on an American building stone: Zinsmeister, Klaus J.H., Norman R. Weiss and Frances R. Gale, "Laboratory evaluation of consolidation treatment of Massillon (Ohio) sandstone," APT Bulletin, XX (3), 35-39 (1988).

²¹Goins, Elizabeth Stevenson, George Segan Wheeler and Sandra A. Fleming, "The influence of reaction parameters on the effectiveness of tetraethoxysilane-based stone consolidants: solvent effects," in Methods of Evaluating Products for the Conservation of Porous Building Materials in Monuments. Rome: ICCROM, 1995, pp. 259-274; see also Goins, Elizabeth S., George Segan Wheeler and Mark T. Wypyski, "Alkoxysilane film formation on quartz and calcite crystal surfaces," in Proceedings of the 8th International Congress on Deterioration and Conservation of Stone (J. Riederer, ed.). Berlin: Moelter Druck und Verlag, 1996.

...ethyl silicate was chosen as the consolidant for the marble of the buttresses and parapet. This consolidant is rarely recommended for the treatment of coarse-grained crystalline marbles, but the unusual composition of this stone, with a relatively high percentage of silicate minerals, allowed for its successful use.²²

Late last year, the principals of MCC Materials, Inc. applied for a United States patent for a new method for the treatment of alkaline calcareous masonry materials, especially limestones and marbles. This invention (provisionally called HCT) is based upon the formation of a well-adhered conversion layer, by chemical reaction, on the carbonate mineral surfaces. Intergrowth of the conversion layer at points of grain contact results in some consolidating effect, and the new layer is reasonably acid-resistant. As it is hydroxy-functional, it provides for the attachment of ethyl silicate consolidants and silane water-repellents.

Two extremely fragile hand specimens from the top of the baluster were treated with a prototype version of HCT at pH = 3.9. (No cores could be successfully taken from this portion of the sample.) Treatment was by immersion, 3 applications with drying between, followed by a "stabilizing rinse" that eliminates any excess reactant by precipitation. A very noticeable strengthening effect was observed upon drying, although the extreme "sugaring" of the specimens prior to treatment made quantification of the improvement impossible.

Several cores from the base and center of the baluster were treated with this version of HCT. Introduction of the liquid was by capillarity, through the weathered surface. The program of treatment was three 30 second applications with drying in between, followed by a one minute capillary treatment with the "stabilizing rinse". No alteration of color or gloss was noted. After 72 hours of air drying at room temperature, pairs of treated cores were surface-coupled with the epoxy adhesive, and were tested in tension, as described earlier.

The mean value for base cores after capillary treatment was 17.2 ± 2.1 lbs. This represents a strength increase of more than 120% from the untreated value. A more reasonable way to regard the data may be to calculate both treated and untreated values in

²²Jerome, Pamela S., Norman R. Weiss, Allan S. Gilbert and John A. Scott, "Ethyl silicate as a treatment for marble: conservation of St. John's Hall, Fordham University," *APT Bulletin*, XXIX (1), 19-26 (1998).

terms of the control data, which represents the tensile strength as measured a considerable distance (more than 20 mm.) from the weathered surface. With this approach, the capillary treatment of weathered base cores “returns” them to 82% of their (presumed) original soundness; in their untreated condition, they were at 37%.

Capillary-treated center cores averaged 7.6 ± 2.2 lbs., a strength increase of more than 70% versus the untreated pairs. (There were no controls for the estimation of unweathered strength from this portion of the baluster.) Some additional center cores were capillary treated with one cycle of Conservare OH as per ProSoCo’s current laboratory protocol, or HCT followed by OH. OH treatment brought the required breaking load for surface-coupled pairs up from 4.4 to 5.5 lbs., but specimens treated with HCT followed by OH averaged a more substantial 9.9 ± 2.8 lbs.

V. Recommendations

Because of the purity of the graded rock particles derived by screening from the shipping debris, it is our intention to include this material in a set of laboratory experiments begun several weeks ago. We have (until now) been working with graded (crushed) Stockbridge dolomite to develop an improved version of HCT at pH = 4.6. Our methodology has involved the measurement of pH versus time (as a measure of reaction progress) to study the impact of changes in solution chemistry.

The improved treatment exhibits reduced evolution of carbon dioxide during reaction with calcite powders passing a 200 screen. This represents a limiting of dissolution of the very smallest grains during formation of the conversion layers, and could increase penetration of the treatment by reducing back pressure of gas in the pore network. With the same experimental design, we are now evaluating the effectiveness of the improved treatment against dissolution by aqueous carbonic acid. Most of this work is with larger aggregates, treated in vitro at a variety of liquid:solid ratios.



Sample area examined during our January 1999 site visit

We visited the site on January 29, 1999.²³ In the light of the encouraging laboratory research results of the past few months, we believe that we can now recommend that a well-documented prototype field treatment be undertaken. This should be done in one or more limited areas with the newer formulation. Details of the exact size and location of the installation would be worked out with National Capital Parks professional staff. Monitoring of quantities used during the field treatment will permit realistic evaluation of coverage; it was not possible to make such measurements with the mini-cores.

Review of the test area(s) should be undertaken after 6 months, and again after 1 year. If there is no recent condition survey of all stonework of the Memorial, this should be done in conjunction with the treatment review, to develop a quantified scope of work for a full program of stone conservation. If there is an established plan of scheduled maintenance for the bronze sculptures, it must be coordinated with any work that is envisioned for the marble.

²³Given the variable physical condition of the stone, it is disturbing that a discussion of the Memorial--as if all of the marble were essentially unweathered--is in a United States Geological Survey web site as follows: "The most notable stone deterioration visible here is the green stain on the marble bases, caused by runoff from the weathered bronze. The green stain does not damage the marble, but it is unattractive, and there are no methods currently available to remove the stain without damaging the marble." This comment is presented in <http://pubs.usgs.gov/gip/acidrain/site3.html>

The full conservation program will certainly give priority to cleaning, most especially the issue of stain removal. We recommend the testing of ammonium carbonate poultices, in conjunction with a complexing agent such as dicalcium EDTA. This work could be a cooperative effort with ProSoCo's scientific staff; they have already expressed an interest in the project, and are involved with us in the field testing, licensing and manufacturing of HCT. In this way, any potential problems of adverse interactions of cleaning residues and the consolidation treatment can be anticipated and avoided.

Other aspects of the conservation program may include pointing, re-setting and limited replacement of stone. We are not aware of quarries in the West Rutland area producing the "Statuary Rutland" stone, but the new owners of Vermarco (Vermont Marble Company) have proved to be extremely helpful to conservators, and may be able to supply some previously stockpiled material.

In summary, our laboratory investigation has strongly suggested that a new treatment for marble, utilized in conjunction with Conservare OH, has the potential to stabilize weathered stone at the Grant Memorial. We urge that there be an opportunity to test this premise in a field application of reasonable size. The risk of an experimental treatment on badly deteriorated marble is modest. The possible benefit to this and other Washington sites, including the Lincoln and Jefferson Memorials, is considerable.

Norman R. Weiss
and
Irving Slavid

May 21, 1999