

A Structural Analysis of the Performance of
Nondestructive Testing Methods

Second Bank of the United States

Independence National Historical Park

Philadelphia, PA

UPE-005

Prepared By:

Ryan-Biggs Associates, P.C.
University of Pennsylvania Architectural Conservation Laboratory

Prepared For:

National Park Service
Cultural Resource Management Office
Independence National Historical Park



December 27, 2011

Mr. Frank G. Matero
University of Pennsylvania
115 Meyerson Hall
210 South 34th Street
Philadelphia, PA 19104

**Re: Second National Bank
Philadelphia, PA
Ryan-Biggs Project 9644**

Dear Frank:

At your request, Ryan-Biggs has performed a study of the Second National Bank in Philadelphia at the Independence National Historical Park. Our study included nondestructive testing and structural analysis of selected marble columns. This report documents the results of our study.

Objectives

The scope of the study included:

1. Reviewing available drawings and investigative documentation for the building, which you provided.
2. Testing several columns using:
 - a. Surface penetrating radar.
 - b. Impact echo.
 - c. Pulse velocity.

The purpose of these tests was to determine the ability to assess the location of incipient surface spalls and cracks that may extend through the columns.

3. Analyzing the marble columns based upon the drawings provided.

Testing

The primary technique employed during testing was surface penetrating radar. Using electromagnetic signals, radar was introduced in 1904. It was developed primarily for use in ground applications (ground penetrating radar or GPR). Since the 1970s, the use of GPR has grown, and the equipment is continually improving. Now, GPR has been extended for use with other materials and is commonly referred to as surface penetrating radar or SPR. SPR detects changes in the electromagnetic properties of materials such as dielectric permittivity, conductivity, and magnetic permeability, which in stone are a function of the stone material, water content, and bulk density. Our primary interest is the change in density that results from voids and the corresponding veining.

The other two test methods, impact echo and pulse velocity, are based upon acoustic waves. Impact echo is based upon impact-generated stress waves (P-waves). These waves propagate through stone and are reflected by internal flaws and external surfaces. Pulse velocity measures the time a sonic wave reflects and returns to the receiver.

1. Surface Penetrating Radar

The fluted columns of the Second National Bank presented challenges for this test method. SPR testing equipment includes a transmitter and receiver that should be electromagnetically coupled to the stone columns. This required a molded medium with one side fluted to closely match the fluted configuration of the column and the other side providing a smooth outer surface for the equipment to be rolled over (Photograph 1). After performing tests with several medium materials, scans were obtained using a gypsum-based medium with a gypsum board outer surface. The medium was prepared by John Hinchman. A key criterion for the medium was that it have a dielectric constant similar to the stone. The material used was still moist and not fully cured at the time of scanning. In future attempts, the medium will need to be dry.



Photograph 1 - Molded medium for SPR.

The medium was supported and strapped to a column. A paper target with a grid was attached to the smooth outer surface of the medium (Photograph 2). This method allowed one 12-inch by 12-inch scan that extended into the stone and covered most of two fluted areas. Since there are 20 flutes, 10 scans are required for each column at each level.



Photograph 2 - SPR scanning.

The scans were performed with a 1.6Ghz antenna from Geophysical Survey Systems, Inc. (GSSI). The equipment represents the current state of the art in SPR equipment; the manufacturer provides software with this antenna. The software allows the user to display a slice from the scan in any of the x, y, or z axes.

The software does not digitally join individual scans together. Figure 1 shows 10 individual scans from Column 7 that were printed and manually pasted together to represent a horizontal slice of the column. Photograph 2 was taken at Column 3 on the south elevation. Drawing S-1 is attached with this information.

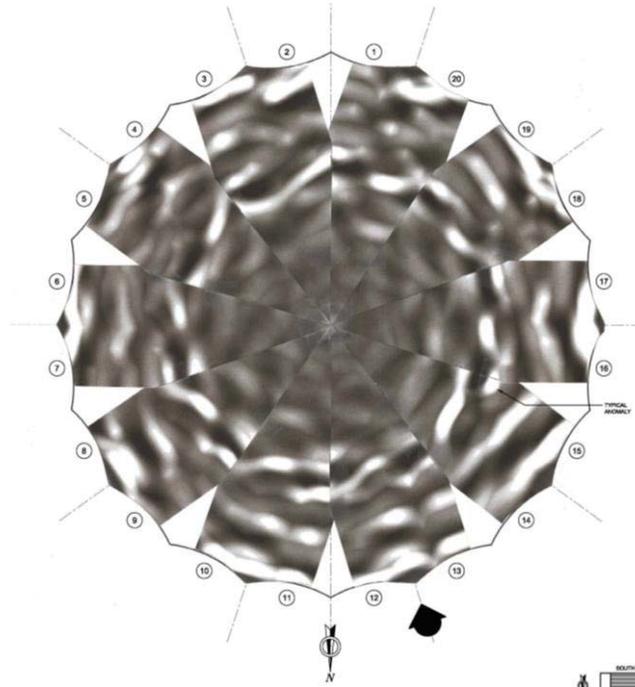
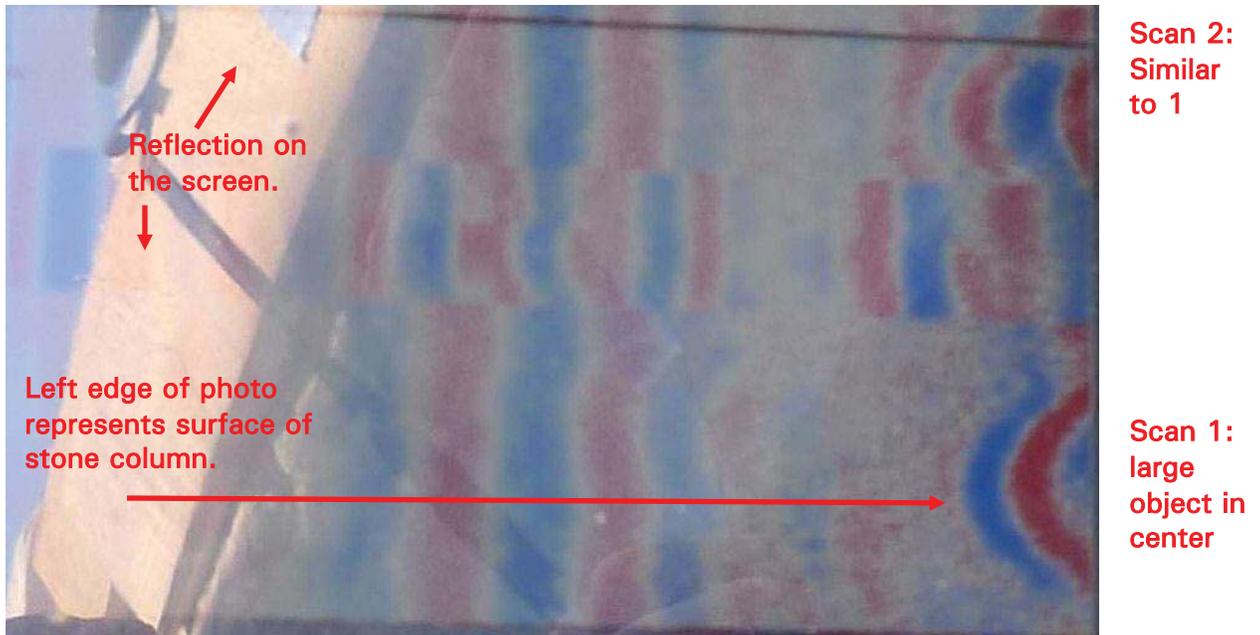


Figure 1 - SPR scan slice.

The 1.6Ghz antenna has a wavelength of approximately 3 - 5 inches; the wavelength is equal to the velocity in the stone divided by the frequency. In concrete, the accuracy of the scan is diminished beyond a depth of about 18 inches. The technology with masonry is still evolving. With interior veining, we are uncertain as to the depth of accuracy.

There are several antennas available for SPR. An additional set of scans was performed with a 900Mhz antenna. The manufacturer does not provide software for this antenna. Scan results are only available as individual views. Photograph 3 was taken of the screen showing two vertical scans at the joint between two drums. Unfortunately, the photograph picked up some reflection of the column itself. The wavelength is approximately 5.5 inches and the resolution is not as clear as the 1.6Ghz antenna. However in both scans, we noted that there is a large spherical object in the center of the joint. There is historical information that the architect, William Strickland, used a cannonball to join the column drums. It is likely he did so for this building as the 900Mhz antenna was able to clearly identify a center object. That same clarity is not evident in the scans performed with the 1.6Ghz antenna.



Photograph 3 - Scan at joint showing large object at center.

2. Impact echo

The equipment for this method includes an impactor and a receiver. The receiver must be in contact with the stone column while the impactor strikes the stone, sends an acoustic signal into the stone, and reflects back to the receiver when it encounters a surface or a defect.

The fluted columns presented two challenges for this test method. Because the receiver must be in acoustic contact with the stone, use of a petroleum-based couplant is recommended. While, staining can often be avoided by using a waxed-paper isolator, use of this couplant would have caused staining.

The second issue is the curvature of the stone. The equipment receiver is flat and did not conform to the stone shape. Because of the difficulties developing a molded medium for the SPR method, additional effort was not expended to develop a suitable molded medium for impact-echo testing.

3. Pulse velocity

The equipment for this method includes a transmitter and a receiver. Both must be in contact with the stone column while the transmitter strikes the stone, sends an acoustic signal into the stone, and the receiver records the time of transmission. This basically records the speed of the wave through the stone. Provided the wave speed is determined in an uncracked portion of the stone, a tomographic representation of the column could be obtained from various readings on the column. The veining was expected to cause difficulties in obtaining consistent results.

The fluted columns presented the same challenges for pulse-velocity testing as for the impact-echo method. Additional effort was not expended to develop a suitable molded medium for this test method.

Correlation of Testing to Visual Survey

John Hinchman provided graphical assistance mating the radar scan of the slice with the stone conditions observations made by University of Pennsylvania students. Figures 2 and 3 are two of the graphics that show the visual observations that have already been reported for different locations on the column drum.

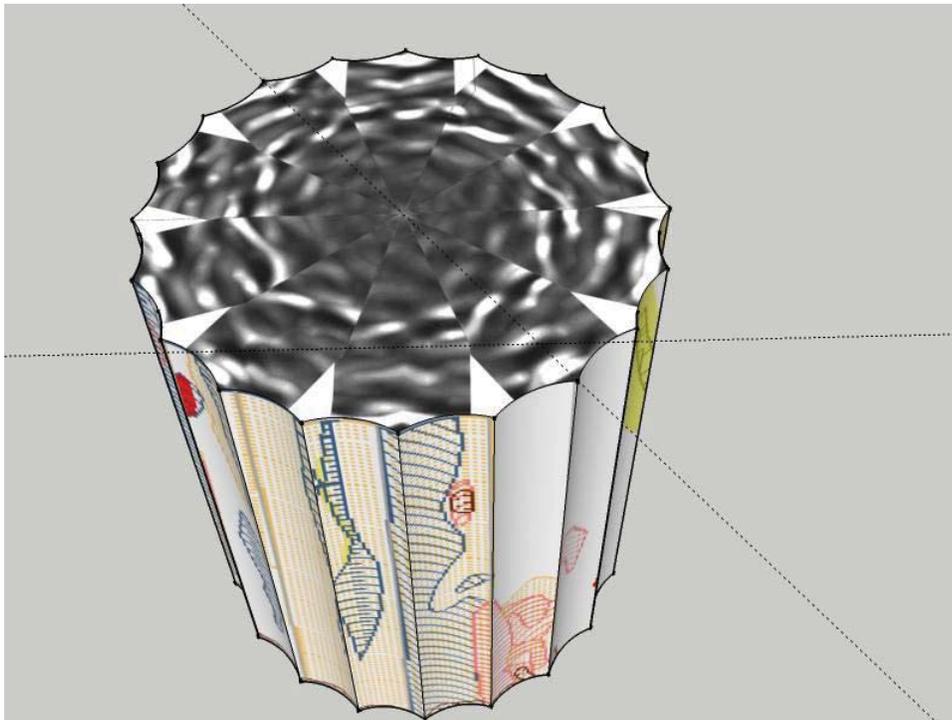


Figure 2 - Scan with visual results.

There is correlation of the surface defects with the scans. Internally, we see what appear to be radially-oriented anomalies (white areas). While they appear discontinuous from one scan to another, this can be a result of the accuracy of pasting multiple scans together. Digital improvements to the software could correct this.

From the scan slice, there does not appear to be any clear veining straight through this column section. However, the white areas likely represent a reduced density that shows up as an anomaly and could be veining or internal fracturing. These need to be confirmed.

Based upon the scan results, internal weakness is a concern for the long-term stability of the columns.

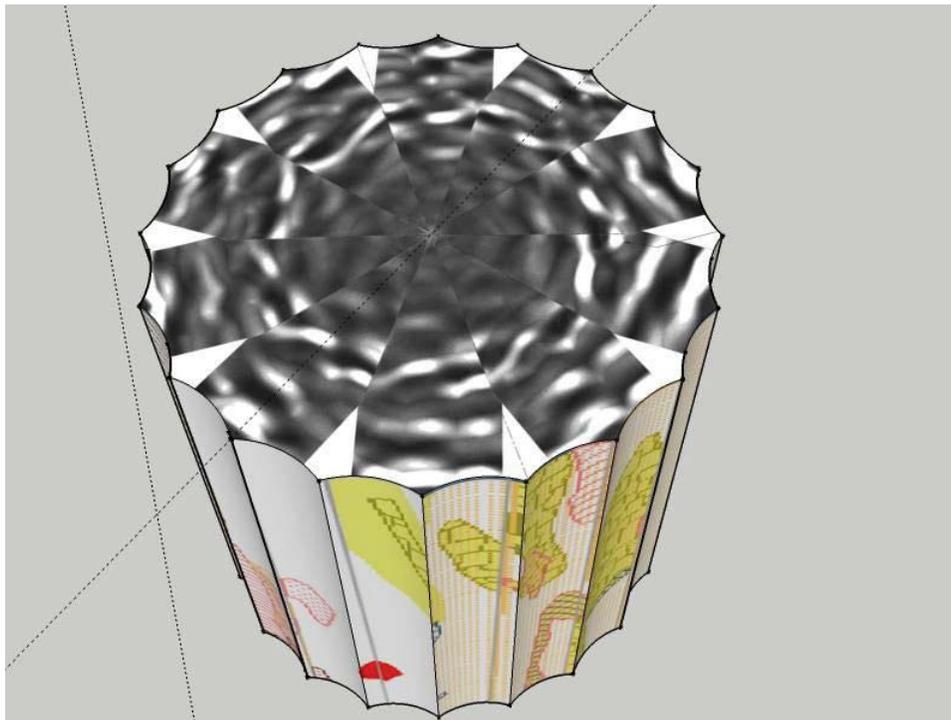


Figure 3 - Scan with visual results.

Figure 4 is a graphic of the relative location of the transmitter and receiver within the equipment. The area above the signals generally does not record accurately; usually the top 2 to 2.5 inches. For this project, that area is mostly in the molded medium. Thus, one unexpected result of using the molded medium is that the scanning is generally accurate on the surface of the columns because the medium places the surface of the stone below the area of poor reception.

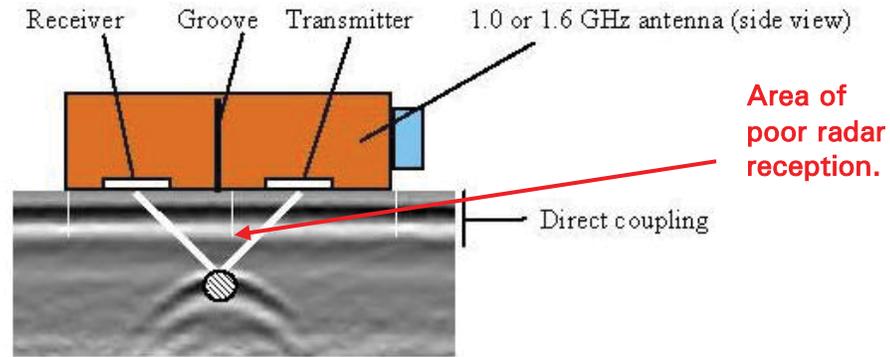


Figure 4 - Graphic of radar transmitter and receiver.

Structural Analysis

Each fluted column is 30 feet tall with an approximate diameter of 44 inches. Assuming the marble has a density of 160 pounds per cubic foot (pcf), each column weighs nearly 40,000 pounds. The stone weight produces a stone stress at the base of the columns of 33 pounds per square inch (psi).

The construction details of the roof and pediments were not available. An assumption was made that the pediment was constructed of 2-foot-thick stone and the roof is a stone slab covering on brick arches. Based upon these assumptions, the stress in the stone from the roof and pediment is approximately 93 psi. With the column weight, the total stress would be 127 psi.

The compressive strength of the marble usually is 10,000 to 13,000 psi. Conservatively assuming the compressive strength of the marble in the existing columns is 6,000 psi, the actual stress is less than 2.5 percent of the compressive strength. The design of modern masonry often approaches 25 percent to 33 percent of its compressive strength.

The height to radius of gyration ratio (h/r) for a column is an indication of the buckling potential for the column if it is in good condition. For these columns, the h/r is approximately 13; h/r values less than 20 generally are not susceptible to buckling.

The columns are lightly loaded and buckling would not be a concern if the columns were intact. Unfortunately, they are not. The stone veining or density changes appear throughout the columns. In addition, the veining for some of the drums is oriented slightly angular from vertical. This orientation can lead to column failure if the veining surface weakens, splits, and fails.

Conclusions

1. The SPR and associated software were not developed for this application. The manufacturer is aware of our need for software and hardware improvements which would make the scanning easier for round and fluted columns.

2. While the SPR scanning appears to be moderately successful, the weak areas within the stone need to be confirmed. Based upon the scan results in Figure 3, there appear to be internal flaws that weaken the columns.
3. The molded medium was fairly tight to the columns. We don't know if the moisture in the medium had a detrimental effect on the scanning.

Recommendations for Next Phase

1. Obtain a piece of stone from the building or the original quarry and perform radar scanning. Using a flat piece, perform scans with and without the medium. This might lead to a change in the medium for subsequent scans.
2. After these scans are complete, perform destructive testing to determine the condition of the scanned white images and changes in the material. This information can be correlated back to the column scans.
3. Test a sample of the stone to determine the compressive strength of the stone columns.
4. Scan a thin slice of the stone using X-ray to see if there is a distinct difference between the radar and the X-ray signature. While X-ray of the columns is not feasible, the comparison of a thin slice may be useful.
5. Perform multiple radar scans on the columns. The higher areas would require scaffolding to form a work platform around each column to be scanned. This would allow slices to be made in multiple locations.
6. Develop a temporary banding reinforcement for selected drums. This method would be non-invasive, temporary, and reversible. However, it will have an aesthetic effect on the columns.
7. Develop a medium for impact-echo and pulse-velocity tests. Perform testing for comparison with radar.

If you have questions with regard to this report, please call our office.

Sincerely,

RYAN-BIGGS ASSOCIATES, P.C.



David T. Biggs, P.E., S.E.
Principal Consultant

DTB/jed/9644-Letter Report

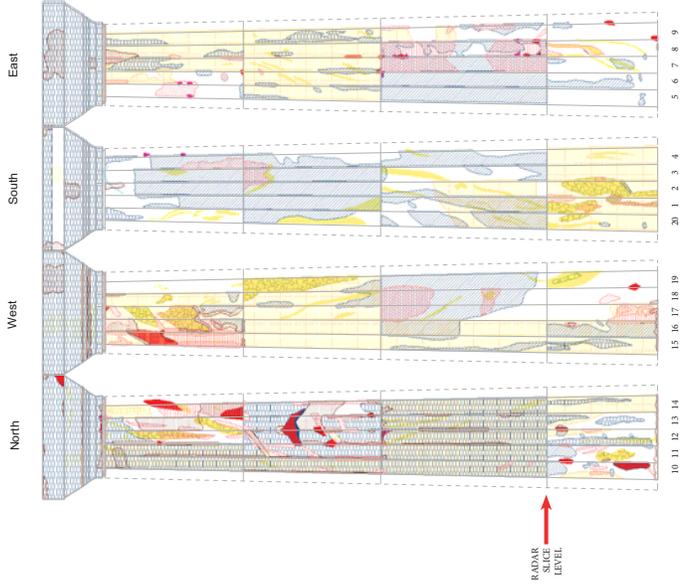
Attachment: Drawing S-1



① SURFACE PENETRATING RADAR TEST COLUMN 7 SOUTH ELEVATION

- NOTES:
 1. DATE: OCTOBER 5, 2011 FOR DR. BRANK MATKO, UNIVERSITY OF PENNSYLVANIA.
 2. OWNER: UNIVERSITY OF PENNSYLVANIA, 3701 MARKET STREET, PHILADELPHIA, PENNSYLVANIA.
 3. COLUMN: PENNSYLVANIA MARBLE, DIAMETER APPROXIMATELY 3'-6".
 4. COLUMN: PENNSYLVANIA MARBLE, DIAMETER APPROXIMATELY 3'-6".

Existing Surface Conditions
 Column Number Seven



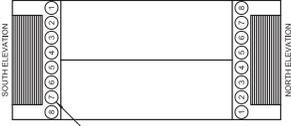
- CONDITIONS LEGEND
- Open Joint
 - Deteriorated Joint Mortar
 - Major Crack
 - Medium Crack
 - Network Map Cracking
 - Fracture Map Cracking
 - Contour Scaling
 - Differential Erosion
 - Incipient Spalling
 - Dimensional Loss

- Filled Crack less than 1/4"
- Filled Crack greater than 1/4"
- Repointing
- Chemical Efflorescence
- Treatment Coating
- Stone Releasing
- Stone Ductman
- Stone Unit Replacement
- Composite Repair
- Substrate
- Foliation Orientation

- Intrinsic Metallic Staining
- Extrinsic Metallic Staining
- Non-Intrinsic Staining
- Micoflora
- Efflorescence
- Encrustation
- Deformation/Displacement
- Mineral Inclusion
- Defective Mechanical System
- Balling Remnant

② SECTION
 S1 SCALE: 3" = 1'-0"

TEST COLUMN
 SCANS TAKEN AT JOINT
 SECOND DRIVING ABOVE
 LANDING



LOCATION PLAN
 NOT TO SCALE

SHEET NO. **S1**

REVISIONS	DATE	BY	CHK

December 6, 2011
 DATE: DFT | DMC: DFT | DMC: DFT

SURFACE PENETRATING
 RADAR TEST COLUMN 7
 SOUTH ELEVATION
 AND SECTION

PHILADELPHIA, PENNSYLVANIA
SECOND NATIONAL BANK

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