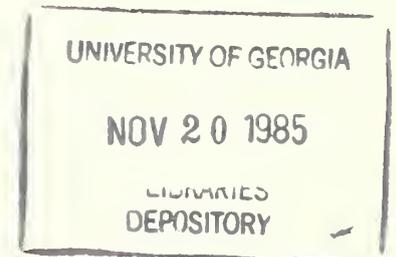


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*Using Photogrammetry
to Monitor
Materials Deterioration
and Structural Problems
on Historic Buildings*

*The Dorchester Heights
Monument:
A Case Study*



**U.S. Department of the Interior
National Park Service
Preservation Assistance Division**

Frontispiece:

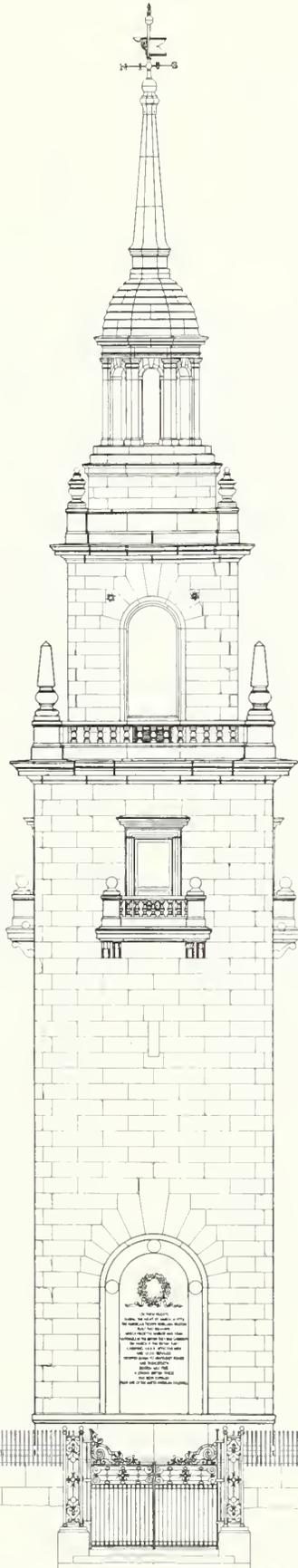
Historic American Buildings Survey drawing of the west elevation, Dorchester Heights Monument, Boston, Massachusetts. Photographed June 8-9, 1982, with a Wild C120 stereometric camera. Plotted and delineated by Angela J. Schiller.

CONDITIONS NOTE

THIS DRAWING SHOWS THE CONDITION OF THE MONUMENT ON JUNE 9-10, 1982 ONLY THOSE CONDITIONS VISIBLE IN THE STEREOPHOTOGRAPHS ARE SHOWN



MANY OF THE INDIVIDUAL MASONRY UNITS HAVE BEEN PUSHED OUT OR HAVE SHIFTED. DOCUMENTATION OF THIS MOVEMENT IS CONTAINED ON THE ORIGINAL PENCIL DRAWING PRODUCED BY THE STEREOPLOTTER



WEST MONUMENT ELEVATION
(SEE WEST ELEVATION OF TOWER BASE, SHEET NO 3)



PHOTOGRAPHED JUNE 9-10, 1982 WITH A WILD C20 STEREOGRAPHIC CAMERA (6/7/1162) PLOTTED ON A WILD A40 AUTOGRAPH BY ANGELA J. SCHILLER DELINEATED BY ANGELA J. SCHILLER, 1982 DENNETT, BUESCH & ASSOCIATES, LTD IOWA CITY, IOWA

Foreword

This report proposes that close-range photogrammetry is useful and cost-effective in monitoring the physical condition of historic masonry structures, and especially of those whose scale, height, location or configuration make access for normal methods of inspection difficult.

This case study is an outgrowth of recording the Monument at the Dorchester Heights unit of the Boston National Historical Park by the Historic American Buildings Survey (HABS). Stereo photogrammetry was used in lieu of costly scaffolding as an effective way of "measuring" the 115' marble tower. This memorial, built in 1902, commemorates the site of the Colonial batteries that threatened the British in Boston and helped to force them to evacuate the city on March 17, 1776.

During the preparation of the HABS elevation drawings from the stereopair negatives, we realized that the stereopairs contained a great deal of information other than what was needed to make measured drawings. The negatives revealed such things as fractured blocks of stone, surface deterioration, prior patching and structural movement not only of individual blocks but of the entire construction. We saw a rather exciting potential for developing a long-range methodology for monitoring the effects of environmental pollution and acid rain, as well as the efficacy of human intervention in the maintenance of historic buildings systems.

We also hoped that such a methodology might lend itself to the purposes of the "Census of Treated Historic Masonry Buildings," which is a modest program begun by the National Park Service several years ago to document the "treatments" carried out on a limited number of masonry structures, and to provide retrievable information about the effectiveness of various products and techniques used on certain historic buildings where such data can be obtained and where there is the likelihood that subsequent monitoring over a period of years may determine the efficacy of those treatments.

While this particular project involved a National Park Service historic property, we also perceived that any reliable methodology for monitoring the on-going condition of historic structures would have application well beyond the National Park Service to any entity, public or private, with a long-term commitment to the conservation of historic structures, sculptures, and other objects continually subject to environmental chemicals and physical stresses. Thus the Preservation Assistance Division, in cooperation with the Park Historic Architecture Division, undertook this case study as a separate contractual project, but which nevertheless was an extension of the original HABS project.

Because this report proposes a new methodology with considerable potential, it should be regarded as a pioneer effort. There is considerable room for improvement. We hope that others can build on this initial case study. The basic questions to be answered are:

1. What can be *seen* in stereo-photogrammetry and *learned* from it that is useful for long-term monitoring of historic structures?
2. How can the observations made from viewing stereo-photogrammetric images be recorded in an accurate notation system, so that it can be used by future observers?

It is upon these basic questions that we invite comments and suggestions from readers and practitioners in the several fields of historic building documentation, conservation, and engineering. Such comments are welcome and we will endeavor to share them and our subsequent use of these methodologies as widely as possible. Please write to Lee H. Nelson, FAIA, and Hugh C. Miller, AIA, National Park Service, P.O. Box 37127, Washington, D.C. 20013-7127.

Introduction

The original contract for recording the Dorchester Heights Monument for the Historic American Buildings Survey was conducted by the firm Dennett, Muessig, Ryan and Associates, Ltd., Iowa City, Iowa. The north and west elevations of the Monument were field recorded on June 8 and 9, 1982. The recording team consisted of Hans Muessig, Robert Ryan, and Firth Dennett.

The monument was photographed along surveyed lines from a distance of 10 meters, using a theodolite to align the stereocamera for each picture. At that distance, seven stereopairs were required for each facade of the 115' monument. The stereopairs were taken from a mobile 150' Condor aerial platform—a "cherry-picker"—with a Wild C120 stereometric camera, using glass plates for dimensional stability. Ink drawings from the glass plate negatives were made with a Wild A40 Autograph stereoplotter. Both the stereoplotting and the final ink delineation were done by Angela Schiller.

In August 1982, the contract was extended so that the feasibility of using stereopairs as a tool for monitoring environmental and physical damage to historic structures could be determined. This phase of the work was conducted under contract with the Preservation Assistance Division, National Park Service, Washington, D.C., and was administered by Anne E. Grimmer, as the Contracting Officer's Representative. Funding for this phase of the contract came from the National Park Service Cultural Resources Acid Rain Research Program, Susan I. Sherwood, Coordinator, at that time administered by the Park Historic Architecture Division.

The contractor asked J. Henry Chambers, FAIA, Medina, Ohio, to assess the viability of using the stereopairs to evaluate the overall condition, the extent of deterioration, and the possible deformation of the structure, and to develop notations for such conditions, from which a generally accepted system of condition notations could be developed for future use. The present case study results from this extensive

project. It was submitted by Dennett, Muessig, Ryan and Associates and J. Henry Chambers, and edited by Michael Auer of the Preservation Assistance Division.

This brief case study assesses the usefulness of stereophotogrammetry from the architectural conservator's point of view. It does not attempt to give an introduction to photogrammetric recording, which is presented in *Photogrammetric Recording of Cultural Resources* and other sources given at the end of this report. Included here are reproductions of the finished HABS drawings for the North and West elevations of the Monument, together with photographic prints (from the stereopairs), overlaid with notations indicating conditions and measurements of such things as cracks, stains, patches, and damage. For the purpose of this case study, we have included photographs covering the North elevation only (see figures 3A-3F). These representative photographs are adequate to suggest the usefulness of stereo-photogrammetry as a "conditions monitoring tool" for historic structures.

Unfortunately, there is a great deal lost between the three-dimensional images seen by the conservator or other trained viewer in the stereoplotting machine and the overlaid photographs in this report. The real *assessment* of the conditions of the structure *must be made in the plotting machine*. That assessment will form the basis for monitoring the problems, for monitoring changes that have occurred, and for making recommendations for remedial actions, whether they are surface treatments or structural interventions. This report can do no more than suggest the usefulness of these tools for the purposes of architectural conservation. We believe that the contracting photogrammetrists and the consulting historical architects have admirably succeeded!

*Lee H. Nelson, FAIA
Chief, Preservation Assistance Division
National Park Service*

Using Photogrammetry to Monitor Materials Deterioration and Structural Problems on Historic Buildings

by J. Henry Chambers, FAIA

PICTORIAL RECORDING

The process of surveying building fabric is a process of gathering information in an organized manner in the field and then analyzing it later at the office. Each survey method has advantages and limitations. Conventional 35 mm photography is readily available and useful in depicting materials and features. It depicts the relationship of one material to another, and it enables the surveyor to write architectural descriptions. It does not, however, furnish dimensions or other technical information. Scaled-rectified photography depicts features and materials, and can provide information similar to that obtained from an architect's building elevation, but its dimensional information is limited to one vertical plane. Photogrammetry offers new potential for recording information about buildings.

In close-range (as opposed to aerial) photogrammetry, two simultaneous photographs of the objects are taken by cameras in two positions. The resulting overlapping photographs form a "stereopair." The stereopair is then placed in a plotting machine, which projects a three-dimensional image of the overlapping area. The projected image is viewed by the operator through eyepieces. By means of pedals and gears, the stereoplotter operator moves a pointer within the three-dimensional image. The pointer is connected to a pencil, and a precisely scaled drawing, a "plot," is made of the image or any part of it. Precise measurements can then be taken from within the image or from the drawing.

The use of photogrammetry in recording the Dorchester Heights Monument indicates that:

1. The quality of a building fabric survey can be improved.
2. The accuracy of a materials inventory can be increased.
3. The productivity of the surveyor can increase in proportion to the difficulty of access.

"Difficult access" probably starts above 30 feet. The accuracy of hand measurements taken from the top of a 40-foot extension ladder to record condition and variability of construction is suspect—and not easily verified.

The dimensional limitation of scaled-rectified photographs (i.e., height and width), is not a severe restriction, in practice, when working with small buildings, e.g., 13' high to the eaves, 30' to 40' long, when such photographs are enlarged to a convenient architectural scale (1/4" to 1/2" per foot). Experience indicates that the use of scaled-rectified photography on 15-story buildings on a single exposure along the street, where camera distance is adequate, gives less detail about materials and their defects than serial stereopairs taken from an elevating platform. The dimensional information from a rectified photograph is adequate to produce a *quantity survey*, but the stereopair increases the amount and variety of information available to the fabric analyst. When observing the stereopair in the plotter, the negative is used; this provides more detail than can be obtained from a high-quality print, since detail is lost, especially in shadows, in the printing process.

Conventional and scaled-rectified photographs are most often taken from ground level because of convenience. This camera position does not significantly reduce information from low, narrow buildings. For high buildings, however, considerable information is lost. Because of the camera position, there is a cut-off angle in which detail in recesses is no longer visible, and the higher the recess, the more detail is lost by cut-off. Most often the recess is a window with the frame and the sash plane several inches behind the main wall surface. Consequently, the top of the sill and the bottom of the sash are not visible. Information not obtained due to cut-off from a ground-level camera could be recorded by scaled-rectified photographs using an elevating platform and taking multiple shots, which could then be assembled to form a photo mosaic. While this is technically possible, the expense of hiring the elevating platform may approach the cost of the photography.

Therefore, the additional cost of photogrammetry would be a small price to pay for obtaining a considerable increase in information. In addition, information obtained from photogrammetry is always retrievable: scaled-rectified prints can be made from the photogrammetric negatives stored in archives. One of the purposes of this report is to comment on the additional amount of information obtainable by using photogrammetry rather than other photographic methods. A vital ingredient is the third dimension which in stereo-photogrammetry is measurable. This yields a surprising amount of additional information.

Comparison of the relative conditions under which hand measurements and measurements from stereo-pair negatives are taken further suggests the superiority of photogrammetry over conventional methods of surveying building fabric. The work of photogrammetric plotting and measurement is performed at a stationary position under normal office conditions. In contrast, hand measurements of structures on site might be made from scaffolding 50' or 100' high. At this level, simple fear, let alone more technical problems, tends to reduce the accuracy of information obtained. Moreover, the cost of scaffolding structures such as the Dorchester Heights Monument exceeds that of photogrammetry.

ENHANCED PERCEPTION OF MATERIAL DETERIORATION OR STRUCTURAL DEFORMATION USING PHOTOGRAMMETRY

Stereo-photogrammetry can be measured in the office in three dimensions—height, width, and depth. This allows masonry damage or effects of displacement to be discerned in a way not possible using a two-dimensional or scaled-rectified photograph. Stones that are without surface defects may have actually moved into or out of the wall plane a small distance. Such slight movements, which produce a “roller coaster effect,” are not detectible in two dimensions, but are discernible when a third dimension is added. Viewed in the plotter, the stereopairs provide that extra dimension.

The three-dimensional quality of the projected stereopairs seen in the viewer, however, is lost when one of the pair is developed into a photographic print, and even when the projected image is “plotted” on paper in the photogrammetric plotter. A graphic notation system is therefore necessary if the information readily seen in three dimensions is not to be lost entirely in the process. The development of such a system is the principal aim of this report.

The “roller coast effect” described above can be observed by scanning the projected images in the plotter, whereupon the irregularity of the surface becomes apparent.

Whether it would be important or not to determine the amount of surface variation would depend on the individual case. At Dorchester Heights, uneven stone surface may only be a construction “defect” and is probably not a concern, but structural movement is more troublesome. Other unexpected information resulting from the “roller coaster effect” occurred when the edge of the cornice was scanned: the edges were considerably chipped. This phenomena was noticeable due to the loss of material. While the surface texture and color did not indicate to the observer

that the edges were chipped, they were discernible due to the depth phenomena. When viewing the stereopairs in the plotter, the magnification of the image can be considerable. For example, the rounded profile of the stone, places where the surface of the mortar joint was worn below the edge of the stone, and points at which the pointing had caused marble to spall were all visible. Stone chips could be distinguished from mortar smears on the stone surface, and chips at the joint edges which had been patched with mortar could be distinguished from chips which were not yet patched. The stereo effect made chipped stone visible even when there was not a tone change in the photographic image.

The photogrammetric analysis for this case study included only two sides of the monument; these were adequate for recording architectural features because the monument is symmetrical. Additional information from the other two sides would have been helpful to study deterioration due to orientation as well as movement patterns. For example, on the north elevation, above the balcony and on the right side of the photograph, is a wedge-shaped crack. The variation in crack width dimension was measured upward, starting from one course above the balcony rail through the cornice and the belfry balustrade. Although there is some variation in movement, the trend becomes wider toward the top. It would be helpful to examine in a similar way the north edge of the east elevation, since distortion could probably be observed as it may be part of the same movement. If a similar crack were to be observed on the east side, then the direction of the crack would probably be diagonal to the corner; if such a crack were not observed, then it would possibly be a twisting action. If so, the treatment recommendation would probably be less extensive in order to keep water from entering the wall at the top joints of the cornice. This degree of building study and consideration prior to an actual site visit is possible by no other photographic method.

The task of plotting projected stereopairs is best left to an operator skilled in photogrammetry rather than to the historical architect or other preservation professionals in charge of the building survey. The experienced plotter can better calculate measurements, search for unexplained phenomena observed on the scaled rectified photographs, translate machine scale into 100ths of a foot, measure masonry distortions in three dimensions, and change the stereopairs. The orthographic plot of the north elevation, which includes the lettering on the bronze plaque, demonstrates the detail that can be plotted by a skilled operator (see figure 1). (Some of the detail on the original, full-size plot has been lost in reducing the drawing to the format presented here.)

The procedures used here result from over ten years' experience on the writer's part with scaled-rectified photographs. Rectified photo negatives

were enlarged from 4" x 5" to 8" x 10" prints for convenience of field recording. A first survey tour recorded each defect observed on the building. Later in the office, this information was organized into a glossary according to building material types. The glossary then became a checklist to look for defects that may have been originally missed. Of course, the quality of field information gathered depends on the skill and freshness of the surveyor, on the quality of light, and other factors. A project-specific checklist increases the accuracy of observations. A standardized checklist normally contains too many inappropriate entries and is usually discarded before the project is far advanced.

Additional information can readily be obtained by the photographer if adequate instructions are provided in advance. A video camera mounted on the elevating platform can be used to scan the building during the ascent or descent or can cover the same area being photographed. This would provide recording in color, making it easier to distinguish different kinds of stains; furthermore, the camera could zoom in to observe color changes and other conditions of small details.

One of the stereopairs rectified and printed at a convenient scale could be used to locate and annotate the defects for treatment purposes. It is helpful to use both black and white lettering on the photograph, so that defect information is not confined to the light areas of the photograph. The photograph can be taken from an off-center position so that the relationship of walls on both sides of the corners are visible. In the Dorchester Heights Monument, the same was true of balcony ends, door cornices, and other features.

DEFECT NOTATION SYSTEMS

This case study is limited both by the photogrammetric information available and by the fact that the Dorchester Heights Monument is a massive masonry structure. Therefore, this study is limited to using a graphic notation system related to massive masonry buildings. Wooden buildings and masonry buildings with small units such as brick will probably require different symbols. For structures with large masonry units, like the Dorchester Heights Monument, it would be possible to number and schedule a treatment for each stone. For larger or more complex structures with individual units numbered in the hundreds of thousands or possibly millions, a different approach would most likely be taken. In these circumstances, statistical survey methods have been effective. Random samples can be taken of such a number that an acceptable confidence level can be determined. Random samples must be taken from all areas with different exposures and degrees of deterioration. A side with prevailing winds, for in-

stance, would probably have a different degree of deterioration than one opposite. A parapet wall would probably have a different deterioration rate than a wall portion well within the body of the wall. The areas with different rates of deterioration exposure are called "universes" and could be determined by the study of stereo-photogrammetric pairs. Locating random samples, analyzing their condition, prescribing a treatment, and estimating the amount of treatment for the total wall could mostly be done with the plotter. The amount of field work necessary to verify the photo assumptions would be considerably less than if field work alone were done.

The following is a suggestion for photogrammetric recording of a building when there is a special interest in the condition of the fabric. First, if the building has access difficulty somewhat similar to that encountered at the Dorchester Heights Monument, the expense of renting "man-lift" equipment is such that it would be economical as well as prudent to ask the photographers to expand their activities to include additional recording.

In advance of the photographic sessions, the historical architect or architectural conservator would compile a list of additional information for the photographers to obtain. For a building such as the Monument, binoculars and telescopes would be required to prepare the "wish list" for the photographers. Prior to field work, available documentary information should be made available to the historical architect so as to gain as much knowledge of the building as possible and also to eliminate destructive investigation. Maintenance records should also be available to the architect in order to identify previous treatments.

The work performed by the photo-technician to retrieve additional information to assist architectural conservation would depend upon the size and condition of the building. For Dorchester Heights it would have required several days for an architectural conservator and an additional one-half day to one day of photo-technician time and equipment rental. The following work items would be necessary: taking photographs in color as well as black and white, attaching a video camera to the main lift, and shooting 60-second video runs. This filming would allow the architect to review the closeups on a video monitor, and to observe conditions that cannot be seen from the ground, thereby allowing the architect on-site to modify the instructions when the "man-lift" is on the ground.

Although worthwhile use can be made from the stereopairs at any time, if the photographer knew in advance what would be helpful to the architect, he might alter his photography procedure somewhat. In the case of the Dorchester Heights Monument, for instance, it would have been helpful for the terraces and the terrace retaining walls to have been recorded in addition to the shaft itself.

GRAPHIC STANDARDS

A literature search by this investigator for symbols that could be used to describe movement in either two or three dimensions for masonry or other materials produced little. John S. F. Pryke describes cracks in relation to width, provides descriptions of possible causes, and offers a "worry index" suggesting when intervention is required and the type of intervention required. (See Sources listed at the end of this report.) Three-dimensional movement, however, is discussed only peripherally. Most references that deal with cracks discuss causes and "theories." Such discussions are helpful to those learning to deal with these problems, but the work methods for recording defects involve discussion with other resource people.

The system used to annotate the scaled-rectified photographs of the Dorchester Heights Monument is a combination of symbols and letters (see figure 2). In general, letters identify defects, stains, and patches while graphic symbols identify movement in various directions. Two-letter abbreviations furnish up to 700 different descriptions. Graphic symbols appear to be easily understood if the graphic form suggests the description. Letter or number annotations require reference to a key, which is time-consuming until memorized. The 4- or 5-letter codes developed by the Construction Specifications Institute (CSI) and the Uniform Construction Index (UCI), both use similar terminology. CSI is organized by building materials or building material functions while the UCI is organized by building functions. For people familiar with these systems, they are convenient, but to others unintelligible. Key word lists covering many historic building subjects are being developed by the Committee on Historic Resources, American Institute of Architects, in order to enhance access by architects to information on historic preservation, materials and treatments; when this publication is available it will be helpful for standardizing nomenclature. (See Sources listed at the end of this report.)

LONG-TERM USE OF THE INFORMATION

Long-term use can be made of the photogrammetric information. For cyclical maintenance inspection, a mylar transparency copy of the scaled-rectified photographs could be printed for low-cost recording sheets. During a cyclical inspection, comments could then be noted for work to be done under contract, and a mylar print of the plot could serve as a base sheet for the graphic part of the contract documents. For monitoring of structural movement, photogrammetric photography could be repeated

every 10 to 15 years. The new plots could then be compared with previously annotated plots to determine whether defects identified earlier had worsened or new ones appeared.

Figure 1. Sections of the monument indicated as 3A-3F are depicted in the ensuing photographs. Each of the photographs is annotated (with the exception of figure 3F) with symbols and letters indicating the location, condition and extent of cracks, stains, and other forms of damage, as well as of the evidence of prior patches. For key to these symbols, see Figure 2. Drawing: Historic American Buildings Survey drawing of the North Elevation, Dorchester Heights Monument. Plotted and delineated by Angela J. Schiller.

3C

3F

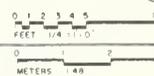
3E

3D

3B

3A

NORTH TOWER ELEVATION

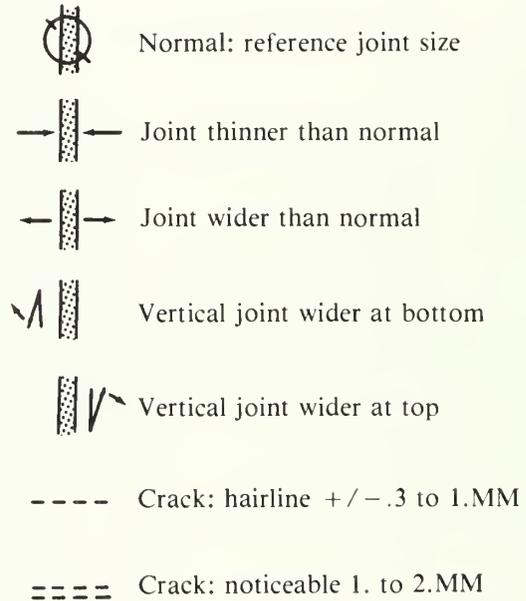


PHOTOGRAPHED JUNE 8-9, 1980 WITH
A WILD C20 STEREOGRAPHIC CAMERA (6A 1154)
PLOTTED ON A WILD B40 AUTOGRAPH
BY ANGELA J. SCHILLER
DELINEATED BY ANGELA J. SCHILLER, 1982
DUNNETT, MESSING & ASSOCIATES, LTD.
KING CITY, KANS.

NOTATION SYSTEM

Dorchester Heights Monument Thomas Park, South Boston, Suffolk County, Massachusetts

- A — Anchor, Star
- C — Chipped edges
- D — Scupper
- E — Chipped corner
- F — Cracked face
- G — Grain of stone
- H — Hairline crack, patched
- I — Hairline crack, open
- K — Metal cramps
- M — Mortar
- N — Negative blemish
- P — Patch
- Q — Warped surface
- R — Copper stain
- S — Stain
- T — Target, Photogrammetric
- U — Unknown, check if possible
- V — Vandalized
- W — Lightning conductor hole
- X — Mortar joint unsympathetic
- Y — Mortar joint worn



Photograph scale: 1/4" = 1'

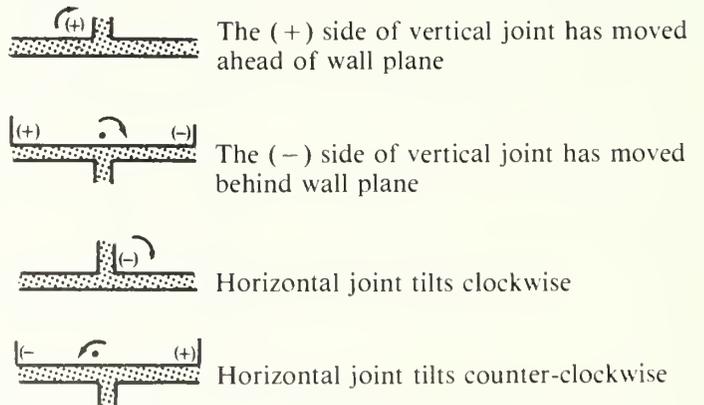


Figure 2. The three-dimensional richness of the projected stereopairs viewed in the plotting machine is lost when the images are developed into two-dimensional photographic prints. To recapture some of that information, the graphic notation system shown here was developed by J. Henry Chambers, FAIA.

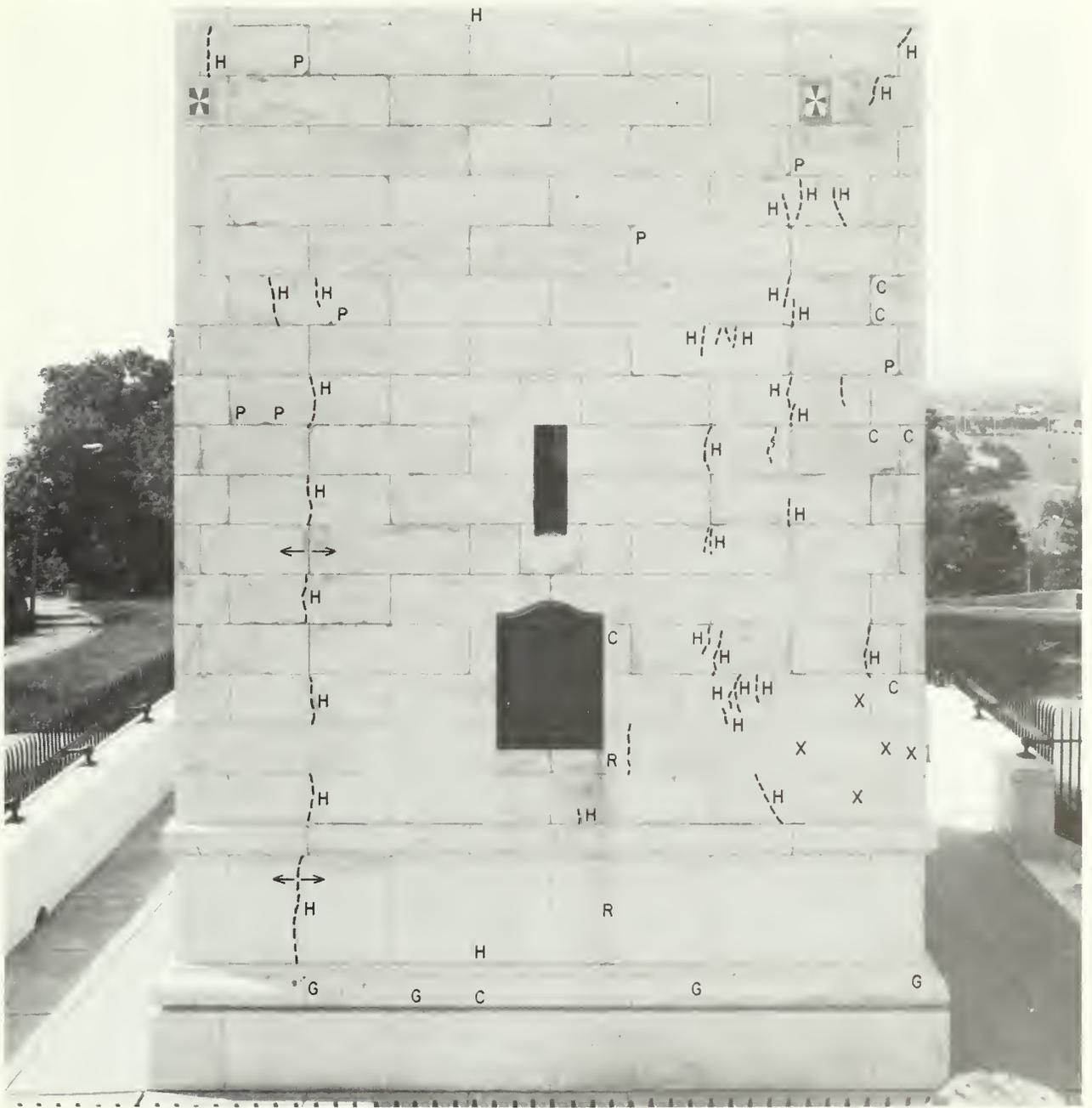


Figure 3A

Figures 3A-3F. The following photographs of the north elevation, Dorchester Heights Monument, display surface deterioration, prior patching and structural movement. Note the preponderance of hairline cracks, especially in the lower portions of the monument, and that the hairline crack visible in the lower left portion of 3A extends upward through about 13 courses, splitting the stones in every other course, extending about 18' from the base of the monument, indicating a pervasive movement within the structure. A number of the stone blocks have moved ahead of the wall plane, especially in the upper portions of the tower, seen in photograph 3D and 3E, and a number of the mortar joints have opened up, some approaching 1" or more.

The materials deterioration and structural problems recorded here can be used to monitor the condition of the structure over the course of time and to develop treatment strategies. (The photograph of the spire end weathervane, figure 3F, was not annotated.)

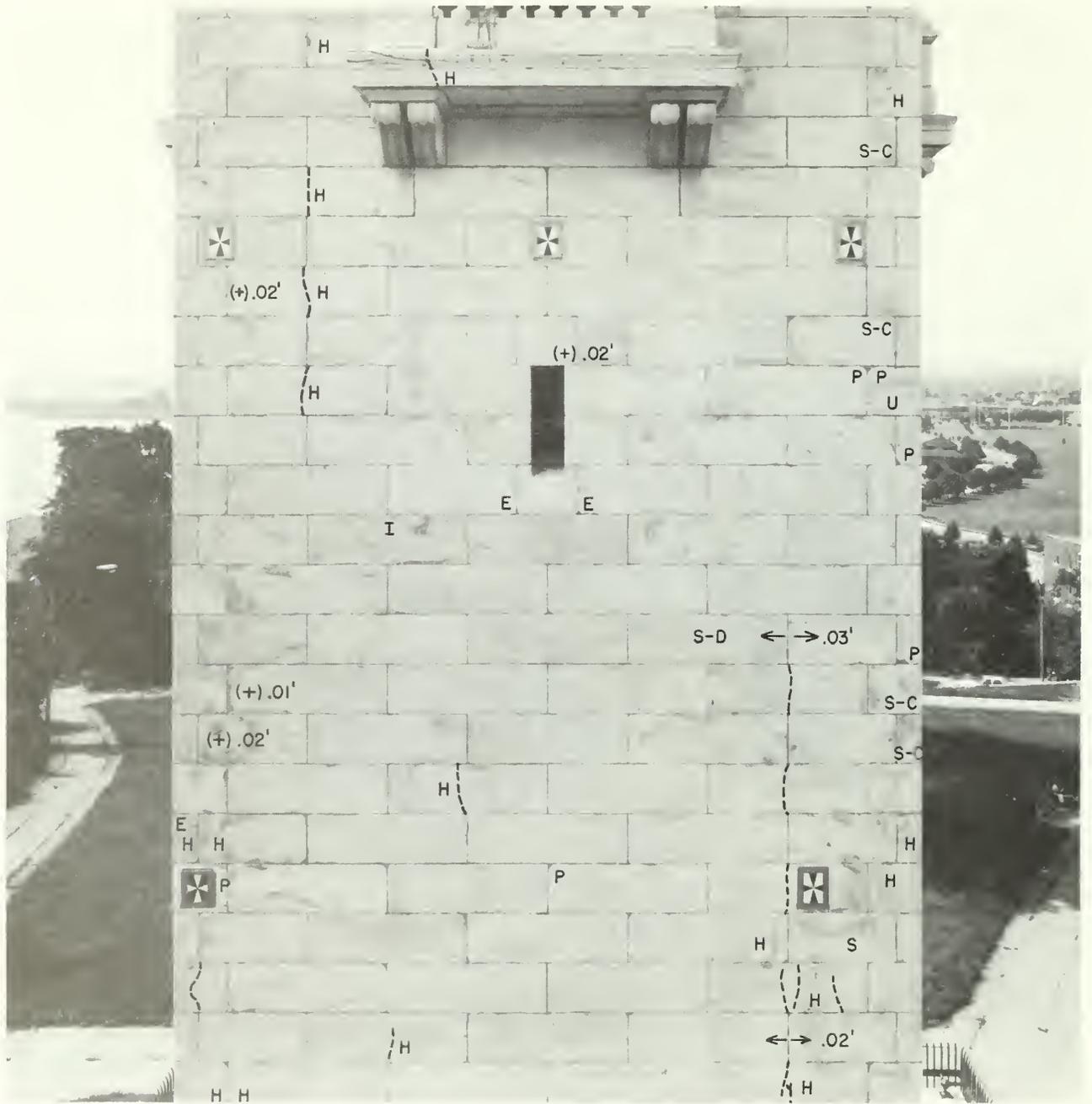


Figure 3B



Figure 3C

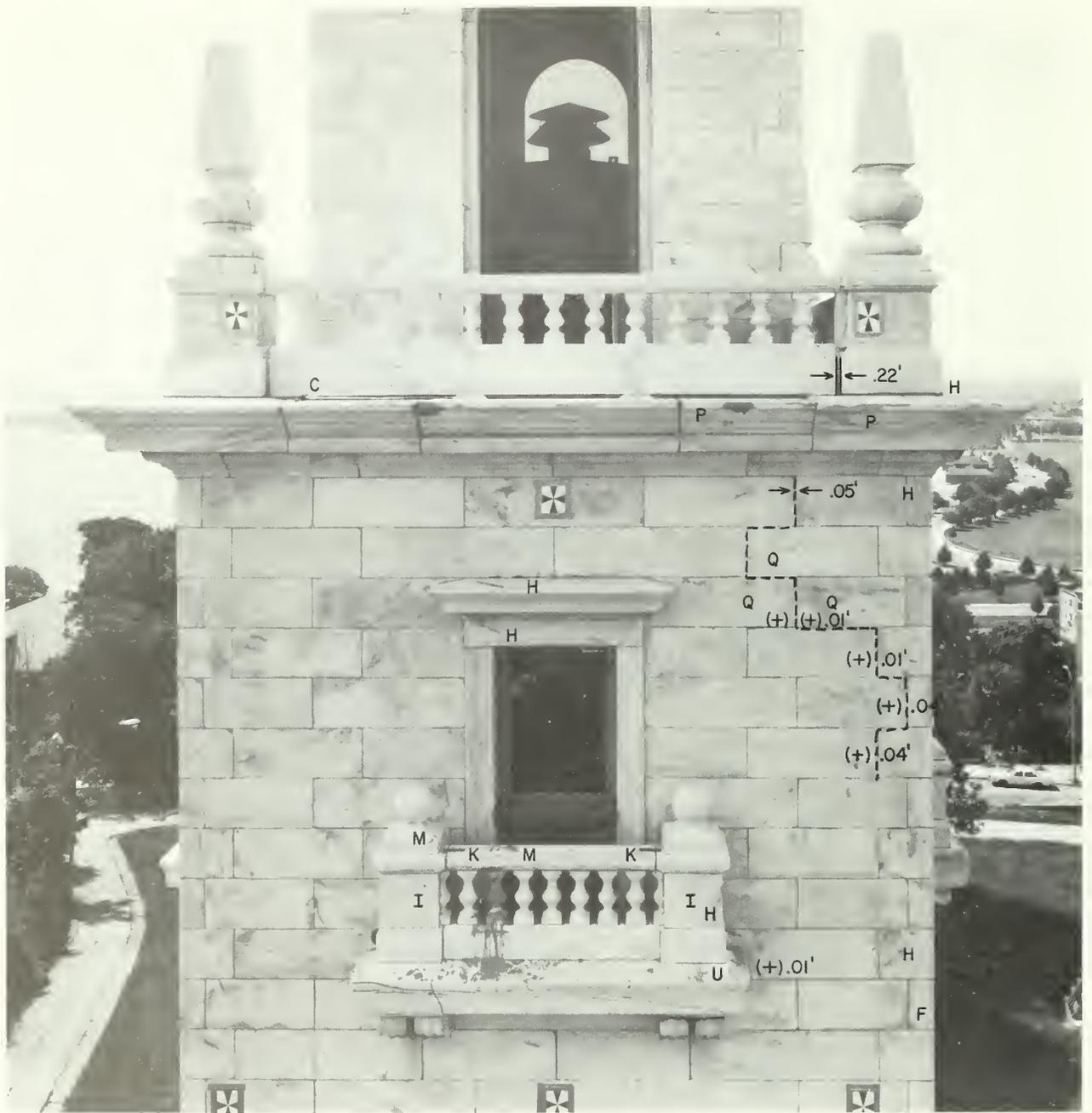


Figure 3D



Figure 3E



Figure 3F

SOURCES OF FURTHER INFORMATION

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