WJE

MASONRY REPAIR AND CLEANING AT THE WEST VIRGINIA STATE CAPITOL

Statement of Interest: RFQ No. GSC066429

1900 Kanawha Boulevard, Charleston West Virginia

Statement of Interest and Qualifications
25 July 2006
WJE No. 2006.2820

Prepared for:
Ms. Krista Ferrell
Department of Administration, General Services Division
Building 1, 1900 Kanawha Boulevard, East
Charleston, West Virginia 25305

Prepared by:
Wiss, Janney, Elstner Associates, Inc.

And
Paul D. Marshall Architects and Engineers, Inc.

WJE ENGINEERS ARCHITECTS MATERIALS SCIENTISTS
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25 July 2006

Ms. Krista Ferrell
Department of Administration, General Services Division
Building 1, 1900 Kanawha Boulevard, East
Charleston, West Virginia 25305

Re: Masonry Repair and Cleaning of the State Capitol
RFQ No. GSC066429

Dear Ms. Ferrell:

Thank you for the opportunity to submit our qualifications for the Masonry Repair and Cleaning of the West Virginia State Capitol. We believe we possess the unique qualifications and skill sets to best guide this work to successful completion in partnership with General Services Division, the Governor's Office, and the many state agencies which use the building on a daily basis.

Wiss, Janney, Elstner Associates, Inc. (WJE) has unique strengths in combining materials analysis with historic preservation. Our architects, engineers, and architectural conservators have distinguished themselves in solving difficult problems on historic buildings while respecting the aesthetics of the building and complying with the *Secretary of the Interior Standards for Preservation*. Likewise, our local partner in the project has an excellent history of preservation projects. Together as a project team, we have an especially strong record of work on State Capitols, Indiana limestone buildings, and museum quality restoration. We invite you to review the projects highlighted in our supporting materials: the State Capitols of Kentucky, Nebraska, Wisconsin, and Georgia, the Metropolitan Museum of Art, The Chicago Tribune Tower, and the FirstMerit Tower, Graceland at Davis and Elkins College, and the West Virginia Governor's Mansion.

The West Virginia State Capitol is an architectural gem of great significance. Designed by Cass Gilbert at the height of his career, it follows his Minnesota State Capital in 1905 and the Woolworth Building in 1912-13, which at the time of the commission was the tallest building in the world. We are familiar with the Dome of the Invalides in Paris from which Gilbert derived his inspiration, and we are committed to the conservation and preservation of your monument.

We know we can make a positive contribution to the care and maintenance of the West Virginia State Capitol and appreciate your time in reviewing our team's qualifications.

Very truly yours,

WISS, JANNEY, ELSTNER ASSOCIATES, INC.

Elwin C. Robison
Senior Associate

Stephen J. Kelley
Senior Consultant

Team Qualifications

Lead Firm Wiss Janney Elstner Associates, Inc. (WJE)

Wiss, Janney, Elstner Associates, Inc. has fifty years' experience in solving complex building problems with specific expertise in masonry, stone, and mortars; windows; roofs; concrete; and archaic structural systems. By combining the efforts of structural engineers, architects, architectural engineers, architectural historians, petrographers, and chemists, WJE has the capability to quickly identify and solve challenging building problems. Eighty percent of our professional staff hold advanced degrees, and many are leaders in their fields, actively publishing, and serving on committees that set industry standards.

WJE has extended the life of countless structures, and improved the construction industry's understanding of why structures fail and the ways they can be preserved. This experience with a wide range of industrial, architectural, and transportation structures gives WJE tremendous insight into details of maintenance, repair, conservation, and restoration of historic buildings.

WJE's staff has special knowledge, expertise, and interest in the preservation of historic structures specializing in investigation, analysis, and design services for historic buildings. Special services include:

- Masonry analysis and repair
- Cleaning of Facades
- Investigations of architectural and structural systems
- Materials conservation analysis
- Field and laboratory testing and analysis
- Construction documents preparation
- Maintenance planning
- Architectural and structural repair design
- On-site monitoring and testing
- Historical, technical, and materials research
- Historic Structure Reports
- Historic American Buildings Survey (HABS) and Historic American Engineering Record (HAER) documentation
- Historic site surveys and inventories

A significant asset to WJE is the Jack R. Janney Technical Center which has more than 25,000 square feet of laboratory space for testing and evaluation of structural components and materials. Among the areas that can be addressed in the lab are accelerated weathering tests, and specialized chemical analysis of materials and deposits. In addition to the Technical Center, the Cleveland Office of WJE has its own petrography lab, providing rapid in house responses to problems involving stone, concrete, brick, and tile.

In addition to providing services in historic preservation, WJE has also distinguished itself through successful forensic studies of collapses and failures, earthquake assessment and analysis, and building envelope evaluation and repair. The overlapping skill sets required by these disciplines has direct application to historic preservation. WJE is uniquely qualified to respond to the technical and aesthetic needs of architecturally significant and historic structures, offering full services from planning and investigation through design implementation.

Our clients for historic preservation projects have included the UNESCO, U.S. Department of State, National Park Service, Department of the Navy, General Services Administration, National Trust for Historic Preservation, ICOMOS, Smithsonian Institute; Getty Conservation Institute, World Monuments Fund, numerous State Governments, and many universities, institutions, and other public and private clients.

Local joint venture firm Paul D Marshall Architects and Engineers, Inc. (PDM)

Paul D. Marshall Architects & Engineers, Inc., has been a regional leader in building design , adaptive re-use of existing buildings & properties and historic restoration, preservation and renovation projects.

Paul D. Marshall Architects & Engineers, Inc., employs a knowledgeable staff of degreed professionals with a credible record of notable accomplishments. Since the firm's inception in 1972, the firm has completed over 400 projects ranging in complexity from simple residential additions, to multi-million dollar private and commercial ventures. Clients have included universities, institutions, owners, and city and state governments.

Paul D. Marshall Architects & Engineers, Inc., is committed to providing its clients with unsurpassed personal service and an array of essential architectural, engineering and consultative services that meet and exceed the client's expectations. These areas of focus include:

- Site Planning
- Land use planning
- Interior space planning
- Architectural design services
- Code compliance
- Historic preservation, restoration & renovation
- Historic tax credit evaluations
- Historic register nominations
- Cultural resource management

A copy of the company brochures of WJE and Paul D Marshall are included in Appendix A.

Team Approach

The West Virginia State Capitol is primarily clad with Indiana limestone, terra cotta coffers, glazed Guastavino tiles, and some granite steps. In most regions of the building the masonry is in generally good repair, with some cracking along joint lines. Soiling of stones was observed due to various factors:

- Asphaltic waterproofing compounds oozing from joints
- Copper elements staining stone
- Water infiltration through skyward joints depositing lime on the stone surface
- Biological growth
- General soiling

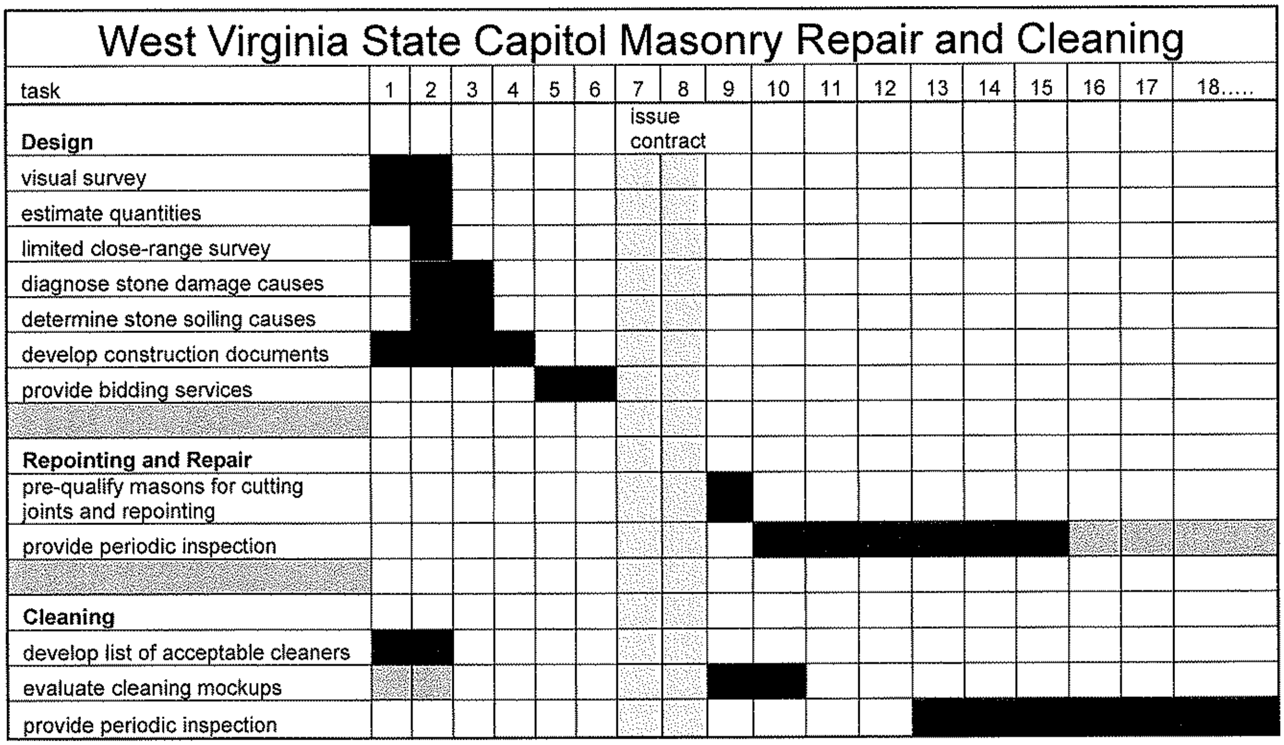
Each of these causes of soiling will require specific cleaning techniques. There is no single technique that will address every cause. The gentlest procedures possible for each condition will be determined and specified. A general outline of the role various professions will play in the design process is outlined below.

West Virginia State Capitol Masonry Repair and Cleaning Task Matrix

task	architects	engineers	architectural historians	petrographers	architectural conservators
Design					
visual survey	*	*	*		
estimate quantities	*	*			
limited close-range survey	*	*			
diagnose stone damage causes	*	*	*	*	
determine stone soiling causes	*	*	*	*	*
develop construction documents	*	*	*		
provide bidding services	*	*			
Repointing and Repair					
pre-qualify masons for cutting joints and repointing	*	*			
provide periodic inspection	*	*			
Cleaning					
develop list of acceptable cleaners			*	*	*
evaluate cleaning mockups	*	*	*	*	
provide periodic inspection	*	*			

Note that the various designations of architects, engineers, and architectural historians are primarily conceptual. Many of the personnel involved are identified by multiple designations. For example, Mr. Kelley is a registered architect and a registered engineer, while Mr. Robison is a registered engineer and an architectural historian.

The October 2006 deadline specified in the Request for Quotation is an aggressive one. A typical compressed schedule is outlined below, with investigative and design activities initiated with a notification to proceed, then a minimum of a two week window for bids and another two week window to conclude a contract with the successful bidder. From the point at which the contractor is on the site working the length of time required to complete the job is dictated primarily by the resources of the contractor. Since repointing should proceed cleaning in order to minimize the amount of water introduced into masonry walls, crews will begin repointing, and then be followed by cleaning crews.



A look at the above schedule shows that even with a compressed schedule it typically would take 8 to 9 weeks to get a contractor on site. The only way an October 2006 deadline would be possible is to award a time and materials contract to a contractor, and initiate mockups for repointing and cleaning immediately. This would result in the bars under Repointing and Repair, and Cleaning to slide to the left of the figure.

Please note that no matter what kind of accelerations are given to the contract, nighttime freezing temperatures will bring a halt to repointing, repair, and cleaning activities. If a contractor was brought on site at the beginning of September, it would require many masons and cleaning operators to complete the job before freezing weather sets in. WJE's experience is that a higher quality job results when a smaller number of highly skilled masons are performing repair and repointing tasks. Also, costs for the contractor and design professional increase under very aggressive scheduling. We recommend that the State of West Virginia carefully weigh the pros and cons of such an accelerated schedule.

WJE has a Cleveland Office staff of 14, with approximately 360 design professionals nationwide. PDM Architects and Engineers have there offices in Charleston and can provide rapid response to issues that may arise. Should the State of West Virginia decide to keep the October 2006 completion date, our Design Team can mobilize experienced architects and engineers from other WJE offices to meet demanding schedules.

Team Experience

Wisconsin State Capitol (WJE)
The National Register designated Wisconsin State Capitol, designed by George B. Post & Sons and constructed between 1907 and 1917, has exterior walls and dome of Bethel White granite. The capitol has four equal wings around a central domed rotunda space, with grand staircases and entrance pavilions between each wing.

WJE documented the existing façade and dome conditions and developed and implemented a plan to restore the exterior granite, as part of a decade-long restoration of the Capitol. WJE also evaluated numerous cleaning techniques for the dome and selected the use of the sponge jet system as the most effective and least harmful.

Kentucky State Capitol (WJE)
The National Register designated Kentucky State Capitol was the result of a 1904 competition and was constructed in accordance with design of Frank Mills Andrews. It is a classically styled edifice faced with Indiana limestone and surmounted by a dome of terra cotta.

In a team with Louisville-based K. Norman Berry Architects, WJE consulted on the restoration of the dome in 1996. In 2000 WJE served as architectural conservator and Preservation Consultant for the same on the preparation of an Historic Structures Report and Master Plan. Tasks include comprehensive visual inspection, laboratory analyses and development of the most appropriate cleaning system. The project implementation awaits funding.

Nebraska State Capitol (WJE)
The National Register designated Nebraska State Capitol, the result of a design competition, was designed by Bertrand Grosvenor Goodhue and constructed from 1922 to 1932. Melding the traditional State Capitol typology with the skyscraper form, Goodhue created a distinctly American architectural style that was heralded by architects of the day as the future of American architecture.

WJE served as project architect for a comprehensive exterior investigation that was completed in 1996, and now serves as special consultant for the Lincoln-based firm of Bahr, Vermeer & Haecker Architects for the restoration of the Indiana limestone exterior façade, bronze and steel windows, and copper roofs. An important part of the project is the selection and augmentation of cleaning and biocide treatments for the limestone façade. Restoration of the Capitol exterior will tentatively conclude in 2012.

Georgia State Capitol (WJE)
The classically detailed National Register designated Georgia State Capitol was constructed in 1888. It is clad in Indiana limestone.

WJE was retained by Atlanta-based architect Lord Aeck and Sargent Architecture to advise on proper cleaning techniques for the façade in 2002. WJE's work entailed the installation of sample cleaning and biocide treatments, directing the contractor on larger mock ups, and preparation of specifications for full scale cleaning. The work was completed in 2003.

Chicago Tribune Tower (WJE)
The National Register designated Chicago Tribune Tower was the result of an international design competition held in 1922 that is recognized today as the search of the architectural community to define a skyscraper style. The winning entry by Raymond Hood and John Mead Howells, completed in 1925, melds the high gothic style with the skyscraper form. The exterior is clad with Indiana limestone.

WJE performed a 10 year façade restoration that was completed in 1998. One focus of this restoration was façade cleaning that entailed research of European façade cleaning techniques to meet the specific requirements of the owner. Cleaning was performed utilizing *façade gommage*, a French micro-abrasive technique. Being the first use of this technique in the US, the National Park Service was involved through the duration of the cleaning.

Metropolitan Museum of Art (WJE)
The first wing of the Metropolitan Museum of Art was built in accordance with the design of Richard Morris Hunt. The balance of the Fifth Avenue facades, completed in 1926, was designed by McKim, Meade and White based on Hunt's master plan. The facades are designed following a Corinthian order and are substantially composed of limestone.

WJE has been retained to investigate the façade and develop masonry repair alternatives. We developed and implemented a coordinated facade evaluation and restoration effort appropriate for the museum's historic architecture and materials. Cleaning systems were tested for effectiveness, risk of damage, cost, environmental concerns, and logistics. A low pressure water cleaning system was selected. The Phase I restoration was completed in 2005.

FirstMerit Tower (WJE)
The FirstMerit Tower is a 28 story Art Deco skyscraper clad with Indiana limestone, glazed brick, and decorative terra cotta. Still the tallest building in Akron, Ohio, it has been the flagship building of the central business district since its construction.

WJE performed inspection services on the masonry facades, and developed construction documents for repair and cleaning of the terra cotta, brick, and Indiana limestone. Damage to the building necessitated rebuilding the parapets, repairing damaged terra cotta, and replacing outlook roofs. In addition WJE developed the National Register nomination for the building and is assisting the client to take advantage of federal tax credits on the project.

Graceland at Davis and Elkins College (PDM)
This mansion, circa 1896, is a National Historic Landmark. Originally built for U.S. Senator Henry Gassaway Davis, this Norman French style mansion is constructed of West Virginia granite and sandstone with several limestone appointments. A massive fireplace in the two-story stair hall highlights the grand interior. Sunlight bathes the interior of the grand hall through numerous Tiffany stained glass windows.

Graceland, as it was affectionately named after Senator Davis' daughter, is now an inn and conference center operated by Davis and Elkins' College of Hospitality. After Davis and Elkins College purchased the property, PDM completely restored the mansion after decades of neglect. Some areas of the mansion were adaptively re-designed for us as an inn, such as the kitchen and several bedroom suites. The two massive porches had to be rebuilt from photographs. Extensive research was done on the interior finishes in order to replicate them as close to the original as possible.

West Virginia Governor's Mansion (PDM)

Listed on the National Register of Historic Places, the Governor's Mansion in the capitol city of Charleston has been home to West Virginia's Governors since 1929. Designed by Walter Martens, this Georgian Colonial style mansion boasts over thirty thousand square feet and twenty-three rooms. The interior features a double grand staircase and a large state dining room. The exterior features a 5000 square foot walled courtyard as part of its two and a half acre landscape.

PDM evaluated needs for restoration and renovation after decades of use. Some unfinished areas of the mansion's third floor were completed enhancing the residence's availability to special guests of the Governor.

Project profiles of each of these projects plus other significant projects are included in Appendix B.

Key Design Team Members

Elwin Robison, PE, will serve as Project Manager. As both an engineer and architectural historian, Dr. Robison combines technical expertise with historic preservation understanding. He specializes in working with historic structures: writing Historic Structures Reports (HSR's), re-engineering old buildings to meet new uses, and conservation of historic materials. He has extensive experience with investigation, repair, and cleaning of historic masonry.

Dr. Robison teaches Preservation Technology in the College of Architecture at Kent State University, and has published articles on historic buildings and their restoration in venues such as the *Journal of the Society of Architectural Historians*, *Association for Preservation Technology Bulletin*, and *Annali d'architettura*. Dr. Robison is a co-author of *Architectural Technology Up To the Scientific Revolution*, and author of *The First Mormon Temple: Design, Construction, and Historic Context of the Kirtland Temple*.

Michael Nagle, AIA, will serve as Assistant Project Manager. Mr. Nagle has worked on many projects that meet the Secretary of the Interior Standards for tax credits, and has special expertise both in historic preservation and in building envelope design.

Mr Nagle is a member of ASTM Committee C24 - Building Seals and Sealants, and he is the principle editor of the 2nd edition the *Guide to Cleveland Architecture.* He has published on building materials problems, and is a member of the Cleveland Restoration Society.

Stephen J. Kelley, AIA, SE, will serve as Architectural Preservation Consultant on the project. Mr. Kelley has been in practice for 30 years and is an internationally recognized preservation consultant. He specializes in the investigation and restoration of historic buildings and monuments. He has extensive experience in the area of skyscrapers; religious structures; façade cleaning; and stone, brick, and terra cotta masonry. He has expertise in the analysis and conservation of historic building materials including the cleaning and repair of stone facades.

Mr. Kelley is the US voting member of the ICOMOS International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage (ISCARSAH). Mr. Kelley is also active in the American Society for Testing and Materials (ASTM). In this capacity, he was the main author of *ASTM Standard Guide for Selection of Cleaning Techniques for Masonry, Concrete, and Stucco Surfaces*. He is presently a Director of the Association for Preservation Technology International (APT). He has written more than 40 articles in books and journals and edited three books on the topic.

Brad Shotwell will serve as Project Materials Scientist. Mr. Shotwell has extensive experience studying stone, concrete, and mortars. He has specific expertise in studying stone failures in historic buildings and evaluating the effects of cleaning procedures. Active in the field for over 30 years, he has worked with many Indiana limestone buildings exposed to a variety of climates and environmental stresses. Mr. Shotwell is a member of ASTM Committee C09.65 - Petrography.

Joshua Freedland will serve as Project Architectural Conservator. Mr. Freedland has extensive experience in conducting and evaluating field and laboratory trials and specifying and administering facade cleaning projects. His experience includes water, chemical, and gentle abrasive techniques on many different substrates including limestone, travertine, marble and granite.

Mr. Freedland serves as Chair of the Membership Committee for the Architectural Specialty Group of the American Institute of Conservation. He has published and presented more than 25 articles on the conservation of historic buildings.

David Marshall, AIA, will serve as Local Architectural Consultant. He has worked as the Building Commissioner for the City of Charleston, and is Senior Vice President of PDM Associates. Mr. Marshall has designed numerous adaptive reuse and preservation projects for commercial and institutional clients, and developed Historic Structures Reports for historic buildings. Mr. Marshall has particular expertise in the application of local and state building codes. His design work has garnered several AIA awards for excellence.

A long form resume of project personnel is included in Appendix C.

Pertinent articles authored by WJE employees are included in Appendix D.

WJE | ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

Wiss, Janney, Elstner Associates, Inc.
Solutions for the built world.

Wiss, Janney, Elstner Associates, Inc. is a firm of structural engineers, architects, and materials scientists, dedicated to providing practical, innovative, and technically sound solutions to problems in existing structures. Since its establishment in 1956, WJE has successfully completed investigative, testing, and design projects involving virtually every type of construction material, structural system, and architectural component. Thousands of clients, from individuals to large corporations and government agencies, rely on WJE professionals to deliver better solutions to their construction-related problems.

Our Approach

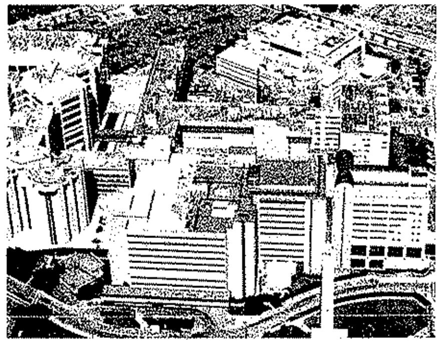
Our approach is to deliver practical, innovative, and technically sound solutions to structural, architectural, and materials problems, based on a detailed understanding of each structure's unique challenge.

Our People

With more than 360 employees, WJE has the resources to respond to virtually any problem, and expertise in all aspects of construction technology. WJE engineers, architects, and materials scientists are supported by technicians who are expert in testing and instrumentation. WJE's understanding of structural behavior and the performance of materials is enhanced by experience gained in more than 60,000 projects worldwide.

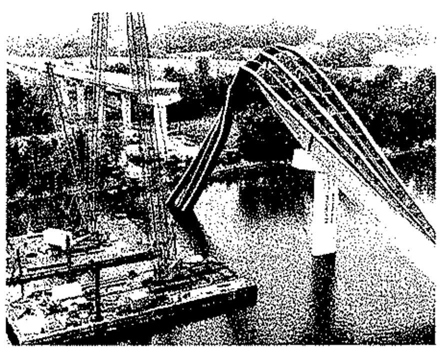
Our Resources

Our resources combine state-of-the-art laboratory and testing facilities, nationwide offices, and knowledge-sharing systems. Our investment in a full spectrum of specialized equipment to examine, sample, and test all types of construction materials puts WJE's capabilities at the forefront of the profession.



TEXAS MEDICAL CENTER
WJE PROVIDED A COMBINATION OF EXTERIOR ENVELOPE CONDITION SURVEYS, REPAIR DESIGNS, AND CONSTRUCTION OBSERVATION SERVICES FOR ELEVEN EXISTING BUILDINGS AT THE M.D. ANDERSON COMPLEX IN HOUSTON'S TEXAS MEDICAL CENTER, AND SERVED AS EXTERIOR ENVELOPE DESIGN CONSULTANT FOR THREE NEW CAMPUS BUILDINGS.

FACADE CONSERVATION
WJE WAS RETAINED TO DEVELOP AND OVERSEE A COMPREHENSIVE FOUR-YEAR RESTORATION PLAN FOR THE HISTORIC LIMESTONE FACADE OF NEW YORK CITY'S METROPOLITAN MUSEUM OF ART.



TENNESSEE RIVER BRIDGE
THE STATE OF TENNESSEE ENGAGED WJE TO INVESTIGATE THE THREE-SPAN, 1,205-FOOT STATE ROUTE 69 BRIDGE AFTER IT COLLAPSED DURING CONSTRUCTION.

Services

STRUCTURAL EVALUATION

- > Structural condition assessment and load rating
- > Design of repairs/retrofits and other modifications
- > Load testing
- > Field monitoring
- > Structural component testing
- > Design review
- > Blast analysis
- > Instrumentation

BUILDING ENVELOPE ASSESSMENT

- > Exterior wall systems
- > Roofing and waterproofing
- > Water entry and condensation studies
- > Repair and rehabilitation design
- > Design peer review
- > Construction troubleshooting
- > Specialized services for new construction
- > Blast analysis and strengthening

HISTORIC PRESERVATION

- > Preservation
- > Materials conservation and analysis
- > Historical, technical, and materials research
- > Historic Structures Reports
- > HABS and HAER documentation
- > National Register nominations

FAILURE INVESTIGATION AND DISASTER RESPONSE

- > Structural collapse
- > Natural disaster (hurricane, tornado, flood, earthquake)
- > Fire
- > Explosion
- > Accident

EARTHQUAKE ENGINEERING

- > Earthquake damage assessment
- > Seismic risk assessment
- > Seismic hazard analysis
- > Structural performance evaluation
- > Seismic repair and retrofit design
- > Seismic performance analysis
- > Peer review
- > Design criteria development
- > Development of seismic guidelines, manuals, and training
- > Assessment of nonstructural systems

BRIDGE ENGINEERING

- > Inspections and load testing
- > Fatigue and fracture studies
- > Seismic evaluation and upgrade
- > Repairs and retrofit
- > Corrosion protection studies
- > Durability studies
- > Preservation studies
- > Structural evaluation and load rating
- > Condition surveys
- > Failure investigations
- > Peer review

REPAIR DESIGN AND CONSTRUCTION

- > Repair and rehabilitation design
- > Preparation of construction documents and specifications
- > Review of bids
- > Construction phase inspection and testing services
- > Construction management
- > Design-build for repair and rehabilitation

CONSTRUCTION MATERIALS EVALUATION AND RESEARCH

- > Materials testing and analysis
- > Materials failure investigation
- > Materials conservation
- > Research
- > Petrographic examination
- > Optical, infrared, and electron microscopy
- > X-ray diffractometry and emission spectroscopy
- > Ultraviolet, infrared, and atomic absorption spectroscopy
- > Differential thermal analysis

LITIGATION SUPPORT

- > Technical investigations
- > Expert testimony
- > Design and code review
- > Construction claims
- > Laboratory testing and analysis
- > 3D graphic representations
- > Models and renderings
- > Construction accident reconstruction

STRUCTURAL TESTING AND INSTRUMENTATION

- > Nondestructive evaluation
- > Water penetration testing
- > Load testing
- > Vibration and noise monitoring
- > Constructability testing
- > Evaluation of fire damage

WORLDWIDE SEISMIC EVALUATION AND DAMAGE EVALUATION. IN ADDITION TO EMERGENCY DAMAGE ASSESSMENT FOLLOWING EARTHQUAKES, WJE HAS PERFORMED SEISMIC ASSESSMENTS AND STRENGTHENING DESIGNS FOR U.S. DEPARTMENT OF STATE EMBASSIES AND RESIDENTIAL FACILITIES AROUND THE WORLD.

MCCORMICK PLACE PARKING. TO REPAIR A SEVERELY DAMAGED PARKING STRUCTURE AT CHICAGO'S CONVENTION CENTER, WJE DESIGNED REPAIRS TO THE CONCRETE COLUMNS, REMOVAL AND REPLACEMENT OF THE CONCRETE SLAB, AND SYSTEM POST-TENSIONING.

HEADQUARTERS

Northbrook, Illinois
800.345.3199

OFFICES NATIONWIDE

Atlanta 770.923.9822
Austin 512.835.0940
Boston 781.213.9266
Chicago 312.372.0555
Cleveland 330.487.1100
Dallas 972.550.7777
Denver 720.962.8688
Detroit 248.593.0900
Honolulu 808.591.2728
Houston 832.467.2177
Minneapolis 952.545.0295
New Haven 203.944.9424
NDE Validation Center 202.493.3118
New York 212.760.2540
Princeton 609.799.7799
San Francisco 510.428.2907
Seattle 206.622.1441
Washington, D.C. 703.641.4601

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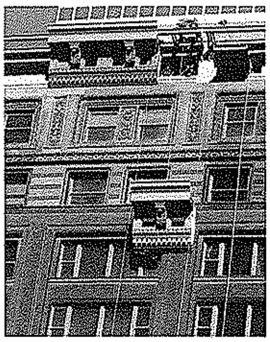
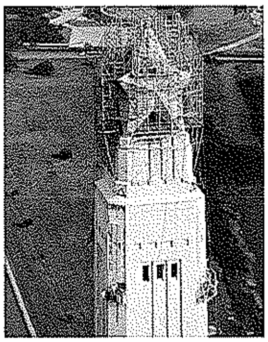
Historic Preservation

WJE is uniquely qualified to respond to the technical and aesthetic needs of architecturally significant and historic structures, offering full services from planning and investigation through design implementation.

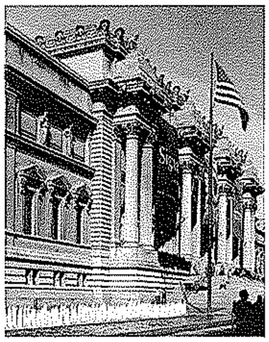
- PRESERVATION
- MATERIALS CONSERVATION ANALYSIS
- HISTORICAL, TECHNICAL, AND MATERIALS RESEARCH
- HISTORIC STRUCTURES REPORTS
- HABS AND HAER DOCUMENTATION
- NATIONAL REGISTER NOMINATIONS



ONGOING SOLUTIONS
AMONG WJE'S MANY PROJECTS AT THE HISTORIC MARQUETTE BUILDING WAS THE DESIGN OF STRUCTURAL FRAMING AND EVALUATION OF MATERIALS FOR REPLICATING THE CORNICE.



MULTIDISCIPLINARY APPROACH
WJE USED A MULTIDISCIPLINARY APPROACH TO REPAIR THE WORLD'S TALLEST COLUMN MONUMENT, THE 570-FOOT SAN JACINTO MONUMENT IN HOUSTON.



FACADE CONSERVATION
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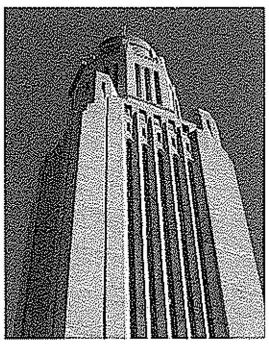


EXTERIOR RESTORATION
WJE WAS RETAINED BY THE STATE TO PROVIDE PROFESSIONAL SERVICES FOR THE RESTORATION OF ALL EXTERIOR BUILDING SYSTEMS FOR THE ARCHITECTURALLY AND HISTORICALLY SIGNIFICANT NEBRASKA STATE CAPITOL.

PRESERVING THE RECENT PAST
WJE INVESTIGATED THE CAST RESIN CLADDING PANELS OF A RESEARCH CAMPUS IN NORTH CAROLINA AND ANALYZED VARIOUS ALTERNATIVES FOR REPAIR AND REPLACEMENT, APPLYING OUR KNOWLEDGE OF MATERIALS AND PRESERVATION PHILOSOPHY TO A MODERNIST LANDMARK.

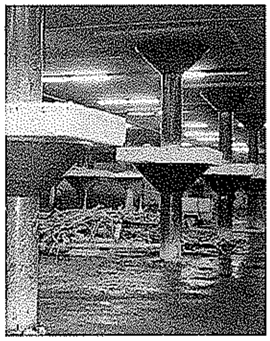
Repair Design and Construction

WJE specializes in design for repair and rehabilitation. Repair details and specifications are developed based on their performance in hundreds of projects. When needed, repair designs can be laboratory-verified before field installation. In addition to traditional construction phase services, we frequently team with qualified constructors to complete projects.

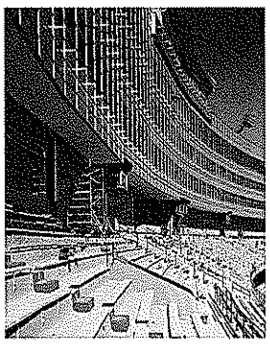
> REPAIR AND REHABILITATION DESIGN
> PREPARATION OF CONSTRUCTION DOCUMENTS AND SPECIFICATIONS
> REVIEW OF BIDS
> CONSTRUCTION PHASE INSPECTION AND TESTING SERVICES
> CONSTRUCTION MANAGEMENT
> DESIGN-BUILD FOR REPAIR AND REHABILITATION

PARKING GARAGE REPAIR
WJE WORKED AROUND THE CLOCK TO INVESTIGATE AND RECOMMEND REPAIRS FOR EXTENSIVE CRACKING OBSERVED AT AN ATLANTA PARKING GARAGE JUST AS IT WAS ABOUT TO OPEN.

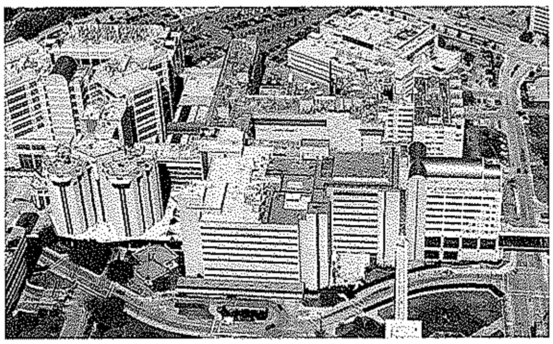
TWIN RESIDENTIAL TOWERS
WJE INVESTIGATED LEAKAGE OCCURRING THROUGH WINDOWS AND EIFS CLADDING, AND RECOMMENDED RECLADDING THE STRUCTURES WITH NEW WINDOWS AND AN ALUMINUM PANEL RAIN SCREEN.



MCCORMICK PLACE PARKING
TO REPAIR A SEVERELY DAMAGED PARKING STRUCTURE AT CHICAGO'S CONVENTION CENTER, WJE DESIGNED REPAIRS TO THE CONCRETE COLUMNS, REMOVAL AND REPLACEMENT OF THE CONCRETE SLAB, AND SYSTEM POST-TENSIONING.



MEMORIAL STADIUM REHAB
WJE'S EXTENSIVE CONDITION SURVEY LED TO A MULTI-YEAR REHABILITATION AND MAINTENANCE PROGRAM FOR THE UNIVERSITY OF NEBRASKA'S 1920s GRANDSTAND STRUCTURE. WORK ALSO INCLUDED A PEER REVIEW OF THEIR SKYBOX STRUCTURE.



TEXAS MEDICAL CENTER
WJE PROVIDED A COMBINATION OF EXTERIOR ENVELOPE CONDITION SURVEYS, REPAIR DESIGNS, AND CONSTRUCTION OBSERVATION SERVICES FOR ELEVEN EXISTING BUILDINGS AT THE M.D. ANDERSON COMPLEX IN HOUSTON'S TEXAS MEDICAL CENTER, AND SERVED AS EXTERIOR ENVELOPE DESIGN CONSULTANT FOR THREE NEW CAMPUS BUILDINGS.

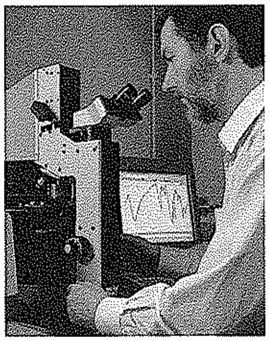
Construction Materials Evaluation and Research

WJE's staff of recognized experts provides comprehensive consulting services for the evaluation of construction materials. Lessons learned in testing and research are applied as solutions to real world problems. We are experienced with all construction materials, including concrete, mortars, grouts, stone, brick, terra cotta, tile, wood, metals, glass, coatings, caulks, sealants, setting beds, and adhesives.

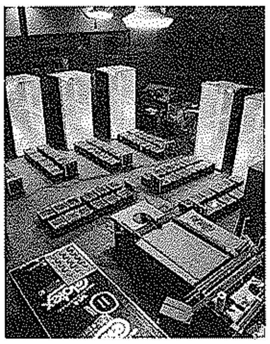
WJE's materials scientists offer a full range of services in petrography, analytical chemistry, organic chemistry, mortar, paint, and coatings analysis.

- MATERIALS TESTING AND ANALYSIS
- MATERIALS FAILURE INVESTIGATION
- MATERIALS CONSERVATION
- RESEARCH
- PETROGRAPHIC EXAMINATION
- OPTICAL, INFRARED, AND ELECTRON MICROSCOPY
- X-RAY DIFFRACTOMETRY AND EMISSION SPECTROSCOPY
- ULTRAVIOLET, INFRARED, AND ATOMIC ABSORPTION SPECTROSCOPY
- DIFFERENTIAL THERMAL ANALYSIS

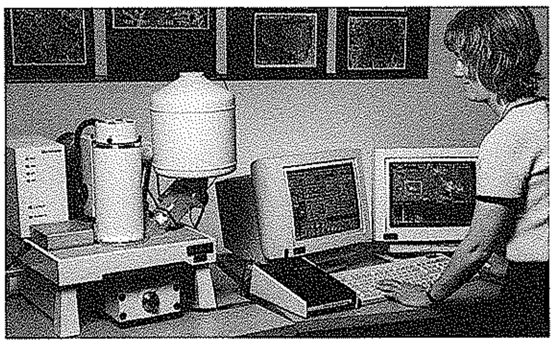
HIGH-PERFORMANCE CONCRETE
AS PART OF CHICAGO'S WACKER DRIVE RECONSTRUCTION PROJECT, WJE EVALUATED HIGH PERFORMANCE CONCRETE MIXES, VERIFIED THEIR EFFECTIVENESS, DEVELOPED CONSTRUCTION SPECIFICATIONS, AND MONITORED REPAIRS AND PERFORMANCE.



FOURIER TRANSFORM INFRARED SPECTROSCOPY
FTIR SPECTROSCOPY IDENTIFIES MOLECULAR STRUCTURES SUCH AS THE ORGANIC AND POLYMERIC COMPONENTS OF CONSTRUCTION MATERIALS.



FHWA STUDY
UNDER A FIVE-YEAR CONTRACT WITH THE FEDERAL HIGHWAY ADMINISTRATION, WJE PERFORMED A COMPREHENSIVE INVESTIGATION OF CORROSION-RESISTANT REINFORCING BARS.

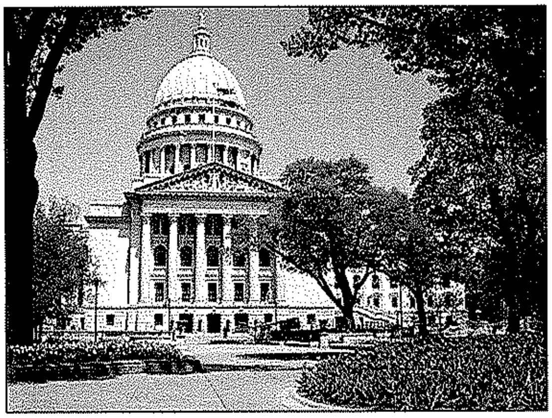


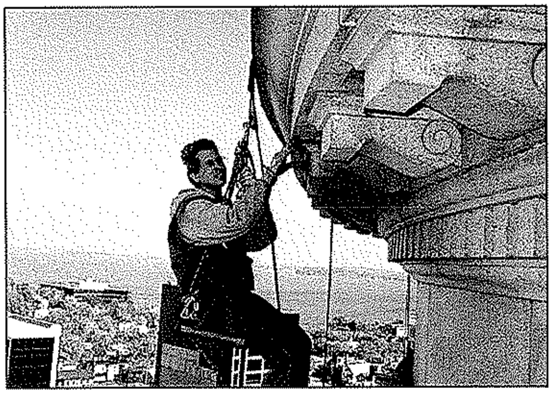
SEM/EDS
THE SCANNING ELECTRON MICROSCOPE AND ENERGY DISPERSIVE SPECTROMETER (SEM/EDS) ARE USED FOR MORPHOLOGICAL AND ELEMENTAL ANALYSIS OF CONSTRUCTION MATERIALS INCLUDING CONCRETE, STONE, METALS, AND COATINGS.

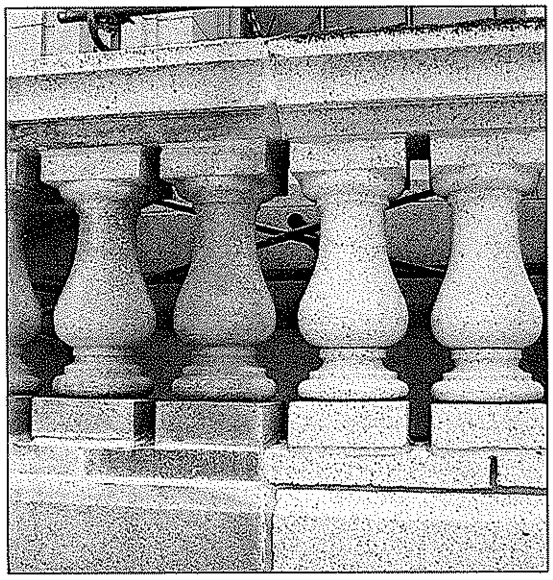
WJE | ENGINEERS
ARCHITECTS
MATERIALS SCIENTISTS

Wisconsin State Capitol

Exterior Stone Restoration and Rehabilitation
Madison, Wisconsin







CLIENT

Wisconsin Department of Facilities Development

STRUCTURE

The Wisconsin State Capitol, designed by George B. Post & Sons and constructed between 1907 and 1917, is a National Historic Landmark structure with exterior walls and dome of Bethel White granite. The capitol has four equal wings around a central domed rotunda space, with grand staircases and entrance pavilions between each wing.

CHALLENGE

The purpose of the project was to document existing conditions and to develop and implement a plan to restore the exterior granite, as part of a decade-long restoration of the capitol.

SCOPE OF SERVICE

- Measured baseline drawings
- Historic structure report
- Condition assessment
- Structural analysis and monitoring
- Stone restoration drawings and specifications
- Construction phase services

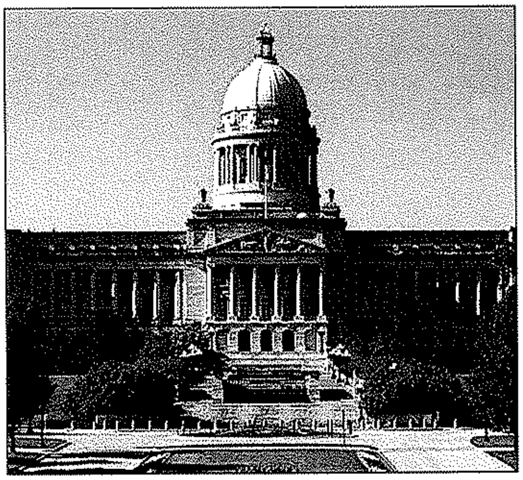
SOLUTION

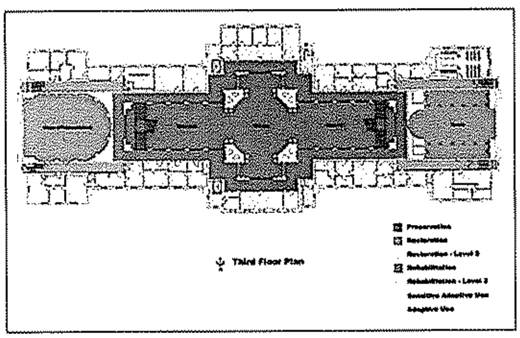
- Researched and reviewed archival documentation, and developed baseline drawings of the exterior
- Participated in the development of a Historic Structure Report for the building
- Performed a detailed condition investigation of the plazas, walls, and dome of the building, including rappelling techniques to inspect the dome and adjacent areas of difficult access
- Evaluated the structural systems of the walls and dome and selectively instrumented and monitored for movement
- Performed additional studies including the evaluation and field testing of cleaning techniques for the granite cladding; field studies of repointing mortar; and evaluation of alternate systems for bird deterrents
- Prepared drawings and specifications for the exterior stone restoration
- Provided continuous on-site documentation and observation of the work, including cleaning all exterior granite, stone masonry repairs, and the replacement of plaza waterproofing
- Upon completion of the restoration, prepared computer-based as-built drawings as a permanent record of the work

WJE | ENGINEERS
ARCHITECTS
MATERIALS SCIENTISTS

Kentucky State Capitol

Historic Conservator for Restoration Master Plan
Frankfort, Kentucky





CLIENT

K. Norman Berry Architects

STRUCTURE

The Kentucky State Capitol, constructed in 1906, was designed in the Beaux Arts Style by Ohio architect Frank Mills Andrews. With visual links to the Parisian Hôtel des Invalides and Opera, the Capitol develops the classical Beaux Arts motif surmounted by a dome. While the exterior is clad with limestone with a dome of terra cotta, the interior is festooned with various types of granite and marble, exotic woods, and "scagliola" plaster surfaces. The public and legislative spaces are finished with a high degree of craftsmanship that is indicative of the era in which it was completed.

CHALLENGE

The Commonwealth of Kentucky made specific recommendations for outlining a strategy for the restoration and preservation of the Kentucky State Capitol. The breadth of the Master Plan included the Capitol Building, Capitol Annex, Parking Structure, Site Improvements and a new Executive Office Building. The intent of the work was to preserve the Capitol and to allow it to serve the people of Kentucky through the next millennium. The Louisville firm of K. Norman Berry Architects was awarded the contract to prepare a Master Plan for the Capitol complex. WJE served as the Project Conservator to the team.

SCOPE OF SERVICE

- Conduct all historical research
- Perform condition assessment of all exterior and interior building systems and materials
- Prepare an Historic Structures Report on findings

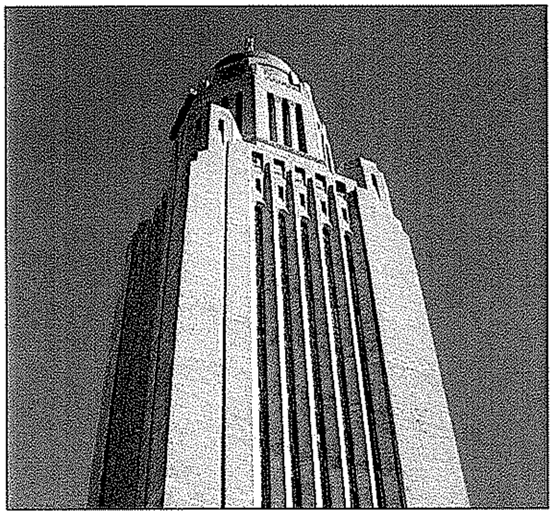
SOLUTION

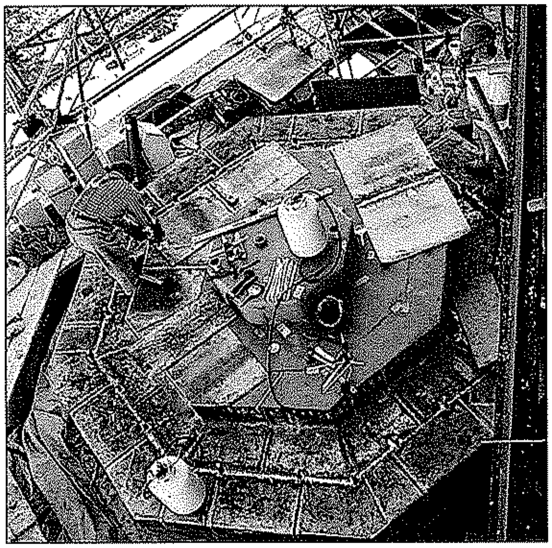
- Multi-disciplinary, in-house WJE team incorporated difficult access techniques to perform an in-depth condition assessment of roofing, facade, and windows
- Managed subconsultants for interior condition survey of MEP, wood, metals, plaster, and paint finishes
- Performed field and laboratory studies
  - Accelerated weathering testing was used to evaluate the terra cotta
  - Biological treatment studies were performed on the building exterior
- Served as the Preservation component of the team

WJE | ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

Nebraska State Capitol

Exterior Facade Investigation and Restoration Design
Lincoln, Nebraska





CLIENT

State of Nebraska

STRUCTURE

The historic Nebraska State Capitol is a 400-foot tall monument designed by Bertram Grosvenor Goodhue, and constructed between 1922 and 1932. A result of a national design competition, the building follows the Beaux-Arts design tenets and melds the traditional domed state capitol building with a post World War I skyscraper.

CHALLENGE

WJE provided specialized architectural and conservator services for the restoration of the building facade, including limestone masonry, ceramic tile dome, clay tile arches, sculptural elements, windows, roofing, and related structural systems.

SCOPE OF SERVICE

- Comprehensive investigation of the exterior building systems including the dome, facades, promenades, windows, copper roofing system
- Rapelling techniques for inspection of dome and difficult access areas
- Petrographic analysis of the limestone masonry
- Evaluation of cleaning and biocide treatments
- Repair drawings and specifications
- Construction observation services
- Continuing laboratory analysis on an as-needed basis

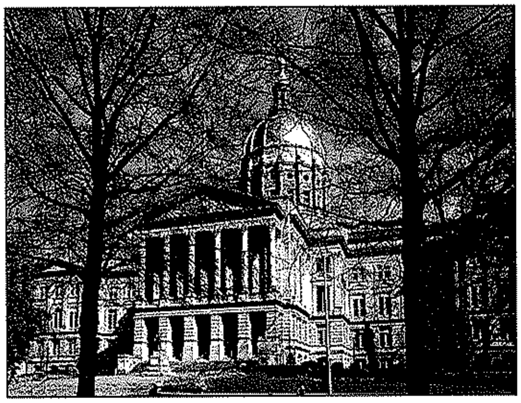
SOLUTION

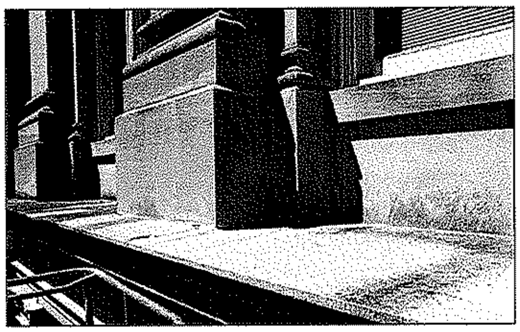
- In cooperation with Bahr, Vermeer & Haecker, developed restoration drawings and specifications for the restoration of the historic structure
- Performed all work in strict accordance with the *Secretary of the Interior Standards*
- Restoration follows "conservation philosophy" and salvages and respects historic building fabric whenever possible
- Redesigned inconsistencies in the original design and construction to give the building fabric increased durability
- Provided construction observation services during restoration
- Observation work entails continued laboratory analysis of building conditions as they become apparent during the multi-phase project set for completion circa 2010

WJE | ENGINEERS
ARCHITECTS
MATERIALS SCIENTISTS

Georgia State Capitol

Cleaning and Material Studies
Atlanta, Georgia





CLIENT

Lord Aeck Sargent

STRUCTURE

The Georgia State Capitol was dedicated on 4 July 1889. It is the work of Chicago architects Willoughby J. Edbrooke and Franklin P. Burnham. The four-story building is clad with Indiana limestone, with Classical architectural features including Corinthian columns, pilasters, cornice moldings, and belt courses.

CHALLENGE

In February 2001, WJE began a series of cleaning studies for Lord Aeck Sargent on the historic capitol. Many of the projecting cornices and moldings had dark area of organic growth. Such organic growth is often found on building elements where moisture can collect, such as horizontal ledges. Other areas of the facade had mild accumulations of surface dirt and light green staining due to runoff from copper-containing metal elements.

SCOPE OF SERVICE

- Cleaning studies
- Cleaning recommendations
- Mortar analysis

SOLUTION

- Performed a series of 23 field cleaning tests on the isolated organic growth and soiling conditions on limestone and granite masonry elements of the facade
  - Tested combinations of household cleaners as well as proprietary fungicide products manufactured for use on masonry
  - Tested poultice cleaning techniques on areas of copper staining
  - Tested mild detergent solutions on areas of dirt accumulation
  - Collected samples of water runoff from the tests to determine environmental impact
- Based on thorough testing, recommended options for full scale cleaning and consulted during the implementation of the cleaning work
- Performed an analysis of original mortar to identify its components, allowing Lord Aeck Sargent to develop a suitable mix for repointing the exterior masonry

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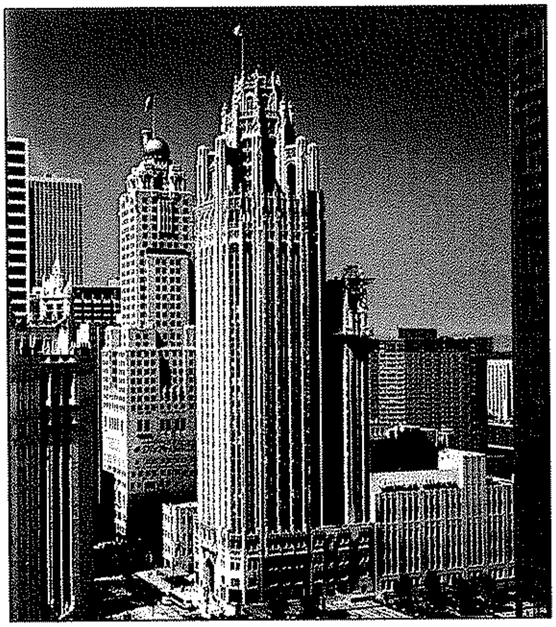
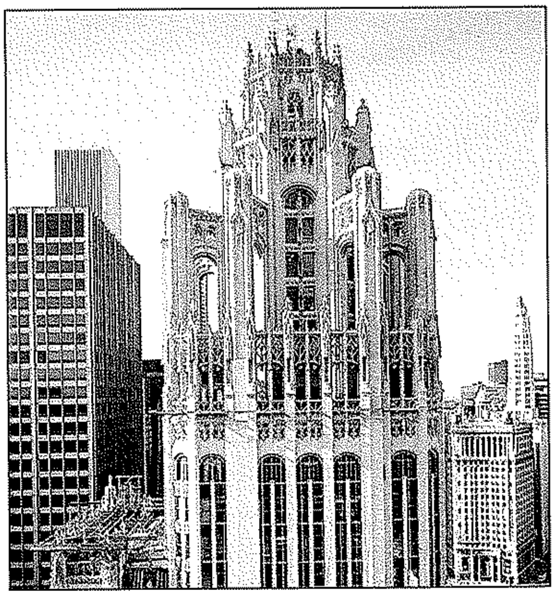
Tribune Building

Inspection and Repair Design of the Limestone Facade
Chicago, Illinois





CLIENT

Chicago Tribune Properties

STRUCTURE

New York architects Raymond Hood and John Mead Howells won the 1922 international design competition for the Chicago Tribune Building. Their design melded the Chicago-born form of the skyscraper with high Gothic detailing. The building, which includes buttressed columns at the 25th floor, is a 34-story, steel-framed, limestone-clad structure.

CHALLENGE

WJE worked continuously with the Tribune Company from 1986 to 1997 on a variety of projects to maintain the historic tower.

SCOPE OF SERVICE

- Investigation and structural analysis
- Repair design
- Window replacement
- Facade cleaning

SOLUTION

- Peformed investigative techniques to evaluate characteristics and condition of the exterior stonework including:
  - Close-up inspections
  - Examination of inspection openings
  - Structural analysis with computer modeling techniques
  - Trial repairs
  - Laboratory petrographic studies
  - Chemical testing
- Designed repairs to address distress of several building features and systems including:
  - Facade stonework
  - Back-up construction
  - Exposed metal elements
- Consulted on window replacement for the building
- Performed conservation studies for ornamental stone at the base of the building
- Conducted extensive technical research, field and laboratory testing, specification and quality control development, and monitoring of the cleaning of the facade
- Technical research included site visits in England, France, and Belgium to evaluate state-of-the-art cleaning techniques that are not extensively used in the United States

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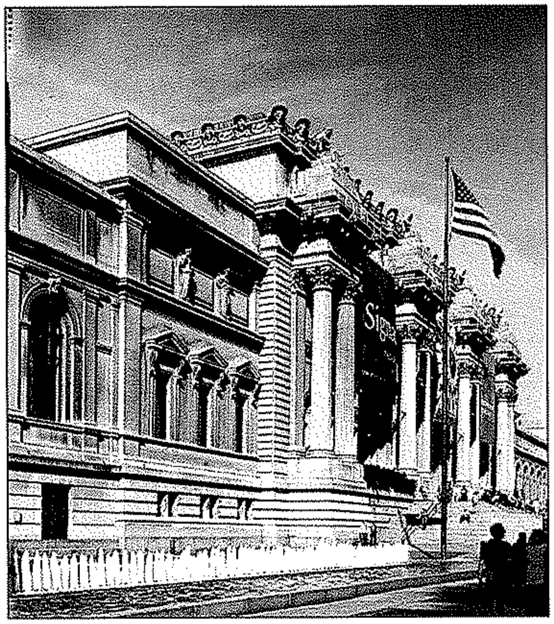
The Metropolitan Museum of Art

Masonry Restoration of the Fifth Avenue Facades

New York, New York



CLIENT

The Metropolitan Museum of Art

STRUCTURE

The five wings of The Metropolitan Museum of Art facing Fifth Avenue extend four blocks and were built over a 24-year period. The first wing to be built was the central wing designed by Richard Morris Hunt. The balance of the Fifth Avenue facades, completed in 1926, was designed by McKim Meade and White based on Hunt's master plan. The facades are designed following a Corinthian order and are substantially composed of limestone.

CHALLENGE

The museum's facade showed symptoms of distress including compression spalling of the limestone at joints attributed to repointing with hard cement; efflorescence, anchor spalls, and unsound deteriorated collar joints attributed to water ingress via failed gutters; and cracking attributed to thermal cycling.

SCOPE OF SERVICE

- Investigate masonry facade distress
- Develop masonry restoration alternatives
- Prepare contract documents
- Provide construction administration services

SOLUTION

WJE's multidisciplinary team developed and implemented a coordinated facade evaluation and restoration effort appropriate for the museum's historic architecture and materials.

- Studied original construction drawings and photographs to provide a basis for understanding existing conditions
- Performed hands-on survey to document severity and extent of typical symptoms and identify unusual conditions
- Tested and specified alternative restoration techniques
  - Traditional dutchman patches
  - Mortar based crack repairs
  - Several types of pinning for stabilization and anchorage
  - Hydraulic lime based mortars and grouts were selected for all masonry repointing and restoration procedures
  - Cleaning systems were tested for effectiveness, risk of damage, cost, environmental concerns, and logistics
- Contract documents, bidding, and construction administration
  - Masonry facade cleaning
  - Masonry facade repair and restoration
  - Monel metal gutter replacements
  - Monumental bronze window restoration
- Successfully completed Phase I on time and on budget with overall project completion scheduled for 2005

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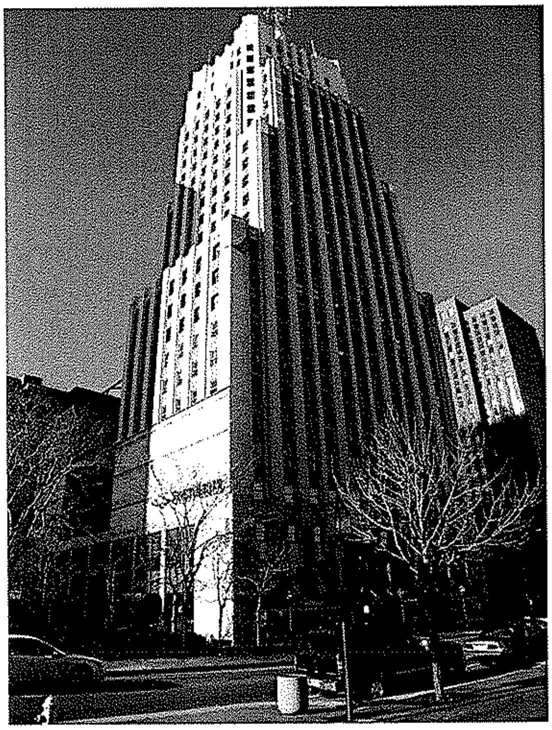
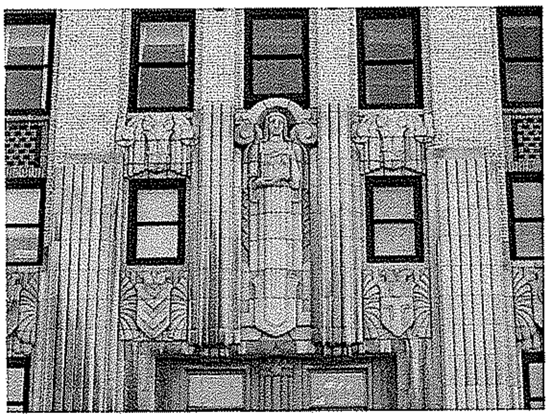
ARCHITECTS
MATERIALS SCIENTISTS

FirstMerit Tower

Terra cotta, Glazed Brick, and Limestone Facade Rehabilitation

Akron, Ohio





CLIENT

FirstMerit Bank

STRUCTURE

The FirstMerit Tower, historically known as the First National Bank of Akron, is a 1931 Art Deco skyscraper which anchors downtown Akron. Still the tallest building in Akron, it features decorative terra cotta parapets, Indiana limestone and glazed brick veneer, and Monel metal storefront enclosures with bold Art Deco designs and motifs.

CHALLENGE

Deterioration of the parapets prompted the bank to restore the building envelope. Initial visual survey of the building identified brick veneer which had separated from the backup on the northeast corner, necessitating emergency stabilization. Corrosion of the steel support plates and outriggers damaged brick and terra cotta where moisture had compromised the building envelope. Exposure had soiled terra cotta and limestone veneers.

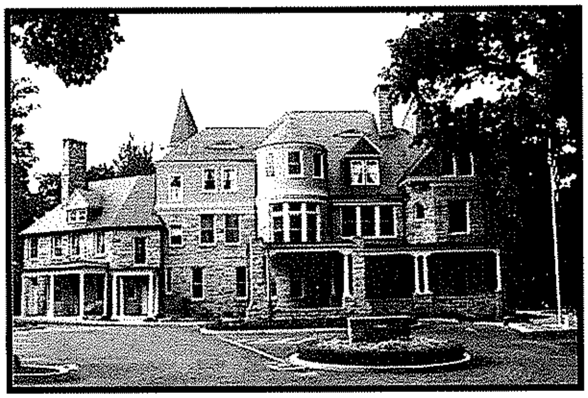
SCOPE OF SERVICE

- Review and documentation of existing conditions
- Design of repair scheme
- Preparation of construction documents
- Petrographic evaluation
- Construction period services
- Preparation of National Register nomination and Tax Credit certification

SOLUTION

- Designed parapet repairs with an internal flashing system with weeps and end dams to protect structural steel
- Worked with the contractor to safely support scaffolding on sidewalk vaults and setback roofs
- Provided construction period services to work with contractor to adapt design details to building elements that do not match original construction documents
- Drafted a National Register nomination and developed tax credit certification documents

Graceland at Davis and Elkins College
Restoration of Historic Mansion
Elkins, West Virginia



This mansion, circa 1896, is a National Historic Landmark. Originally built by U.S. Senator Henry Gassaway Davis, this Norman French style mansion is constructed of West Virginia granite and sandstone with several limestone appointments.

A massive fireplace in the two-story stair hall highlights the grand interior. Sunlight bathes the interior of the grand hall through numerous Tiffany stained glass windows.

Graceland, as it was affectionately named after Senator Davis' daughter, is now an inn and conference center operated by Davis and Elkins' College of Hospitality. After Davis and Elkins College purchased the property, PDMAE completely restored the mansion after decades of neglect. Some areas of the mansion were adaptively re-designed for us as an inn such as the kitchen and several bedroom suites. The two massive porches had to be rebuilt from photographs. Extensive research was done on the interior finishes in order to replicate them as close to the original as possible.

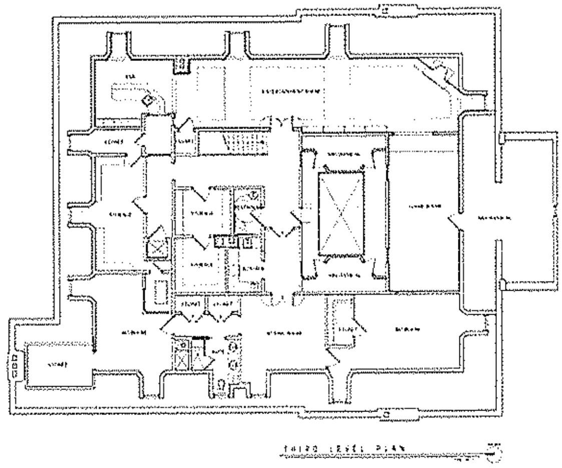
Paul D. Marshall Architects & Engineers, Inc.
305 Washington Street, West
Charleston, WV 25302

Phone: (304) 342-0300
Fax: (304) 342-4300
www.pdmae.com

Governor's Mansion
Restoration & Renovations
Building No. 8, Capitol Complex
Charleston, West Virginia

Listed on the National Register of Historic Places, the Governor's Mansion in the capitol city of Charleston has been home of West Virginia's Governors since 1929. Designed by Walter Martens, this Georgian Colonial style mansion boasts over thirty thousand square feet and twenty-three rooms. The interior features a double grand staircase and a large state dining room. The exterior features a 5000 square foot walled courtyard as part of its two and a half acre landscape.

PDMAE evaluated needs for restoration and renovation after decades of use. The unfinished areas of the mansion's third floor were completed enhancing the residences ability to host special guests of the Governor.



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WJE | ENGINEERS
ARCHITECTS
MATERIALS SCIENTISTS

Elwin C. Robison

Senior Associate

EDUCATION

Brigham Young University
  Bachelor of Science, Civil Engineering, 1978
Cornell University
  Master of Arts, Architectural History, 1983
Cornell University
  Doctor of Philosophy, Architectural History, 1985

REGISTRATION

Professional Engineer in Ohio, Pennsylvania, Michigan, and Indiana

PRACTICE AREAS

Historic Preservation
Historic Structures Reports
Masonry Deterioration
Repair and Rehabilitation Design
Structural Analysis
Structural Investigation
Wood Testing and Analysis

EXPERIENCE

Dr. Robison has affiliated with WJE since 2003 and has performed condition assessments on building envelopes in brick and terra cotta, structural analysis on steel and wood systems, and investigative services for building failures.

Dr. Robison is the engineer-of-record for National Register building restorations, and has written Historic Structures Reports for National Register and National Landmark buildings. His work has received awards from AIA Ohio and the Ohio State Preservation Office. He serves on the Advisory Board for the Ohio State Preservation Office. Dr. Robison is a co-author of *Architectural Technology Up To the Scientific Revolution* (MIT Press, 1993) and the author of *The First Mormon Temple: Design, Construction, Historic Context of the Kirtland Temple* (BYU Press, 1997). He is the author of articles on the architecture of Andrea Palladio, Guarino Guarini, early skyscraper technology, and nondestructive testing.

REPRESENTATIVE PROJECTS

Historic Preservation

- N.K. Whitney Home: Restoration of the 1826 structure as a house museum, Kirtland, Ohio
- St. Peters Church: Vibration analysis of impact from light rail system, Cleveland, Ohio

Historic Structures Reports

- John and Elsa Johnson Home: Restoration of a 1828 structure as a house museum, Hiram, Ohio
- Kirtland Temple: A three-story stone meeting house built in 1836, Kirtland, Ohio
- Salmon Carter Home: 1836 house museum of the Portage County Historical Society, Ravenna, Ohio

Structural Investigation

- Akron YMCA: Investigation of corroded steel structure, Akron, Ohio
- Frank Lloyd Wright's Westcott House: Structural stabilization and restoration as a house museum, Springfield, Ohio

Repair and Rehabilitation Design

- Robinson Music Store: Restoration of a turn of the century store, Steubenville, Ohio
- The Chalet: Investigation of deteriorated glulam beams, Cleveland Metroparks

Masonry Deterioration

- Mt. Sinai Hospital complex: Conditions assessment of terra cotta, brick, and stone facades, Cleveland, Ohio
- Townshend Library: Conditions assessment of limestone building envelope, Ohio State University, Columbus, Ohio
- First Merit Tower: Facade restoration of an Art Deco skyscraper of terra cotta, limestone, and glazed brick, Akron, Ohio

Wood Testing and Analysis

- Eleutherian College Chapel: analysis and design of repairs to 1854 wood trusses, Lancaster, Indiana

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers (ASCE)
Association for Preservation Technology (APT)
Society of Architectural Historians

PROFESSIONAL ACTIVITIES

- Governor's appointment to the Ohio State Preservation Advisory Board (2004 -2007)
- Editor-in-Chief, *Architronic: The Electronic Journal of Architecture* (1993-97)
- Chair, Ad-Hoc Committee on Electronic Resources in Architectural History, Society of Architectural Historians (1994-98)

HONORS AND AWARDS

- Cleveland Restoration Society, 2004 Preservation Award, Cultural Heritage Preservation, Historic Mormon Sites, 2004
- Ohio AIA Design Award of Merit, Kirtland Historic District master Plan, Kirtland OH, with Chambers, Murphy & Burge, Benke Associates, and John A. Werne, 2003
- AIA Akron Chapter Design Award, John and Elsa Johnson Home, Hiram, OH, with Chambers, Murphy & Burge, November 2002
- Preservation Merit Award for the Robinson Music Company Building, Steubenville, OH, with Chambers, Murphy & Burge, September 2002.
- Western Reserve Architectural Historians Annual Award, *The First Mormon Temple: Design, Construction, and Historic Context of the Kirtland Temple*, Brigham Young University Press: 1997
- National Endowment for the Arts, $45,000 grant to develop *Architronic: The Electronic Journal of Architecture,* June 1995-97

REPRESENTATIVE PROJECTS

FirstMerit Tower, Akron, Ohio, Project engineer for restoration and cleaning of the masonry facade of a 1931 Art Deco skyscraper consisting of Indiana limestone, glazed brick, and terra cotta.

Pennsylvania House, Springfield, Ohio, Project engineer for the restoration of a brick 1839 National Road Tavern.

Burton F. Westcott Home, Springfield, Ohio, Project engineer of the restoration of Frank Lloyd Wright's only Prairie Home in Ohio.

Cleveland Jewish Hospital, Cleveland, Ohio, consultant on the masonry facade restoration on George Post's 1914 building of brick, limestone, and terra cotta.

Ohio State University Main Library, Columbus, Ohio, consultant on the masonry facade restoration of the original 1912 Indian limestone library, the 1948 stone veneer addition, and the 1977 limestone veneer addition.

Newel K. Whitney Home, Kirtland, Ohio, researched and wrote the Historic Structures Report and was project engineer for the restoration of this 1826 house museum.

John Johnson Home, Hiram, Ohio, researched and wrote the Historic Structures Report and was project engineer for the restoration of this 1828 house museum.

PUBLICATIONS

Books

Robert Mark, gen. ed., with Sheila Bonde, Lynn Courtney, Clark Maines, R. Richards and Elwin C. Robison, *Architectural Technology Up To the Scientific Revolution*, MIT Press, 1993.

Robison, Elwin C., *The First Mormon Temple: Design, Construction, and Historic Context of the Kirtland Temple*, Brigham Young University Press: 1997

Selected Articles

Elisabetta Rosina and Elwin C. Robison, "Applying Thermography to North American Wood-Framed Buildings," *Association for Preservation Technology Bulletin* 33 (2002):p. 23-32.

Robison, Elwin C., "Heavenly Aspirations and Earthly Utopias: Four Northeast Ohio Religious Utopias," *Timeline*, v. 17, no. 6, Nov/Dec, pp. 2-25.

Robison, Elwin C., "Structural implications in Palladio's use of harmonic proportions," *Annali di architettura: rivista del centro internazionale di studi di architettura Andrea Palladio,* 1998-1999, n.10-11, p.175-182.

The St. James Press Dictionary of Artists and Architects, Nov 1992, entries on "Villa Barbaro in Maser," "Andrea Palladio," "Guarino Guarini," "San Lorenzo in Turin," "Palazzo Carignano," "Home Insurance Building in Chicago," "Reliance Building in Chicago," and "Monadnock Building in Chicago."

Robison, Elwin C., "A British Proposal for American Settlement: Granville Sharp's Plan for a Town and Township." *Planning History: Bulletin of the Planning History Group*, vol. 14, no. 3, pp. 23-27.

Robison, Elwin C., "Optics, Mathematics, and the Domed Churches of Guarino Guarini," *Journal of the Society of Architectural Historians* 50:384-401 (December 1991).

Robison, Elwin C. "Early Skyscrapers and Engineering Calculation Methods," in *On Architecture: The City and Technology* (Butterworth, March 1991) pp. 114-116.

Robison, Elwin C. "St. Peter's Dome: The Structural and Aesthetic Contribution of Giacomo Della Porta, " in *Structural Studies, Repair, and Maintenance of Historic Structures*, Southhampton, England, 1989.

WJE | ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

Michael R. Nagle

Senior Associate

EDUCATION

State University of New York at Buffalo
Bachelor of Architecture, 1991
Erie Community College
Associates Degree of Applied Science, Architecture, 1988
State University of New York at Buffalo
Master of Architecture, 1993

REGISTRATION

Registered Architect in New York, Ohio, and Florida
NCARB Certification

PRACTICE AREAS

Building Envelope Assessment
Historic Preservation
Masonry Deterioration
Peer Review
Repair and Rehabilitation Design
Roofing and Waterproofing
Windows and Curtain Walls

EXPERIENCE

Since joining WJE in 2004, Mr. Nagle has performed numerous condition assessments, water leakage investigations, peer reviews, and developed remedial designs for both contemporary and historic structures involving masonry, stone, concrete, terra cotta, windows, and EIFS. Mr. Nagle is a member of WJE's Difficult Access Team, which utilizes industrial roped access techniques to perform facade investigations.

Mr. Nagle has directed projects encompassing historic tax credits, storefront incentive programs, and historic landmark approvals. From 1997 to 2004, he managed several significant restoration and repair projects from initial investigation through remediation. Mr. Nagle is principal editor of the published *Guide to Cleveland Architecture, 2nd Edition*, and co-author of the article, "Internal Sulfate Attack: Distress Caused by Improper Gypsum Use", which appeared in the July 2006 edition of *The Construction Specifier*.

REPRESENTATIVE PROJECTS

Building Envelope Assessment

- Triangle Complex: Pre-purchase survey of five masonry structures, Cleveland, Ohio
- Kelvin Smith Library, Case Western Reserve University: Air and water leakage investigation, Cleveland, Ohio

Historic Preservation

- First Merit Bank Tower: Facade rehabilitation and repair, Akron, Ohio
- Renaissance Cleveland Hotel: Facade repair and stabilization, Cleveland, Ohio

Masonry Deterioration

- West Quad Redevelopment, Case Western Reserve University: Masonry and terra cotta repair, Cleveland, Ohio
- National Terminal Warehouse Apartments: Masonry facade remediation and stabilization, Cleveland, Ohio

Repair and Rehabilitation Design

- Fenn Tower, Cleveland State University: Cast stone assessment and stabilization, Cleveland, Ohio

Roofing and Waterproofing

- McCoy Natatorium, Pennsylvania State University: Roof condition assessment, University Park, Pennsylvania
- W.O. Walker Center: Peer review services, Cleveland, Ohio
- Gund Arena: Roof condition assessment, Cleveland, Ohio
- Hurricane Katrina and Wilma: Roofing damage assessment, Various properties, Florida, Mississippi, and Louisiana

Windows and Curtain Walls

- Gund Arena: Glazed canopy assessment, Cleveland, Ohio
- SS&G Office Building: Water leakage assessment, Akron, Ohio

PROFESSIONAL AFFILIATIONS

American Institute of Architects (AIA)
Association for Preservation Technology (APT)
Cleveland Restoration Society (CRS)
Construction Specifications Institute (CSI)
National Trust for Historic Preservation (NTHP)

TECHNICAL COMMITTEES

ASTM International C24 - Building Seals and Sealants

PROFESSIONAL ACTIVITIES

- AIA Cleveland, Guidebook II Committee (1993 to 1998)
- AIA Ohio Associate Member Director (1995-1997)

HONORS AND AWARDS

- AIA Cleveland, President's Award 1997, Cleveland, Ohio.
- Cleveland Restoration Society Awards 2002,Sustained Maintenance Award for Historic Structures, Parma Reservoir Renovation, Parma Heights, Ohio
- Build Ohio Awards 2003, Industrial/Heavy Award, Baldwin Water Works Plant, Cleveland, Ohio.
- American Council of Engineering Companies of Ohio (ACEC Ohio) Awards 2003, Outstanding Achievement Award, Baldwin Water Works Plant, Cleveland, Ohio.
- Cleveland Restoration Society Awards 2004, Trustees Award for Preservation Achievement, Weizer Building, Cleveland, Ohio
- Cleveland Restoration Society Awards 2005, Public Building Award, Baldwin Water Works Plant, Cleveland, Ohio

RELEVANT PROJECTS

Baldwin Water Works Plant, Cleveland, Ohio, Project Manager and Architect for the comprehensive interior rehabilitation and exterior building restoration of several historic buildings including the administration building, filter wings, gatehouses, and the design for a new guardhouse.

City of Avon Lake Safety Center, Avon Lake, Ohio, Project Manager and Architect for the new police, municipal court, jail and renovation of the fire station.

Historic Newton Avenue Apartments, Cleveland, Ohio, Project Manager and Architect for the interior renovation and exterior restoration of two historic apartment buildings involving historic tax credits and compliance with The Secretary of the Interior's Standards for the Treatment of Historic Properties.

John Hay High School, Cleveland, Ohio, Project Architect for a comprehensive masonry restoration of the historic school building.

Lake County Courthouse, Painesville, Ohio, Project Manager and Architect for the multi-phased interior renovation and rear addition of the historic courthouse.

Parma Water Reservoir Renovation, Parma Heights, Ohio, Project Manager and Architect for the restoration of an historic brick, stone, and concrete water reservoir.

Weizer Building, Cleveland, Ohio, Project Manager and Architect for the historic exterior restoration and interior renovation from a former bank and apartment use to child and family services.

PUBLICATIONS: TECHNICAL JOURNALS AND MAGAZINES

Hime, William and Nagle, Michael, "Internal Sulfate Attack, Distress Caused by Improper Gypsum Use," The Construction Specifier, vol. 59 no. 6, July 2006.

PUBLICATIONS: BOOKS

Nagle, Michael, principal editor. ***Guide to Cleveland Architecture***, Cleveland, Ohio: Second Edition, 1997.

Stephen J. Kelley

Senior Consultant

EDUCATION

University of Illinois, Urbana-Champaign
Bachelor of Architecture, 1976
University of Illinois, Urbana-Champaign
Master of Architecture, 1978

REGISTRATION

Architect in Illinois and Tennessee
Structural Engineer in Illinois

PRACTICE AREAS

Brick, Stone, and Terra Cotta Deterioration
Facade Cleaning
Fire Damage Investigation
Historic Preservation
Historic Structures Reports
Materials Conservation Analysis
Repair and Rehabilitation Design
Windows and Curtain Walls

EXPERIENCE

Since joining WJE in 1984, Mr. Kelley has developed expertise in the restoration of historic buildings and monuments. He has extensive experience in the area of skyscrapers; churches; facade cleaning; stone, brick, and terra cotta masonry; and curtain walls and windows. He has expertise in the analysis and conservation of historic building materials and systems including wood log buildings, plasters, and stained glass artwork. Mr. Kelley has investigated numerous historic churches that have been damaged by fire, wind, and flood.

His work in the area of preservation stretches from investigation, extensive use of laboratory techniques, coordination of all disciplines, document preparation, and construction observation. Mr. Kelley has consulted on preservation projects in the former Soviet Union, Eastern Europe, and Asia. He has lectured extensively, in the US, Europe, and Asia on aspects of technical preservation and has written numerous articles in journals and edited books on the topic.

REPRESENTATIVE PROJECTS

Facade Cleaning

- Georgia State Capitol: Facade cleaning, Atlanta, Georgia
- Tribune Tower: Facade restoration, Chicago, Illinois
- Holy Family Church: Facade cleaning, structural stabilization, restoration of slate roofing, Chicago, Illinois

Historic Preservation

- Nebraska State Capitol: Facade cleaning, restoration of facade and windows, Lincoln, Nebraska
- St. Cecilia's Cathedral: Restoration of tile roofing, facade, and interior sanctuary, Omaha, Nebraska
- Basilica of St. Adalbert: Restoration of tile roofing, facade, stained glass, Grand Rapids, Michigan
- Church of Our Savior of Berestove: Coordinator for development of restoration plan, Kyiv, Ukraine
- Wood Log Church Survey: Development of master conservation for 28 churches, Eastern Slovakia

Historic Structure Reports

- Kentucky State Capitol: Historic Structures Report, preservation planning, Frankfort, Kentucky
- Illinois State Capitol: Difficult access inspection, Historic Structures Report, Springfield, Illinois

Repair and Rehabilitation Design

- Qasr al-Bint Temple Ruin: Engineering feasibility study for seismic stabilization, Petra, Jordan
- West Baden Springs Hotel: Structural stabilization after collapse, West Baden, Indiana
- Old St. Patrick's Church: Structural stabilization of wood truss system, Chicago, Illinois

Terra Cotta

- Reliance Building: Facade cleaning, restoration of facade and windows, Chicago, Illinois
- Carbide and Carbon Building: Facade cleaning, restoration of facade and windows, Chicago, Illinois

PROFESSIONAL AFFILIATIONS

American Institute of Architects (AIA)
Association for Preservation Technology (APT) (Fellow and Director)
International Council on Monuments and Sites (US/ICOMOS) (Past Director)

TECHNICAL COMMITTEES

ASTM E06.24 - Building Preservation and Rehabilitation Technology (Chairman 1988 to 1998)
International Science Committee on Analysis and Restoration Structures of Architectural Heritage (ISCARSAH)

PROFESSIONAL ACTIVITIES

- Board of Directors, Association for Preservation Technology (2003 to present)
- US Representative to the ICOMOS International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage, (1997 to present)
- Board of Directors and Executive Committee, US/ICOMOS (1997 to 2003)
- Chair, ASTM E06.24, Building Preservation and Rehabilitation Technology (1988 to 1998)
- Founding Board Member, DOCOMOMO/US (1999)
- Board of Directors, Landmarks Preservation Council of Illinois (1994 to 2000)

HONORS AND AWARDS

- Structural Engineers Association of Illinois (SEAOI) Award of Merit 2005, Restoration of the cornice of the Marquette Building, Chicago, Illinois.
- Excellence in Masonry 2004, Illinois Indiana Masonry Council, Silver Award, Exterior Restoration of the Hard Rock Hotel (Carbide and Carbon Building) Chicago, Illinois.
- Friends of Downtown Awards 2004, Best Restoration Project, Hard Rock Hotel (Carbide and Carbon Building) Chicago, Illinois.
- Midwest Construction Best of Awards 2004, Project of the Year - Renovation/Rehabilitation, Hard Rock Hotel (Carbide and Carbon Building), Chicago, Illinois.
- 2004 Driehaus Award, Outstanding Rehabilitation, Hard Rock Hotel (Carbide and Carbon Building), Chicago, Illinois.
- 2004 ICRI Award of Excellence, Historic Repair of Jefferson Davis Monument, Fairview, Kentucky.
- Midwest Construction Best of Awards 2003, Award of Merit - Renovation/Rehabilitation, Holy Family Church Steeple Restoration, Chicago, Illinois.
- AIA Nebraska Chapter Restoration Award 2001, Restoration of St Cecelia's Cathedra, Omaha, Nebraska.
- Commissioned a "Kentucky Colonel" by Paul E. Patton, Governor of Kentucky (2001).
- Excellence in Masonry 1999, Illinois Indiana Masonry Council, Honorable Mention, Exterior Restoration of the Reliance Building, Chicago, Illinois.
- Kentuckiana Masonry Institute 2000, Restoration of the Dome of the Kentucky State Capitol, Frankfort, Kentucky.
- Elected to Association for Preservation Technology (APT) College of Fellows (1998).
- Excellence in Masonry 1996, Illinois Indiana Masonry Council, Honorable Mention, Exterior Restoration of the Tribune Tower, Chicago, Illinois.
- 1995 Richard H. Driehaus Foundation Preservation Award, Exterior of the Reliance Building, Chicago, Illinois.

RELEVANT PROJECTS

Nebraska State Capitol, Lincoln, Nebraska, Project architect for the comprehensive investigation and special consultant for the restoration of the exterior facade and roofs.

Kentucky State Capitol, Frankfort, Kentucky, Architectural Conservator and Preservation Consultant on the preparation of an Historic Structures Report, Master Plan, and restoration of the terra cotta dome.

Illinois State Capitol, Springfield, Illinois, Preparation of an Historic Structure Report and continued preservation consulting.

Georgia State Capitol, Atlanta, Georgia, Investigation of the façade and appropriate cleaning techniques for landmark structure constructed in 1888.

Eisenhower Executive Office Building, Washington DC, Historic Preservation Specialist for Design-Build Team to restore the interior of Second Empire Style National Historic Landmark constructed in 1868-1888.

Gateway Arch, Jefferson National Expansion Monument, Saint Louis, Missouri, Investigation of corrosion on stainless steel exterior of 603 foot catenary arch.

Tribune Tower Building, Chicago, Illinois, Project architect and engineer for the investigation, testing, structural analysis, and restoration of the exterior facades of landmark skyscraper.

Reliance Building, Chicago, Illinois, Project architect and structural engineer for investigation and restoration of terra cotta facades and windows of landmark skyscraper.

Hard Rock Hotel, Chicago, Illinois, Façade consultant for the investigation, laboratory analysis, restoration and rehabilitation of historic terra cotta clad landmark skyscraper.

PUBLICATIONS: BOOKS

Kelley, Stephen, "The Glass and Metal Curtain Wall: History, Diagnostics, and Treatment," ***Preserving Post-War Heritage***, Edited by Susan MacDonald, London: Donhead, 2001.

Kelley, Stephen, Joseph Loferski, Alexander Salenikovich, and George Stern, co-editors. ***ASTM STP 1351: Wood Structures: A Global Forum on the Treatment, Conservation and Repair of Cultural Heritage***. Philadelphia, Pennsylvania: American Society for Testing and Materials, 2000.

Kelley, Stephen and Dennis Johnson, "The Glass and Metal Curtainwall: The History and Diagnostics," ***Modern Movement Heritage***, London: E & FN Spon, 1998.

Kelley, Stephen, "An American History of the Curtain Wall," ***Curtain Wall Refurbishment, A Challenge to Manage***, Eindhoven, Netherlands: DOCOMOMO International, 1997.

Contributing author, ***Historic Building Facades, the Manual for Maintenance and Rehabilitation***, New York: John Wiley and Sons, 1997.

Kelley, Stephen, "The History of the Glass and Metal Curtain Wall: From the Reliance Building to the Lever House," ***Window Rehabilitation Guide for Historic Buildings***, Washington DC: Historic Preservation Education Foundation, 1997.

Kelley, Stephen, editor. ***ASTM STP 1258: Standards for Preservation and Rehabilitation***. Philadelphia, Pennsylvania: American Society for Testing and Materials, 1996.

Kelley, Stephen and Philip Marshall, co-editors. ***ASTM STP 1098: Service Life of Rehabilitated Buildings and Other Structures***. Philadelphia, Pennsylvania: American Society for Testing and Materials, 1990.

Kelley, Stephen, Conrad Paulson, and Deborah Slaton. "Assessment Techniques Utilized with Historic American Highrises," in ***Structural Repair and Maintenance of Historical Buildings***. Southampton, England: Computational Mechanics Publications, 1989.

PUBLICATIONS: TECHNICAL JOURNALS AND MAGAZINES

Kelley, S., and D. W. Look. "A Philosophy for Preservation Engineers," APT Bulletin, Volume 36, Number 1, 2005.

Kelley, S., "The American Skyscraper Heritage: History and Treatment," More Than Two Thousand Years in the History of Architecture: Proceedings of the International Congress, UNESCO, 2004.

Kelley, S., and D. Worth, "Restoring a Nebraska Landmark," Architectural Record, November 1998.

Kelley, S., and T. Crowe "ASTM Standards in Masonry Preservation and Restoration," The Construction Specifier, vol. 51 no. 11, October 1998.

Kelley, S., "Office Buildings of the Chicago School: The Restoration of the Reliance Building," Konservierung Der Moderne, ICOMOS, Hefte des Deutschen NationalKomitees XXIV (Journal of the German National Committee No. 24), Munich 1998.

Kelley, S. and D. Slaton. "Cleaning Up," Building Renovation Magazine, Summer 1995.

Hunderman, H., D. Slaton and S. Kelley, "Cleaning Old Buildings," The Construction Specifier, Volume 47, Number 7, July 1994.

Kelley, S. and D. Slaton. "Standards for Preservation," Building Renovation Magazine, Spring 1994.

Kelley, S. and Guest Editor. APT Bulletin, Volume 23, November 1, 1991. Fredricksburg, Virginia: Association for Preservation Technology.

Kelley, S. and M. Lynch. "A Forum on Preservation Engineering," APT Bulletin, Volume 23, Number 1, 1991.

Kelley, Stephen, "Preserving Our Past for the Future," Standardization News, December 1990.

WJE | ENGINEERS ARCHITECTS MATERIALS SCIENTISTS

L. Brad Shotwell

Consultant

EDUCATION

Kent State University
Bachelor of Science, Earth Science, 1971
Kent State University
Master of Science, Geology, 1973

REGISTRATION

Professional Geologist in Illinois

PRACTICE AREAS

Concrete Deterioration
Concrete Production
Facade Cleaning
Historic Preservation
Petrographic Examination
Precast Stone
Stone Cladding

EXPERIENCE

Mr. Shotwell joined WJE in 1985 and is responsible for providing materials testing and evaluation services. His current work includes petrography of concrete and concrete raw materials, mortars, plaster, dimension stone, and the application of petrographic techniques to solve materials problems. Mr. Shotwell has gained special expertise in petrography of early concrete structures for historic preservation. He has also been responsible for development of a computer-assisted modified point-count apparatus used for air void system analysis of hardened concrete.

Prior to joining WJE, Mr. Shotwell performed numerous petrographic studies and managed petrographic laboratories for both a major construction materials manufacturer and a national materials testing laboratory. In this capacity, he was responsible for failure analyses of concrete from a variety of structures, evaluations of aggregates for use in nuclear power plant construction, and approval of raw materials for high-performance packaged grouts and mortars.

REPRESENTATIVE PROJECTS

Concrete Deterioration

- County of Los Angeles Storm Drainage: Petrographic evaluation of concrete condition, Los Angeles, California
- NASA Vehicle Assembly Building: Petrographic evaluation of concrete, Kennedy Space Center, Florida
- New York School Construction Authority: Petrographic evaluation of self-leveling underlayments, New York, New York

Concrete Production

- Chicago Skyway Reconstruction: Quality control of replacement concrete, Chicago, Illinois

Facade Cleaning

- John F. Kennedy Center for the Performing Arts: Investigation of dimension stone staining and evaluation of facade cleaning, Washington, D.C.
- Petrographic evaluation of dimension stone facades treated with various potential cleaning methods: Idaho, Wisconsin, Nebraska State Capitol Buildings:

Historic Preservation

- Fort Mott: Interpretation of historic mass concrete placement techniques, New Jersey
- Metropolitan Museum of Art and New York Public Library: Field and petrographic evaluation of dimension stone and mortar repairs, New York, New York
- Pennsylvania Monument: Evaluation of historic concrete, Gettysburg, Pennsylvania
- Petrographic characterization of early portland cement concrete, Portland Hall perimeter wall, Kent, England

Stone Cladding

- Mormon Temple: Evaluation of quarry proposed as a source for dimension stone, Nauvoo, Illinois
- American Museum of Natural History: Field and laboratory studies of stone proposed for use in façade repairs, New York, New York
- New York State Capitol Complex: Field and laboratory studies of marble and sandstone façade materials, Albany New York

PROFESSIONAL AFFILIATIONS

American Concrete Institute (ACI)
American Institute of Professional Geologists (AIPG)
American Society for Testing and Materials (ASTM)
Geological Society of America

TECHNICAL COMMITTEES

ASTM C09.65 - Petrography

Joshua Freedland

Senior Architectural Conservator

EDUCATION

Brandeis University
  Master of Arts, Comparative History, 1995
Brandeis University
  Bachelor of Arts, History, 1995
University of Pennsylvania
  Master of Science, Historic Preservation, 1999
University of Pennsylvania
  Advanced Certificate, Architectural Conservation, 2000

PRACTICE AREAS

Construction Specification
Facade Cleaning
Finishes Analysis
Historic Preservation
Masonry Deterioration
Materials Conservation Analysis
Materials Investigation

EXPERIENCE

Since joining WJE in 2001, Mr. Freedland has been involved in many architectural preservation and materials conservation projects. His work has included materials analysis, historic research, building documentation, facade investigations, condition surveys, and construction observations. His work has included a variety of materials including brick, terra cotta, stone, mortar, stucco, scagliola, architectural metals, and wood. In addition, Mr. Freedland has extensive experience with the preservation of historic finishes and facade cleaning.

Mr. Freedland was previously a post-graduate research fellow with the Architectural Conservation Laboratory at the University of Pennsylvania, directing and implementing conservation treatments of 18th and 19th century tombstones at Trinity Cathedral Burying Ground in Pittsburgh. His professional career has also included research on new polymers for stone protection, and conservation work at numerous archaeological sites in the U.S. and abroad. Mr. Freedland has published and presented on materials and site conservation including laboratory studies on desalination efficiency, stone consolidants, and masonry cleaning and preservation.

REPRESENTATIVE PROJECTS

- Kentucky Commonwealth Capitol: Materials conservation evaluation and limestone facade cleaning, Frankfurt, Kentucky
- Nebraska State Capitol: Materials conservation testing and treatment recommendations and limestone facade cleaning, Lincoln, Nebraska
- Georgia State Capitol: Limestone facade cleaning, Atlanta, Georgia
- Chicago Tribune Building: Limestone facade cleaning and limestone evaluation, Chicago, Illinois
- Metropolitan Museum of Art: Limestone facade cleaning and masonry repairs, New York, New York
- First Merit Tower: Limestone facade Cleaning, Acron, Ohio
- 30th Street Station: Limestone facade cleaning, window evaluation, stone evaluation, and construction documents Philadelphia, Pennsylvania
- Lyndon B. Johnson Library and Museum: Travertine plaza and wall cleaning, Austin, Texas
- Kennedy Center for the Performing Arts: Granite plaza cleaning, Washington D.C.
- Blackstone Hotel: Facade cleaning and repairs, Chicago, Illinois
- Carbide and Carbon Building: Facade cleaning and repairs, Chicago, Illinois
- LaSalle Bank Building: Limestone facade cleaning and replacement of fire damaged windows and cast aluminum spandrels, Chicago, Illinois
- Marquette Building: Facade cleaning, historic finishes analysis, masonry evaluation, construction documents, construction observations, Chicago, Illinois
- Chicago City Hall: Granite facade evaluation, facade cleaning, and repair design, Chicago, Illinois
- Johnson Square Business Center: Facade cleaning, Savannah, Georgia
- 260 South Broad Street: Facade cleaning, Philadelphia, Pennsylvania

PROFESSIONAL AFFILIATIONS

American Institute for Conservation of Historic and Artistic Works
Chicago Area Conservation Group
International Council on Monuments and Sites (ICOMOS)
International Institute for Conservation of Historic and Artistic Works (IIC)
Association for Preservation Technology International (APTI)

DAVID M. MARSHALL, AIA
Sr. Vice President,
Paul D. Marshall, Architects and Engineers Inc.

B.S., Construction Management, West Virginia State College, 1975
Registered Architect, West Virginia, #2377, 1989

David M. Marshall, AIA, served in several key positions at PDM Associates, Inc. since joining the firm in 1987. Since December 1998, he served as President and Project Architect, serving as Lead Architect on PDM Associates' projects and manages the day-to-day operations of the company.

Mr. Marshall first joined PDM Associates in 1979. His initial responsibilities included design, design development, working drawings, cartography, and contract administration for the firm's projects. In 1982, he was appointed by the Mayor of Charleston, West Virginia to serve as Building Commissioner for the City. As such, he supervised major commercial developments such as the Charleston Town Center, Laidley Tower, United Bank Center, and major residential developments. He also fulfilled the duties of office manager, building inspection coordinator, and administrative consultant.

After his tenure with the City ended, Mr. Marshall rejoined PDM Associates in 1987 and resumed his responsibilities of design, design development, cartography, working drawings, contract administration. He has remained with the firm ever since.

In May 2003 PDM Associates merged with Gaddy Engineering Inc. a prominent land management and engineering firm. Both entities are estabilishing combined headquarters in the historic Ort building, Tennessee and Washington street, West, Charleston WV. Mr. Marshall continues to serve as Lead Architect and Project Manager.

Mr. Marshall is a member of the American Institute of Architects, Building Officials and Code Administrators International (BOCA), the American Institute of Architects Historic Resources Committee, the Kanawha Valley Historical Society, the East-End Historic District Review Board, and the West Virginia State Capitol Building Commission. He serves as Architectural Advisor of the Charleston Urban Renewal Authority's Village District Review Board.

His project experience includes:

- West Virginia Southern Community and Technical College, Allied Health and Technology Center, Logan, WV. A five-story lab and classroom building scheduled for construction in 2005.
- Capitol Market, Smith St., Charleston, WV. A circa 1915 railroad depot adapt ably re-used and restored for use as a farmer's market facility for the WV Department of Agriculture.
- Shoenbaum Family Enrichment Center, Charleston, WV. A circa 1940 heavy equipment sales and service facility in the art deco style adapt ably re-used as a human services facility.

- Sunrise, Charleston, WV. A circa 1905 mansion, the former home to Governor MacCorkle, it has been restored and re-used as a law office.
- The Governor's Mansion, State Capitol Complex, Charleston, WV. A renovation and restoration of West Virginia's state residence involving all new infrastructure, interior renovations and restorations, new slate roofing, etc.
- Performing Arts Center, Conceptual Plan, Southern Community and Technical College, Williamson, WV. Adapting a circa 1950's armory building into a performing arts center and administration offices.
- Restoration and reconstruction of historic Dutch Hollow Wine Cellars, a vaulted stone structure that housed wine-aging facilities, c. 1850, for the City of Dunbar, WV.
- Renovation and preservation of Federal Building and Courthouse, c. 1905, Wheeling, WV for Region Three of the Gèneral Services Administration, Washington, D.C.
- Phase I restoration and adaptive use of Graceland mansion, former home of Senator Henry G.
- Davis, built 1891-94 in Elkins, West Virginia, for Davis and Elkins College, Elkins, WV.
- Restoration, renovation and space study of Kanawha County Courthouse, c. 1892-1926 (two additions), for the Kanawha County Commission, Charleston, WV.
- Preservation and adaptive use of servant's quarters and original kitchen of main house on Glenwood plantation, c. 1850, Charleston, West Virginia, for the West Virginia College of Graduate Studies Foundation, Charleston, WV.
- Cultural resource study of the New River Gorge National River, WV for the National Park Service, U.S. Department of the Interior. Resulting data were used to develop a general management plan and associated documents. Project consisted of three components: history, archaeology (prehistory), and historical architecture and community.
- Breezemont Mansion (1905), Charleston, WV. Restoration and adaptive reuse of 7,000-square-foot, classical-revival mansion as a small architectural office and residence.
- Consulting services for restoration of portico at Glenwood Mansion for West Virginia College of Graduate Studies Foundation, Inc., Charleston, WV.
- Historical and architectural survey of Downtown Charleston to be used as a guide for the renaissance of downtown Charleston.
- Phase I of an historical and architectural survey of Putnam County, WV.
- Consulting services for restoration work at City Hall, Charleston, West Virginia.
- Relocation and restoration of Blaker Mill, an eighteenth-century grist mill to be moved from Greenbrier County to Jackson's mill complex in Lewis County.
- Level I archaeological survey of the site of a sewage-treatment plant belonging to the City of Buckhannon, WV.
- Consulting services for an historical and architectural survey of Kanawha County, WV.
- Phase II of historical and architectural survey of buildings and sites in Putnam County, WV to identify sites that may be eligible for the National Register of Historic Places. The County also used the study as a planning tool.
- Architectural and historical consulting for streetscape renovation of downtown Charleston, WV.
- Restoration recommendations and building survey of Ruffner Log Cabin for the Charleston chapter of the Colonial Dames.
- Restoration and adaptive use of historic Capitol Theater in Charleston, WV.
- Phase III restoration and renovation of Glenwood Mansion, circa 1852, in Charleston, WV

for the College of Graduate Studies Foundation.

- Architect services for restoration and renovation of public corridors in the Kanawha County Courthouse, Charleston, WV.
- Historical survey of Fort Scammon Civil War Historical Site, Fort Hill, Charleston, WV.
- Feasibility study for restoration and Phase II restoration of Courtroom No. 4 of Kanawha County Circuit Court, Kanawha County Courthouse, Charleston, WV.
- Archaeological investigation of powder magazine, artillery platforms and infantry trench at Fort Scammon Civil War Historical Site, Fort Hill, Charleston, WV.
- Facade restoration of Chitwood Hall, an historic classroom building in the original Woodburn Circle area of the downtown campus of West Virginia University in Morgantown, WV.
- Design of eighteenth-century interiors for Blennerhassett Mansion, a reconstructed mansion on Blennerhassett Island, Wood County, Parkersburg, WV, for the Historic Blennerhassett Foundation.
- Historic structure report for West Virginia Independence Hall's Wheeling Custom House (1859), the birthplace of the state of West Virginia, in Wheeling, WV.
- Stabilization of historic Kaymoor mining site in the New River Gorge National River for the National Park Service, Fayette County, WV.
- Consulting services for design of relocation of Mary Conrad Log House to new site near the Stonewall Jackson Dam, WV. The new site is a roadside park administered by the West Virginia Department of Highways.
- Historical and architectural survey of six square blocks in northern Wheeling, WV. Project included 122 buildings and a successful nomination of the district to the National Register of Historic Places.
- West Virginia Capitol Building, Charleston, WV. Architectural inspection services for the gilding of the dome.
- Sites Homestead, Seneca Rocks, WV. Stabilization and restoration of an historic, mid-nineteenth-century farm house for the National Forest Service.
- Restoration of brick-and-stone masonry and slate roofing on the Old Main building (1885) at Glenville State College, Glenville, WV.
- Masonry cleaning, repair and repainting; restoration of polychrome, patterned slate roof; restoration of wood dormers and trim; and restoration of iron cresting and finials at Woodburn Hall (1870), West Virginia University, Morgantown, WV.
- Philippi Covered Bridge (1852), Philippi, WV. Restoration of historic covered bridge to its appearance when the first land battle of the Civil War occurred there on June 3, 1861.
- First Presbyterian Church (1915), Charleston, WV. Repair and restoration of terra-cotta cupola and roof areas; restoration of original Byzantine-patterned, domed sanctuary ceiling.
- Restoration and adaptive use of High Gate Carriage House, a 1920s Elizabethan-style carriage house in Fairmont, WV.
- Historical and architectural survey of buildings along U.S. Route 52 between Huntington and Williamson, WV to determine mitigation process on highway right-of-way alternatives.
- National Cemetery in Grafton, WV. Conditions survey with recommendations for restoration of buildings and walls. Cemetery established in 1867 and stone walls built in 1876.
- Historical and architectural survey of properties on Merritt's Creek in Cabell County, WV for various proposed new highway alignments to determine mitigation process for Department of Highways.
- Feasibility study and restoration recommendations for exterior facade of City Hall in

Huntington, WV.

- Restoration of slate roof and structural elements of Mannington Round Barn in Mannington, WV.
- Restoration and adaptive use of the Arthurdale Community Center in Arthurdale, WV.
- Marlinton Opera House (1902), Marlinton, WV. Restoration of concrete and wood opera house for the Pocohontas County Historical Society.
- Restoration of Barrackville Bridge (1853), a covered bridge, for the West Virginia Division of Highways.
- Design of a new South Plaza for the West Virginia State Capitol Building in Charleston, WV as originally conceived by master architect Cass Gilbert.
- Restoration of Dent's Run Covered Bridge, a late nineteenth-century covered bridge in Monongalia County, WV.
- Restoration of Center Point Covered Bridge, a late nineteenth-century covered bridge in Doddridge County, WV.
- Feasibility study of adaptive use of Sunrise Mansion, the historic home of former Governor William MacCorkle, in Charleston, WV.
- Restoration and adaptation of Capitol Farmer's Market, early-twentieth-century railway freight depot, for use as an indoor specialty market on behalf of the City of Charleston, WV. The project also entailed the conversion of the railroad yard into an outdoor farmer's market with customer parking.
- Restoration and adaptation of Giltinan House, a historic house in Charleston, WV for Tabor, Lindsay & Associates for use as a law office.
- The Arcade, Charleston, WV. For McCabe-Henley developers, an in-depth historical survey and physical documentation of two-story, nineteenth-century, glass-roofed arcade building in downtown Charleston.
- Putnam/Hauser House, Blennerhassett Island State Park, WV. Relocation of eighteenth-century, original homestead of the Putnam family to Blennerhassett Island, where it has been preserved as an interpretive historic site.
- McFarland/Hubbard House, Charleston, WV. Consulting services—including production of measured drawings—for adaptive-use feasibility study of historic 1834 house.
- McFarland/Hubbard House, Charleston, WV. Stabilization and restoration of 1834 house for West Virginia Humanities Council.
- Coyle & Richardson Building, Charleston, WV. Comprehensive restoration and renovation of 1907 Coyle and Richardson drygoods store and offices built in the classical-formalism style. Facilities now serve as the corporate offices of AMFM Corporation.
- Charleston Municipal Auditorium, Charleston, WV. National Register of Historic Places nomination for 1939, art-deco performing hall for Kanawha Valley Historical & Preservation Society.
- West Virginia Governor's Mansion, Charleston, WV. Design of retrofit railing for 1928 governor's mansion originally designed by architect Walter F. Martens.
- Scott Brothers Drug Store, Charleston, WV. Restoration and renovation of 1896 Victorian building to house the law firm of Bailey and Glasser.

Since 1994, Mr. Marshall has furthered his education by attending 129 hours of architectural training sessions. His work has been recognized with several awards, including:

- 1997 Merit Award, AIA West Virginia, for the Peterson Residence, Charleston, WV. Served as Project Architect.

- 1996 Honor Award, AIA West Virginia, for the Law Offices of Hill, Peterson, Carper, Bee and Deiztler. Served as Project Architect.
- 1982 West Virginia Innovative Home Design competition, sponsored by the West Virginia Housing Development Fund.

Among Mr. Marshall's publications are:

- "Professional Responsibility—Clear and Specific," *The West Virginia Architect*, published by the West Virginia Society of Architects, Fall 1986, vol. 2, no. 1.
- *Wood Heating Appliance Safety Manual* for the City of Charleston Building Department, published by the City of Charleston Printing Department, 1986.
- "West Virginia State Building Code," *The West Virginia Architect*, published by the West Virginia Society of Architects, Fall 1985, vol. 1, no. 1.

ARCHITECTURAL RECORD

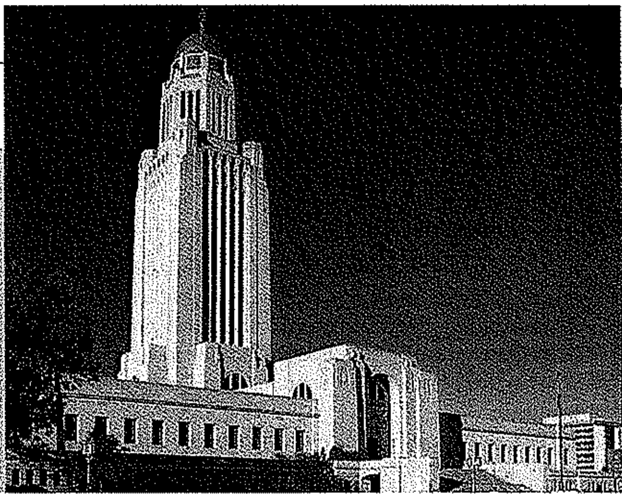
MAJOR ARRIVAL
Foster's Hong Kong International Airport

Aga Khan Award:
Rewarding Substance over Style

Special Section: **Record Lighting**

Restoring a Nebraska Landmark

CREATING A DATABASE THAT MAPS OUT EACH STONE ON THE FACADE MAKES IT POSSIBLE TO CHART AND DIAGNOSE FLAWS IN THE CAPITOL BUILDING.



by Stephen J. Kelley, AIA, and Dan Worth, AIA

PHOTOGRAPHY: COURTESY BAHR VERMEER & HAECKER AND WISS, JANNEY, ELSTNER ASSOCIATES, EXCEPT AS NOTED

The Nebraska State Capitol rises 400 feet above the mostly low buildings of Lincoln and the surrounding agricultural fields. Lee Lawrie's statue *The Sower* balances atop its dome, reminding viewers that this is a state founded on farming, a place where the land is often more important than the buildings on it. An exception to this is the capitol itself, a significant example of American art, landscape design, and civic architecture.

The Nebraska capitol is the result of a national design competition in 1920 that attracted some of the nation's best architectural firms. Each of the entrants remained loyal to the neoclassical traditions of the Beaux-Arts, submitting designs that were de rigueur for state capitols in those days. The exception was Bertram Grosvenor Goodhue. This vigorous New York designer, who was never formally trained as an architect, came up with a building that set an example for civic structures throughout the nation; it's a distinctly American building from a period when styles were almost always adapted from European examples.

Goodhue's plan achieved great beauty without resorting to all the traditional elements of Classical design that characterized most state capitols. The archetypal gold dome is still there, but it's perched on brilliant blue tile necking at the top of the high-rise office tower. The tower is an example of another evolving American form: the skyscraper. According to historic documents, it symbolizes the hopes and aspirations of the state, while the two-story base, which also stretches 400 feet, but on a horizontal plane, signifies the broad expanse of the Nebraska plains.

Stephen J. Kelley, AIA, is an engineer and a senior consultant in the Chicago office of Wiss, Janney, Elstner Associates. He specializes in the investigation and restoration of historic buildings. Dan Worth, AIA, is the managing principal of the Lincoln office of Bahr Vermeer & Haecker. He specializes in historic preservation.

Goodhue was among the first to incorporate an iconographic program into a capitol, using indigenous elements as architectural and decorative ornamentation. There are buffalo, pioneer, and corn motifs, as well as Native American references, all of which were sculpted after the stone blocks were in place, the sculptors working from scaffolding.

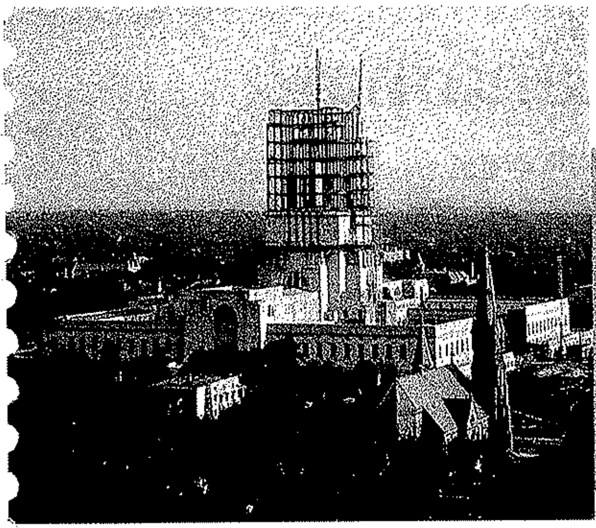
The building was the third capitol erected on the site; the first two structures were poorly built and had to be demolished. It was thus an essential part of the program that this rendition be built to last. To that end, Goodhue specified what he perceived to be the best construction materials available and was fastidious in how they were assembled. The stone coursing is different on all four sides of the tower, a detail that made construction more difficult and provided almost no aesthetic or structural improvement. The real impact was philosophical; Goodhue wanted a building that would endure.

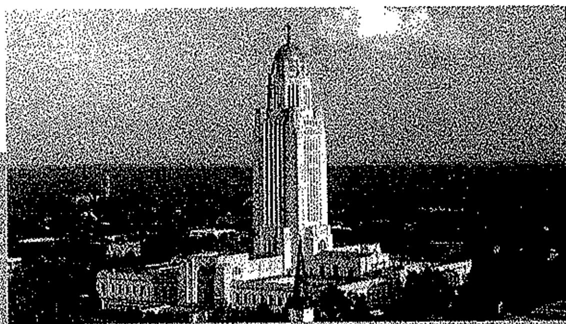
But even before the new capitol was completed, in 1932, eight years after Goodhue's death, a light web of cracks became apparent on the tower facade. As early as 1929, an Omaha architect reported, "Cracks in

Continuing Education *Use the following learning objectives to focus your study while reading this month's ARCHITECTURAL RECORD/AIA Continuing Education article.* *To receive credit, turn to page 192 and follow the instructions.*

Learning Objectives *After reading this article, you should be able to:*

1. *Identify the significance of this building in American civic architecture.*
2. *Describe the flaws found in the exterior facade of the capitol.*
3. *Explain what caused the problems with the exterior facade.*
4. *Describe how the site survey and condition report were collected.*
5. *Explain how computer technology was used to document and design the work on the capitol.*





THE CAPITOL'S 437-FOOT TOWER RISES high above the low surrounding buildings and flat prairie of Lincoln. The two-story base echoes and symbolizes the landscape.

the capitol are due to weather and no defects in construction will be found." This was the first of many reports of the cracking, spalling, delamination, efflorescence, stone displacement, cracked mortar, and algae growth that were to become common on the exterior walls, though the seriousness of the distress was discounted at the time.

The committee looked to WJE because of its building diagnostics and laboratory capabilities, as well as its experience in restoring early skyscrapers; the firm's recent projects included the Woolworth Building in New York City and the Tribune and Reliance Buildings in Chicago. That expertise would help diagnose the problems with the capitol.

SKYSCRAPERS WERE A RECENT INNOVATION IN THE 1920S AND THE DESIGN AND ENGINEERING BEHIND THEM WAS SOMETIMES DICEY.

Photographic records indicate that the first remedial intervention took place in the decade following World War II, though specifics of the treatment remain sketchy. The capitol was repaired again in the 1960s when, among other things, organic growth was removed from the facade by pressurized water spray. In 1973, a major facade campaign included sandblasting, tuckpointing, and sealing cracks with epoxy. Each restoration attempt addressed the effects rather than the causes of the stone distress.

Despite these repairs, the cracks continued to form—often right alongside the places where epoxy repairs had been made. Finally, in the summer of 1995, the Capitol Environs Committee, set up by the state of Nebraska to take care of the capitol, hired Bahr Vermeer & Haecker Architects (BVH) of Lincoln, together with Wiss, Janney, Elstner Associates (WJE) of Chicago, as consultants for the Nebraska State Capitol Masonry Restoration Project. Their goal was to preserve the building's original fabric wherever possible; it had been designated a National Historic Landmark in 1976. That meant hiring an architect with preservation experience and knowledge of local construction practices and materials.

This buffalo is one of many iconographic elements on the building.

BVH's proximity to the capitol allowed the firm to offer prompt service. The committee was also impressed with BVH's grasp of computer technology. One committee member tells of visiting the firm's offices in 1995 "and not seeing a single drafting table." With its technological expertise, BVH was able to create a database to map flaws on the building's exterior. Such a database could guide restorationists in the repair process.

Building pathology

The team's first step was to conduct a site survey and prepare a condition report for the building. Like physicians, project directors Steve Kelley for WJE and Dan Worth for BVH, as well as other members of the team, became well acquainted with the patient, analyzed all the symptoms, and developed a diagnosis before embarking on restorative treatments.

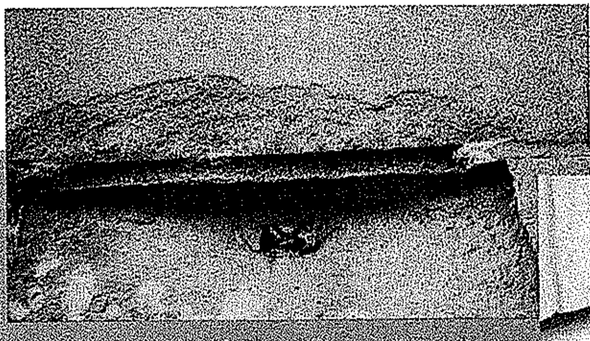
The analysis of the exterior facade began with a review of the Capitol Collections archive, which contains about 200,000 papers related to the building, including correspondence, specifications, product samples, photographs, and, most important, 3,000 drawings, which range from Goodhue's original and priceless ink-on-linen working drawings to detailed shop drawings. The latter, which include numbered references to every stone on the building, became the basis of the inspection work and were used to prepare survey sheets on which WJE's field personnel took notes and recorded the various types of stone distress.

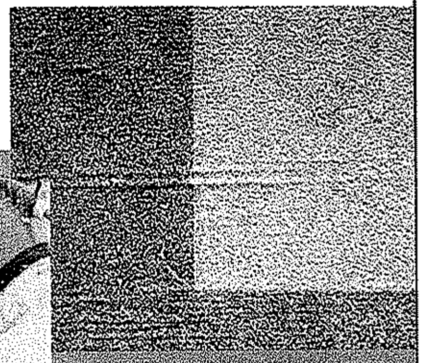
The capitol sits on a series of poured-concrete pilings, which rest sturdily on bedrock 30 feet below grade. Large reinforced-concrete grade beams, poured between these pilings, provide continuous support for the perimeter quadrangular masonry bearing wall. The tower is similarly supported on bedrock by a system of reinforced-concrete caissons on which the structural steel frame bears the tower. Settlement, therefore, was not a source of building distress.

WJE next conducted a site survey to generate a condition report. This would do the following: document, in written and graphic form, the condition of the various components of the building envelope; prioritize the restoration work required; develop construction cost estimates; and provide information to create a computerized database that would record distress on the facade.

Perched on rolling scaffolding and using binoculars, workers spent the fall of 1995 investigating the base portion of the building. The

PHOTOGRAPHY: © SID SPELTS; COURTESY NEBRASKA STATE HISTORICAL SOCIETY (THIS PAGE)





THE STONE IS SPALLED AT SOME JOINTS where ties bind the expanding masonry to the shrinking steel frame (above). Test panels were cleaned using nondestructive methods (right).

exterior surface of the tower was inspected from a swing-stage that was suspended from the 14th-floor observation deck. The dome and drum above the deck were examined by engineers who rappelled like mountaineers from lines attached to *The Sower.* Inspection openings, carefully conducted to cause a minimum of disruption to the building, uncovered hidden conditions. Building samples, including stone, brick, mortar, concrete, and sealant, were carefully removed and taken to the WJE laboratory for petrographic and chemical examination.

What went wrong?

Skyscrapers were a recent innovation in the 1920s and the design and engineering behind them was sometimes dicey. Goodhue conferred with H. G. Balcom, later the engineer for the Empire State Building, though he used an in-house engineer to do the work. Balcom and Goodhue both realized that the interplay between the envelope and frame of the tower and, to a lesser extent, the base could be, as Balcom said, "problematic," but they never realized how extensive the problems would be.

The Nebraska State Capitol is clad in buff-colored Indiana limestone—the same used on the Chrysler and Empire State Buildings—the stone par excellence for building construction at that time and still popular today. Goodhue selected it for its durability, despite opposition from politicians who wanted him to specify a locally quarried sandstone. (It turns out that the sandstone, used on other buildings in the region, is soft and has a tendency to separate into its bedding plains.) The stone company from which the limestone was purchased set aside portions of its quarry for the exclusive use of the capitol project, resulting in an especially homogeneous color across the building. The stone ranges from four to 12 inches in thickness.

Beneath the stone is a layer of brickwork. The masonry rests on steel shelving, part of the sophisticated steel framing. An extremely cement-rich mortar, composed of one part white Portland cement and two parts sand tempered with hydrated lime, bonds the masonry, while galvanized-metal anchors tie the stone and brick. There is also a cavity wall made of brick and plaster.

Goodhue and Balcom knew the steel frame would contract with the building's weight and the masonry would expand and move as it took on moisture. Pressure-relieving joints, inserted horizontally into the stone joints at each floor, were designed to allow the masonry and steel to accommodate these conflicting forces. Made of a kind of corrugated lead, the joints were designed to crush in order to absorb movement and building stress.

The first of many problems is that these relief joints penetrate the stone, but not the brick. With no room to move, enormous compressive forces quickly mounted within the masonry walls, causing them to crack. Because of the strength and tenacity of the mortar, the stone and brick act as a single unit. The situation is exacerbated by the ties between the masonry; as the frame compresses, the masonry is pulled, causing stones to spall and crack. In addition, the mortar between the stone and brick joints is harder than the surrounding masonry, so there is no give, causing related cracks in the stone.

While the cracking is worst on the tower—approximately 25 percent of these stones are damaged—there are cracks on the lower part of the building as well. These are the result of wind-driven water entering the brick substrate and causing it to expand. The stone units, larger on this portion of the building, don't expand when exposed to moisture. The

GLOSSARY

Spall A fragment or flake broken from the surface of the stone.

Hairline crack An extremely thin crack.

Medium crack A crack about 1/32 inch wide.

Wide crack A crack more than 1/32 inch wide.

Pointed crack A crack that has been ground out and filled with mortar.

Sealed crack A crack filled with sealant or epoxy.

Delamination A separation of part of the stone along a plane roughly parallel to the surface.

Stain Visible surface contaminants on the stone.

Organic growth Living biological contaminants such as algae, mold, or mildew.

Dutchman A previous stone panel repair which entails removing a portion of the stone panel and replacing it with a closely matched new stone.

Sealed mortar A mortar joint filled with sealant or epoxy.

Pointed mortar joint A mortar joint that has been ground out and repointed after completion of initial construction.

Efflorescence Water-soluble salts on the surface of the stone that originated within the stone, mortar, or other material within the wall and migrated to the surface.

RAPPELLING FROM THE SOWER, A STATUE atop the capitol dome (left), field inspectors performed visual inspections and applied nondestructive testing methods to examine cracks in the dome (far left) and assess the tower's condition.

bricks, however, expand significantly, resulting in pressure on, and ultimately fractures in, the stone.

Based on the high proportion of cracks that occurred after the 1973 renovation, WJE and BVH realized that unless steps were taken to alleviate the stress, the building was in danger of cracking apart. Meanwhile, water, leaking into the walls from the cracks, was creating more insidious problems.

Technology meets masonry

While WJE conducted its fieldwork, BVH was transforming the original shop drawings for the stone into CAD drawings. The originals contained different drawing styles, which indicates various draftsmen in the stone fabricator's office were involved in their preparation. After working with the drawings for some time, BVH recognized that one draftsman was noticeably inaccurate. The discovery meant the architects had to take extra care in interpreting the plans. But it also reinforced the need for accuracy and thoroughness as vital components of the new, computerized database, if only to make future restoration efforts easier.

For historical purposes, consistency, and future reference, the original naming conventions established in the shop drawings were used to create the CAD drawings. By using the features of a relational database, each drawing could be identified by many different names and still tied to its original designation.

When examining the existing documents and considering the size of the building, it was evident that there would be a substantial amount of data. A computer with adequate "horsepower" was required to complete the job. In 1995, the optimum model for the job was a Pentium 133 with 32 megabytes of RAM and a one-gigabyte hard disk. All of the machines used on the project were part of BVH's office network, which allowed several staff members to work on the project simultaneously.

The software packages used in 1995 are somewhat dated today. However, updated versions of these would still be appropriate. The CAD software that created the computer drawings was Microstation 95. Microsoft Access 7.0 was the main database software, while Microsoft Visual FoxPro 3.0, another database software package, was used early in the design of the database tables. Realistic images of the capitol were created and enhanced from the CAD data with Adobe Photoshop 3.0. All of the software used has been upgraded and revised, but each package was chosen to enable the data contained to withstand the test of time.

The database allowed the architects to generate tables that quantified all instances of stone distress.

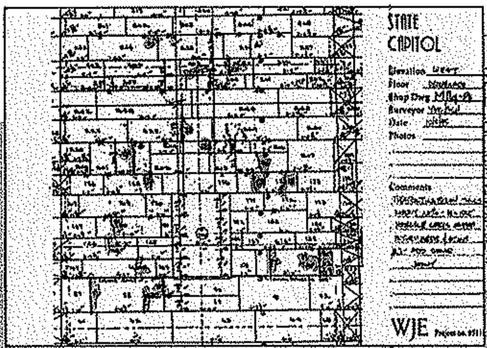
With the vast quantity of data, it was necessary to create several new software tools to help ease the burden of some of the repetitive tasks, such as drawing each stone on the building facade. Microsoft Visual Basic 4.0, a simple programming language, was used to create several of the custom tools. Because of the large quantity of stones to input (35,861), it was critical to maintain consistency. Software was written to create the graphics for the stone, coordinate the stone mark number, assign the proper layers for the CAD drawing, and choose the proper screen colors.

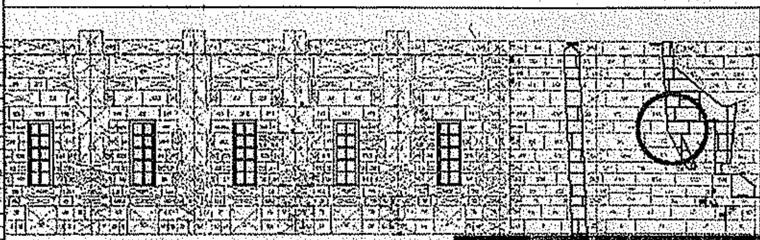
Once a baseline CAD drawing was finished, the stone distress data from the field survey sheets was overlaid. From those composite

STONE DISTRESS SUMMARY TABLE

DISTRESS TYPE	NUMBER OF STONES	PERCENT OF STONES
DISPLACEMENT	3	0%
DUTCHMAN	4	0%
FACE DISTRESS		
DELAMINATED	2	0%
PATCHED SPALL	797	2.02%
SPALL	402	1.12%
TOTAL	**1,201**	**3.35%**
MORTAR CRACK	**NUMBER OF STONES**	**LINEAL FEET**
MORTAR CRACK	575	552.08
MORTAR SEALED	120	87.48
PREVIOUSLY POINTED	862	601.77
TOTAL	**1,557**	**1,241.31**
STAINS	**NUMBER OF STONES**	**PERCENT OF STONES**
EFFLORESCENCE	49	0.13%
ORGANIC GROWTH	1	0%
STAIN	523	1.45%
TOTAL	**573**	**1.58%**
CRACKS	**NUMBER OF STONES**	**LINEAL FEET**
CRACK HAIRLINE	763	480.46
CRACK MEDIUM	224	167.58
CRACK POINTED	97	83.94
CRACK SEALED	1,571	1,526.89
CRACK WIDE	32	36.90
NOT ORIGINAL JOINT	3,641	9,259.60
TOTAL	**6,328**	**11,555.35**

SOURCE: COURTESY BAHR VERMEER & HAECKER





DAMAGE DONE BY SANDBLASTING encouraged organic growth (right). Maps of stone stress on the tower (left) and facade (above).

CAD drawings, the relational database, which allows the linking of several tables of different data, was created. It consists of a full list of the CAD drawings, which is linked to a full list of each stone on those drawings, which in turn is linked to a list of all stone distress discovered during the exterior survey of the building. The linking allows data to be joined in a one-to-many relationship without having to duplicate data each time.

Ultimately, the real convenience of such a database was in accessing and organizing the information. This helped the team to quickly study, comprehend, and diagnose the problems with the capitol. Large-scale plots with overlays of cracks and the estimated date of occurrence helped reveal many of the building's basic problems.

The computerized information and software, created and stored in standard formats, will be available to the state so that it can be used for future phases in the project. The CAD drawings and the relational database form a strong beginning for the design development phase of the project and the contract documents required to complete the work. In addition, many conclusions from the database are being used to secure funding of the project.

Tables were generated describing the size, shape, and number of each stone in the building facade.

STONE DISTRESS TABLE EXCERPT	
DATABASE FIELD	DESCRIPTION
DGNMK	DRAWING NAME AND STONE MARK NUMBER ARE COMBINED TO JOIN THE DATABASE TABLES. THIS IS A UNIQUE FIELD THAT IS NOT REPEATED WITHIN THE DATABASE.
DGN	THIS IS THE CAD FILE NAME.
MK	THIS IS THE STONE MARK NUMBER FROM THE ORIGINAL STONE-SHOP DRAWING. WHEN THERE ARE DUPLICATE NUMBERS, A NEW SUFFIX IS USED.
LEVEL	THE CAD LEVEL ON WHICH THE DISTRESS IS LOCATED. ALSO USED FOR QUALITY REVIEW.
DISTRESS TYPE	THE TYPE OF DISTRESS AS IDENTIFIED FROM A LIST OF 17 DISTRESS TYPES, INCLUDING SPALL, DELAMINATION, AND STAIN.
LINEAL FEET	THE LINEAL DIMENSION OF THE DISTRESS. IN THE CASE OF AN AREA, SUCH AS A STAIN, THIS IS THE HORIZONTAL DIMENSION.
AREA	THE AREA OF THE DISTRESS, SUCH AS A STAIN OR A SPALL.
PERCENT	THE PERCENTAGE OF THE STONE THAT IS DISTRESSED.
HEAD/BED JOINT	IN CASE OF DISTRESS WITH A MORTAR JOINT, THIS IDENTIFIES WHETHER IT IS IN A HEAD OR BED JOINT.

SOURCE: COURTESY BAHR VERMEER & HAECKER

Making repairs

In June 1996, WJE and BVH generated the condition report, based on field research and computer analysis, which details distress and decay with the capitol facade, diagnoses the causes of distress, and offers suggestions for treatment. These include:

Modifying the relief joints to make the overall behavior of the tower more like a steel skyscraper. This will involve temporarily removing some stone and redesigning the brick behind it.

Repairing the stone masonry on the facade and ornamentation by carefully disassembling and repairing the damaged elements. Limestone blocks will be conserved and reused when possible to retain the homogeneous color of the facade.

THE DATABASE ALLOWED THE TEAM TO QUICKLY STUDY AND COMPREHEND THE PROBLEMS WITH THE CAPITOL.

Selecting an appropriate cleaning technology to remove organic growth from the facade. Cleaning of the building base may be necessary every 10 to 15 years, while cleaning of the tower may be needed only every 30 to 40 years.

Tuckpointing as necessary, using the least destructive method of removing mortar from the existing joints. The texture and color of any new mortar will closely match the original. However, this time a softer mortar is proposed.

The building is scheduled to be wrapped in scaffolding this fall, weather permitting, so contractors can begin work on the turrets and walls of the promenade and Memorial Room on the 14th floor, an area that includes an observation deck open to the public. Repairs to this area were identified as top priority because of safety concerns—there is a possibility that a section of stone could fall. Also, because this level is open and exposed to the weather on all sides, it is among the most deteriorated sections.

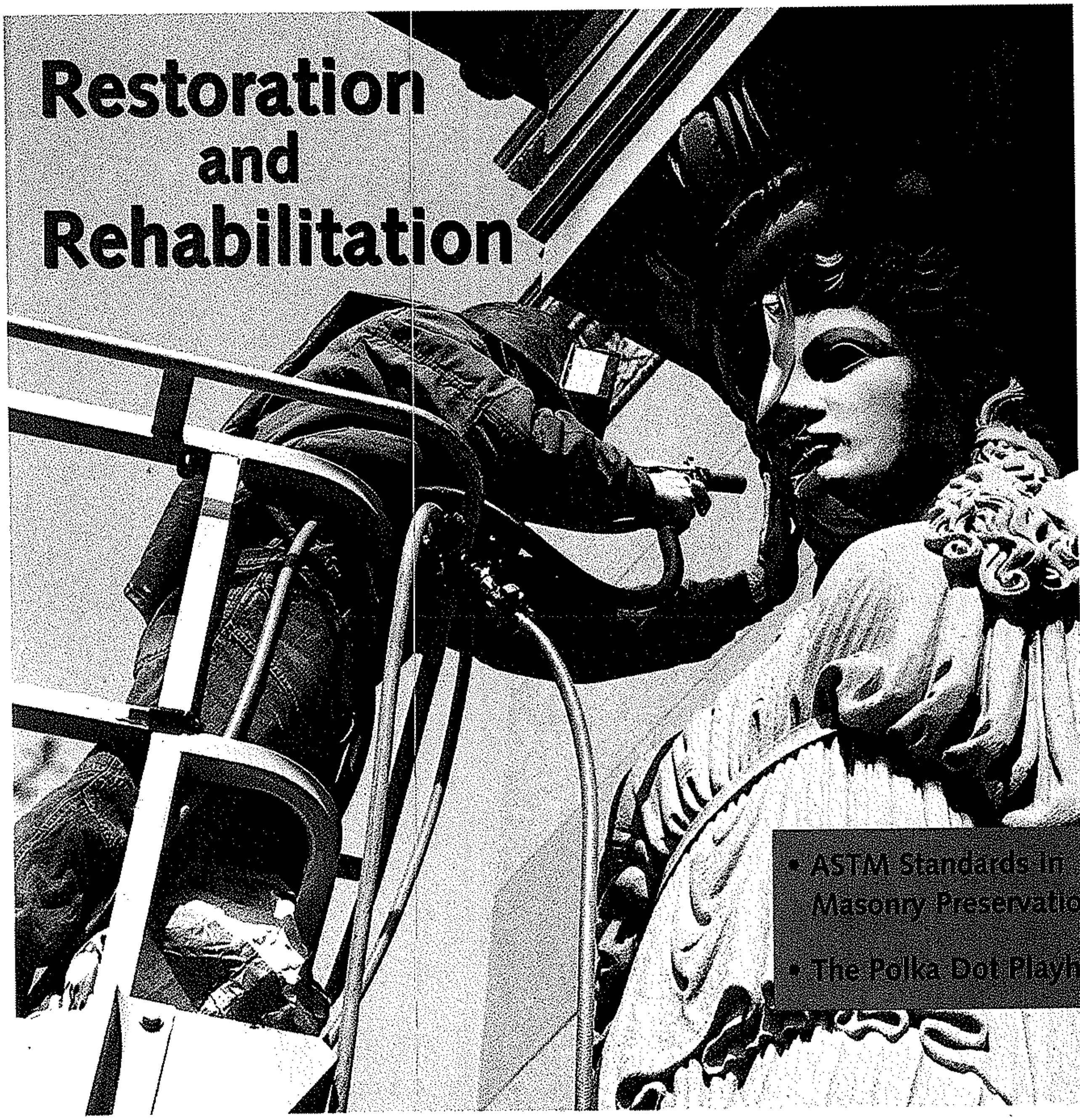
The work, which is likely to continue over nine years, will progress down the tower and, finally, encompass the base. The state has taken a long-term view toward building preservation, assuming that the Nebraska State Capitol is to have a useful life span well into the next millennium. It also plans to inaugurate an ongoing program of building conservation. ■

DRBs AND THE BOSTON CENTRAL ARTERY/TUNNEL PROJECT • THE COLLABORATIVE PROCESS

The Construction Specifier

SOLUTIONS FOR THE CONSTRUCTION INDUSTRY
October 1998

Restoration and Rehabilitation



- ASTM Standards in Masonry Preservation
- The Polka Dot Playhouse

The Magazine of the Construction Specifications Institute

ASTM Standards in Masonry Preservation and Restoration

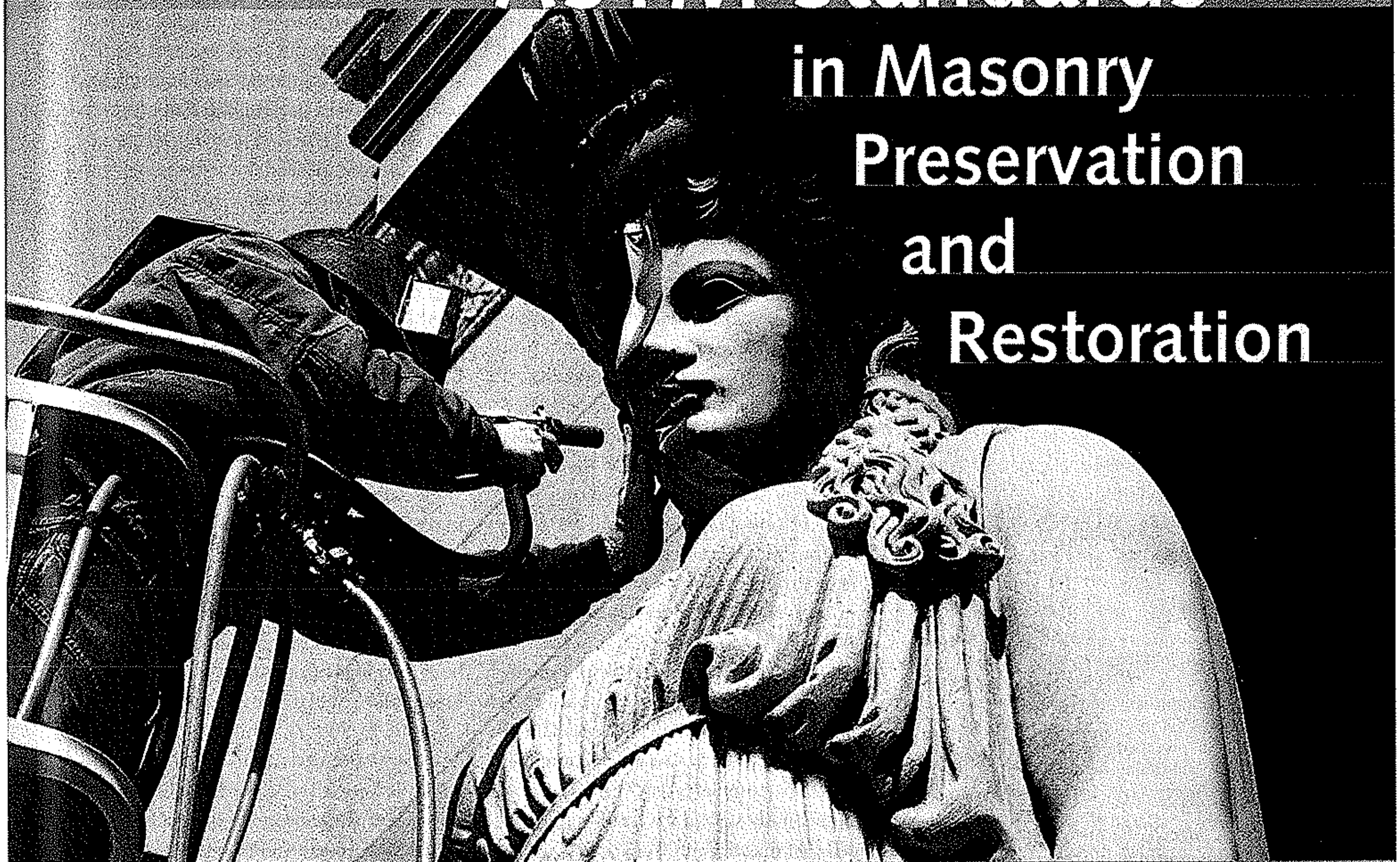


PHOTO: YORK CHAN

By Stephen J. Kelley and Timothy M. Crowe

ASTM Subcommittee E6.24 on Building Preservation and Rehabilitation Technology was established in the early 1980s to "develop standards in the technology of conservation, preservation, and rehabilitation of buildings and structures." Since then, the Subcommittee has helped define the technical problems facing the preservation professional and has led the way in achieving recognition of technical issues in preservation.

The Subcommittee is composed of private and public sector architects, engineers, scientists, conservators, contractors, product manufacturers, and historians, with participation and support from the Association for Preservation Technology (APT), the American Institute for the Conservation of Historic and Artistic Works (AIC), and the International Council on Monuments and Sites (ICOMOS), among other organizations.

Preservation Standards

At the ASTM International Symposium on the "Use of and Need for Standards in Architectural Conservation," held in Atlanta in April 1998, standards used in building conservation were placed into the following four categories:

ADDITIONAL INFORMATION

Author

STEPHEN J. KELLEY, AIA, SE, and TIMOTHY M. CROWE, RA, SE, are preservation specialists with the Chicago-based firm of Wiss, Janney, Elstner Associates, Inc. The authors have expertise on masonry structures, windows and curtain walls, skyscrapers, churches, and archaic structural systems.

MasterFormat No.

General Data—Renovation, Restoration, Rehabilitation

Key Words

ASTM Subcommittee E6.24
philosophical standards
governmental regulations
procedural or methodological standards
technical standards
cleaning techniques
stone consolidants
tuckpointing
terra cotta

Abstract

Standards have a profound influence on what our buildings look like and how they are built. They have proven very useful in preservation work. The authors discuss the kinds of standards used in preservation and the work of ASTM Subcommittee E6.24.

Photo 1, page 27. Façade gommage testing on a caryatid on the Museum of Science and Industry in Chicago. Until recently, the commonly accepted interpretation of the Secretary of the Interior Standards *ruled out the consideration of abrasive cleaning techniques (e.g., sandblasting) while accepting chemical and water methods. However, the actual aggressiveness of specific techniques depends on numerous factors. For instance, for a given substrate, a high-pressure water blast may actually be less gentle than mechanical cleaning with walnut shells under low pressure. Chemical treatments that are proven gentle and effective on brick and terra cotta may damage façades made of limestone or marble.*

Philosophical standards include the Carta del Restauro, developed in Athens in 1931, and the International Charter for the Conservation and Restoration of Monuments and Sites (Charter of Venice), developed in Venice in 1964. The Charter of Venice formed a precedent for the BURRA Charter, adopted by Australia ICOMOS in 1981, the Nara Convention on Authenticity adopted by the world community in Nara, Japan, in the early 1990s, and the Secretary of the Interior Standards for Rehabilitation, commonly referred to as "The Standards," used exclusively in the United States.

Philosophical standards provide guidelines for approaching preservation of historic structures as well as examples of applications that can help educate and sensitize owners, architects, and developers to the goals of preservation. In the United States "The Standards" have typically been adopted by municipal governments as the basis for ordinances to administer historic districts and neighborhoods.

Governmental regulations are building codes and the like. Preservation professions have traditionally dealt with building codes that address issues of public health, safety, and welfare. The BOCA and UBC codes generally allow some deviation from strict code compliance for "historically or architecturally significant" buildings, provided that unsafe conditions are corrected and the restored building is no more hazardous (i.e., life safety, fire safety, and sanitation) than before restoration. The federal Occupational Safety and Health Administration (OSHA) standards provide for the protection of contractors, workers, and others who maintain buildings and structures.

Procedural or methodological standards have caused the greatest stir in the preservation community. Many feel that standardizing approaches to preservation will hinder innovation and creativity. Professor David Yeomans of the United Kingdom described the need for this type of standard at the ASTM symposium when he said, "I think one of the things that we need to ensure is not simply that people are ultimately doing the right thing but that they are doing the right thing by going about it in the right way."

A standard approach is at the heart of the documents being drafted by the International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage (ISCARSAH). ISCARSAH, an international body of engineers, architects, and scientists, realizes that the variety of methodologies available to engineers and the proliferation of new and more sophisticated analytical technology makes standardizing methodologies a good idea. In this instance, a standard approach represents the best possibility of achieving results that are above question.

Procedural standards for preservation in ASTM have remained controversial and difficult to develop. The most successful of these ventures, the Guide for the Preparation of Historic Structures, remains at the brink of ratification after 10 years of development.

Technical standards typically are used in evaluating new products, for quality control, and in laboratory analysis and testing. Technical standards, particularly those that deal with the care and treatment of brick and stone masonry, have been the focus of the ASTM Building Preservation Subcommittee.

Masonry Preservation

ASTM technical standards for preservation, as they have been envisioned by the Subcommittee, are guides rather than regulations that will help in routine decision-making, freeing the preservation specialist and encouraging greater creativity. Furthermore, these guides have been envisioned as voluntary to account for the variety of conditions and situations encountered in preservation work.

ASTM has a framework for developing consensus standards using "round robin" balloting facilitated by the postal service. Electronic mail balloting is under development. Due to its existing collaborative flavor, international scope, and support framework, ASTM has proven to be a good arena for technical preservation standard activities.

Under the direction of its task groups, ASTM Subcommittee E6.24 is actively developing standard guides for the treatment of masonry on heritage structures as described below.

ASTM E 1857-97, Standard Guide for the Selection of Cleaning Techniques for Masonry, Concrete, and Stucco Surfaces

Façade cleaning is undertaken for many reasons, including aesthetic improvement, stabilization, surface treatment, and preservation. The recently published Standard Guide is designed for selecting, testing, and evaluating cleaning techniques for removal of soils and stains from façades.

Cleaning treatments can be so aggressive that, in the process of removing dirt, they can permanently damage the substrates. The Guide recognizes that façade cleaning may be contrary to preservation goals. Unfortunately, façade cleaning is sometimes undertaken without establishing whether cleaning is actually a good idea or, if it is, what cleaning techniques and methods are acceptable. The Guide also recognizes that the desirable level of cleanliness may be less than 100 percent and that a performance goal of 100 percent cleanliness could compromise the historic fabric.

Identifying soils and stains is discussed as an appropriate strategy for selecting, implementing, and evaluating test samples. Cleaning techniques divided into water, chemical, and abrasive cleaning strategies help establish a framework for traditional techniques as well as new techniques being introduced from Europe.

Guidelines for the Selection and Use of Stone Consolidants

Stone consolidants, which are widely used in Western Europe, offer the potential for increased use in North America on preservation projects. Decay of stone, typically sandstone, often takes the form of dissolution of the material that cements the stone grains together from severe weathering or the effects of acid rain. Consolidants are chemical treatments formulated to reinstate cohesion between adjacent grains of stone when the natural cementing material has been undermined or lost. Consolidants show promise on some preservation projects because they can strengthen exposed portions of the stone, reducing further deterioration, and extend durability and service life of masonry materials.

However, consolidant treatments are irreversible because they saturate the stone and thus will permanently alter historic material. Additionally, when improperly used, consolidants can actually accelerate rather than retard stone decay mechanisms, and irreplaceable material will be forever lost.

The task group on Stone Consolidants continues to be a synergistic exercise where experts from the United States and worldwide work together on this complex issue. The Guide currently in the ASTM balloting process offers much needed guidance to preservation specialists. It recognizes the importance of proper diagnosis of the problems encountered and a full understanding of the stone decay mechanisms being experienced.

Consolidant treatments, in most cases, address the effects of decay but not its causes. The causes of stone decay also must be considered, and addressing the causes may take priority over treating the effects. When selecting a consolidant treatment, the stone mineralogy must be studied as well as previous treatments to which the stone may have been subjected. Also to be considered is the effect the proposed consolidant treatment may have on future maintenance treatments. Once the performance goals of a consolidant treatment can be established, the Guide offers an arsenal of known testing procedures to help assess the efficacy of the treatments being considered.

To participate in further development of this standard, contact David Wessel of Architectural Resources Group in San Francisco at wesselarg@aol.com.

Guide for Repointing Masonry

Masonry structures normally require repointing (i.e., tuckpointing) as a maintenance procedure during their service life. Repointing entails removing deteriorated joint mortar and replacing it with sound mortar. Repointing is performed to improve weather resistance by reducing water permeance, replace inappropriate mortar, maintain structural and visual integrity, and prolong a building's service life. Repointing is so commonplace that it is often implemented on large projects without the participation of a professional consultant. However, with historic buildings the need for special guidance becomes immediately apparent, and these cases are addressed in the proposed ASTM Guide.

According to Dick Bonin, masonry specialist with Western Waterproofing in St. Louis, it is not possible to remove mortar without damaging adjacent masonry units. Therefore, the gentlest methods available for removing mortar should be determined.

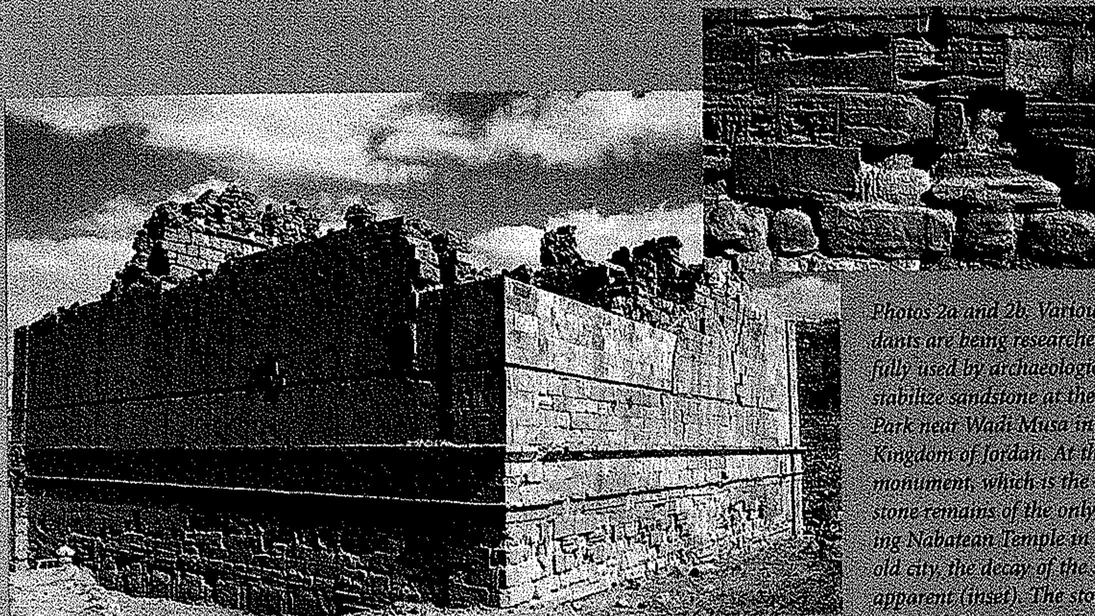
Appearance—color, texture, and profile—of the mortar is not the only criterion for selecting appropriate mortars. A harder cement-based mortar installed in a wall of softer masonry materials meant for lime mortars can cause the stone or brick to break and spall as it fights a losing battle with the hard mortar in a now stiffer, less forgiving wall. Portland cement mortars are less permeable than lime-based mortars. When used to replace lime mortar, they will cause freeze-thaw damage within rubble walls as water that once evaporated through the joints now remains in the wall cavity over extended periods.

The Guide has just entered its initial cycle of ASTM balloting. To participate in further development of this standard, contact Dr. Lauren B. Sickels-Taves of Biohistory International in Huntington Woods, Michigan, at lstaves@ibm.net.

Technical Manual for the Treatment, Repair, and Replacement of Terra Cotta

Terra cotta, a baked clay masonry material, experienced its heyday from the 1880s to the 1930s. In the United States and the United Kingdom, it was used to clad countless landmark structures that are now the focus of preservation projects. Terra cotta is still manufactured, though not in the quantities that it once was. The primary use of new terra cotta is for preservation as well as for unique new structures.

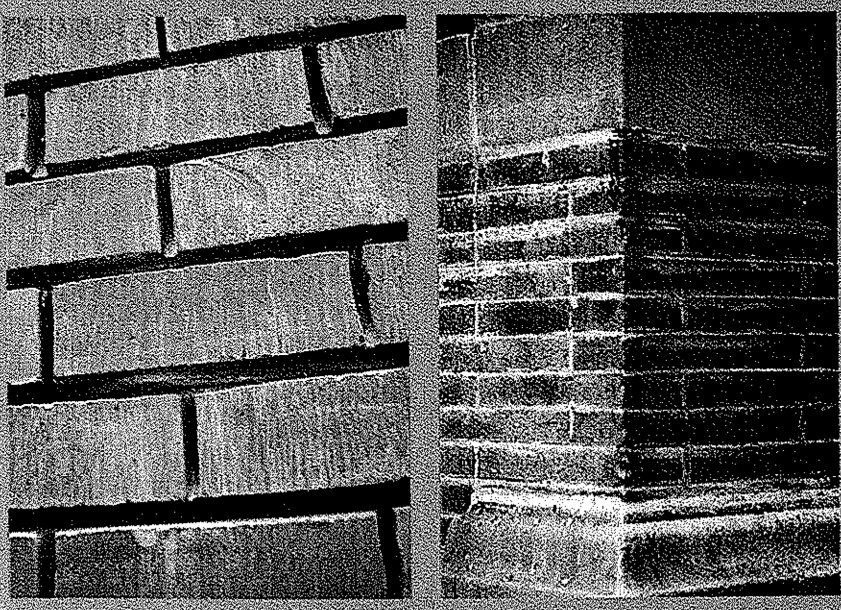
Though there are extensive articles and books on terra cotta, none of these documents speak comprehensively to the technical concerns facing those who investigate, care for, and repair structures clad with this material. Those who seek technical guidance with terra cotta are faced



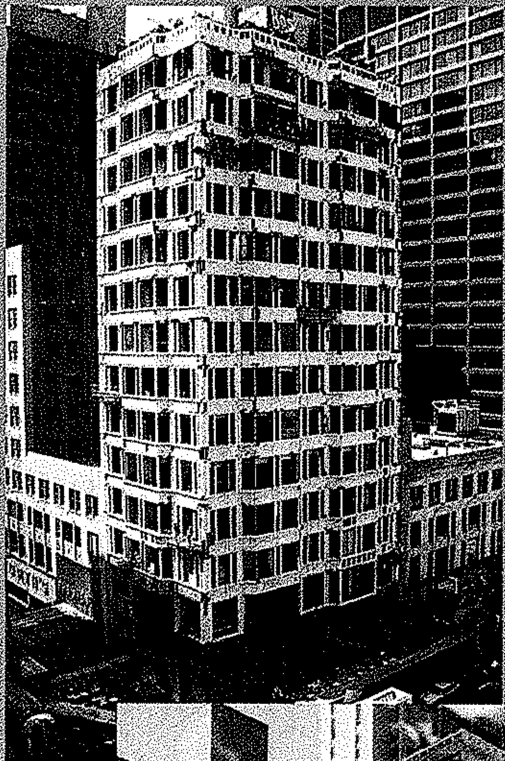
PHOTOS THIS PAGE COURTESY THE AUTHORS

Photos 2a and 2b. Various stone consolidants are being researched and successfully used by archaeological teams to stabilize sandstone at the Petra National Park near Wadi Musa in the Hashemite Kingdom of Jordan. At the Qasr al-Bint monument, which is the 2,000-year-old stone remains of the only known standing Nabatean Temple in the heart of the old city, the decay of the stone is readily apparent (inset). The stone decay is the result of more than a thousand years of capillary movement of moisture from the soil. The consequent deposit and crystallization of soluble salts originating from the soil, mortar, or the stones themselves, has severely decayed many of the stones that are near grade. Consolidant treatments on the walls of the Qasr al-Bint would address the effects rather than the cause of this stone decay and illustrate the importance of using a specialist in stone decay and diagnosis before entering into a consolidant treatment program.

As historic landmarks grow older and newer buildings become historic landmarks, the problems that the preservation practitioner faces will become more complex.



Photos 3a and 3b. No matter how skillful the artisan, it is not possible to perform a repointing procedure without causing some damage to adjacent masonry units. The two side-by-side photos illustrate walls that have been damaged due to improper mortar removal and repointing techniques. Numerous criteria must be examined before repointing, such as whether repointing is necessary, how much repointing is necessary, what are the proper mortar removal and replacement techniques, what mortar types will be compatible with the existing masonry, and what will be authentic in appearance.



Photos 4a and 4b. The restoration of the exterior façade of the Reliance Building in 1995 has been the focus of international attention due to the pivotal position of this landmark edifice in the history of the American skyscraper. Not only was the facade cleaned but a comprehensive diagnosis of building problems led to the replacement of more than 2,000 units of terra cotta, as well as terra cotta patching, pinning, epoxy repairs, and the use of substitute materials.

PHOTOS THIS PAGE: LESLIE SCHWARTZ

with research into documents that are sometimes contradictory and may provide questionable data.

The Technical Manual will provide a beginning point where all treatments can be discussed and compared, and bibliographic data is provided to encourage further research. A technical history of the material, its fabrication, and installation will be presented as a supplement to understanding the material. There is nothing like this manual in print in the United States.

The manual is a collaborative effort and authored by those who are known specialists in this field, representing numerous firms, organizations, and societies. To participate in the development of this manual, contact Stephen J. Kelley of Wiss, Janney, Elstner Associates, Inc., in Chicago, at sjk@wje.com.

A Road Map to Preservation

As historic landmarks grow older and newer buildings become historic landmarks, the problems that the preservation practitioner faces will become more complex and the need for standard approaches to evaluation, testing, and repair will increase. With these complex materials and systems, standards can act as a bridge between the architect, conservator, engineer, scientist, consultant, contractor, artisan, and owner. Historic landmarks are unique structures, and there is no argument that each project should be approached on an individual basis.

As Professor Giorgio Croci, author of *The Conservation and Structural Restoration of Architectural Heritage*, and chair of ISCARSAH, recently said, "Let the building be the standard." The development of standards—be they philosophical, governmental, procedural or technical—should encourage innovation and creativity. The standards should be like a road map, providing all the tools by which a course can be charted—but a road map that still leaves the user with a choice about the route chosen. And also like a road map, standards must change and be revised on a continuing basis to keep in tune with changes in our culture, buildings, materials, and technological advancement. ■

Failures

The Writing on the Wall

Graffiti can be particularly difficult to remove, especially when the writing medium penetrates the stone or brick surface. In the case illustrated below, graffiti was applied with permanent markers in cold weather to a recently completed cast stone and limestone monument. Graffiti is best addressed as soon as possible to ensure the best possible chance for removal—this can be challenging, as graffiti is often applied at night.

Maintenance workers attempted to remove the markings with a medium- to high-pressure abrasive system (2758 to 8274 kPa [400 to 1200 psi]) with sodium bicarbonate as the cleaning medium. This salt can damage masonry substrates through abrasive action and, because it can penetrate the material, contribute to future deterioration. Additionally, sodium bicarbonate and water form a paste that is difficult to rinse off. In this particular case, the high application pressures also contributed to erosion of the cast stone surface in the sample area being cleaned.

With guidance from a conservator, small-scale cleaning trials were attempted with a variety of cleaning systems to remove the graffiti without damaging the limestone and cast stone substrates. However, air temperatures were at –1 C (30 F) during the cleaning process, causing chemical cleaners to work more slowly and less effectively. Therefore, and it was necessary to limit the amount of water used to avoid potential cyclic freeze-thaw damage to the masonry.

A wide range of products was tested in small samples, with the more effective ones re-tested in larger samples. The selection of products was made based on prior experience and included


Photo courtesy Joshua Freedland

After cleaning with abrasive sodium blasting, graffiti remained on the cast stone. Paint stripper improved the situation without risking deterioration.

chemical cleaners, paint strippers, and a micro-abrasive system using glass particulate at (up to 35-psi) application pressure. Although gentle enough to avoid damage to the substrate, this last method was not successful in removing the graffiti because the stain had deeply penetrated the surface.

Since the graffiti was localized and near-grade, and it was possible to provide protection and controls, certain applications were possible that may be unfeasible in other situations. An N Methyl-2Pyrrolidone (NMP)-based paint stripper was the most effective of the products tested. Based on the initial cleaning tests, all affected areas were cleaned using the paint stripper following manufacturer's recommendations, with an extended dwell time of up to 24 hours.

After the first cleaning, a faint shadow of the graffiti marking was visible when the surface was wet after rain or snow. The cleaning process was repeated one week later when the temperature rose, leading to an acceptable level of cleaning.

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Failures

Abrasive Masonry Cleaning too Rough?

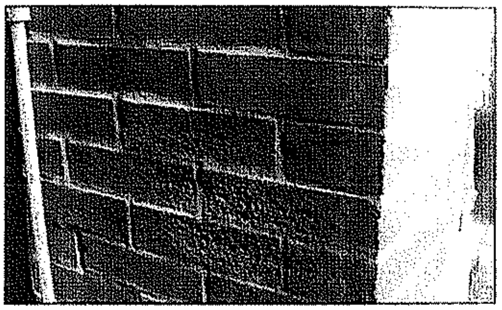
Deborah Slaton is an architectural conservator and consultant with Wiss, Janney, Elstner Associates Inc. (WJE) in Northbrook, Illinois, specializing in historic preservation and materials conservation. She can be reached via e-mail at **dslaton@wje.com**. **Joshua Freedland** is an architectural conservator with WJE's Chicago office.

Abrasive cleaning methods have been used on masonry facades for decades. Traditional methods propel media—typically sand and aluminum oxides—against walls at high pressures, successfully removing dirt and grime. Unfortunately, this process also scars masonry, removing surface detail and texture, or the glaze/outer surface from brick or terra cotta. With its less durable interior surface exposed, masonry becomes more vulnerable to water penetration, accelerated freeze/thaw deterioration, and dirt accumulation.

Sometimes referred to as 'microabrasion,' new techniques are marketed with the promise of gentler cleaning, and reduced health, safety, and environmental risks in comparison to many cleaning chemicals. The systems employ a variety of very fine particulates (*i.e.,* crushed glass, dolomite powder, or plastic beads) as the cleaning media, which also vary in hardness, size, and shape.

Microabrasives are applied either wet or dry at very low pressures (typically 172 kPa to 345 kPa [25 psi to 50 psi]). Some proprietary systems use specially-designed nozzles, and may require specially trained and/or certified contractors. These systems may also provide for the containment of debris and cleaning media, and the recycling or reuse of the particulate.

Professionals should be consulted about the suitability and implementation of specialized abrasive methods, and field samples must be



Traditional sandblasting permanently scarred the surface of this facade.

performed and examined microscopically prior to implementation. Without proper selection, testing, and control during application, substrate damage can occur. Failures with new abrasive systems typically occur when:

- application pressures are too high;
- the nozzle is held too closely to the surface;
- the medium is inappropriate for the substrate;
- cleaning leaves residue on the substrate;
- the application technique is inconsistent; or
- the substrate is too delicate for this type of cleaning.

As with other cleaning systems, it is imperative to determine whether microabrasives can effectively remove soil, surface contaminants, or coatings without damaging the facade. Microabrasion requires strict quality control, but when used properly, it can be a gentle and effective cleaning technique for certain masonry substrates.

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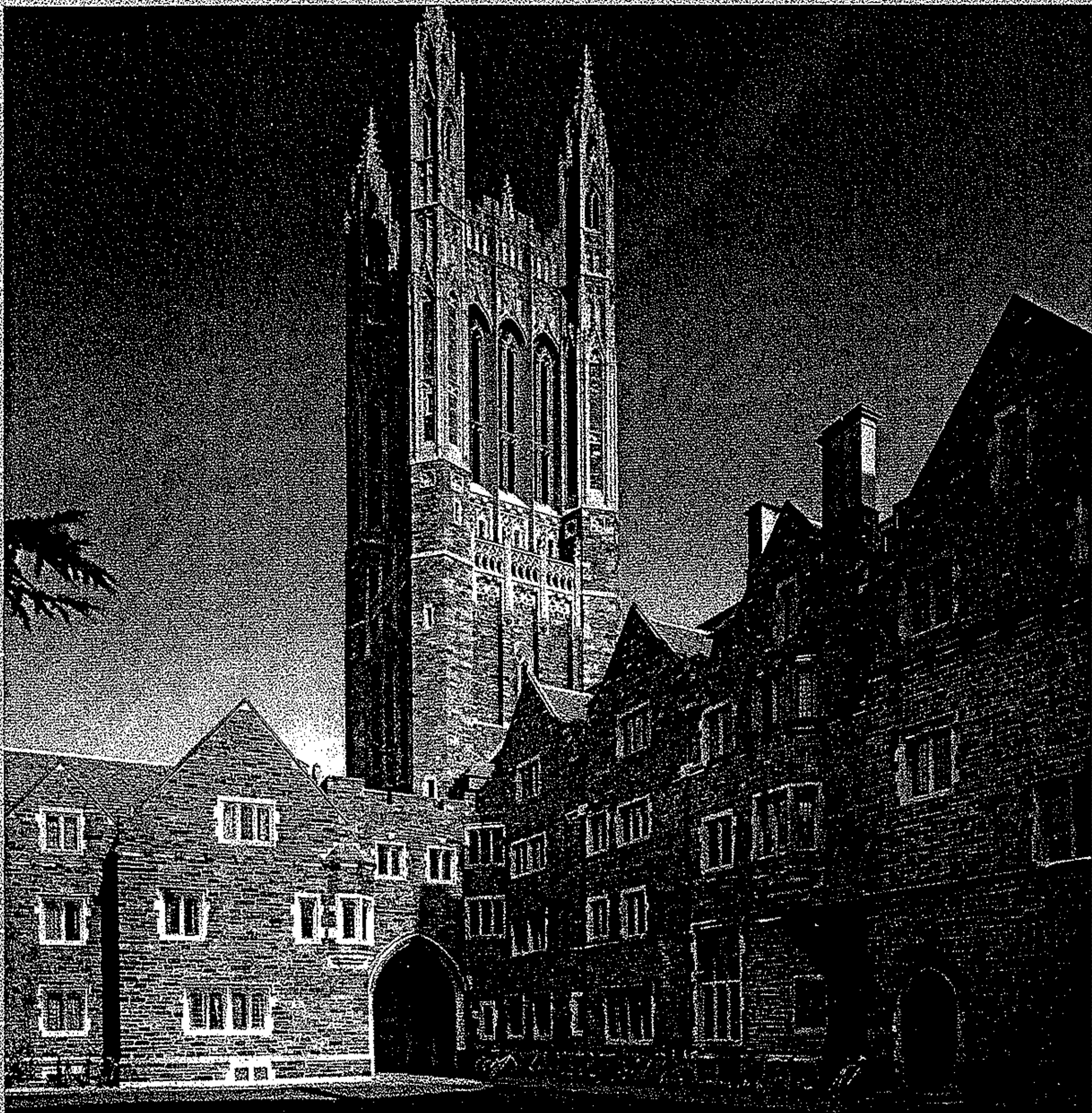

THE JOURNAL OF PRESERVATION TECHNOLOGY

The Association for Preservation Technology APT Association pour la preservation et ses techniques

Applying Infrared Thermography to Historic Wood-Framed Buildings in North America

ELISABETTA ROSINA and ELWIN C. ROBISON

Thermography provides the conservator with a nondestructive tool for locating structural members, defects, and moisture diffusion in wood-framed historic structures.

Infrared thermography (IRT) is a telemetric, or remote measuring, technique that maps emitted radiation into a two-dimensional image representative of the distribution of the temperature on the emitting surface.[1] In the 1960s the first IRT applications were carried out by the aerospace, welding, automotive, and electric industries. Then, in the 1970s and 1980s, the technique was applied to medical, agricultural, and building-maintenance uses. In the same period thermal math models of heat transfer inside structures and materials were developed to improve the comparative evaluation between sound areas and anomalies and to improve the temperature distribution in those regions.

In recent decades considerable IRT research has been conducted in Italy, both in the laboratory and in the field at buildings important to Italy's cultural heritage. Thermal anomalies have been shown to be related to the local thermal properties of the materials and to defects in the elements examined.[2] Controls became reliable thanks to new algorithms applied in signal processing in the thermocameras. Today IRT is often used in different phases of building restoration: during preliminary investigations, during the restoration process itself, as a tool for final inspection, and later as part of a cyclical maintenance plan.

IRT investigation permits researchers to gather information about the location, shape, material characteristics, and state of decay of building elements and systems. Surface-temperature distribution evaluated with respect to particular boundary conditions permits the detection of discontinuities and alterations to building structures.

Much research regarding the application of IRT on solid masonry construction was conducted in North America in the 1980s.[3] Over the last decade improvements in techniques, instruments, and the algorithms for mathematical modeling have facilitated additional research on both solid and hollow-core masonry walls. However, only a small number of IRT investigations on wood structures are found in the scientific literature. While no comprehensive studies on wood structures exist, there have been studies of specific wood elements,[4] most notably Ljungberg's study.[5]

This paper draws upon the IRT techniques developed for studying historic buildings in Italy and applies them to wood cavity-wall structures common in the United States, focusing in particular on historic nineteenth- and twentieth-century buildings with balloon frames and masonry buildings with plastered, wood-furred walls in the Great Lakes region.[6] The species used in construction ranged from indigenous oaks and poplar to pines and fir trees imported from other regions. The area of the study has freezing winters and warm, humid summers, resulting in significant relative humidity and temperature differentials between seasons.

The IRT Technique

IRT is a nondestructive and noncontact method of mapping the temperature patterns of the surface of building elements. Under the proper boundary conditions — such as heating from sunshine, central heating, or during rapid cooling — it can reveal textures, shapes, and the connections between building elements not visible on the surface. This permits subsurface investigation without destroying historic fabric. IRT measurement also has these other advantages:

- Surface temperature is measured in real time.
- IR images are photographed at a distance from the surface. As a result most buildings of three or four stories or less can be investigated without requiring lifts or scaffolding.
- Large areas can be investigated in a short time.

IRT is based on the change in the heat flux as it passes through building materials, brought about by the presence of anomalies. These include voids, delaminations, or repairs using different building materials. The changes in heat flux cause localized temperature differences on the surface of the material. A change in heating conditions (warming or cooling) is the key mechanism in revealing those anomalies.

Passive Thermography

The goal of passive investigations generally is to locate anomalies in walls or roofs. This is often sufficient for a preliminary survey of decay. The passive approach is particularly suitable for buildings because it allows examination of large surfaces in a short time. In passive thermography no artificial sources of heat are applied to cause changes in the heat flow inside the material. The approach is qualitative in nature because precise boundary conditions (i.e., changes in cloud cover during the test; changes in wind speed, which changes convective cooling; precise thermal/optical properties of the surfaces; or the rate of exchange of heat between the surface and the environment) often are unknown. For the tests to be successful, such conditions as cloud cover, rain, shadows from trees or nearby buildings, or interior heating cannot produce temperature patterns that will erase or overcome the temperature patterns produced by building anomalies.

Sunshine is generally the most important factor in passive thermography. It provides an excellent source of heat because of its power (up to 1,000 W/m^2), homogeneity (the radiation rays are parallel), and cost (zero). The passive approach requires taking thermograms at the proper time, when the boundary conditions are most suitable, usually just as a heating or cooling phase begins. For east facades, the proper times are just before dawn or after noon; for south facades (in the northern hemisphere), midmorning or late afternoon (with precise times dependent upon season and solar alignment); and for west facades, noon or after sunset. In the northern hemisphere, north-facing facades require measurement during the early morning or late afternoon in the summer; in winter, investigations usually depend upon internal heating to produce a heating flux. The potential advantage of quick results can vanish in the absence of careful planning of the sequence of photography in the field.

Active Thermography

In active thermography thermal images are taken during or after artificial heating of the surface. This approach is often used to enhance the differences in surface temperature previously found using the passive approach. The active approach does not require optimal environmental conditions for success.

Most traditional building materials (stone, brick, mortar, or layers of wood construction) have thermal properties that are very similar: at steady-state conditions differences in surface temperature are hardly detectable by thermal cameras. However, a significant increase of the heat flow in a defined time can cause surface-temperature patterns that indicate the presence of different building materials under the surface or inside the walls. Any anomalies within the walls also appear because they interrupt or deviate the heat flow that determines the surface-temperature pattern.

If the materials used in the wall and the thermal characteristics of the building components are known, appropriate modeling of the heat transfer may be used to quantify the amount of energy and the time of heating needed to obtain the best results. This approach is more time consuming than the passive approach, and it can be difficult to produce even heating over a large surface and to maintain a unidirectional and constant heating flux. As a consequence, the active approach generally is used on small sections of a building, and the results are extrapolated over a larger area.

When applied to buildings, the active approach commonly relies upon a semi-quantitative measurement of the heating flux and response of the building materials. In other words, a comparison is made between the thermal performance of a sound area and one of unknown quality, instead of using software for quantitative evaluation. The semiqualitative procedure is used because some approximations are necessary in the field to adapt the procedure in the event of sudden changes in the environment and because the thermal properties of the specific materials employed are mostly unknown.[7] The scientific literature provides some values of the thermal characteristics of building materials, but the variability of the materials and their state of conservation causes a high variation in thermal parameters, reducing the effectiveness of a strictly quantitative model.

Quantitative IRT is used in the second phase of analysis, when all the data regarding the materials and the building techniques are known and the goal is to quantify and determine precisely the nature of the anomaly. The industrial thermography procedure of Lockin and Pulsed (named for the shape and frequencies of electromagnetic waves) can then be applied, even if the low diffusivity of porous materials decreases the advantages of these techniques.[8]

Discovering Anomalies of Buildings

In the preliminary phase of an investigation, when there is little time and a limited budget for the basic study, IRT can quickly locate areas that require further investigation. In situations where materials have widely different thermal properties — for example, stone and lime mortar — using the passive approach and relying on solar irradiation or favorable natural convective flux yields the best results. Where materials have similar thermal characteristics, as with brick and clay mortar, good results can also be achieved by means of numeric modeling of the thermal exchanges occurring between the wall and the environment and by modeling of the heat transfer inside the wall.[9]

Fig. 1. The Wescott House, Springfield, Ohio.

Conditions Causing False Readings

The optical and thermal properties of the exterior surface of the wall (parging, stucco, plaster, or just the skin of stone, bricks, and wood) affect the measurement of the heating flux influenced by the inner layers. Often, these surfaces before restoration are characterized by areas of varying color, porosity, and different paint or wall coverings, as well as by damage. During irradiation these differences can cause differentials in local absorption rates and consequently an uneven heat flow inside the structure. In addition, these surface irregularities are the main filter of any thermal signal coming from inside the structure.

An example of a false reading comes from Frank Lloyd Wright's Westcott House (1908), in Springfield, Ohio (Fig. 1). A comparison between the visual and thermographic views shows variations in thermal signals that merely follow the variations in surface color and texture. Figure 2 illustrates the west elevation, and Figure 3 is the corresponding thermogram. The Westcott House has a balloon frame, and the exterior finish is portland-cement stucco. The image was shot after artificial heating of the exterior by halogen lamps. The dark areas produced a higher temperature (ΔT ranging 1.2–1.8°F; 0.7–1°C). The black and grey deposits on the surface of the stucco follow the same pattern as the temperature distribution. The temperature change was caused by the color variation and not by some underlying anomaly.

Variations in surface texture are also important. For instance, dark crusts on stucco or stone often correspond to a zone in which the porosity is higher because the surface has been damaged. The quantitative evaluation of such variations is not directly linked to changes in optical properties. It is therefore not possible to measure such alterations only via thermography.[10] Nevertheless, the qualitative location of damaged areas is easily accomplished, greatly aiding building restoration specialists.

Detection of Intermediate Layers

IRT can also be used to investigate the materials beneath the plaster and the stucco, such as wooden furring strips and wood studs or joists. Active IRT requires heating the wall with a suitable source of artificial heat, thereby enabling specific layers to be analyzed in detail, but the energy to be delivered and the time for measurement must be determined precisely.[11] The ability to read information at a given depth is strongly dependent on the available power of the heating flux. In practice the actual limit is a few centimeters. In the field only a transient state can be achieved, because a large amount of energy is needed to heat large building elements like a wall. Despite these restrictions, the ability to detect materials underneath the surface improves knowledge of the building and sometimes can lead to unexpected discoveries.

For example, at the Westcott House a refined mathematical modeling of the heat transfer inside the wood stud wall and between the stucco surface and the outside environment was used to detect the structure binding the stucco to the substrate.[12] Archival documents, including Wright's original drawings, described the building as having a balloon frame with diagonal sheathing boards, wood lath, and a stucco finish. A preliminary test was based on that information, and the result was unexpectedly unfocused (Fig. 4). The failure of IRT to read any information regarding the underlying structure led the researchers to inspect the building more carefully and led to the discovery that metal lath, rather than wood lath, had been used on the house. New data that reflected this information were then used

Fig. 2. Westcott House, west elevation. Halogen lights were used as the heating source to produce a heating flux within the wall. The portland cement stucco of the exterior is stained, changing its heat absorption properties. Note especially the area in the lower left hand corner of the photograph.

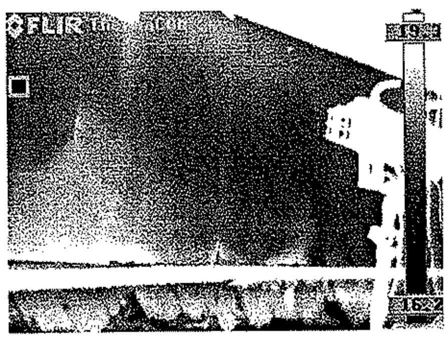

Fig 3. Westcott House, western elevation. Thermogram corresponding to Fig. 1. Note the greater heat absorbtion (lighter color) of the surface in the lower left-hand corner of the thermogram.

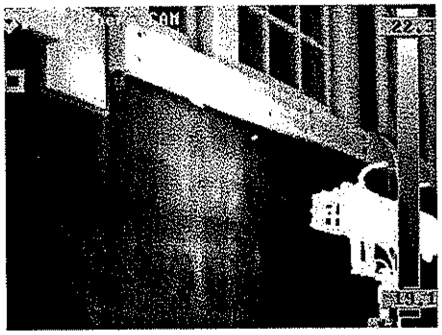

Fig. 4. Westcott House, west elevation. In the first heating IRT shows an unfocused image of the inner layer of the wall. The amount of energy and the time for recapturing the images was based on incorrect data.

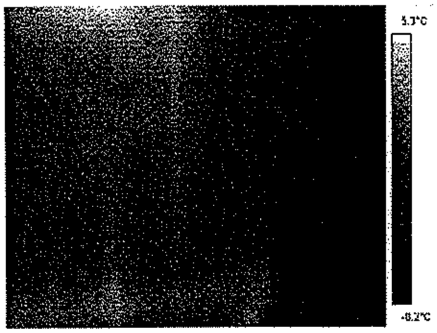

Fig. 5. Westcott House, west elevation. Using the adjusted heating procedure, the change in heating flux caused by the furring strips inside the wall is now registered on the surface in the thermogram.

to recalculate the optimum heating power and the best recapture time.

With the adjusted heating procedure, the image was clear enough to permit identification of the underlying structure (Fig. 5). The vertical lines, occurring at approximately 24 cm (9-1/2-in.) intervals, correspond to the spacing of the vertical furring strips to which the expanded metal lath is nailed. Contemporary building standards recommended a spacing of 22 cm (9 in.) for the furring strips, supporting the interpretation of the image seen in the thermogram.[13] Unseen in the thermogram is the outline of the metal lath. Theoretical models predicted that metal lath can mask the structure of a wall if the openings in the lath are too small. Although the metal lath was not detected in the field via thermography, the Westcott House example demonstrates that thermography can be applied effectively to twentieth-century buildings with metal lath.

Location of Structural Elements

IRT can be used to determine the position, shape, and dimension of such structural elements as studs, posts, and joists. Since the hollow cavity of a wood-stud wall does not readily transmit heat, the surface temperature of the wall is affected by the wood structure where it is in contact with the finish layers. The most reliable testing procedure involves shooting images of transient conditions when the thermal characteristics of the materials are known. The elements in balloon frames have standardized sizes and spacings, and deviations from the repetitive pattern are readily detected.

In the Peck House (1888), in Youngstown, Ohio, the floor joists and the wall studs are easily viewed using IRT (Fig. 6).[14] The thermograms also show the wood lath.

This investigation was performed in cold weather while the house was heated. The high thermal gradient between the interior and the exterior induces the necessary heat flow to detect the structural elements (Fig. 7).

Detecting Moisture Diffusion

The presence of water in a wood structure causes problems primarily because it promotes the growth of mold and fungus, which can cause the deterioration of wood elements and sicken inhabitants. Moisture detection by IRT is well documented.[15]

The passive approach qualitatively follows moisture distribution due to the cooling effect of water evaporation.[16] During evaporation, the high value of latent heat cools surface areas. This phenomenon depends on the strong thermal energy dissipation due to the change of water from liquid to vapor.[17] The evaporation rate is related mainly to the relative humidity (RH) of the air near the surface, the temperature (T°), the water and soluble salts content in the material, and its chemical-physical characteristics.[18] Where RH is greater than 80 percent and/or temperatures below 42 or 43°F (6 or 7°C), any evaporative process is inhibited, and it is almost impossible to detect damp areas.[19]

Another approach is based on water's high thermal capacity as it is revealed during transient thermal tests.[20] In the case of temperatures below 40°F (5°C), protracted heating (even with a low thermal gradient), and no evaporative flux, moist areas have higher temperatures than dry ones. This approach is particularly suitable in severe climatic conditions and can be applied also in interiors with artificial heating, although the simplest procedure consists of comparing the increase of temperature as a function of time in the sound areas to the areas under investigation.[21] Current IRT procedures measuring water content are not easily applied in the field.[22]

The area of water diffusion across the surface is extremely helpful in locating the source of infiltration, even

Fig. 6. Peck House, interior, living room. The thermogram shows the wooden lath nailed between the studs and joists. The thermograms were shot in cold weather conditions while the home was heated.

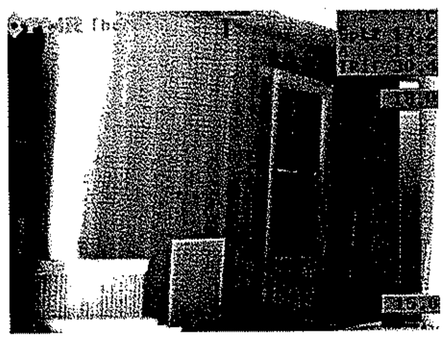

Fig. 7. Peck House, interior, living room. The IRT image shows the structure of the wood studs underneath the plaster. The surface thermal pattern is highly affected by the presence of the radiator and its supply pipe (the lighter area) and the thermal bridge at the corner of the room.

though the visible damage often does not correspond to the current moisture distribution. Liquid can evaporate, while the decay remains. In other cases the diffusion of water spreading inside the structure is not yet apparent because a waterproof surface prevents moisture from escaping. Using only visible indications on a wall, even an experienced investigator cannot always determine the actual distribution of water in the building. However, IRT detects such moisture readily.

IRT has the following advantages in detecting moisture:

- It locates the moisture distribution on surfaces without the collection of any samples.
- The technique is nondestructive, so measurements can be repeated, and the phenomenon of water infiltration can be monitored over time. Changes in the thermal-hygrometrical status of the wall can be detected under different climatic conditions, also.
- IRT readings are not dependent on soluble-salts content.

However, there are disadvantages:

- The results are qualitative and only related to the surface.
- There is not a direct correspondence between surface temperature and water content.
- In short, thermography cannot directly measure water content inside the wall.

Currently, the simplest solution for overcoming these disadvantages is to integrate IRT moisture mapping with the direct measurement of water provided by other testing methods, such as weighting tests or moisture probes. The advantage of using IRT is that thermal scanning can quickly determine the zones in which the temperature (and consequently the water content) is constant. Currently, there is no effective procedure to measure water content by measuring temperature, but there is a qualitative correlation between temperature variation and hydric gradient. Although thermography cannot measure the amount of water, it can determine similar water-content states. This means that a water-content measurement by other, more time consuming methods at only one point is valid for the entire area

Fig. 8. Westcott House, interior of the north dining room wall. Wood paneling removed, revealing the original plaster surface with painted areas corresponding to the outline of the wood cabinetry designed by Wright.

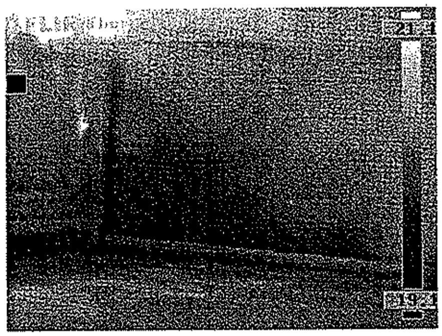

Fig. 9. Thermogram corresponding to Fig. 8. The IRT shows that the distribution of moisture does not follow the shape of the damage on the surface of the plaster. Moreover, the surface temperature distribution (cooler toward the west) indicates that the source of infiltration starts at the western corner (passive approach, T° = 58.5°F, 16°C; RH = 41%).

having the same temperature within the limits of the analysis (and obviously for the same material, state of conservation, and boundary conditions). Thus, only a few measurements using other methods must be taken. Such large savings enable researchers to repeat the investigation at different times in order to observe the relationship of moisture content in building features to surrounding conditions and changing climate, building occupancy, equipment, HVAC conditions, and weather factors.

The dining room wall of the Westcott House (Fig. 8) demonstrates how IRT distinguishes the actual damp areas from dry areas in a wall by using the passive approach. Despite damage to the plaster surface, the distribution of moisture does not follow the shape of the damaged surface (Fig. 9). Moreover, the surface temperature distribution (cooler toward the west) shows that the source of infiltration starts at the corner. This pattern indicates that the water flows from the west into the structure and is not caused by groundwater near the surface being drawn up by capillary action from the stone foundation.[23]

Moisture can also be detected in masonry walls with wood furring strips and plaster. At the Episcopal Church of the Transfiguration (designed by the architectural firm of Cram and Goodhue, 1902; additions 1904), in Cleveland, Ohio, IRT was used as a nondestructive method for locating areas of potential damage and assisting the congregation with effective maintenance.

The building has solid ashlar walls with interior plaster over wood furring strips. Inside, the plaster appeared to be in generally good condition. However, IRT detected the spread of water in the structure before damage was visible. Figure 10 shows a metal box in the wall between the clerestory windows. The area between the box and the stringcourse, at 56.6°F (16°C), is the coldest portion of plaster wall (Fig. 11). Water is likely entering at the box and running down inside the cavity of the wall, between the furring strips. At the stringcourse the cold area widens, indicating that the molding stops the flow of water, at which point it spreads horizontally. Analysis of the IR image shows the finished surface to be nonporous, probably due to the many coats of paint: as a consequence, the trapped water spreads extensively before evaporating. Infrared detection shows the diffusion of water in the plaster, while the wood lath absorbs water and stores it. This situation promotes fungal growth and will eventually damage both the plaster and the substructure of the wall.

Thermal Bridges

Buildings with a low mass, like wood-frame construction, can exhibit poor thermal performance due to air infiltration and thermal bridging, or the short-circuiting of insulation with a more

Fig. 10. Church of the Transfiguration, west side. Interior nave elevation.

highly conductive material. As a result humid air condenses on the colder areas of the wall surface and causes damage. In the following example a significant difference between indoor and outdoor temperature facilitated the investigation.

In the Peck House a large thermal bridge is located at the first floor, in the main bedroom (Fig. 12). The plaster around the right window is heavily damaged. A downspout is located just outside, and staining from water leakage

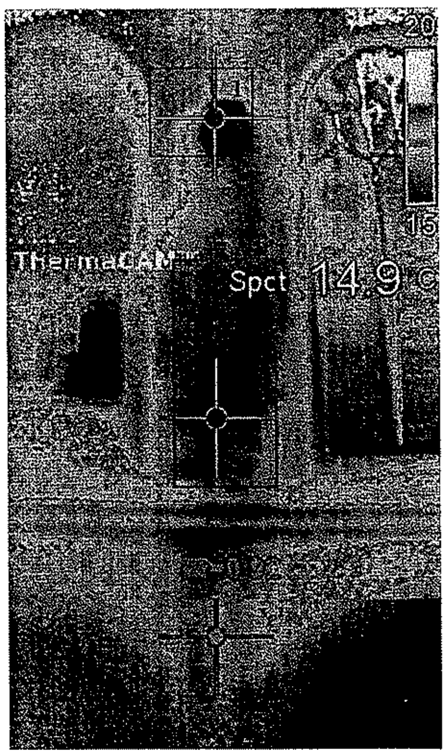

Fig. 11. Thermogram corresponding to Fig. 10. Note the cold area descending from the box set into the wall and the spreading of the cold area at the stringcourse.

is visible on the exterior wall. The thermogram (Fig. 13) shows a large cold area around the window, but the shape of the darker zone does not correspond to the visual damage, indicating that the leaking water damaged not only the plaster but the insulation inside the wall.[24] Heating the bedroom and repair of the downspout caused the water to evaporate from the surface, but the damage to the insulation and plaster remains, resulting in a cold area susceptible to condensation.[25] Thermal bridges can also be detected from the exterior, the only difference being that the thermal bridge appears warmer.

Conclusion

IRT can be used successfully with wood structures. The procedures developed with masonry buildings in Italy work well in wood buildings in North America because in most cases thermograms were taken not of the wood structure directly but rather of a plaster surface. Water travels through vessel cells and fibers of wood very differently than it does through masonry, but the diffusion of water from wood to plaster provides a medium that is readily detected by IRT using the passive approach.

Wood-frame construction in North American building systems frequently employs multiple layers of building materials (e.g., clapboard, tar paper, sheathing, studs, lath, and plaster). Investigation of a particular layer requires the quantitative approach, with heating power, time, and material properties properly modeled. Experience shows that the heat-transfer model must be relatively accurate for IRT to be successful.

The passive approach is an excellent tool for locating wood structural elements, moisture infiltration, and thermal bridges. Because IRT can quickly cover large areas and do it at a distance, it can be a cost-effective tool for conservators, architects, and maintenance personnel. Depending upon the size and depth of the object under investigation, either the passive or active approach can be used. By appropriately choosing times and exposures, it can potentially be done in all seasons and HVAC conditions. It is especially useful with historic buildings because it is nondestructive and noncontact.

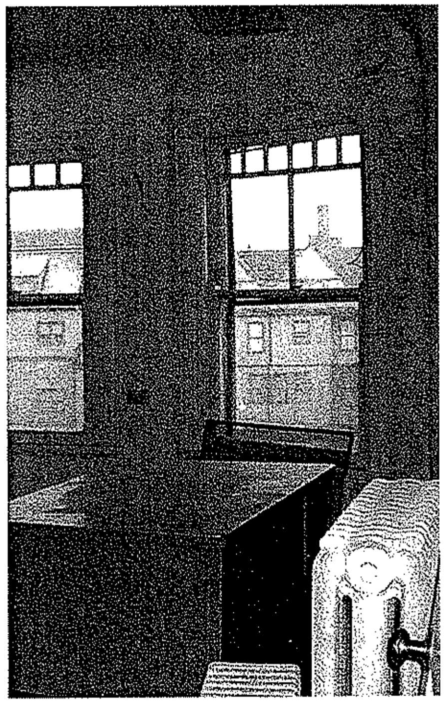

Fig. 12. Peck House, interior, main bedroom. Image of the plaster around the right-hand window in the visible spectrum showing heavy damage to the surface.

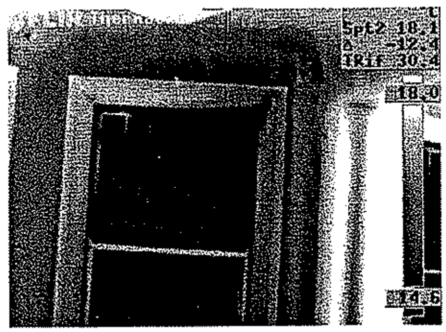

Fig. 13. Thermogram corresponding to Fig. 12. Note the cold area above the window, the result of damage to insulation from an old downspout leak.

The active approach is most useful as a second level of analysis. It usually investigates a small portion of a building or wall, due to difficulties in heating large areas evenly. In the authors' experience proper mathematical modeling of the building system is important in determining optimal heating powers and times. The active approach also is the most suitable for determining the relative water content in wood. However, differences in color, grain, species, and condition make it difficult to apply in the field without applying the carefully controlled Lockin and Pulsed procedures. Whether using a qualitative or semi-quantitative approach, it is important to exercise common sense and carefully evaluate the results.

When used under proper conditions and interpreted according to the boundary conditions, thermal imaging can be an effective tool for preserving historic buildings.

Acknowledgments

The authors thank Donna De Blasio, Youngstown State University; the Westcott House Foundation; the congregation of the Episcopal Church of the Transfiguration in Cleveland; Yolita Rausche; Stefano Vinci, Novatech Inc. (Catania, Italy); Blair Jennings, FLIR Systems US; and Ermano Grinzato, CNR, Padova.

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Notes

1. Any body emits IR radiation above the 0°K (-459.69°F, -273.15°C) as heat, and the measure of intensity of particle motion is the temperature. The radiation emitted increases proportionally to the energy associated with the random motion of the atomic particles of the matter. The measure of the temperature on the body surface also depends on the nature of the surface. Most IRT instruments have a high sensitivity threshold and can detect only high amounts of emitted radiation. The higher the temperature, therefore, the higher the accuracy of the measurement. The best use of IRT on historic buildings is for materials whose temperature is above 40°F (5°C).

2. E. Grinzato, "Stato dell'Arte sulle tecniche termografiche per il controllo non distruttivo e principali applicazioni" (paper presented at the Ninth National Congress of AIPND, Padova, Italy, September 1997).

3. In the proceedings of Thermosense, the annual conference of the International Society for Optical Engineering (SPIE), many papers on thermal imaging were published between 1982 and 1988. Chief among these are the systematic overviews by A. Colantonio, S. A. Ljungberg, and T. Kauppinen. The topics most frequently presented were moisture detection and heat loss due to insulating defects, and air leakage in building envelopes. The majority of these papers deal with modern buildings, but attention to cultural heritage and the application of nondestructive testing on historic buildings increased in the 1990s.

4. A. Wyckhuyse and X. Maldague, "A Study of Wood Inspection by Infrared Thermography, Part I: Wood Pole Inspection by Infrared Thermography," *Research in Nondestructive Evaluation* (March 2001); A. Wyckhuyse, and X. Maldague, "A Study of Wood Inspection by Infrared Thermography, Part II: Wood Pole Inspection by Infrared Thermography" *Research in Nondestructive Evaluation* (March 2001); S. Naito, Y. Fujui, Y. Sawada, and S. Okumura, "Thermographic Measurement of Slope of Grain Using the Thermal Anisotropy of Wood," *Mokuzai Gakkaishi* (2000); F. Quin, P. H. Steele, and R. Shmulsky, "Locating Knots in Wood with an Infrared Detector System," *Forest Products Journal* (1998); K. Murata and T. Sadoh, "Heat Absorption and Transfer in Softwoods and Their Knot Surfaces," *Mokuzai Gakkaishi* (1994); Y. Xu, S. Okumura, and M. Noguchi, "Thermographic Detection of Starved [sic] Joints of Wood," *Mokuzai Gakkaishi* (1993).

5. S. A. Ljungberg, "Infrared Survey of Fifty Buildings Constructed during 100 Years: Thermal Performances and Damage Conditions" (paper presented at Thermosense XXIV: An International Conference in Thermal Sensing and Imaging, Orlando, Fla., April 1995).

6. E. Rosina, E. Grinzato, and E. Robison, "Mapping Masonry Bonding by Quantitative IR Thermography," (paper presented at Thermosense XXIV, Orlando, Fla., April 2002).

7. Rosina et al., "Mapping Masonry Bonding."

8. These techniques are based on the time dependency of heating, by processing a sequence of thermograms shot during the propagation of the heating. The low diffusivity of the material highly affects the propagation of the heat, requiring algorithms for the analysis of the signal based on the actual properties of the investigated material. See "Infrared and Thermal Testing," *Nondestructive Testing Handbook*, vol. 3, 3rd ed. (Columbus, Ohio: ASNT, 2001). Grinzato refers to the application of dynamic thermography to plaster in "Thermal Characteristics of Defects in Building Envelopes Using Long Square Pulse, and Slow Thermal Wave Techniques," *Research in Nondestructive Evaluation* 9 (1997). Regarding the same application, see also A. Mazzoldi, P. Bison, S. Marinetti, and C. Bressan "Crack Detection in Fresco Painting," *Atti della Fondazione Ronchi* 1 (Jan.-Feb. 2001).

9. Rosina et al., "Mapping Masonry Bonding."

10. G. Stagno, E. Rosina, E. Costantino, N. Ludwig, A. Casarino, F. Vitali, and L. Rosi, "La manutenzione del moderno: il monitoraggio del calcestruzzo al quartiere ARTE di Genova (1980–1999)" (paper presented at Scienza e Beni Culturali XV, Bressanone, Italy, July 1999).

11. V. Vavilov, D. G. Kourtenkov, E. Grinzato, P. G. Bison, S. Marinetti, and C. Bressan, "Inversion of Experimental Data and Thermal Tomography Using Thermo. Heat and Termidge Software," *Eurotherm Seminar, Qualitative Infrared Thermography*, no. 42 (1994).

12. Rosina et al., "Mapping Masonry Bonding."

13. F. Chouteau Brown, *Cyclopedia of Architecture, Carpentry, and Building*, vol. 9 (Chicago: American School of Correspondence, 1908).

14. The Peck House is the future home of the Youngstown State University Center for Historic Preservation, and it served as a study case during the seminar on IRT application on Historic Building held in the Historic Preservation program at Youngstown State University on October 2001.

15. E. Grinzato, C. Bressan, P. G. Bison, A. Mazzoldi, P. Baggio, and C. Bonacina, "Evaluation of Moisture Content in Porous Material by Dynamic Energy Balance" (paper presented at Thermosense XIV, Orlando, Fla., April 1992; P. G. Bison, C. Bressan, E. Grinzato, S. Marinetti, and V. Vavilov, "Active Thermal Testing of Moisture in bricks," (paper presented at Thermosense XV, Orlando, Fla., April 1993); E. Grinzato, P. G. Bison, and V. Vavilov, "Nondestructive Evaluation of Moisture Content in Buildings: Theory and Experiments," (paper presented at *International Symposium: Dealing with Defects in Buildings*, Varenna, Italy, September 1994; E. Rosina and N. Ludwig, "Optimal Thermographic Procedures for Moisture Analysis in Buildings Materials" (paper presented at Diagnostic Imaging Technologies and Industrial Applications Conference, Munich, Germany, June 1999); K. A. Busher, W. Wild, and H. Wiggenahauser, "Moisture Measurements in Buildings Materials by Amplitude-Density Modulation Thermography," (paper presented at Diagnostic Imaging Technologies and Industrial Applications Conference, Munich, Germany, June 1999.

16. N. Ludwig, M. Milazzo, and G. Poldi, "Misura di umidità superficiale nelle murature mediante termografia," Ninth National Congress of AIPND, Padova, Italy, September 1997).

17. The cooling due to evaporation varies between a few tenths of a degree and more then ten degrees, depending on the material characteristics.

18. G. Cruciani Fabozzi, D. Ferrieri, N. Ludwig, E. Rosina, R. Sartori, and S. Vannucci, "Nuovo approccio al progetto diagnostico dell'umidità nelle murature: casi esemplificativi in area lombarda," (paper presented at Scienza e Beni Culturali XIV, Bressanone, Italy, July 1998); G. Baronio, A. Cantoni, D. Daniotti, and D. Ferrieri, "Diagnosis of Masonry Surfaces: Influence of Environmental Conditions on the

Decay" (paper presented at the Fourth International Masonry Conference, London, 1995).

19. E. Rosina, N. Ludwig, and L. Rosi, "Optimal Conditions to Detect Moisture in Ancient Buildings: Study Cases from Northern Italy" (paper presented at Thermosense XX, Orlando, Fla., April 1998).

20. A. Colantonio, "Thermal Pattern Solid Masonry Exterior Walls of Historic Buildings" (paper presented at Thermosense XIX, Orlando, Fla., April 1997); G. P. Bison, E. Grinzato, and S. Martinetti, "Moisture Evaluation by Dynamic Thermography Data Modeling" (paper presented at Thermosense XVI, Orlando, Fla., April 1994).

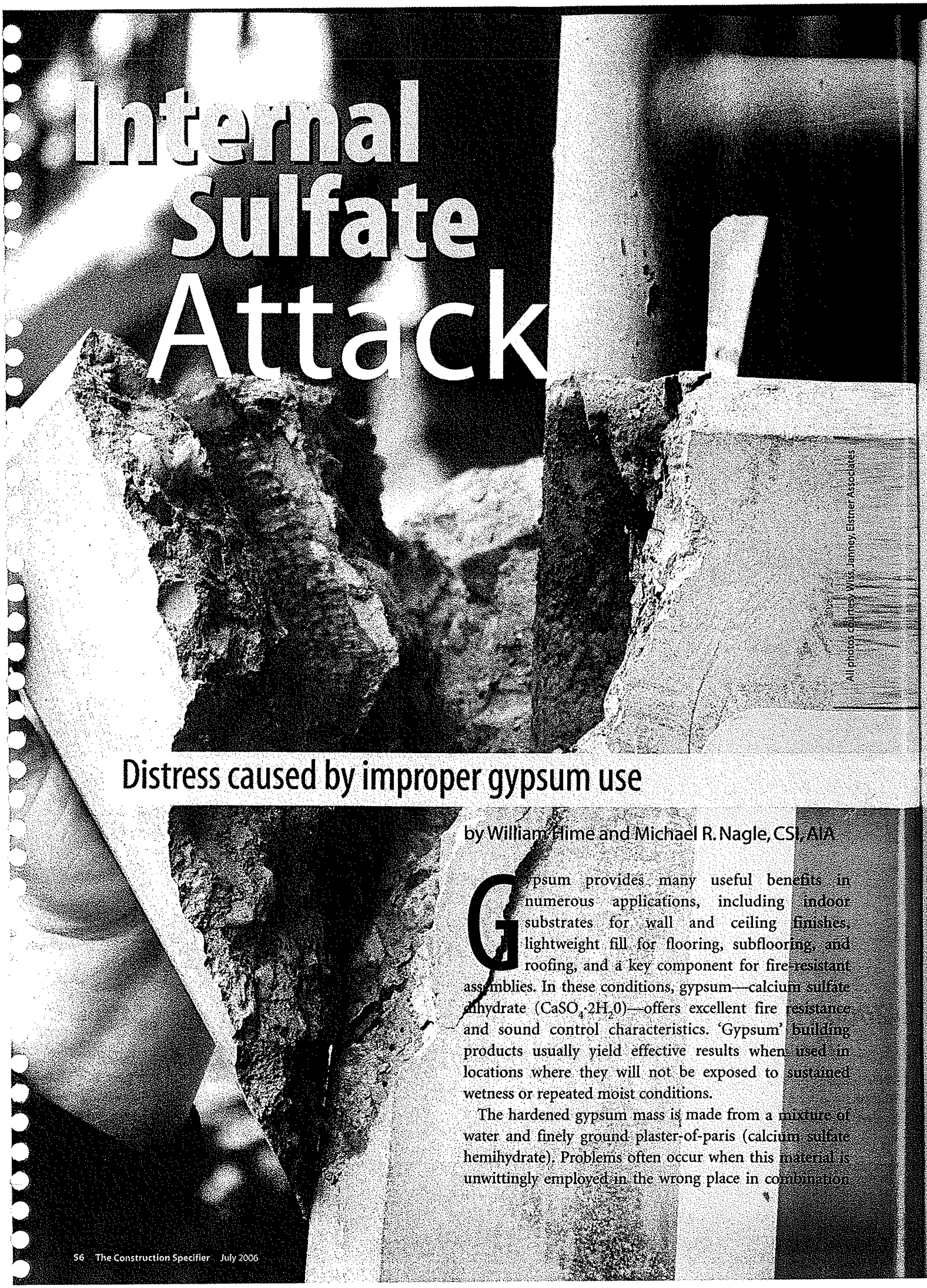
21. Although the relationship between thermal inertia (or effusivity) and moisture is clear and makes this parameter attractive for moisture evaluation, the artificial stimulation of the surface can be evenly performed only for small areas at the same time. Moreover, if the surface is not homogeneous the heating will be uneven. This reduces the possible application in the field and requires accurate selection of the areas represented to determine the presence of water diffusion. More information regarding this topic can be found in E. Rosina and E. Grinzato, "Infrared and Thermal Testing for Conservation of Historic Buildings," *Materials Evaluation* 59, no. 8 (August 2001): 942–954.

22. P. G. Bison, C. Bressan, E. Grinzato, S. Marinetti, and V. Vavilov, "Active Thermal Testing of Moisture in bricks," Thermosense XV, Orlando, Fla., April 1993).

23. Prior to the investigation there had been heavy rains in the region. Improperly sloped terrain to the west, exacerbated by runoff from an adjacent parking lot, resulted in moisture entering the structure from the west. The thermograms were taken in October on a sunny day (T° = 66.6°F, 19°C and 71% RH) with optimal environmental conditions for detecting moisture using the passive approach.

24. V. Vavilov, A. I. Ivanov, and A. A. Sengulye, "Quantitative and Qualitative Evaluation on Moisture Thermal Insulation by Using Thermography" (paper presented at Thermosense XIII, Orlando, Fla., April 1991).

25. A. Colantonio, "Identification of convective heat loss on exterior cavity wall assemblies" (paper presented at Thermosense XXI, Orlando, Fla., April 1999); A. Colantonio, "Infrared Thermographic Investigation Procedures for Four Types of Generic Exterior Wall Assemblies" (paper presented at Thermosense XXI, Orlando, Fla., April 1999).



Internal Sulfate Attack

Distress caused by improper gypsum use

All photos courtesy Wiss, Janney, Elstner Associates

by William Hime and Michael R. Nagle, CSI, AIA

Gypsum provides many useful benefits in numerous applications, including indoor substrates for wall and ceiling finishes, lightweight fill for flooring, subflooring, and roofing, and a key component for fire-resistant assemblies. In these conditions, gypsum—calcium sulfate dihydrate ($CaSO_4{\cdot}2H_2O$)—offers excellent fire resistance and sound control characteristics. 'Gypsum' building products usually yield effective results when used in locations where they will not be exposed to sustained wetness or repeated moist conditions.

The hardened gypsum mass is made from a mixture of water and finely ground plaster-of-paris (calcium sulfate hemihydrate). Problems often occur when this material is unwittingly employed in the wrong place in combination with the wrong companion components. This unsuitable amalgamation has been the impetus for numerous investigations, failures, and repairs. At numerous structures throughout the United States, instances of distress related to this inappropriate union have occurred with each of the following systems:

- sand and plaster grout fillers;
- non-shrink cementitious grout containing plaster-of-paris; and
- grout fillers with added plaster-of-paris or gypsum.

Mixtures of plaster-of-paris, sand, and water are formulated to produce inexpensive grout fillers that can offer excellent early and late strength. Non-shrink cementitious grout mixes are sometimes made using varying amounts of plaster-of-paris to produce shrinkage-compensating concrete. Manufacturers and applicators often add plaster-of-paris to grout matrices to improve workability and provide a cheap alternative to portland cement.

In the presence of moisture, gypsum can react with portland cement to cause an expansive formation of ettringite (*i.e.* internal sulfate attack). While mechanisms pertaining to this chemical reaction have been debated for years, building distress related to the combination of moisture, portland cement, and too much gypsum, are numerous and costly to repair.

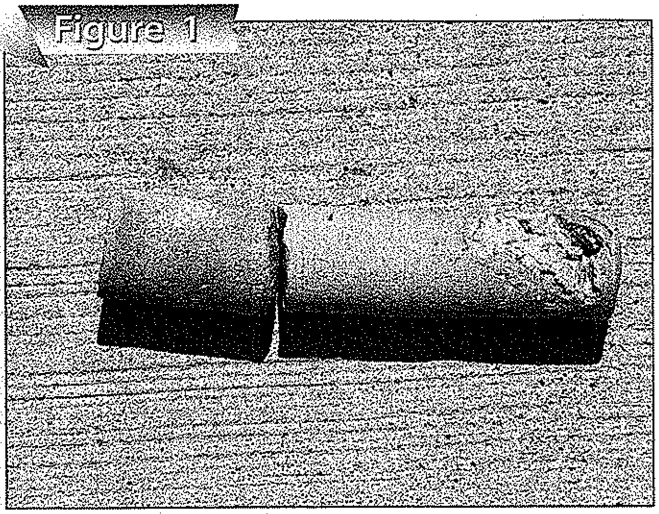
Understanding the causes

Chemical deterioration mechanisms, such as internal sulfate attack, require water to provide a transport medium for chemicals to migrate through cement-based matrices. Consequently, moist conditions set the stage for this destructive process involving the reaction between sulfate (SO_4) from the gypsum and tricalcium aluminate (C_3A) within the hydrated portland cement.

Until the late 19th century, gypsum was not deliberately introduced into cement. In the early 1900s, it was added at about 1.5 to two percent sulfur trioxide (SO_3) by weight to the clinker and interground during the portland cement-making process to control the hydration of the C_3A.[1] Over the past 50 years, changes in cement manufacturing have lead to increased sulfate content, with some matrices containing more than twice the historical level.

The allowable amount of SO_3 within portland cement is limited by practice and construction standards, including ASTM International C 150, *Standard Specification for Portland Cement*. However, an increasing number of

Figure 1



Core samples extracted from the embedded railing post pockets revealed a gray grout material beneath a cementitious grout cap. The gray grout material was later determined to contain elevated levels of SO_3.

manufacturers produce Type III cement containing SO_3 levels exceeding the standard ASTM C 150 limits, with more than four percent (by weight) SO_3, the equivalent of 10 percent gypsum.[2] While certain proprietary grout mixtures and patching materials with higher levels of sulfate have been marketed as 'non-shrink' materials, they actually have expansive characteristics under some circumstances.

Someone who understands the consequences posed by cement matrices with elevated gypsum levels in moist environments might still misinterpret the composition of products being used. One source of confusion is 'gypsum' is seldom present as a separate component in grout and mortar mixes. As previously described, plaster-of-paris is the common raw material used by manufacturers and installers; as such, looking for the term 'gypsum' on the container or within the product literature is often ineffective. Identifying constituents in proprietary cement mixes requires either the knowledge of closely guarded ingredients or the resources to conduct material testing.

Figure 2

Railing posts were embedded in concrete using gypsum-based grout. Gypsum and portland cement under normal moisture exposure caused internal sulfate attack, leading to numerous instances of concrete distress at a major league stadium.

While water reacts with plaster-of-paris to produce gypsum, more water is often added to make the system workable. However, excessive water quantities can lower the strength. High strength requirements call for a special form of plaster, consisting of a crystalline variety of plaster-of-paris (alpha plaster) that provides workability at lower water contents. This alpha plaster is more expensive than normal 'beta plaster' and is the 'secret' ingredient of some products.

Manufacturers are required to thoroughly evaluate the hazard potential of chemicals they produce or import and to communicate any hazards to workers through Material Safety Data Sheets (MSDS). However, the hazards referenced in the MSDS refer only to the user's health. Thus, the absence of gypsum or plaster-of-paris in a formulation cannot be established based on a simple perusal of an MSDS sheet for a proprietary product.

Sulfate can be introduced into a cement matrix through numerous media, including certain water sources and recycled aggregates. Mix water obtained from the vast majority of domestic water supplies has relatively low sulfate levels and is suitable for most concrete and mortar applications.[3] However, mix water obtained from wash water used during cement mixing, as well as water with a perceivable taste or odor, may have elevated levels of sulfate and should undergo appropriate testing. In other instances, recycled aggregate from crushed concrete can introduce gypsum particles and other foreign materials into the cementitious mix.

Designers should also be aware hardened gypsum promotes the corrosion of most contacting metals. In a moist environment, the porous nature and low pH of a set gypsum matrix cannot protect embedded metals from corrosion. This is unlike set portland cement, which is very alkaline and can help protect embedded metals against corrosion. Portland cement and added gypsum may be combined to produce effective results, but only when used in dry environments.

One additional concern is hardened gypsum is quite soluble under sustained moist or saturated conditions. Once exposed to either condition, subsequent drying may not restore the full structural integrity to products like gypsum board. Therefore, hardened gypsum products are inappropriate for applications potentially exposed to moisture. In instances where gypsum floor substrates are installed over a slab-on-grade floor, distress can occur if moisture is present beneath the concrete slab.

Common forms of distress

Investigators and material scientists have proven portland cement matrices containing gypsum have been at least partly responsible for numerous failures involving internal expansion, spalling, and disintegration. These failures include grout fillers in terra cotta, masonry, and other façades, as well as post-pocket fillers used to install stair and balcony railings. These failures can often have negative economic repercussions and tend to occur far more frequently than reports indicate. Each of the following case study examples resulted from the use of grout mixtures that contained gypsum exposed to moist environments.

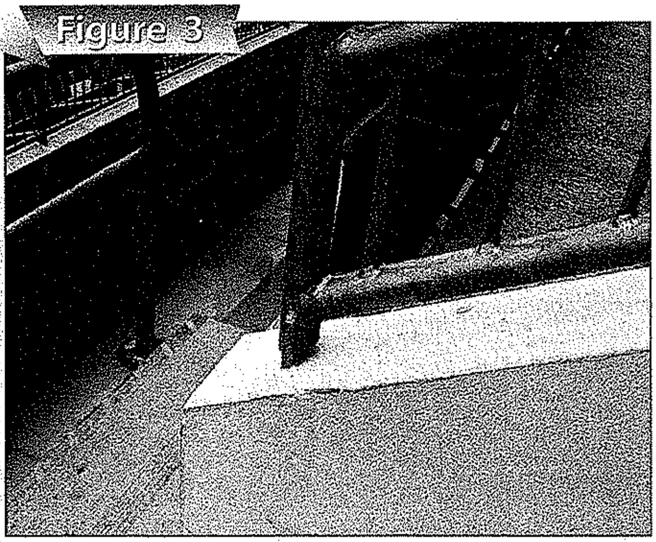
Ballpark damages

Two years after the opening of a major league stadium, numerous locations of severely distressed concrete were found throughout the ballpark (see photo on page 56). These material spalls originated in the area of the embedded railing posts. Thirty-five samples of grout from embedded railing post pockets were subjected to chemical testing to determine the composition and total sulfate content (Figure 1). Studies revealed varying amounts of gypsum and portland cement were mixed into the grout in order to embed the railing posts into field-cored pockets. All the samples contained sulfate levels above the expected value of portland cement grout without added gypsum.

Post pockets, subjected to normal moisture exposure, became distressed due to internal sulfate attack of the grout itself, resulting in expansion and severe distress of the surrounding concrete (Figure 2).

Over two years, the gypsum-based grout was completely removed from more than 3000 post pockets, and concrete repairs were implemented during the off seasons. Railings

Figure 3



During remediation, a ballpark's hollow railing posts were reconfigured to accommodate a solid plate embedment into the grout pockets.

were removed, re-galvanized, and the posts reconfigured to avoid embedment of the hollow tube sections into the existing grout pockets (Figure 3). The new design prevented the collection of water within the hollow tube that contributed to the original distress. Repairs exceeded $4 million in construction costs.

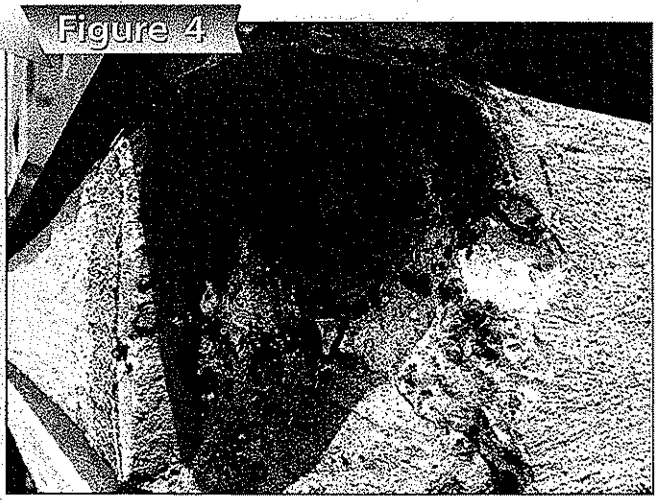
Balcony cracking

At a high-rise building in New York City, railing posts were embedded in concrete balcony slabs and set with grout. Visible concrete distress on 40 percent of the balconies led to an investigation to determine the cause of cracks in the vicinity of the railing posts. During the close-range assessment, an incipient spall was identified and deemed a potential fall hazard. Removal of the displaced concrete allowed the engineer to more closely examine the railing post condition.

Visual assessment revealed heavy corrosion on the embedded steel sleeve used to form a grout pocket for setting the handrails (Figure 4). Material analysis of the setting grout confirmed extraordinarily high levels of sulfate. In instances where 'pure' or nearly pure gypsum products are used, there can be a reaction with the matrix of the surrounding concrete, causing distress. When aluminum or steel is embedded in grouts with high levels of gypsum, internal expansion can result from a combination of metal corrosion and sulfate attack to the adjacent portland cement concrete.

As a result of the high sulfate levels, more than 100 balconies suffered damages due to a combination of corrosion and internal sulfate attack. Replacement of the railing posts and repairs to the surrounding concrete exceeded $250,000 in construction.

Figure 4



Gypsum-based products that use gypsum as the primary binder can cause both sulfate attack of surrounding concrete and metal corrosion, as evidenced above.

Terra cotta troubles

In the early 1990s, façade repairs were performed on a multi-story building located in the Midwest. Repairs to the 80-year-old building involved resetting the majority of the terra cotta cornice elements on the 15th floor. Subsequent repairs to an isolated portion of the same cornice were performed to remediate water infiltration. During this process, the architect observed fractures in the terra cotta units (Figure 5).

Fill grout was found completely packed in the hollow cavities of about two dozen terra cotta units. Material analysis showed the grout contained portland cement and elevated sulfate levels. Thorough removal of the grout from the fragile terra cotta would have required aggressive methods that would have ultimately destroyed the already distressed façade elements. While the majority of the terra cotta pieces were salvageable, those containing gypsum-based grout were discarded and replaced. (Costs for the replacement pieces were relatively inexpensive since repairs were already underway.)

In this example, the full extent of gypsum-based grout-induced disruption has not yet been determined. Cracking is evident throughout much of the remaining 15th floor cornice. If the entire floor's cornice has been previously repaired using gypsum-based grout, future remediation might exceed $1 million in construction costs. Portions of the cornice have been temporarily stabilized with stainless steel strapping to secure displaced pieces while the building owner seeks funds for a more comprehensive repair.

Raising awareness

Engineers and architects should exercise appropriate care when specifying bagged mixes, or should carefully select field mixing parameters for potentially moist environments. Specification writers should be aware portland cement itself contains a small, regulated amount of gypsum or other form of sulfate. Stipulations need to be employed to prevent increased levels of sulfate in portland cement-based products, so the tricalcium aluminates in the portland cement do not react deleteriously with sulfate compounds.

Sulfate-resistant cements, such as Type II (moderate sulfate-resistance) and Type V (high sulfate-resistance), are intended to endure external attack from sulfates in soil or water. Sulfate-resistant cement may not be suitable to resist internal sulfate attack over long periods. Unmodified gypsum products, like gypsum board, should not be used in environments where moisture may be encountered, unless it can be demonstrated the product will not be softened or undergo significant deterioration.

The acceptable amount of sulfate within a cement matrix varies depending on the exposure conditions, adjacent material compatibility, intended use, and cement mix constituents. Based on these authors' experiences, most failures in fill grout occur in wet environments when sulfate levels exceed 1.5 percent SO_3 by weight of grout.

Figure 5

Gypsum-based grout fillers, used to reset several terra cotta units, caused internal expansion of the setting grout and cracking of the terra cotta bisque.

Some designers have attempted to seal gypsum-containing materials with protective coatings or cementitious cap grouts. However, if adequate maintenance is not employed or the protective cover traps the inherent moisture within the grout mixture, promotion of one or more of the distress mechanisms occurs.

Designers might consider surface-mounted railing posts to avoid the use of grout pockets in moist environments altogether. Designers can also seek advice from suppliers who can provide useful information regarding the use of their products, as well as materials that react deleteriously with other products and constituents. In applications where the grout installation may be subjected to moisture, specifications should require the manufacturer submit a letter stating the entire grout matrix does not contain any of the following:

- added gypsum;
- plaster-of-paris; or
- sulfur trioxide levels in a portland cement component exceeding ASTM C 150's published limits.

The specifier may also wish to add provisions allowing the architect/engineer to subject dry samples of the proposed products and field mixes to chemical testing to determine the sulfate levels.

The acceptable level of sulfate varies and is highly dependent on the chemical composition and component ratios of the grout mix. As a general rule, SO_3 levels of the cementitious component in excess of the standard composition requirements in ASTM C 150 are more susceptible to internal sulfate attack and should be avoided in moist environments.

Much of the published resources concerning internal sulfate attack can be complex and confusing to the average consumer. Guide specifications generally do not adequately address the concern either. Perhaps for this reason, many design professionals seem to be unaware of the potential consequences linked to the improper use of gypsum-containing systems. Unfortunately, gypsum-based grouts and cement are frequently used in moist environments and, as a result, there have been numerous failures across the country.

It is the authors' hope industry leaders, design professionals, and manufacturers start acknowledging the importance of this issue, its potential physical and economic consequences, and the need for an industry-accepted standard for design professionals to implement.

Notes

[1] Sulfates can be present in various forms, but chemists typically quantify sulfate by measuring the amount of total sulfate ion present and report it as 'percent SO_3' in a sample.

[2] However, the SO_3 limits can be exceeded if the cement passes certain requirements.

[3] For more information, see the Portland Cement Association's (PCA's) *Design and Control of Concrete Mixtures* (1994).

Additional Information

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03 01 00–Maintenance of Concrete
03 30 00–Cast-in-place Concrete
09 24 00–Portland Cement Plastering

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Abstract

In the presence of moisture, gypsum can react with portland cement to cause internal sulfate attack—an expansive formation of ettringite. While the mechanisms pertaining to this chemical reaction have been debated for years, the ensuing building distress is costly to repair. This article examines considerations for those wishing to use gypsum with concrete.