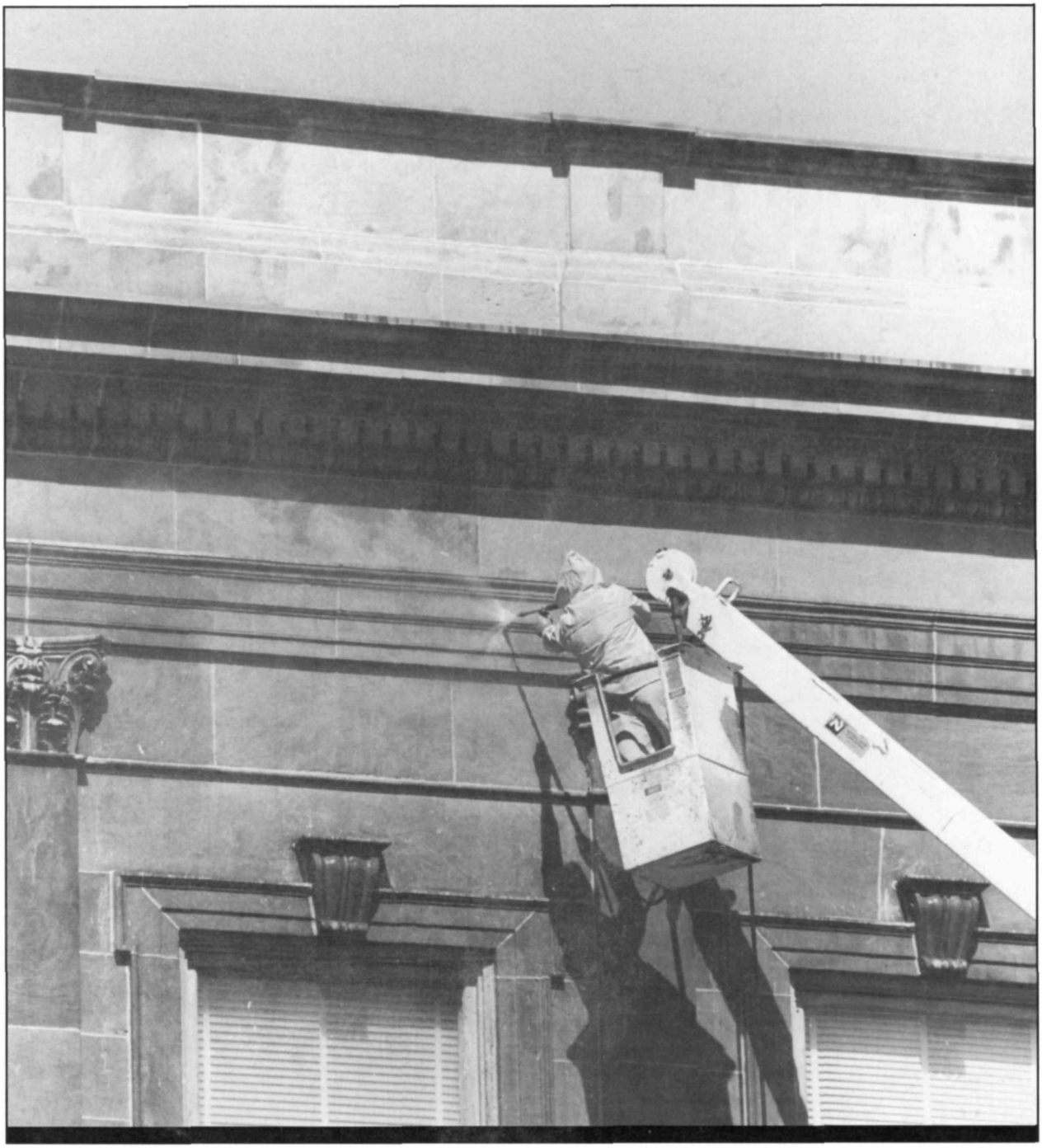
Historic Masonry Deterioration and Repair Techniques



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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally-owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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The Legacy Resource Management Program was established by the Congress of the United States in 1991 to provide the Department of Defense with an opportunity to enhance the management of stewardship resources on over 25 million acres of land under DoD jurisdiction.

Legacy allows DoD to determine how to better integrate the conservation of irreplaceable biological, cultural, and geophysical resources with the dynamic requirements of military missions. To achieve this goal, DoD gives high priority to inventorying, protecting, and restoring biological, cultural, and geophysical resources in a comprehensive, cost-effective manner, in partnership with Federal, State, and local agencies, and private groups.

Legacy activities help to ensure that DoD personnel better understand the need for protection and conservation of natural and cultural resources, and that the management of these resources will be fully integrated with, and support, DoD mission activities and the public interest. Through the combined efforts of the DoD components, Legacy seeks to achieve its legislative purposes with cooperation, industry, and creativity, to make the DoD the Federal environmental leader.

Cover photo: Low-pressure water cleaning of historic masonry facade. National Park Service files.

Historic Masonry Deterioration and Repair Techniques

An Annotated Bibliography

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

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Reading lists have been published by the National Park Service, Preservation Assistance Division, since 1975. Most are selected bibliographies rather than a comprehensive overview of a particular subject. Some of the reading lists are annotated. Comments or suggestions for additions to the Reading List should be sent to: Preservation Assistance Division, National Park Service, P.O. Box 37127, Washington, D.C. 20013-7127.

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Introduction

This bibliography on the deterioration and conservation of historic masonry provides information on a subject encompassing both diverse materials and numerous processes. Although a range of such materials was often used in combination in traditional (and subsequently historical) structures, their research, analysis and treatment have become increasingly more specialized, resulting in technical literature quite different from that published even ten years ago. Because of the breadth of the topic and increasing specialization in the field of conservation, this bibliography has focused on the major sources which have defined the subject in the past and present for the North American profession.

On the other hand, the methodological nature of conservation requires practitioners to address most masonry projects holistically. As a result much of the technical literature published as case studies includes the entire panoply of processes including documentation, investigation, pathology, diagnosis, and treatment. Research on the other hand has grown more and more specific on the very same topics.

In order to assess this dichotomy between the literature of building conservation research and practice, the following bibliography has been prepared in a manner reflective of both. This has resulted in an organization of the literature primarily by masonry material (stone, brick, terra cotta, concrete and cast stone) and secondarily within each type by general process (characterization, investigation, deterioration diagnostics). Sources addressing these materials or their deterioration and treatment in a general or comprehensive manner have been selected out to form the first major heading rather than as repetitive entries under each material category. Entries under each material category generally contain information specific to that material or process.

Because of the increasing specialization in technical issues, organizations and related conference proceedings have become focused on specific subjects providing a wealth of detailed information previously unknown. These have been included here as single citations because of their importance to the subject and to allow for the inclusion of other singular more obscure citations.

Conservation indices such as Art and Archaeology Technical Abstracts (AATA) and on-line data bases such as the Getty Conservation Information Network (CIN) now provide easy access to the specific articles contained within these technical proceedings.

General References on Masonry, Deterioration, and Repair

Beall, Christine. "Inspecting Masonry Construction." *Construction Specifier.* Vol. 41, No. 6 (June 1988), pp. 25-27.

This article is directed mainly towards the construction industry but is of value for historically significant structures of modern construction. Beall gives detailed guidelines for methodological evaluation, protection, cleaning and cyclical inspection of masonry.

Blades, Keith, Gail Sussman, and Martin Weaver. *Masonry Conservation and Cleaning.* Ottawa, Ontario: The Association for Preservation Technology, 1985.

A collection of published materials dealing with various aspects of masonry cleaning: its chemistry and suitable methods, with discussion of the various cleaning systems; control of damp in masonry buildings; stone decay and preservation; a review of available treatment methods; masonry repointing; repair of brick work; grouting walls; water repellents; and coatings for masonry surfaces. Bibliography.

Canadian Ministry of Citizenship and Culture. *Annotated Master Specifications for the Cleaning and Repointing of Historic Masonry.* Toronto, Ontario: Ministry of Citizenship and Culture, 1985.

A collection of specifications to encourage best practice in conservation of historic masonry surfaces. Includes discussion of products and techniques.

Davis, Gerald, editor. *Building Performance: Function, Preservation, and Rehabilitation. A Symposium sponsored by ASTM Committee E-6 on Performance of Building Constructions, Bal Harbour, Florida, October 1983.* Philadelphia, PA: American Society for Testing and Materials, 1986.

Thirteen papers about preservation and rehabilitation of buildings, presented at a symposium held at Bal Harbour, Florida on October 17, 1983. The Symposium was divided into two parts: a.) the scope and structure of total building performance, and b.) historical buildings and building materials. The properties of masonry, stone and wood and their rehabilitation are discussed. Two approaches to non-destructive testing are presented.

Feilden, Bernard M. *Conservation of Historic Buildings.* London, England: Butterworths, 1982.

Handbook on architectural conservation. Divided into four parts: structural aspects of historic buildings; causes of decay (earthquakes, biodeterioration, environment); the work of the architectural conservator; building repairs and special techniques. Glossary and bibliography.

Fitch, James Marston. "Conservation of Historic Masonry: The Social and Technical Parameters." *Durability of Building Materials.* Vol. 5, No. 3-4, pp. 279-290.

An essay which discusses some of the social and technical aspects of conservation of historic masonry with special reference to North America: conservation of exotic american materials (adobe and terra cotta); environmental attack; historic uses of inappropriate building materials; graceful ageing in traditional masonry; rationale for cleaning historic masonry fabrics.

Grimmer, Anne E. *A Glossary of Historic Masonry Deterioration Problems and Preservation Treatments*. Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1984.

An illustrated glossary providing an explanation of all terms likely to be used to describe conditions of masonry deterioration, repair techniques, and treatments for historic masonry preservation. The first section lists and defines masonry deterioration problems in alphabetical order, the second one describes preservation treatments, grouped according to maintenance and repair techniques.

Harris, Harry A. "Masonry Materials: Design, Construction and Maintenance." *ASTM Special Technical Publication*. Philadelphia, PA: American Society for Testing and Materials, 1988.

Contains 12 papers presented at the Symposium on Masonry held in New Orleans on December 2, 1986. Contributions deal with current technologies in four major areas: 1. testing procedures and properties of masonry materials and assemblage; 2. design of masonry construction; 3. masonry construction problems; 4. maintenance.

This carved limestone capital was probably painted after wind- or rain-caused erosion began to occur in an attempt to prevent further deterioration. *Photo:* National Park Service files.

Hueck-Van Der Plas, Eleonora H. "Microbiological Deterioration of Porous Building Materials." *International Biodeterioration Bulletin*. No. 1 (1968), pp. 11-28.

A survey of technical literature on microbiodeterioration of stone, brick, concrete and plaster. Table listing organisms, morphology and protective compounds.

Lauersdorf, Lynn R., and Albert W. Isberner. "Masonry: Preventative and Corrective Maintenance." *Construction Specifier*. Vol. 42, No. 9 (September 1989), pp. 84-92.

This is a general review of the required maintenance to exterior masonry envelopes focusing on excess water, differential movement and the expansion and contraction units and a discussion of specific causes of deterioration in conjunction with proposed solutions.

McKee, Harley. *Introduction to Early American Masonry: Stone, Brick, Mortar and Plaster*. Washington, DC: National Trust for Historic Preservation, 1973.

This well-illustrated guide is an excellent introduction to the subject. It includes information on stone types and quarries, masonry tools, brick-making, historic mortars, and interior and exterior plaster and stucco.

Mack, Robert C., AIA. *Preservation Briefs No. 1: The Cleaning and Waterproof Coating of Masonry Buildings*. Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1975.

This Brief offers guidance on the techniques of cleaning and waterproofing, and explains the consequences of inappropriate use and potential problems.

Mamillan, Marc. *Pathology of Building Materials*. Rome, Italy: ICCROM, 1970.

Pathology and conservation of stone, terracotta, brick, mortars and renderings.

Meadows, Robert E. *Historic Building Facades: A Manual for Inspection and Rehabilitation*. New York, NY: New York Landmarks Conservancy, 1986.

Maintenance, repair and restoration manual for building facades including discussions of materials, deterioration repair, replacement and case studies, with legislative appendices and an extensive bibliography.

Noland, J. National Science Foundation Conference proceedings: *Evaluation and Retrofit of Masonry Structures*, a joint US-Italy workshop held August 19-29, 1987 (NSF/ENG 87061). Washington, DC: National Science Foundation, Directorate of Engineering, and Consiglio Nazionale delle Ricerche, Rome, 1987.

This workshop provided for the exchange of concepts and information in the areas of evaluation and retrofit of masonry structures and identified areas that require further research beneficial to both countries.

Powys, A.R. *Repair of Ancient Buildings*. London, England: Society for the Protection of Ancient Buildings, 1981.

Methods for repairing historic buildings. Included are masonry walls, foundation defects and treatment, and surface decay of buildings. Ancient timber roofs and roof coverings, church bells, window glazing, ceilings, and wall paintings are also dealt with.

Rosvall, Jan, editor. *Air Pollution and Conservation: Safeguarding our Architectural Heritage.* New York, NY: Elsevier Technical Press, 1988.

A premier compilation of articles by international experts on the deleterious effects of particulates on the built environment, with a comprehensive opening article by Rosvall.

_____. "Air Pollution and Conservation." *Durability of Building Materials.* Vol. 5, No. 3-4 (1980), pp. 209-237.

Discusses the interaction between air pollutants and building facade materials. Includes sections on: conservation principles, physical and chemical; biological factors of deterioration; air pollutants (sulfur nitrogen oxides and carbon oxides) their source and historical trends; properties and deterioration of masonry materials (stone, concrete/mortar/plaster, diagnosis, methods of cleaning, consolidation and consolidants, maintenance.)

Simpson, John W., and Peter J. Horrobin. *The Weathering and Performance of Building Materials.* New York, NY: Wiley Interscience, 1970.

Basic information on what can and will go wrong with building materials, including brick and mortar.

Stambolov, Todor, and J.R.J. Van Asperen De Boer. "The Deterioration and Conservation of Porous Building Materials." *ICOM Committee for Conservation, Fifth Triennial Meeting, Zagreb. October 1-8, 1978.* Paris, France: International Council of Museums, 1978.

Literature concerning stone deterioration published since early 1975 are reviewed as a supplement to the previous ICOM Publication. Cites studies on the role of soluble salts in crust formation and surface disruption; influence of rain on the deterioration of stone monuments. The effects of the microclimate surrounding a monument or structure; the effects of wind erosion; deterioration by biological agents; measurement of the mechanical condition of stone; chemical cleaning; consolidation and protection; silicone esters; and synthetic polymers.

_____. *The Deterioration and Conservation of Porous Building Materials in Monuments: A Review of the Literature.* Third edition. ICOM 6th Triennial Meeting Supplement, Ottawa, September 1981. Rome, Italy: ICCROM, 1981.

Discussion of published contributions to the study of masonry deterioration and preservation since 1978.

Tomassetti, Albert A. "Problems and Cures in Masonry." ASTM Conference Proceedings: *Masonry: Components to Assemblages.* held December 5, 1989, Orlando, FL. (ASTM Special Technical Publication #1063). Philadelphia, PA: American Society for Testing and Materials, 1990.

This document provides a general review of problems in masonry construction including, but not limited to, efflorescence, blush, creep, staining, cleaning, lime deposit, metal corrosion, and mortar failure. Specific buildings are cited and illustrated as examples.

Torraca, Giorgio. "Brick, adobe, stone and architectural ceramics: deterioration processes and conservation practices." *Preservation and Conservation: Principles and Practices. Proceedings of the North American International Regional Conference. 1972.* Washington, DC: The Preservation Press, 1976, pp. 143-165.

Discusses the role of porosity and water in degradation of masonry materials including terra cotta. Water penetration must be

eliminated prior to treatments. Consolidation methods now in use on stone also applicable to terra cotta including ethyl silicates, silicones, silicate/silicone mixtures.

Torraca, Giorgio. *Porous Building Materials.* Third Edition. Rome, Italy: ICCROM, 1988.

A basic introduction to the technology of building materials. Porous stone, brick and mortar undergo deterioration processes when exposed to the aggressive actions of the environment. The rate and symptoms of such processes are influenced by a number of variables, including the properties of the material and the environmental factors which act upon it. In the model presented, deterioration is shown as resulting from chemical processes (corrosion) acting in conjunction with mechanical stresses (both external and internal).

Weiss, Norman. "Cleaning of Building Exteriors." *Technology and Conservation.* Vol. 1 (Fall 1976), pp. 8-13.

Discusses the nature of soiling, use of test patches, advantages and disadvantages of water, steam, acid, alkaline and abrasive cleaning.

Stone

Dimension stone is a comprehensive term for rock that is cut, split or worked to form masses or units of desired shapes and sizes for specific uses, or that is selected from naturally occurring material to meet requirements of shape and size. The term does not cover crushed, broken or ground stone. All of the three main generic rock types -- igneous, sedimentary and metamorphic -- are utilized as dimension stone.

Virtually every variety of rock that is firm enough to hold together until it can be put into its intended place has been used, somewhere and at some time, as building stone, but only five lithologic types of rock are produced commercially to any appreciable extent. These are granite, limestone, marble, sandstone and slate. Several of the terms as they are used in the stone industry have greater latitude than the strict petrologic definition would permit. [From: *Concise Encyclopedia of Building and Construction Materials*. Fred Moavenzadeh, editor. Cambridge, MA: The MIT Press, 1991.]

General Reference

Ashurst, John, and Francis G. Dimes. *Conservation of Building and Decorative Stone*. Volumes I & II. London, England: Butterworth - Heinemann, 1990.

These two volumes discuss the theory and practice of conservation with an objective comparison of different methods and approaches to the discipline. Volume I provides an introduction to the restoration, conservation and repair of building stone along with chapters on the nature, geology and weathering of masonry. Volume II discusses various treatments in conservation.

Amoroso, Giovanni, and Vasco Fassina. *Stone Decay and Conservation*. New York, NY: Elsevier Science Publishing Co., Inc., 1983.

The book analyzes the most recent studies in the field of conservation and restoration of stone in buildings and monuments of historical, archeological and artistic value. Particular attention has been given to the deleterious influence upon stone of the industrial urban environment, which adds its effects to those of natural degradation agents. Fundamental importance has been given to the study of environmental deterioration agents, including carbon dioxide, sulphuric acid, and their reaction with building materials. Special emphasis has also been given to those meteorological parameters in stone degradation that have a bearing on the transport, diffusion, accumulation and deposit of atmospheric pollutants. Extensive bibliography.

Baer, N.S., editor. *Conservation of Historic Stone Buildings and Monuments*. Washington, DC: National Academy Press, 1982.

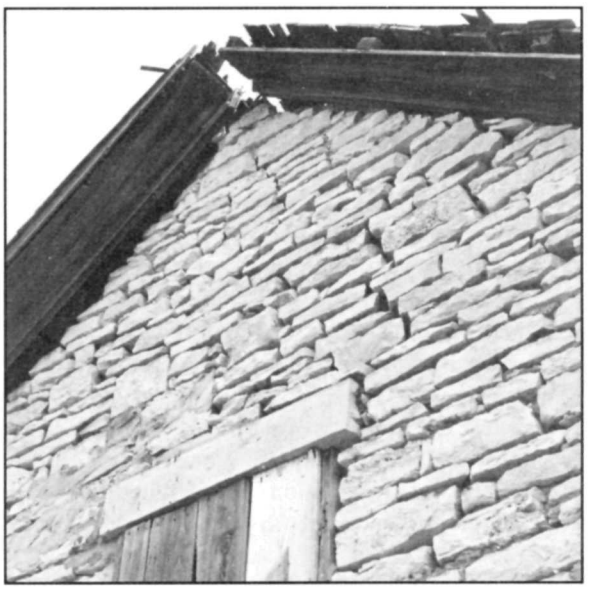
Proceedings of a conference of scientists, preservationists, architects, engineers and architectural historians interested in the problems of historic masonry structures held in 1981. The series of papers describe an up-to-date account of stone conservation. The conference was designed to achieve three goals: to summarize the state of research on stone conservation, to define research needs and priorities, and to interest scientist from many disciplines in the problems of conservation. The coverage of the papers is broad but not comprehensive. The papers provide the scientist with a basic introduction to historic preservation while giving the preservation architect a general introduction to the relevant scientific and engineering disciplines. Topics range from the "Geological Sources of Building Stone" to "The Evaluation of Stone Preservatives."

Bates, Robert L. *Geology of the Industrial Rocks and Minerals*. New York, NY: Dover Publications, 1969.

A handbook on the major nonmetallic rocks and minerals in North America. Topics discussed include chemical formulation, varieties, properties, and geological occurrence. Also included is a comprehensive bibliography for each rock and mineral described.

Bowles, Oliver. *The Stone Industry: Dimension Stone, Crushed Stone, Geology, Technology, Distribution, Utilization*. Second Edition. New York and London: McGraw-Hill Book Company, 1939.

Description of building stone and building stone techniques in North America including: history, geological definition, composition, origin and variety. Also physical properties discussing hardness, specific gravity and weight per cubic foot, solubility, color, translucence, texture, rift or grain, porosity, strength. The uses of the material, distribution of deposits, quarry methods, equipment, and the industry by state.



Much of the soft lime mortar has been washed away from this rough cut limestone wall of the Goodnow barn, c. 1860, Manhattan, Kansas, due to lack of roof maintenance. The stone will be repointed after the roof has been repaired. *Photo:* National Park Service files.

Ciabach, J., editor. *Sixth International Congress on Deterioration and Conservation of Stone*. Torun, Poland: Nicholas Copernicus University, 1988.

Papers presented at the Sixth International Congress on Deterioration and Conservation of Stone, held in Torun, Poland. Current research and case studies discuss properties and durability of stone, physical and chemical weathering, biological degradation, consolidation, cleaning and preservation treatments, experience and ethics of restoration. Bibliographic references are listed.

Gauri, K. L., and J. A. Gwinn, editors. *Fourth International Congress on the Deterioration and Preservation of Stone Objects*. Louisville, KY: University of Louisville, 1983.

Papers presented at the Fourth International Congress on Deterioration and Conservation of Stone Objects, held in Louisville, Kentucky. Current research and case studies discuss properties and durability of stone, physical and chemical weathering, biological degradation, consolidation, cleaning and preservation treatments, experience and ethics of restoration. Bibliographic references are listed.

Felix, G. and, V. Furlanz, editors. *Proceedings from the Fifth International Congress on Deterioration and Conservation of Stone*. Lausanne, Switzerland: Presses Polytechniques Romendes, 1985.

Papers presented at the Fifth International Congress on Deterioration and Conservation of Stone held in

Lausanne, Switzerland. Current research and case studies discuss properties and durability of stone, physical and chemical weathering, biological degradation, consolidation, cleaning and preservation treatments, experience and ethics of restoration. Bibliographic references are listed.

Marchesini, L., editor. *Third International Congress on the Deterioration and Preservation of Stones*. Padova, Italy: B. Badan, 1979.

Papers presented at the Third International Congress on Deterioration and Conservation of Stones held in Venice, Italy. Current research and case studies discuss properties and durability of stone, physical and chemical weathering, biological degradation, consolidation, cleaning and preservation treatments, experience and ethics of restoration. Bibliographic references are listed.

Merrill, George P. *Stones for Building and Decoration*. New York, NY: John Wiley and Sons, 1910.

Part I: Historical overview of the stone industry. Sections on the distribution of building stone in the United States, minerals present in building stones, physical and chemical properties, including: density, hardness, structure, state of aggregation, rift and grain, color and chemical characteristics of rocks. Classification of rocks used for construction: Igneous, Aqueous (Sedimentary), Aeolin and Metamorphic. Part II: Discusses rocks, quarries and quarry regions including for each type: composition and general properties, geological age and mode of occurrence. Also varieties of rock and uses, listing states and territories where the rock is found and quarried.

Rodrigues, J. Delgado, Fernando Henriques, and F. Telmo Jeremias, editors. *Proceedings from the Seventh International Congress on Deterioration and Conservation of Stone*. Three volumes. Lisbon, Spain: Laboratorio Nacional de Engenharia Civil, 1992.

Compilation of one hundred and sixty papers presented at the Seventh International Congress on Deterioration and Conservation of Stone held in Lisbon, Portugal. Current research and case studies discuss properties and durability of stone, physical and chemical weathering, biological degradation, consolidation, cleaning and preservation treatments, experience and ethics of restoration. Bibliographic references are listed.

Romanovsky, V., editor. *First International Congress on the Deterioration of Building Stones*. Chambrey, France: Les Imprimeries Reunies de Chambrey, 1973.

Papers presented at the First International Congress on Deterioration and Conservation of Building Stones held in La Rochelle, France. Current research and case studies discuss properties and durability of stone, physical and chemical weathering, biological degradation, consolidation, cleaning and preservation treatments, experience and ethics of restoration. Bibliographic references are listed.

Skoulikidis, Th., editor. *Second International Congress on the Deterioration of Building Stones*. Athens, Greece: Ministry of Culture and Science of Greece, 1976.

Papers presented at the Second International Congress on Deterioration and Conservation of Building Stones held in Athens, Greece. Current research and case studies discuss properties and durability of stone, physical and chemical weathering, biological degradation, consolidation,

cleaning and preservation treatments, experience and ethics of restoration. Bibliographic references are listed.

Tassios, T. P., editor. *Structural Conservation of Stone Masonry, International Technical Conference, Athens, October 31-November 3, 1989.* Rome, Italy: ICCROM, 1990.

Papers presented on recent research and application of the structural conservation of historic stone buildings. Topics covered include diagnosis and assessment, structural modeling of damaged, repaired and strengthened stone masonry, problems related to execution and durability, and relevant codes and recommendations.

Winkler, Erhard M. *Stone, Properties, Durability in Man's Environment.* New York, NY: Springer-Verlag, 1973.

A thorough guide discussing properties and use of stone as a building material. Includes physical categorizations, and deterioration mechanisms including decay, moisture and salts, chemical weathering, weathering by plants and animals, rust, freeze/thaw, silicosis. Stone glossary.

Deterioration Mechanisms

Arnold, Andreas. "Behavior of some soluble salts in stone deterioration." In *Proceedings, Second International Symposium on the Deterioration of Building Stones.* Athens, Greece: Universite Technique Nationale, 1977, pp. 27-36.

Hydration and dehydration of sodium sulfates and other soluble salts such as sulfate, nitrate, chloride, carbonate of sodium, potassium and magnesium. Atmospheric conditions cause daily change of hydration state and stress in porous stone. Cement mortar is cited as an important source of soluble salts.

Buil, Michel. "Thermodynamic and Experimental Study of the Crystallization Pressure of Water-Soluble Salts." In *Proceedings from the International Conference: Materials Science and Restoration.* Lausanne, Switzerland: Lack und Chemie, 1983, pp. 373-377.

A new method of measuring the salts crystallization pressure relevant to the deterioration of porous building materials is presented and compared with pre-existing ones. A micro porous membrane is used to separate the salt solutions for the measure. Illustrated.

Cassaro, M.A., M.A. Gauri, M. Sharifian, and K.L. Sharifinassab. *On the Strength and Deformation Properties of Indiana Limestone and Concrete in the Presence of Salts.* Louisville, KY: University of Louisville, 1982, pp. 57-76.

Salts comprised of sulfates and chlorides can deteriorate concrete and natural stones. Chlorides and sulfates can combine with the free lime in concrete. In the case of natural stones, the deterioration occurs due to repeated crystallization and hydration of these salts. Sodium nitrate did not produce deterioration on either material.

Laurie, Principal A.P., and John Milne. "The Evaporation of Water and Salt Solutions from Surfaces of Stone, Brick and Mortar." *First Proceedings of the Royal Society of Edinburgh.* Vol. 47 (1926), pp. 52-69.

Study of the conditions necessary for the passage of soluble salts from mortar or cement to the stone or brick, and the deterioration that these can cause. Evidence is presented for the passage of lime from the mortar into bricks. The effect of silicon ester treatment on the evaporation rate of water is discussed.

Lazzarin, Lorenzo, and Richard Pieper. *The Deterioration and Conservation of Stone: Notes from the International Venetian Courses on Stone Conservation*. Paris, France: UNESCO, 1988.

The publication of fifteen lectures delivered during a series of courses held in Venice from 1975 to 1987 on the subject of the "treatment and conservation of stone." This handbook places special emphasis on deterioration due to two basic factors: a.) biological and microbiological agents which affect buildings in non-industrialized countries; and b.) atmospheric pollution which threatens the stone buildings in industrialized countries. The second part of the handbook describes various treatments in detail.

Lehmann, Janusz. "Damage by Accumulation of Soluble Salts in Stonework." *Conservation of Stone*. Vol. 1, 2nd edition. London, England: International Institute for the Conservation of Historic and Artistic Works, 1970, pp. 35-45.

Discussion of examination of damage. The role of moisture in the destruction of stone material with salt crystals within it, and how materials can be conserved.

Lelikova, D.S., and G.N. Tomashevich. "The protection of quarry stone and brick of architectural monuments against physico-chemical effects and biological deterioration." *Preprints from ICOM Committee for Conservation, Fourth Triennial Meeting*. Paris, France: ICOM, 1975.

This paper examines the biodeteriorators of limestone and brick and recommends methods for their control which includes: preventive, construction repairs, cleaning of brick and limestone with water, detergent and ammonium fluoride, extermination of vegetation, protection of bricks and stone with hydrophobic compounds.

Mamillan, Marc. *Pathology of Building Stone*. Rome, Italy: ICCROM, 1970.

A basic primer on the pathology of masonry materials. Part one deals with stone: the various types of stone and their properties, causes of decay, and suitable conservation remedies. Part two deals with materials such as brick, mortar, and renderings.

Merrill, George P. *Rocks, Rock-Weathering and Soils*. New York, NY: The Macmillan Company, 1921.

Discussion of rocks and rock-forming minerals, their origin, structure and composition, and subsequent relation to the weathering of the material.

Schaffer, R.J. "The Weathering of Natural Building Stone." *Building Research*. No. 18. London, England: His Majesty's Stationery Office, 1932.

A pioneering work on the weathering of building stone. It deals with weathering due to: natural defects, or faulty craftsmanship; atmospheric pollution; chemical phenomena such as acid gases; physical phenomena such temperature and frost; soluble salts and fluorescence; and living organisms. Final chapters describe remedial measures and the development of test methods.

_____. "The Weathering, Preservation and Restoration of Stone Buildings." *Journal of the Royal Society of Arts*. No. 103, 1955.

Factors affecting the deterioration of stone buildings such as: air pollution, frost, soluble salts and micro-organisms are examined. Cleaning, stone preservatives and restoration of buildings are discussed. Some testing procedures: freezing, salt crystallization and chemical tests are describes.

Weaver, Martin E. "Acid Rain." *Construction Specifier*. Vol. 41, No. 7 (July 1988), pp. 54-62.

This journal article states that there is a distinct correlation between concentrations of sulfur dioxide and the destructive formation of carbonates into sulfates in natural and artificial stone, as well as other building materials. The increase in deterioration through synergistic reactions of other acidic air pollutants, including oxides of nitrogen, are noted.

Winkler, Erhard M. "Salt Action of Stone in Urban Buildings." William J. Young, editor. *Application of Science in Examination of Works of Art: Proceedings of the Seminar: June 15-19, 1970*. Boston, MA: Museum of Fine Arts, 1973, pp. 139-146.

Salts may be derived from ground moisture, stone weathering and from polluted air; they travel in stone both by diffusion and by capillarity. Surface efflorescence, near-surface sub-fluorescence, salt crystallization, and salt hydration on stone can produce considerable pressure.

_____. "A Macrostereogrammetric Technique for Measuring Surface Erosion Losses on Stone." Edited by James R. Clifton. *Cleaning Stone and Masonry: ASTM Special Technical Publication, No. 935*. Philadelphia, PA: American Society for Testing and Materials, 1986.

Discussed is a technique of macroscopic recording using close-up stereo-photographs of a strongly weathered surface of Georgia Marble. Overlapping close-up photographs are taken at a 1:1 size ratio with the optical axis perpendicular to the stone surface; light was provided by both a ring flash mounted in front of the lens and reflected natural light. An ultra-fine grained black and white film (Kodak Technical, Pan TP 2415) was used, printed onto 12.7 by 17.8 cm (5" x 7") contrast paper for pocket stereo-viewer with about two to three power magnification lenses. The accuracy of the optical height measurements was about (pm) 0.1 mm, based on comparison with measurements employing a needle-point depth micrometer. The method described here is applied to the comparison of uncleaned stone surfaces in terms of both surface, shape and surface reduction.

_____, and Philip C. Singer. "Crystallization of pressure of salts in stone and concrete." *Geological Society of America Bulletin*. Vol. 83 (1972), pp. 3509-3514.

Analyzes the complex mechanism of crystallization of salts in pores and discusses its physico-chemical action.

Zehnder, Konrad, and Andreas Arnold. "Stone Damage due to Formate Salts." *Studies in Conservation*. Vol. 29, No. 1, (1977), pp. 32-34.

Serious damage to sandstone in a building reconstructed in 1977 is the result of the efflorescence of magnesium formate and calcium formate. It was confirmed experimentally that these are produced by the reaction of formic acid within the carbonate containing sandstone. It is concluded that the formates were introduced by a previous cleaning treatment with formic acid.

Treatment and Repair

Ashurst, John. "Cleaning of Marble". *Research and Technical Advisory Service Technical Notes*. No. 30 (1981). London, England: Department of the Environment, 1981.

Techniques described include washing with gentle spray or clay pack; removal of iron and copper stain, oil stains and organic growth; and repolishing.

_____, and Francis G. Dimes. *Conservation of Building and Decorative Stone.* Volumes I & II. London, England: Butterworth - Heinemann, 1990.

These two volumes discuss the theory and practice of conservation with an objective comparison of different methods and approaches to the discipline. Volume I provides an introduction to the restoration, conservation and repair of building stone along with chapters on the nature, geology and weathering of masonry. Volume II discusses various treatments in conservation.

_____, and Nicola Ashurst. *Practical Building Conservation, English Heritage Technical Handbook, Vol. 1: Stone Masonry.* (Five volume set). New York, NY: Halsted Press, 1988.

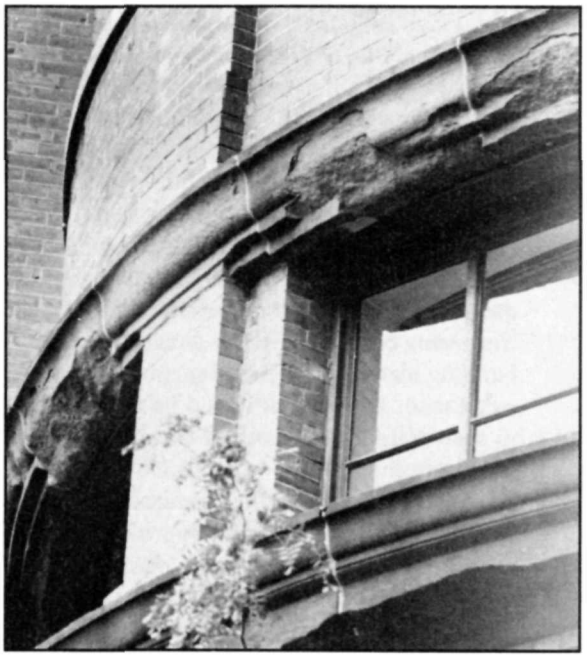
One of a five volume set on the theory and practice of conserving buildings. The information presented relates to most traditional building construction as well as methods of repairing, preserving and maintaining historic buildings with a minimum loss of original fabric.

Building Research Establishment. "Cleaning External Surfaces of Buildings." *BRE Digest.* No. 280. London, England: Her Majesty's Stationery Office, c. 1988.

Surface cleaning techniques are described: water washing, water lances, steam, chemical (acid and alkali), dry and wet grit blasting, mechanical, poultices and laser. Advice for the choice of the best technique are given according to the material and importance of the surface. Actions before and after cleaning are recommended.

Clifton, James R., editor. *Cleaning Stone and Masonry - ASTM Special Technical Publications, No. 935.* Philadelphia, PA: American Society for Testing and Materials, 1986.

Nine papers cover various problems of cleaning stone and masonry buildings, both ordinary and historic. The papers are divided into four sections: selection of cleaning methods and materials; historic structures; case studies; determining the effects of cleaning.



Exfoliation of brownstone lintel and sill due to the expansion and contraction of trapped moisture within the stone. *Photo:* National Park Service files.

Golubtzova, T.P., M.K. Nikitin, S.A. Shadrin, and O.O. Vasilieva. "Removal of Copper Salt from Marble". *ICOM Committee for Conservation, Sixth Triennial Meeting, Ottawa.* September 21-25, 1981. Paris, France: ICOM, 1981, p. 6.

Describes a method of removing copper salts and hydroxides from marble using a mixture of (poly) vinyl alcohol, ammonia, and metabolic cation resin in the form of NH_4. The substance has a high enough viscosity to remain on vertical surfaces. A polyvinyl film eventually forms in which copper ions are complex, and this film can be easily removed without damage to the marble.

Grimmer, Anne E. *Preservation Briefs No. 6: Dangers of Abrasive Cleaning to Historic Buildings*. Washington, DC: Technical Preservation Services, National Park Service, US Department of the Interior, 1979.

Brief explanation of abrasive cleaning methods, how they can be physically and aesthetically destructive and why they are generally not accepted as preservation treatments because they can damage historic building material. Alternative methods are mentioned, however, it would be impossible to state definitively which of these will be the most effective. There is no formula that will be suitable for all building surfaces and meantime, cleaning must be approached with caution through trial and error, "using the gentlest means possible."

_____. *Keeping it Clean: Removing Exterior Dirt, Paint, Stains, and Graffiti from Historic Masonry Buildings*. Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1988.

A publication from the Preservation Assistance Division of the National Park Service addressing issues of restoring historic structures. Part I discusses factors to consider before cleaning including identification of both substrate and materials to be removed, preservation consultant and contractor, testing, scheduling, and hazards. Part II describes selection of the "gentlest means possible" for removing dirt, paint, stains, and bird droppings using water, chemical cleaners, or poultices. A full-page chart summarizes techniques.

Hutchins, Nigel. *Restoring Houses of Brick and Stone*. Scarborough, NY: Van Nostrand Reinhold, 1982.

A practical guide to the repair and preservation of old stone and brick houses, covering all the relevant topics, form historical aspects to the inspection process, and the various intervention techniques. Individual chapters deal with interior finishes, chimneys, fireplaces, and stoves, while others are devoted to period landscape and the conversion of non-domestic buildings. Recipes are provided for mixes, washes, and plaster. The basic questions on historic masonry building repair are answered.

Ireson, A.S. *Masonry Conservation and Restoration*. Painscastle: Attic Books, 1987.

A practical concise guide to masonry restoration including a bibliography and masonry glossary.

Johnson, Byron. "Towards a Decision-Making Strategy." *ASTM Special Technical Publications No. 971*. Edited by J.T. Conway and J.C. Grogan. Philadelphia, PA: American Society for Testing and Materials, 1983.

The author proposes a decision chart for the use of building owners, designers and contractors to assist with the selection of an appropriate technique for cleaning masonry walls. The decision chart considers the nature of the masonry, the source of the soiling, and most importantly, the reason for the cleaning initiative. The decision chart is presented as a suggested approach and the author requests constructive criticism.

Lewin, Seymour Z., and Elizabeth J. Rock. "Chemical Considerations in the Cleaning of Stone and Masonry." *The Conservation of Stone I: Proceedings of the International Symposium*. June 19-21, 1975, Bologna. Edited by Raffaella Rossi-Manaresi. Bologna, Italy: Centro per la Conservazione delle Sculture all'aperto, 1976.

Determination of materials, staining agents and cleaning treatments. A summary listing of common formulations is given.

London, Mark. "How to Care for Old and Historic Brick and Stone." *Respectful Rehabilitation.* Washington, DC: The Preservation Press, 1988.

A handbook on the care and repair of old brick and stone buildings based on official standards that guide work on historic buildings in the United States. Contains: basic guidelines on building rehabilitation; a brief summary of the history, manufacture and basic physical and chemical properties of various types of stone and brick commonly used in North America; diagnosis of masonry problems and building inspection (including detailed checklists); cleaning and stone; repointing; repair of decayed surfaces and building portions; treatment of moisture problems. Explores the basic steps in diagnosing and treating dozens of typical problems, explaining necessary safety precautions and explaining why masonry deteriorates. Photographs, drawings, reading lists.

Lynch, Michael, and William J. Higgins. *The Maintenance and Repair of Architectural Sandstone.* New York, NY: New York Landmarks Conservancy, 1982.

This pamphlet covers the signs and causes of sandstone deterioration, protection and maintenance programs, and repair techniques. It is intended for use by building owners, architects and contractors.

Martin, Wilson G. "Oolitic Limestone Conservation: A Case Study in Conservation and Maintenance, Governor's Mansion, Salt Lake City, Utah." *Association for Preservation Technology Bulletin.* Vol. 17, No. 2 (1985), pp. 25-33.

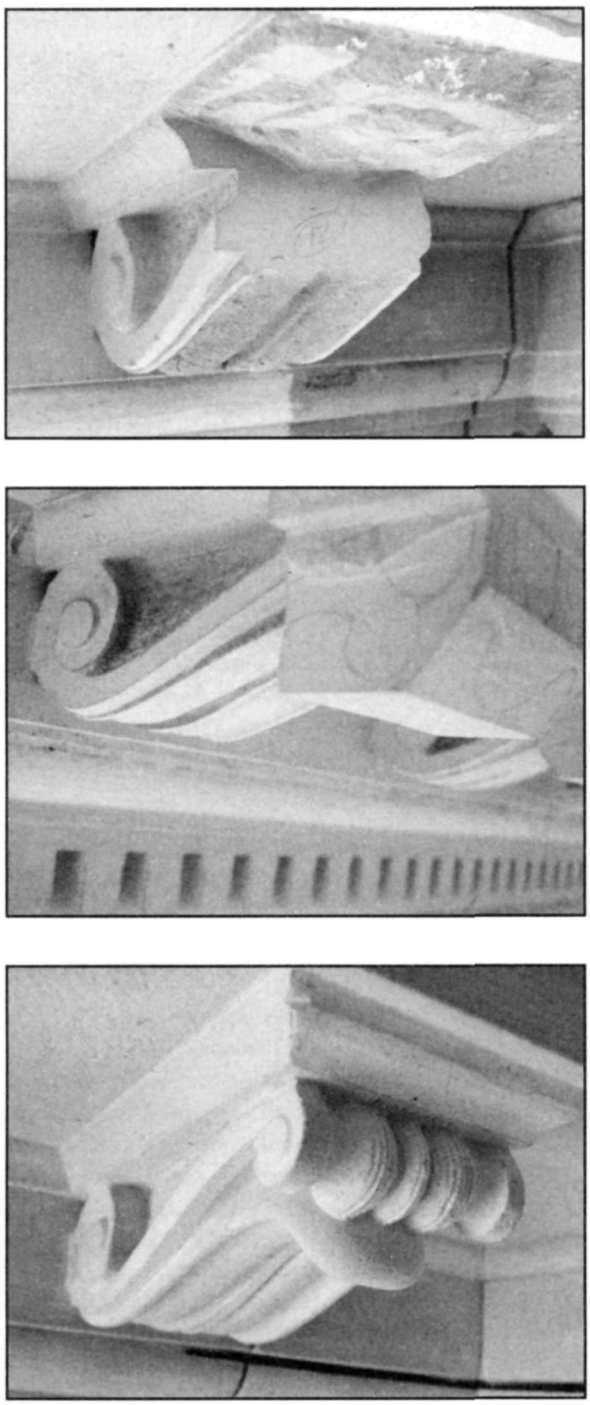
A case study of limestone conservation and maintenance: The Kearns Mansion, in Salt Lake City where four categories of stone condition had been treated, according to their deterioration, to bring the stone back to a uniform appearance. A new stone treatment was developed since 1983 by the division of state history for stone conservation after determination of the specific decay mechanisms and the recording of the existing physical conditions. Appropriate treatment was applied only to stones likely to be lost in the near future. It will be watched for 5 to 10 years to determine its acceptability.

Matero, Frank G., and Jo Ellen Freese. "Notes on the Treatment of Oil and Grease Staining on a Masonry Surface." *Association for Preservation Technology Bulletin.* Vol 10, No. 2 (1978), pp. 133-141.

Dark yellowish staining on interior limestone surfaces. Selection of a medium for a poultice included cotton pad, talc and rag pulp. The last was preferred. Butyl cellosolve alone or mixed with water gave best results.

Matson, Stacey A., and Walter Sedovic. "The High Art of Low Tech: Interior Marble Conservation of Federal Hall National Memorial." *Preprints of paper presented at the Sixteenth Annual Meeting of the AIC, New Orleans, LA, June 1-5, 1988.*

The interior stone cleaning and conservation project for Federal Hall National Memorial in New York City illustrates a process of defining and implementing a large scale project for the conservation of architectural materials. Techniques included detergent washing, chemical treatment and application of protective flow sealant. An examination of the project delineates its essential phases and show how each -- individually and combined -- contributed to a successful result. A suppliers list of all materials used is available from the authors.



Restoration of an oolitic limestone cornice bracket at the Thomas Kearns Mansion, 1901-5, Salt Lake City, Utah. After the deteriorated section was removed (top), a new section of limestone was mechnically attached to the bracket (middle), then carved to match the original profile (lower). *Photo:* National Park Service files.

National Park Service. *Masonry Products for Historic Buildings. Technical Preservation Database*. Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1988.

A list of proprietary products used on the exterior of historic masonry buildings compiled by the Center For Architectural Conservation, Georgia Institute of Technology. The listing, which is not comprehensive, contains ninety-nine entries, arranged alphabetically by product name, and intended to give as much information as possible on each product in order to aid the consumer in making informed preservation decisions. Individual treatment categories include: bonding agents, chemical cleaning products, consolidants, paint removers, water-repellant and waterproof coatings. Indexes by product name and product type.

Pepi, Raymond M. "Masonry Cleaning in Practice Today." *Bronze and Masonry in the Park Environment. A Symposium, New York, October 20-21, 1983.* Co-sponsored by Center for Building Conservation, Central Park Conservancy, and New York City Department of Parks and Recreation, 1983, pp. 1-16.

Gives a summary of each of the most commonly employed masonry cleaning techniques and their suitability for monument and building conservation: chemical cleaning; chemical paint stripper; cold water soaking, misting, rinsing; steam and hot water; poultices; mechanical methods; protective coatings. Six references.

Powers, Robert M. "Masonry No. 1: Substitute Materials: Replacing Deteriorated Serpentine Stone with Pre-Cast Concrete." *Preservation Tech Notes*. Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1988.

This *Tech Note* details the replacement of over 90% of a green serpentine stone veneer

with individually molded and tinted pre-cast concrete units on a rowhouse in Washington, D.C.

_____. "Masonry No. 3: Water Soak Cleaning of Limestone." *Preservation Tech Notes.* Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1992.

This *Tech Note* discusses the successful method of cleaning used on the Widener Building in Philadelphia, PA in which a timed water soaking gradually dissolved and loosened the pollutant crust.

Prudon, Theodore. "Removing Stains from Masonry." *The Old-House Journal Compendium.* Woodstock, NY: The Overlook Press, 1980, pp. 97-98.

The importance of selecting the appropriate solvent in cleaning stained masonry is stressed. Techniques for the removal of different stains (iron, lichens, copper, oil, asphalt and tar, manganese, vanadium), with the recipes of the various poultices are described.

Rogers, Anne, and Doyle Wilhite. "Exterior Restoration of the West Virginia State Capitol: Cleaning and Structural Stabilization Procedures." *Technology and Conservation.* Vol. 4, No. 1 (Spring 1979).

Study of deterioration mechanisms and treatments including: efflorescence, cleaning stone and terra cotta, filling mortar joints, then grouting them, epoxy injections, restoration and protection of terra cotta with pigmented acrylic emulsion, water repellent coating and repair of broken stones.

Rossi-Manaresi, Raffaella, and Giorgio Torraca. "The Treatment of Stone." *Proceedings of the Meeting of the Joint Committee for the Conservation of Stone, Bologna. October 1-3, 1971.* Bologna, Italy: Centro per la conservazione delle sculture all'aperto, 1972.

Sixteen papers presented at the meeting. The main topics are cleaning and consolidation of stone masonry and objects, and protection of terra-cotta facades.

Sleater, Gerald A. "Stone Preservatives: Methods of Laboratory Testing and Preliminary Criteria." *National Bureau of Standards Technical Note 941.* Washington, DC: US Department of Commerce, May 1977.

Reports on the efficacy of over fifty stone preservatives for use on historic buildings and monuments. Samples were subjected to accelerated decay, chemical attack, salt and water action and thermal effects in addition to sulfurous acid and sodium chloride fog, water condensation/evaporation cycling, sodium sulfate penetration and crystallization, and ultraviolet radiation. The result and performance criteria are listed in numerous tables, supplemented by graphs, diagrams and photographs.

Sowden, A.M. *The Maintenance of Brick and Stone Masonry Structures.* London, England: 1990.

A series of papers following maintenance of masonry from initial identification of defects and their diagnoses to treatment and monitoring cost efficiency. Limited to civil engineering structures.

Spry, Alan H. *Principles of Cleaning Masonry Buildings: A Guide to Assist in the Cleaning of Masonry Buildings.* Technical Bulletin 3.1. Victoria, Australia: Victorian National Trust, 1982.

Reasons for cleaning buildings and monuments, nature of soiling and urban

grime. Treatment of limestone, marble and render. A review of methods. Selection of treatment.

Stevens, Hollis J., Seymour Z. Lewin, and A. E. Charola. "Facade restoration of the Renwick Gallery of Art: materials investigation and architectural analysis." *No future without past. Proceedings of the sixth ICOMOS general assembly, Rome-Bari-Florence-Verona, 25-31 May 1981*. Paris, France: ICOMOS, 1981.

An important North American case study describing the condition of the brick and sandstone facade and failed previous restoration efforts. New restoration proposals with natural stone and precast architectural stone discussed.

Weber, Helmut, and Klaus Zinsmeister. *Conservation of Natural Stone, Guidelines to Consolidation, Restoration and Preservation.* Germany: Expert-Vertag, 1990.

This book defines conservation technology as an area which comprises different disciplines in science and technology, including chemistry, mineralogy, physics, architecture, etc. The text identifies those points of each discipline which are essential and vital to conceive a restoration strategy for historically valuable, architectural building stone. Discussions include both the classification, physical properties and deterioration of building stone and conservation techniques ranging from consolidation to cleaning.

Brick

Brick is a term often used to describe a variety of manufactured dimensional masonry units -- from clay to concrete to adobe. For the purposes of this document, brick is defined as it is most commonly used: as a solid, structural masonry unit, usually rectangular, manufactured by the molding or forming of clay, dried and kiln-fired.

The characteristics and physical properties of brick are determined by the wide range of raw materials, forming methods, and firing conditions used in production. Their individual properties, collective use in construction, maintenance, and environmental conditions determine the performance of brick structures.

General Reference

Ashurst, John, and Nicola Ashurst. *Practical Building Conservation, English Heritage Technical Handbook, Vol. 2: Brick, Terra-cotta and Earth*. New York, NY: Halsted Press, 1988.

A comprehensive, practical text for the conservation of brick and other architectural clay materials. Includes discussions of: rising damp and damp-proofing, salt formation and damage, desalination techniques and analysis, mortar analysis and repointing, brick composition and classifications, and maintenance and preservation methods. Numerous diagrammatic illustrations

_____. *Practical Building Conservation, English Heritage Technical Handbook Vol. 3: Mortars, Plasters & Renders*. New York, NY: Halsted Press, 1988.

A comprehensive, practical text for mortars, plasters, stuccos and other sacrificial renders. Includes discussion of: hydraulic and non-hydraulic lime and cements, additives, exterior and interior plasters and renders, limewashes and paints, repair techniques, and conservation case studies. Diagrammatic illustrations and numerous material recipes.

Beall, Christine. *Masonry Design and Detailing*. Englewood Cliffs: Prentice Hall, 1984.

Provides a basic overview of the processes of brickmaking and brickbuilding -- primarily for builders and designers, but useful for a general understanding of brick construction.

Bidwell, T.G. *Conservation of Brick Buildings: The Repair, Alteration and Restoration of Old Brickwork*. London, England : Brick Development Association, 1977.

This report discusses the conservation of brick buildings: survey, structural failures to brickwork, brick failure, water penetration, biological growth, alterations to historic fabric, surface appearance and treatments.

Brownell, W.E. *Structural Clay Products*. New York, NY: Springer-Verlag, 1976.

According to the Brick Institute of America, this is the bible of brick manufacturers -- a blend of the theoretical and technical. History and classification of brick, clay mineralogy and properties, structure, raw materials, industrial production and deterioration.

Davis, Charles Thomas. *A Practical Treatise on Brick, Tile, and Terra Cotta*. London, England: Henry Carey Baird, 1895.

This is a valuable 19th century documentation of 19th century brick technology.

Grimm, Clayford T. "Brick Masonry Workmanship Statistics." *Journal of Construction Engineering and Management*. Vol. 114, No.1 (March 1988), pp. 147-149.

In 1986 masonry engineering students at the University of Texas, Austin, examined and

documented twenty-four Austin buildings ranging from 1 to 92 years old for workmanship characteristics. Study results are presented and discussed.

Grimm, Clayford T. "Water Permeance of Masonry Walls: A Review of the Literature." Edited by J.G. Borchelt. *Masonry: Materials, Properties and Performance; A Symposium.* December 9, 1980. ASTM Special Technical Publication #778. Philadelphia, PA: American Society for Testing and Materials, 1982.

Technical literature review on the permeance of brick and concrete walls to wind-driven rain: design, movement, materials, sealants and repairs.

Gurke, Karl. *Bricks and Brickmaking: A Handbook for Historic Archaeology.* Moscow, ID: University of Idaho Press, 1987.

An extensive handbook for the identification (brand, brickyard, dates) of historic and contemporary bricks with detailed discussions of the industrial history, topology and archaeology of bricks. Extensive bibliography.

Handisyde, C.C., and B.A. Haseltine. *Brick and Brickwork.* London, England: Brick Development Association, n.d.

A general reference on the properties and uses of brick: appearance, durability, strength, water exclusion, fire resistance, sound and thermal insulation, manufacture, topology, walling, paving, mortar, ties, pointing and repointing, damp control, cracking, rendering, structural movement and safety, and maintaining appearance.

McGrath, Thomas. "Notes on the Manufacture of Hand-made Bricks." *Association for Preservation Technology Bulletin.* Vol. 11, No. 3 (1979), pp. 88-95.

A summary of the process of making bricks by hand or with limited equipment: winning and working the clay, molding, drying and firing.

McKee, Harley. "Brick and Stone: Handicraft to Machine." *Building Early America.* Edited by Charles E. Peterson. Mendham, NJ: Astragal Press, for the Carpenters' Company of Philadelphia, 1976.

A brief study of the ways in which bricks and other masonry units were formed with particular attention given to the early advent of hand-operated machinery.

Minter, Peter, and William Nash. Jack Bowyer, editor. "Brickwork." *Handbook of Building Crafts in Conservation.* London, England: Hutchinson, 1981, pp. 68-131.

Historical development of brickwork and brick manufacture, brick-laying methods, tools, pointing and details.

Nelson, Lee H. "Early American Brick Masonry and Restoration of Exterior Brick Walls." *Third Annual Historic Structures Training Conference*, National Park Service, August, 1963, Philadelphia, PA.

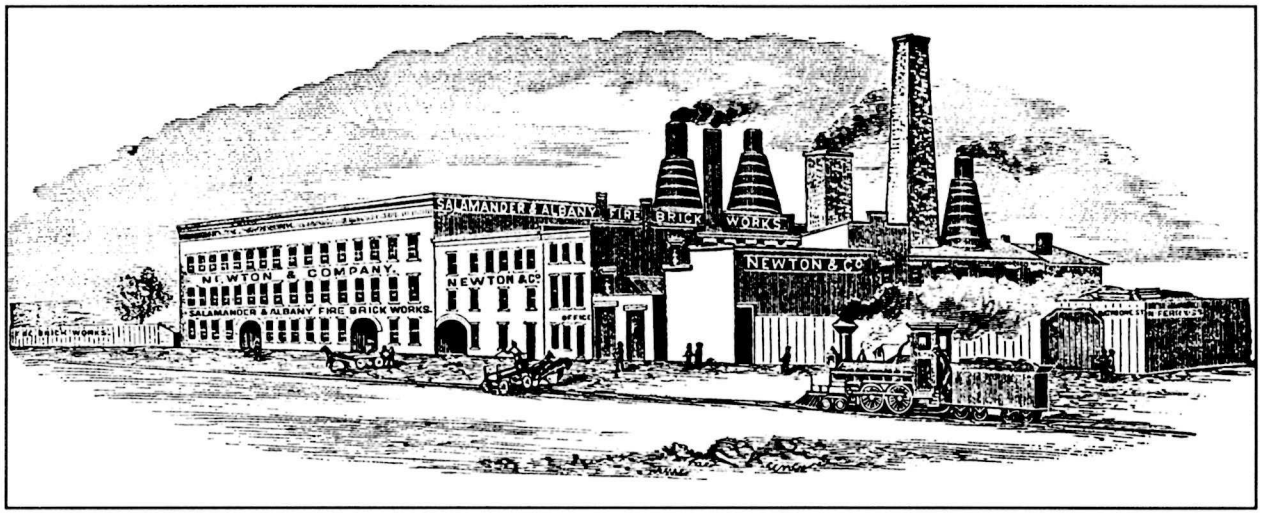
American brick manufacture, particularly as used in Philadelphia. Includes a discussion of glazed headers, pointing, cleaning, terminology, manufacturers, bibliography and a survey of seven Philadelphia buildings.

Ries, Heinrick. *Building Stones and Clay Products.* New York, NY: Wiley, 1912.

Comprehensive historic resource on the manufacture of bricks at the turn of the century. Includes a glossary.

Volz, John R. "Brick Bibliography." *Association for Preservation Technology Bulletin.* Vol. 7, No. 4 (1975), pp. 38-49.

Compiled for the National Trust for Historic Preservation conference: Preservation of



Newton and Co.'s Salamander and Albany Fire Brick Works, Albany, N.Y., c. 1884. Reprinted in *Early Illustrations and Views of American Architecture*, Edmund V. Gillon Jr., New York, N.Y., Dover Publications Inc., 1971, p. 263.

Ghost Towns and Mining Camps held in Flagstaff, AZ in 1975.

Worrall, W.E. *Clays and Ceramic Raw Materials*. London, England: Elsevier Applied Science, 1986.

A basic text on clay mineralogy and industrial ceramic technology.

Deterioration Mechanisms

Army Engineers Experiment Waterways Station, Structures Lab. *Investigation of Deterioration of Brick in Navigation Lock Control House Structures, Tulsa District.* Vicksburg, MS: US Army Corps of Engineers, 1980.

The deterioration of brick at five structures characterized by partial or complete exfoliation from moisture intrusion. Damaged and non-damaged samples were evaluated by physical testing and petrographic examination. Six model walls were coated with different protective coatings and observed for performance.

Boscardin, Marco D., and Edward J. Cording. "Building Response to Excavation-induced Settlement." *Journal of Geotechnical Engineering*. University of Massachusetts, Amherst, Vol. 115, No. 1 (January 1989), pp. 1-21.

Both analytical and field models were used to develop procedures to evaluate the tolerance of brick bearing-walls to ground displacements due to excavations under or near the structure. Case studies are used to verify the procedures for estimating potential damage.

Brown, Maureen T., and Brick Institute of America. "Critical Review of Field Adapting ASTM E514 Water Permeability Test Method." ASTM Proceedings: *Masonry: Components to Assemblages*. December 5, 1989, Orlando, FL. (ASTM Special Technical Publication #1063). Philadelphia, PA: American Society for Testing and Materials, 1990.

This paper is an experimental investigation into a field adaptation of the ASTM lab test for permeability in brick masonry.

Building Research Establishment. *Sulphate Attack on Brickwork*. BRE Digest #89. Lancaster, England: Construction Press, 1977.

Detection of sulphate attack and its remedies and prevention, including information on sulphate resisting mortars and renders.

Charola, A.E., and L. Lazzarini. "Deterioration of Brick Masonry Caused by Acid Rain." Conference proceedings: *Materials Degradation Caused by Acid Rain*. American Chemical Society, Division of Industrial and Engineering Chemistry held June 17-19, 1985, Arlington, VA.

A review by the Metropolitan Museum of Art, New York, to the chemical industry summarizing the deterioration mechanism of acid rain on bricks -- specifically the selective dissolution of glassy matrices and subsequent water-salt migration through bricks and mortar.

Collepardi, M. "Degradation and Restoration of Masonry Walls of Historic Buildings." *Materials and Structures*. Vol. 23, No. 134 (March 1990), pp. 81-102.

Collepardi, of the University of Ancona, Italy, has published a general review of the chemical deterioration mechanisms to brick, mortar and other masonry materials based upon the performance of the walls of fifty historic buildings. Conservation techniques and materials are discussed in terms of their compatibility with the original masonry.

Kralj, B., G.N. Pande, and J. Middleton. "On the Mechanics of Frost Damage to Brick Masonry." *Computers and Structures*. Vol. 41, No. 1 (1991), pp. 53-66.

This is a theoretical experiment from the University of Wales, Swansea, presenting a computer-calculated model for the assessment of frost damage to brick masonry. The model is applied to the problem of a partially saturated free-standing wall subjected to frost damage. Actual results obtained qualitatively agree with frost damage observed in the simulated tests.

Livingston, Richard A. "X-ray Analysis of Brick Cores from the Powell-Waller Smokehouse, Colonial Williamsburg." Conference proceedings: *Third North American Masonry Conference*, June 3-5, 1985, Arlington, TX.

A report upon the accuracy of the non-destructive measurement of salt and moisture by prompt gamma neutron method -- as compared to the destructive testing method of taking cores for more traditional instrumental analysis.

Peterson, Ivars. "A Material Loss." *Science News*. 128 (September 7, 1985), pp. 154-6.

A discussion of the weathering effects of acid rain on stone and bricks.

Raths, Charles H. "Brick Masonry Wall Nonperformance Causes." Conference proceedings: *Masonry: Research, Application and Problems*, American Society for Testing and Materials held December 6, 1983, Bal Harbour, FL (ASTM Special Technical Publication #871).

A review of typical nonperforming characteristics of modern-construction brick masonry walls in regard to brick and mortar water penetration, durability, efflorescence, design, ASTM requirements, specifications and workmanship. Preventative recommendations are given.

Ritchie, Thomas. "Efflorescence." *Canadian Building Digest*. Vol. 2 (1960).

This article focuses on the formation of salts in brick-mortar systems, particularly in cold climates: visual and physical disfigurement to the units, the chemical nature of

efflorescence, weather and mortar as sources for efflorescence, the treatment and prevention of salt damage through proper design and material selection, and the hazards of water repellents.

Robinson, Gilbert C. "Characterization of Bricks and their Resistance to Deterioration Mechanisms." *Conservation of Historic Stone Buildings and Monuments*. Edited by N.S. Baer. Washington DC: National Academy Press, 1982, p. 145-62.

A concise discussion of the durability, susceptibility and rate of deterioration of brick and mortar systems -- from a combined stand-point of ceramic engineering and conservation science. Topics include: raw materials, shaping, firing, coloration, aging, water penetration, mortar bond, freeze-thaw conditions, salt and chemical attack, expansion, coating, design, material compatibility, cleaning and restoration.

Taylor, Thomas H., and Richard A. Livingston. "Diagnosis of Salt Damage at a Smokehouse in Colonial Williamsburg." *Association for Preservation Technology Bulletin*. Vol. 23, No. 3 (1991), pp. 3-12.

Examination and testing systems for the qualitative and quantitative diagnosis of deterioration mechanisms in historic brick masonry.

Wickersheimer, D.J. "Brick Expansion." *Forensic Engineering*. Vol. 2, No. 1-2 (1990), pp. 294-95.

This article reviews the unique moisture and temperature related expansion characteristics of fired clay brick and its potentially deleterious effect on structures, regardless of meeting ASTM standards. Useful information if replacement bricks are a consideration.

Treatment and Repair

Ashurst, John. "Cleaning and Surface Repair: Past Mistakes and Future Prospects." *Association for Preservation Technology Bulletin*. Vol. 17, No. 2 (1985), pp. 39-41.

A survey of the condition of thirty exterior architectural surfaces in urban England that were cleaned by various methods ten years prior. Discussions and observations.

Bidwell, Timothy G. *The Conservation of Brick Buildings: The Repair, Alteration and Restoration of Old Brickwork*. London, England: Brick Development Association, 1977.

Guidelines for the assessment and conservation of brick buildings: survey, failures, water penetration, organic growth and appearance.

Bullock, Orin M. "Brick, Adobe, Stone, and Architectural Ceramics: Problems and Techniques of Preservation." *Preservation and Conservation: Principles and Practices*. Conference proceedings, North American International Regional Conference, 1972. Washington, DC: The Preservation Press, 1976.

A general survey of the preservation problems and techniques of brick masonry unit systems.

Chapman, William. *Preservation Guideline 4: The Cleaning and Repair of Exterior Brick Walls*. St. Croix, VI: Virgin Island Planning Office, Division for Archaeology and Historic Preservation, n.d.

A technical leaflet on the care of brick walls in the tropical climate of the Virgin Islands.

Collier, Richard. "Guidelines for Restoring Brick Masonry." *Parks*. Vol. 8, No. 4 (1984), pp. 15-21.

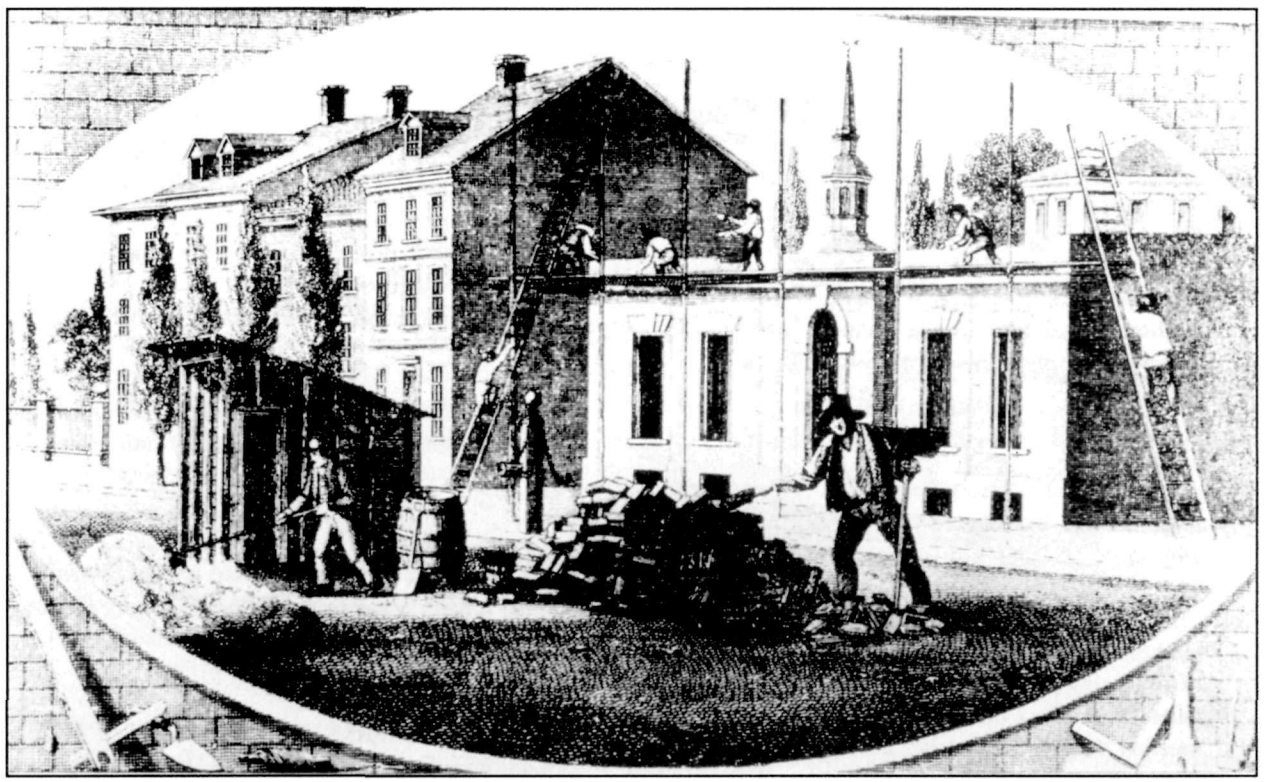
A discussion of the hazards of surface blasting with specifics about replacements, rebuilding, repointing, mortar composition matching, cleaning, detergents, paint removal, stucco repair and replacement, painting and sealing.

Harity, Michael H., and Janet L. Hansen, edited by Lee S. Tabor. *Masonry Conservation Technology*. Charlestown, MA: Massachusetts Masonry Institute, 1976.

A short history of masonry materials and techniques, brick manufacture and bonding patterns, mortar materials and joint work, deterioration, cleaning, paint removal, waterproofing and repairs.

Hutchins, Nigel. *Restoring Houses of Brick and Stone*. Toronto, Ontario: Van Nostrand Reinhold, 1982.

A practical guide to the repair and preservation of old stone and brick houses, covering all the relevant topics, form historical aspects to the inspection process, and the various intervention techniques. Individual chapter deal with interior finishes, chimney, fireplaces, and stoves, while others are devoted to period landscape and the conversion of non-domestic buildings. Recipes are provided for mixes, washes, and plaster. The basic questions on historic masonry building repair are answered.



The Bricklayer's Company of the City and County of Philadelphia. Portion of membership certificate, c. 1792. *Photo:* National Park Service files.

Jones, Gordon. "Brick Cleaning: The Pressure is On." *Construction Specifier*. Vol. 40, No. 5 (May 1987), pp. 133,135.

A discussion of the pros and cons of high-pressure water cleaning of bricks and mortar -- stressing the selection of appropriate cleaning processes and apparatus based on methodical test cleaning.

Lass, Herb. "New Bricks Fired to Look Old (Boston's United Shoe Machinery Company Building)." *Engineering News-Record*. 216 (June 12, 1986), pp. 18-19.

Techniques used to produce replacement materials for a brick structure.

Mack, Robert C., AIA, de Teel Patterson Tiller, and James S. Askins. *Preservation Briefs No. 2: Repointing Mortar Joints in Historic Brick Buildings*. Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1980

A concise and comprehensive step-by-step guide to the basics of repointing brick, including discussions of workmanship, life expectancy, mortar constituents, material specifications, execution and roles and responsibilities of the owner, consultant and contractor.

Plecnik, Joseph, Thomas Cousins, and Edward O'Conner. "Strengthening of Unreinforced Masonry Buildings." *Journal of Structural Engineering*. Vol. 112, No. 5 (May 1986), pp. 1070-1087.

This describes an experiment at North Carolina State University which proposed a method for the rehabilitation and strengthening of multi-wythe, unreinforced, load-bearing, brick masonry walls. Performance tests were performed on buildings (approximately 80 years old) using sand/cement, sand/epoxy and sand/polyester grouts.

Prudon, Theodore H.M., Clem Labine, and Carolyn Flaherty. "Removing Stains from Masonry." *Old House Journal*. Vol. 5, No. 5 (May 1977), pp. 58-59. Reprinted in *Old House Journal Compendium*. Woodstock, NY: Overlook Press, 1980.

Guidance on selecting appropriate cleaning solvents and techniques for stain removal, with a focus on poultices.

Ritchie, Thomas. "Cleaning of Brickwork." *Canadian Building Digest*. No. 4 (1978).

Discussion of using acid and alkali cleaners in preference to sandblasting with specific information on the removal of metallic stains, paint, tar and plant growth.

_____. "On Using Old Bricks in New Buildings." *Canadian Building Digest*. Vol. 138 (1971).

A discussion of the use and properties of reclaimed bricks, their intrinsic and extrinsic differences from new brick, and their effect upon exterior performance of a structure.

Thomas, James Cheston. "Restoring Brick and Stone: Some Do's and Don'ts." *History News*. Vol. 30, No. 1 (January 1975). Reprinted by the American Association for State and Local History as Technical Leaflet #81.

Brick and stone restoration: identifying and treating deterioration, defining types of mortar joints and cleaning methods.

Architectural Terra Cotta

Terra cotta is a fired clay body which may or may not be coated on the exposed surface with a glaze or similar fused protective covering. It is manufactured mostly in the shape of hollow pieces made to the design of the architect, so that by fitting the numbered pieces together in accordance with a key drawing, the elevation of a complete building is produced. An essential character of architectural terra cotta and faience is that it is pressed by hand in absorbent molds. [From William McIntyre, *Investigations into the Durability of Architectural Terra Cotta*, 1929.]

General Reference

Brownell, W.E. *Structural Clay Products*. New York, NY: Springer-Verlag, 1976.

According to the Brick Institute of America, this is the Bible of brick manufacturers -- a blend of the theoretical and technical. History and classification of brick, clay mineralogy and properties, structure, raw materials, industrial production and deterioration.

Davis, Charles Thomas. *A Practical Treatise on Brick, Tile, and Terra Cotta*. London, England: Henry Carey Baird, 1895.

This is a valuable 19th century documentation of 19th century brick, tile and terra cotta technology.

Hamilton, David. *Architectural Ceramics*. London, England: Thames and Hudson, 1978.

Handbook describing techniques related to the methods of making bricks, tiles, faience, terra cotta and large scale sculpture, as well as roofing tiles, chimney pots and decorative features. Includes glossary and bibliography.

Lockhardt, William. "Architectural Terra Cotta." *General Building Contractor*. (January 1931).

Period literature containing thorough discussion of terra cotta fabrication, proper support and setting practices, potential construction problems, post construction cleaning. Note: this article recommends the use of strong acidic cleaners not generally approved today.

Mack, Robert. "The Manufacture and Use of Architectural Terra Cotta in the United States." *The Technology of Historic American Buildings: Studies of the Materials, Processes, and the Mechanization of Building Construction*. H. Ward Jandl, editor. Washington, DC: Foundation for Preservation Technology, 1983.

History of terra cotta use from ancient through modern times. Discusses types of terra cotta including ingredients, forms, manufacturing processes, advantages and disadvantages. Also includes design drawings and installation details.

National Terra Cotta Society. *Terra Cotta, Standard Construction*. New York, NY: National Terra Cotta Society, 1914 and 1927.

Standard period construction details for architectural terra cotta including steel supporting structures and masonry configurations for walls, cornices and other building elements.

Prudon, Theodore H.M. "Terra Cotta as a Building Material: A Bibliography." Supplement to *Association for Preservation Technology Communique*. V (June 1976).

Extensive bibliography of period literature on manufacturing, testing, setting and inspection of architectural terra cotta. Also contains citations for literature regarding use of terra cotta polychromy in architecture.

Ries, Heinrick. *Building Stones and Clay Products*. New York, NY: Wiley, 1912.

Comprehensive historic resource on the manufacture of bricks and terra cotta at the turn of the century. Includes a glossary.

Tindall, Susan M., and James Hamrick. "American Architectural Terra Cotta: A Bibliography." *Architectural Series: Bibliography*. A-531 (July 1981).

Extensive bibliography addressing all aspects of terra cotta use, manufacturing, deterioration and conservation. Includes both period and contemporary literature, both American and foreign.

Wilson, Hewitt. "Monograph and Bibliography on Terra Cotta." *Transactions of the American Ceramic Society*. XIX (1917), pp. 209-215.

Extensive period bibliography oriented predominantly toward manufacture of architectural terra cotta. Addresses clays, grogs, slips, molding and firing processes, testing and deterioration. Particularly large section on colored glazes including recipes.

Deterioration Mechanisms

British Clayworker. "The Place of Terra Cotta in Post-War, with special reference to the problem of atmospheric pollution." 53 (1944), pp. 76-77.

Atmospheric pollution affects building materials in two ways: 1) discoloration and disfigurement, and 2) chemical disintegration. Advantages of terra cotta in areas of heavy pollution, potential misapplications are also discussed.

Bullock, Orin M. "Brick, adobe, stone and architectural ceramics: problems and techniques of preservation." *Preservation and Conservation: Principles and Practices. Proceedings of the North American International Regional Conference, 1972*. Washington, DC: The Preservation Press, 1976, pp. 131-141.

Survey of the preservation problems and techniques of bricks, adobe, stone and terra cotta. Primary deterioration mechanisms are water, settlement and poor workmanship. Includes bibliography.

Coates, M.A. "The Influence of Soluble Salts in a Clay Upon the Behavior of a Slip and a Glaze." *American Ceramics Society Transactions*. 16 (1914), pp. 162-168.

Presence of soluble salts in clay body prior to glazing contributes to crazing and peeling of fired pieces. The amount of salt present does not appear to influence the extent of damage.

Eskesen, Eckardt V. "The Investigation of Terra Cotta Work at the Bureau of Standards." *Bulletin of the American Ceramic Society*. 3 (May 1924), pp. 158-161.

Status report of ongoing research addressing spalling and chipping due to moisture and temperature fluctuations and testing of porosity, etc. Followed by a wide range of manufacturers' responses on a variety of manufacturing problems.

Everhart, J.O. "Some Simulative Service Tests for Glazed Building Materials." *American Ceramic Society Journal*. 13 (June 1930), pp. 404-410.

Comparison of several methods of freeze-thaw testing including standard autoclave test. Data on changes in glaze porosity with repeated exposure. Nature of glaze failures.

Fidler, John. "The Manufacture of Architectural Terra Cotta and Faience in the United Kingdom." *Association for Preservation Technology Bulletin.* Vol. 15, No. 2 (1983), pp. 27-32.

Notes on the use of terra cotta and faience in British historical architecture, its manufacturing process and related faults as a starting point in the field of conservation problems.

Hunderman, Harry J., and Deborah Slaton. "Terra Cotta Evaluation." *Building Renovation.* (November/December 1992), pp. 63-66.

Discussion of archival resources and period trade literature. Field inspection techniques covered include baroscope and sounding. Laboratory testing techniques include petrographic examination, strength testing, absorption, etc. Symptoms and diagnoses, conservation and maintenance.

What may have begun as a hairline crack that allowed water to enter beneath the glaze and to rust the metal armature has caused pieces of this terra cotta baluster to spall off. *Photo:* National Park Service files.

McIntyre, W.A. *Investigation into the Durability of Architectural Terra Cotta.* Special Report #12. London, England: Department of Scientific and Industrial Research, Building Research Station, 1929.

Discussion includes history of terra cotta use and manufacturing process. Conservation oriented information includes intrinsic defects and extrinsic weathering, case studies of terra cotta failures and ongoing research into factors affecting durability of architectural ceramics. Ongoing research examining mechanical, physical and chemical properties and resistance to biological attack.

_____. "Factors Governing the Durability of Clay Building Materials." *Transactions of the British Ceramic Society.* 28 (March 1929), pp. 101-123.

Factors include weathering mechanisms, defects due to filling of blocks, moisture and thermal expansion, rupture by freeze-thaw and salt crystallization, abrasion by windborne materials, etc.

Spurrier, Harry. "Some Fundamentals of Terra Cotta." *Journal of the American Ceramic Society.* 9 (1926), pp. 771-778.

Discusses characterization of terra cotta by microscopic examination, osmosis of soluble salts, fracturing by freeze-thaw cycling.

Stockbridge, Jerry G. "Analysis of In-Service Architectural Terra Cotta." *Association for Preservation Technology Bulletin.* Vol. 18, No. 4 (1986), pp. 41-45.

Discussion of tests available for terra cotta evaluation including water leakage, metal detection, copper/copper sulfate testing, crack monitoring, strain relief testing, petrography, etc.

Thomasen, Sven, and Carolyn Searls. "Diagnosis of Terra Cotta Glaze Spalling." *Masonry: Materials, Design, Construction and Maintenance, ASTM Special Technical Publication 9992.* Philadelphia, PA: American Society for Testing and Materials, 1988.

Glaze spalling is one of the most common types of deterioration observed in terra cotta buildings. Defined as the separation of the hard impermeable glaze from the underlying clay bisque. Spalling leaves the clay body exposed to water infiltration and accelerated decay. Article reviews the causes of spalling, maintenance guidelines and diagnoses of damage. Bibliography included.

U.S. Bureau of Standards. "Architectural Terra Cotta Investigations." *National Bureau of Standards Technical News Bulletin.* 98 (1925), p. 3.

Outlines research program then underway to characterize architectural terra cotta by its physical and mechanical properties, investigation of over 500 buildings, observation of manufacturing practices, analysis of mortar mixtures, etc. Little information on actual findings.

Treatment and Repair

Ashurst, John. "Cleaning and Surface Repair: Past Mistakes and Future Prospects." *Association for Preservation Technology Bulletin.* Vol. 17, No. 2 (1985), pp. 39-41.

Inspection of thirty terra cotta buildings ten years after cleaning including evaluation of the cleaning and water repellent treatments used. Concludes that regular low impact cleaning preferable to drastic cleaning at longer intervals.

Berryman, Nancy D., and Susan M. Tindall. *Terra Cotta.* Chicago, IL: Landmarks Preservation Council of Illinois, 1984.

A practical guide for the use and preservation of architectural terra cotta. The manufacture of architectural terra cotta, deterioration and maintenance, preservation and replacement are exhaustively dealt with. Useful glossary and bibliographic references.

Bristow, J. Alan. "Renovating Terra Cotta Work on Birmingham's Central Mission." *Building Conservation.* Vol.3, No. 6 (1981), pp. 10-12.

Cleaning and renovation of molded terra cotta elevations of a Victorian building.

Ferriday, Virginia Guest. *Last of the Handmade Buildings: Glazed Terra Cotta in Downtown Portland.* Portland, OR: Mark Publishing Company, 1984.

Study of glazed terra cotta buildings in Portland, OR divided in three parts. Part 1 traces the development of terra cotta building district, analyzing building types, production and installation of glazed terra cotta and related materials. Part 2 deals with preservation and restoration of district buildings and glazed terra cotta. Part 3 is an inventory of surviving glazed terra cotta buildings.

Fidler, John. "The Conservation of Architectural Terra Cotta and Faience." *Friends of Terra Cotta Newsletter.* Vol. 2, No. 3 (Fall 1983), pp. 10-13; Vol. 2, No. 4 (Winter 1983-84), pp. 8-12; Vol. 3, No. 1 (Spring 1984), pp. 12-16; and Vol. 3, No. 2 (Summer 1984), pp. 8-10. 4-part serialization reprinted from *Association for Studies in the Conservation of Historic Buildings,* Vol. 6 (1981).

Architectural terra cotta, a detailed study. History, manufacture, deterioration, conservation, soiling, maintenance, repair and restoration are investigated. Discussion of cleaning methods concludes that detergent cleaning is presently least harmful approach.

Special mortars and coatings for patching are discussed.

Fidler, John. "The Repair of Architectural Terra Cotta and Faience, Part I." *The Society for the Protection of Ancient Buildings News.* Vol. 4, No. 4 (1983), pp. 51-53.

Architectural terra cotta decay mechanisms and cleaning systems.

_____. "Repairing Terra Cotta, Part II." *The Society for the Protection of Ancient Buildings News.* Vol. 5, No. 1 (1984), pp. 3, 5, 7, 9.

The restoration of terra cotta on buildings is a difficult problem. Buildings have been damaged in the past due to inadequate repairs or flaws in construction. Emphasizes thorough study of elements composing the material before examining measures to be adopted for preserving and restoring. Cleaning, bonding, reassembly and consolidation discussed.

Fitch, James Marston. "The Renovation of Alwyn Court, New York City: Restoring the facades and improving the public spaces." *Technology & Conservation.* Vol. 5, No. 2 (1980), pp. 24-31.

Cleaning of glazed terra cotta with acid and alkaline cleaners. Replacement blocks made of cement.

Glance, Richard A. "Terra Cotta: Rehabilitation of a Courthouse Dome." *Association for Preservation Technology Bulletin.* Vol. 17, No. 1 (1985), pp. 39-45.

Report on the restoration of the terra cotta dome of Washington County (PA) Courthouse. Description of preliminary investigations, damage diagnoses, analysis of coatings applied to terra cotta surface. Dome surface was recoated with suitable material to approximate original dome color and expand and contract with thermal changes while remaining watertight.

Kelly, Stephen J., and Jerry Stockbridge. "The Railway Exchange Building: A Terra Cotta Renovation." *Association for Preservation Technology Bulletin.* Vol. 20, No. 3 (1988), pp. 15-22.

Case study of the restoration of a 1913 facade of the Railway Exchange Building (St. Louis, MO). Results of tests and lab analyses show that water penetration not a serious problem. Work consisted of stabilization of loose terra cotta with stainless pins and epoxy, removal of badly deteriorated units and replacement with precast concrete.

Levine, Jeffrey S., and Donna Anne Harris. "Masonry No. 2: Stabilization and Repair of a Historic Terra Cotta Cornice." *Preservation Tech Notes.* Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1991.

This *Tech Note* details the stabilization of the terra cotta cornice on the Land Trust Office Building in Philadelphia, PA, that included extending vertical and horizontal anchors through the cornice that tied into new and existing steel angles.

Marusin, Stella, and K.B. Kellermeyer. "Cleaning of the Terra Cotta in the Wrigley Building in Chicago, IL." *Third North American Masonry Conference, University of Texas-Arlington, June 3-5, 1985.*

Testing of chemical cleaners followed by scanning electron microscopy to evaluate effects on glaze surface. Best results with concentrated alkaline cleaner followed by dilute acid wash.

Matthews, Mary J. "Kansas City Experiments with Terra Cotta Replacement." *Friends of Terra Cotta Newsletter.* Vol. 2, No. 3 (1983), pp. 3-4.

Report on recent restoration of the Bellevue Hotel (Kansas City, MO), a National Register property restored to its original brilliance using precast concrete to replace terra cotta elements. The original granite-tex finish reproduced by casting duplicate pieces with integral color and specking with latex paint.

Pouchol, Jean-Marie. "Methyl Siliconate for Terra Cotta." *European Coatings Journal.* Vol. 11 (1990), pp. 633-636.

Discusses principal deterioration mechanisms of terra cotta under the influence of water and concludes that hydrophobic impregnation using silicone resins is suitable treatment. Aqueous solutions of potassium siliconate are preferred.

Prudon, Theodore H.M. "Architectural Terra Cotta: Analyzing the Deterioration Problems and Restoration Approaches." *Technology and Conservation.* Vol. 3, No. 3 (Fall 1978), pp. 30-38.

Manufacture and mounting of terra cotta panels and decorative elements on the facades of buildings in the U.S. (1880-1940). Terra cotta incorporated in wall or cladding experiences thermal expansion problems and deteriorating anchoring. Backfilling used to protect iron structure. Deterioration of glazes includes crazing and spalling. Moisture penetration causes expansion of terra cotta. Corrosion of anchoring systems. Restoration techniques discussed include substitution with concrete, application of acrylic coatings and epoxy grouting of blocks.

Rogers, Anne, and Doyle Wilhite. "Exterior Restoration of the West Virginia State Capitol: Cleaning and Structural Stabilization Procedures." *Technology & Conservation.* Vol. 4, No. 1 (1979), pp. 14-16.

Study of deterioration mechanisms including efflorescence. Preservation techniques include cleaning of stone and terra cotta, filling and grouting of mortar joints, epoxy injections, water repellent coatings and repair of broken stones.

Stockbridge, Jerry G. "Woolworth Building Renovation: Precast Concrete Used for Terra Cotta Facade." *Prestressed Concrete Institute Journal.* Vol. 28, No. 4 (1983), pp. 136-147.

Renovation of terra cotta facade of the Woolworth Building (New York City) where precast concrete has been chosen as alternate material for replacement of weathered units due to high cost and limited availability of original material. Investigation in the field and laboratory are discussed. Selection, fabrication and installation of replacements.

"Stone and Terra Cotta." *Progressive Architecture.* (June 1983), p. 94.

A short account of the revival in the tradition of crafts associated with ornamental masonry and the companies that produce cast stone as a form of pre-cast concrete with a dense and finely grained surface.

"Terra Cotta and Faience: Special Issue." *Friends of Terra Cotta Newsletter.* 1985.

Discussion of deterioration mechanisms, cleaning of surfaces, paint and stain removal for terra cotta and other masonry. Presented in clear concise format.

Thomasen, Sven, Geoffrey Rohnsdorff, and Barbara Horner. "Degradation and Rehabilitation of Terra Cotta." *Durability of Building Materials and Components. 2nd International Conference, Gaithersburg, MD, September 14-16, 1981.* Washington, DC: National Bureau of Standards, 1981.

Distress, deformation, ion and strain accumulation due to weathering and thermal movement in architectural terra cotta cladding are investigated. Field and laboratory tests show different types of failure. Causes of deterioration analyzed and recommendations for rehabilitation are discussed.

Tiller, de Teel Patterson. *Preservation Briefs No. 7: The Preservation of Historic Glazed Architectural Terra Cotta.* Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1979.

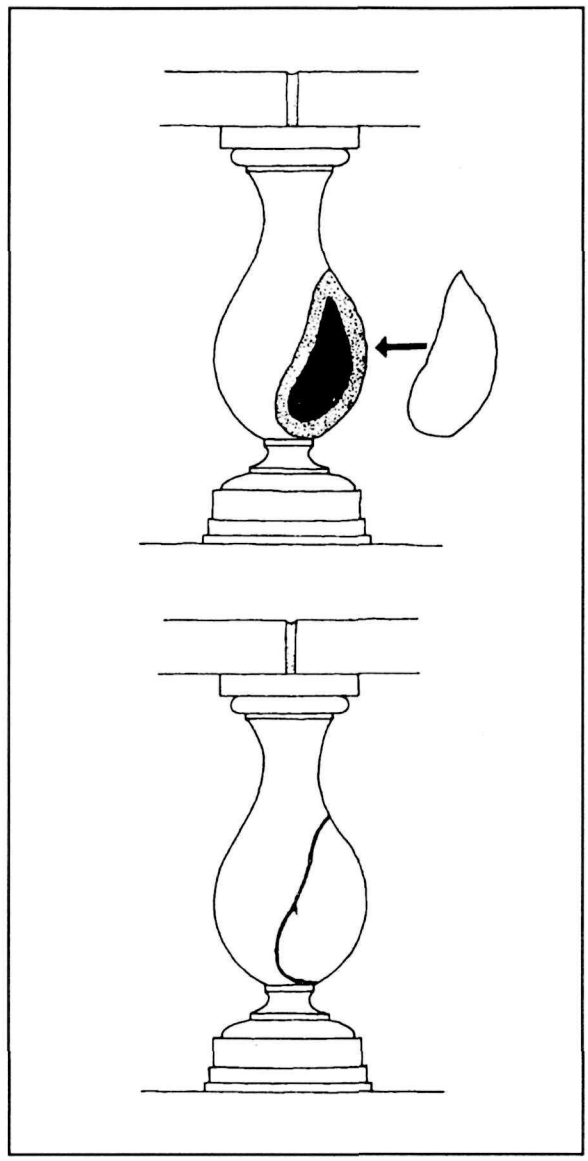
Definitions and types of materials and mounting details are discussed. Deterioration mechanisms include faults in design and manufacture crazing, spalling, anchor deterioration, mortar decay, stress, inappropriate repairs. Inspection and testing suggestions. Maintenance and restoration options include cleaning, waterproofing, repointing, substitution.

Tindall, Susan M. "Egyptian Theater." *Friends of Terra Cotta Newsletter.* Vol. 2, No. 3 (Fall 1983), p. 5, 14-15.

Report on the restoration of the Egyptian Theater (DeKalb, IL) in 1978. Special emphasis on facade cleaning and repair which made use of hand sponging for dirt removal and employed a soft lime mortar (tinted green to match the original) for repointing.

_____. "How to Prepare Project-Specific Terra Cotta Specifications." *Association for Preservation Technology Bulletin.* Vol. 21, No. 1 (1989), pp. 26-36.

Summarizes history of terra cotta production in the United States. Explains variables to be considered when specifying terra cotta replacement such as compressive strength, shear strength, modulus of elasticity, bending strength, absorption, hardness and expansion coefficients.



Epoxy repair of a broken terra cotta baluster in which epoxy is applied to the break. The broken piece is reattached and the joint smoothed so the repair is not visible. *Illustration:* Christina Henry.

_____. "Technical Notes." *Friends of Terra Cotta Newsletter.* Vol. 3, No. 1 (Spring 1984), p. 4.

Discussion of terra cotta crazing. Crazing is not necessarily indicative of water leakage. Painting probably does more harm than good. Most helpful repairs include repointing and repair of flashings and drains.

_____. "Terra Cotta Replacement." *Association for Preservation Technology Bulletin.* Vol. 20, No. 3 (1988), pp. 12-14.

Describes tests, visual and written documentation required for fabrication of terra cotta replacement units. Provides sample contract language.

U.S. Bureau of Standards. "Cleaners for Architectural Terra Cotta." *National Bureau of Standards Technical News Bulletin.* 131 (1928), p. 32.

Several chemical cleaners briefly evaluated. Alkaline cleaners perform best without damaging glazes while acidic cleaners clean well but leave the substrate badly etched. Sodium hydrosulphite determined best cleaner.

Concrete

"Concrete" is a name applied to any of a number of compositions consisting of sand, gravel, crushed stone, or other coarse material, bound together with various kinds of cementitious material, such as lime or cements. When water is added, the mix undergoes a chemical reaction and hardens. An extraordinarily versatile building material, concrete is used for the utilitarian, the ornamental, and the monumental. [From: *Preservation Briefs No. 15: Preservation of Historic Concrete: Problems and General Approaches.* William B. Coney, AIA. Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1987.]

General Reference

American Concrete Institute Committee 201 - 2R. 77. *Guide to the Durability of Concrete* (Reaffirmed in 1982). Detroit, MI: ACI Publications, 1982.

Guidelines for the basic understanding of concrete in consideration of repair and rehabilitation. Durability is defined as the ability to resist weathering action, chemical attack, abrasion, or other process which result in deterioration.

American Concrete Institute Committee 201 - 1R. 68. *Guide for Making a Condition Survey of Concrete in Service.* (Reaffirmed in 1979). Detroit, MI: ACI Publications, 1979.

This guide provides a system for reporting on the condition of concrete in service. It includes a checklist of details to be considered and provides standard definitions of forty terms associated with the durability of concrete.

American Concrete Institute Committee 345 - 1R. 83. *Routine Maintenance of Concrete Bridges.* Detroit, MI: ACI Publications, 1983.

This guide deals with various potential sources of distress in bridges. Guidelines for avoiding or correcting such problems are given with emphasis or day to day maintenance and the use of preventative maintenance guides.

Coney, William B., AIA. *Preservation Briefs No. 15: Preservation of Historic Concrete - Problems and General Approaches.* Washington, DC: Preservation Assistance Division, National Park Service, US Department of the Interior, 1987.

This publication gives a general overview on the historic uses of concrete and its manufacture. Causes of deterioration are explained, with examples of damage which occurred due to improper maintenance. Repair methods and guidelines for planning a preservation project are included.

Newlon, Howard Jr. "Evolution of Concrete Structures." *Structural Renovation and Rehabilitation of Buildings.* Boston Society of Civil Engineers, Nov. 1979.

An overview of the evolution of cement, concrete, reinforced concrete and related standards. Includes a bibliography of 68 references.

_____. *A Selection of Papers on Concrete 1867 - 1926.* Detroit, MI : American Concrete Institute, SP-52, 1976. (Reprinted by University Microfilm International - Out of Print Books on Demand.)

A selection of papers dealing with early concrete structures and their makers. Concrete mixtures and materials are listed and techniques are explained. Serves as an excellent primary resource for historic concrete research.

Neville, A.M. *Properties of Concrete.* New York, NY: John Wiley and Sons, 1975.

The book presents an integrated view of the various properties of concrete: workability, compressive strength, density, durability, tensile strength, impermeability, resistance to abrasion, resistance to sulphate attack, etc.

Deterioration Mechanisms

Abbatticchio, P., V. Amicarelli, and M. Petrella. "Effect of Calcium Chloride Content on Reinforcement." *Building Materials: Proceedings of the 1980 European Conference.* The Construction Press, 1981.

Chloride content in reinforced concrete is correlated with corrosion of reinforcement and possible structural failure. Four extraction methods for analysis are compared.

American Concrete Institute Committee 224. IR - 84. "Cracking in Concrete Structures: Why concrete structures crack and what to do about it." *Concrete International.* Vol. 7, No. 1 (January 1985). (Reprinted in ACI Journal, Vol. 81, No. 3 (May/June 1984), pp. 211 - 230.)

Identifies that cracks in a concrete structure do not mean the structure is unsound. Causes and preventative methods of crack repair are outlined.

American Concrete Institute. *Mechanisms and Control of Cracking in Concrete, SP - 20.* Detroit, MI: ACI Publications, 1968.

Published papers from a symposium dealing with basic mechanisms of cracking and how to identify them. Intrinsic, environmental, load and temperature are factors discussed. Practical preventative measures to control cracking and repair of cracks in concrete and reinforced concrete are included.

_____. *Durability of Concrete.* Detroit, MI: ACI Publications, 1975.

Includes seventeen papers on factors effecting the performance of concrete in various structures and environments. Freeze/thaw, marine environments and sulfate attack are addressed.

_____. *Performance of Concrete in Marine Environments, SP - 65.* Detroit, MI: ACI Publications, 1980.

Thirty three papers from twelve countries dealing with the durability of concrete when exposed to sea water. Outlines the mechanisms of corrosion of the reinforcement. Includes case studies by the U.S Army Corps at Treat Island, Maine, and navigational lock concrete with measurements of deterioration and repair techniques.

Bungey, J.H. *The Testing of Concrete in Structures.* London, England: Surrey University Press, 1982.

Handbook aimed at planning and interpreting results of non-site testing of structural concrete. The author points out wide variations in quality of concrete problems which are ever increasing. It includes surface hardness, ultrasonic penetration resistance, cores, loading, chemical and more complex tests, and analyses of their results and reliability.

Building Research Establishment. *The Durability of Steel in Concrete. Part 2, Diagnosis and Assessment of Corrosion - Cracked Concrete.* Digest no. 264. London, England: Her Majesty's Stationery Office, 1982.

The understanding of the mechanism of deterioration is necessary for a correct choice for repairs. Physical damage by impact, explosion, frost, fire. Flowchart of corroded iron replacement. Tests for carbonation and chlorides. Effect of corrosion on performance and overall structure.

Building Research Establishment. *The Durability of Steel in Concrete. Part 3, The Repair of Reinforced Concrete.* Digest no. 265. London, England: Her Majesty's Stationery Office. 1982

This digest deals with the protection of steel, bonding with substrate, use of bond aids: latex, cement mixtures or epoxy. Discusses requirements for repair materials.

Deloye, Xavier, Guy Maine, and Marie Jose Buisson. "Stalactites, concrete masses and efflorescence as a guide to diagnosis of chemical damages in structures." *Materials Science and Restoration. Proceedings of the International Conference.* Esslinger, 1983

The analysis of exudates (stalactites, concretions or efflorescence) gives a non-destructive method to detect the nature and degree of deterioration of building materials including concrete. About ten characteristic examples are reported.

Honeyborne, D. B. *Changes in the Appearance of Concrete on Exposure.* Building Research Station Digest (2nd Edition). No. 126 (1971).

Suggests that internal deficiencies are the main causes of the changes in appearance of concrete on exposure. The causes of such undesirable changes are explained as an aid to diagnosis.

Malhorta, V.M. *Testing Hardened Concrete: Non-Destructive Methods.* Iowa State University Press and American Concrete Institute, 1976.

A monograph on testing methods that can be used to monitor the behavior of historic concrete structures over a long period of time. These methods do not yield absolute values but provide an estimate of the properties of hardened concrete from which a repair program can be designed.

Mather, Katharine. "Preservation Technology: Evaluating Concrete in Structure." *Concrete International.* Vol. 7, No. 10 (October 1985), pp. 233-241.

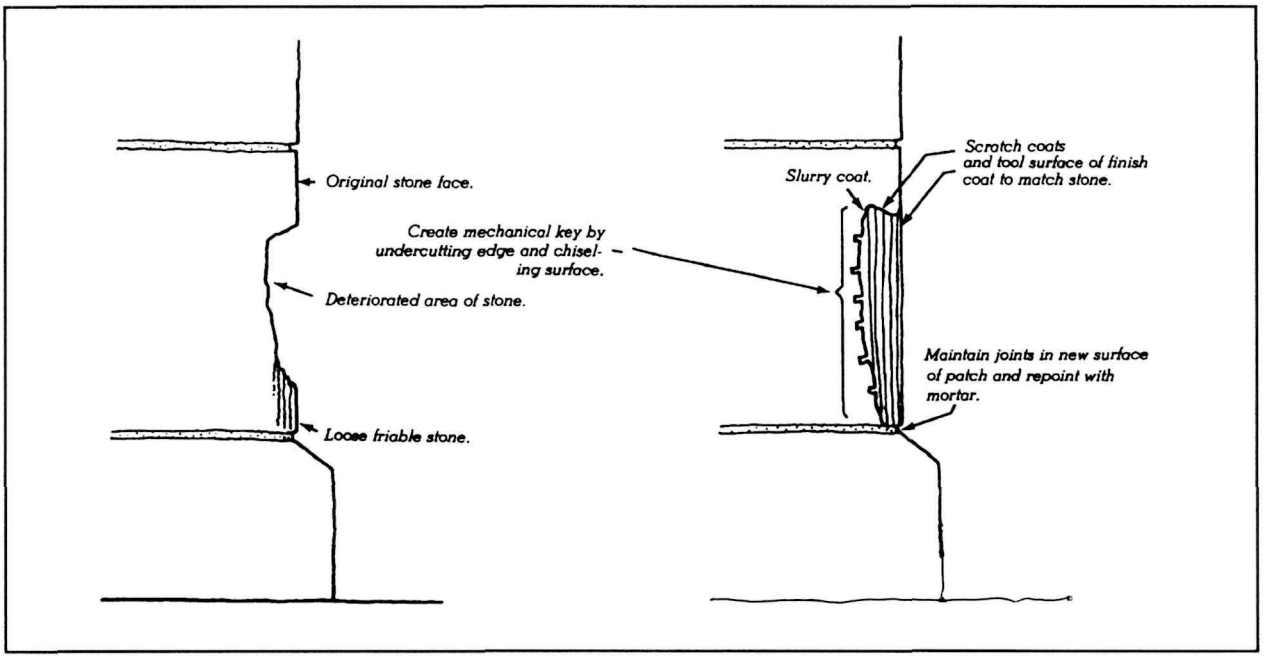
Discusses the need to evaluate the condition of concrete structures due to significance of visible evidence of changes, such as cracks, and the stability of the structure for rehabilitation, adaptive reuse, enlargement or extension or future uses of the structure. Evaluations are based on visual examinations, in-situ nondestructive testing, sampling and laboratory analysis. Appropriate laboratory analysis includes polarized light microscopy, X-ray diffraction, chemical tests and physical tests.

Morena, Elena Marcheso. "Causes of Deterioration in Reinforced Concrete." *Architecture.* (March 1988), pp. 132-133.

Identifies that many major causes of deterioration of reinforced concrete are intrinsic. Explains the deleterious relationship between the two materials and provides options for repair. Deals mainly with cases from the 1960's and 1970's, but the methodology can also be applied to earlier structures.

National Institute of Standards and Technology. "Models for Predicting Service Life of Concrete." *Durability of Building Materials and Components.* Proceedings of the Fifth International Conference. November 1990, pp. 361-373.

Guidelines for a comprehensive approach for predicting the service life of a concrete structure. Includes developing mathematical models, identifying experimental investigations to obtain data needed to solve and validate models, creating a database and developing test methods to predict concrete performance.



Composite patch of deteriorated stone section in which a cementitious patching material is used to fill in small cavities of missing stone. Patch material should be shaped to match the original profile of the stone and joints in new patched areas should be maintained, and repointed with mortar. *Illustration:* Christina Henry.

Portland Cement Association. *Concrete Inspection Procedures*. New York, NY: John Wiley and Sons, Inc., 1975.

Chapter 12 - Problems in Hardened Concrete - defines the most frequently encountered problems with concrete. Symptoms, causes and cures are outlined in this publication for the industry.

Powter, Andrew. "History, Deterioration and Repair of Cement and Concrete in Nineteenth Century Fortifications Constructed by the Royal Engineers." *Association for Preservation Technology Bulletin*. Vol. 10, No. 3 (1978), pp. 59-74.

History of lime binders and modern cement. Early 19th century concrete in building, mortar and renders, precast concrete, in-situ construction and formwork. Use of concrete in fortress construction after 1860. Outlines deterioration: cracks due to shrinkage, temperature difference in quality, iron joists in roof slabs, tree roots and frost. Disintegration caused by polluted water, inferior material, faulty mix and lime efflorescence and stains.

RILEM; American Society for Testing and Materials. *Rilem/ASTM/CIB Symposium on Valuation of the Performance of External Vertical Surfaces of Buildings*. Otaniemi, Finland. Helsinki, Finland: Technical Research Centre of Finland, 1977.

Proceedings from symposium dealing with temperature variations, heat loss, paint on concrete, steel corrosion, thermal expansion, and weathering of concrete. Protection of monumental buildings is discussed.

Scott, Gary. "Historic Concrete Preservation Problems at Fort Washington, Maryland." *Association for Preservation Technology Bulletin.* Vol. 10, No. 2 (1978), pp 123-131.

This work discusses the history, construction, and preservation problems of the eight surviving Endicott Batteries at Fort Washington, the former headquarters for the "Defenses of the Potomac."

Searls, Carolyn L., and Sven E. Thomasen. "Deterioration and Restoration of Historic Concrete Structures." *Structural Repair and Maintenance of Historic Buildings.* Edited by C.H. Brebbia. Computational Mechanics Publishing, 1989.

Concrete has been one of the most widely used building materials of the last 100 years. Many early structures are now beginning to require restoration and strengthening. The deterioration has commonly been caused by a combination of environmental factors, inferior materials and detailing and inadequate maintenance.

Swenson, E. G. "Durability of Concrete Under Winter Conditions." *Canadian Building Digest.* No. 116, Ottawa: National Research Council of Canada, 1969.

Deterioration due to frost action in concrete focusing on moisture as the critical factor with continuous or frequent wetting combined with aggravation of de-icing salts. Horizontal areas or ground level surfaces are most susceptible. Evidence of frost damage, scaling, map cracking, crumbling microstructure of concrete and moisture condition. Evaluates preventative measures and recommended practices to produce resistant concrete.

_____. Editor. *Performance of Concrete; Resistance of Concrete to Sulphate and other Environmental Conditions. A Symposium in Honour of Thorberger Thorvaldson.* Toronto: University of Toronto Press, 1968.

Papers presented at a symposium dealing with concrete performance in sulphate environments. Issues addressed are controlling sulphate attack and sulphate resistant repair materials. Field performance tests are included.

Tuthill, Lewis H. "Performance Failures of Concrete Materials and Concrete as a Material." *Concrete International.* Vol. 2, No. 1 (January 1980), pp. 33-39.

A review of what can go wrong with concrete structures and what to do to make sure things do not go wrong in concrete structures of all ages. A discussion of different materials and how they affect failure.

Volkwein, A., and R. Springenshmid. "Corrosion of Reinforcement in Bridges at Different Age due to Carbonation and Chloride Penetration." *Durability of Building Materials and Components, Second International Conference.* Gaithersburg, 1981. Washington, DC: National Bureau of Standards, 1981, pp. 199-201.

Twenty reinforced concrete bridges 12 to 80 years old were analyzed to check reinforcement corrosion due to chloride penetration. Reports that carbonated concrete is more affected than alkali concrete due to its higher porosity.

Whittman, F.H. (Editor) *Fundamental Research on Creep and Shrinkage of Concrete.* The Hague: Martinus Nijhoff Publications, 1982.

Includes papers on concrete bridges and methods to measure creep and shrinkage. Provides analytical techniques to evaluate deterioration of concrete structures.

Treatment and Repair

American Concrete Institute. "Concrete Repair and Restoration - Design and Construction, American Concrete Institute." *Concrete International.* Vol. 2, No. 9 (September 1980). (Reprinted as ACI Compilation No. 5).

An issue devoted to topics and case studies on the repair of concrete structures.

Cotton, Randall. "Repairing Ornamental Concrete Block." *Old House Journal.* Vol. 12, No. 1 (1984).

Repair techniques for ornamental concrete block: painting and cleaning, repair of cracks and deteriorated mortar joints, patching of disintegrated areas and large chips, replacing blocks, recasting of the new ones for replacement.

Dawes, Rosemarie. "Restoration of the Cleft Ridge Span." *Concrete International.* Vol. 7, No. 1 (January 1985), pp. 14-20.

A historical overview and the problems and solutions for this Frederick Law Olmsted and Calvert Vaux structure in Brooklyn's Prospect Park. The work described includes cleaning, consolidation and selective replacement to repair this cast concrete bridge.

Kuenning, W. "Removing Stains from Concrete." *Concrete Construction.* Vol. 31, No. 6 (June 1986), pp. 539-545.

This article, the first in a five part series, describes several methods for cleaning various stains on concrete. Chemical and mechanical cleaning techniques are discussed.

_____. "Methods of Removing Some Stains from Concrete: Aluminum to Finishing Discoloration, Part II." *Concrete Construction.* Vol. 31, No. 7 (July 1986), pp. 655-661.

Part II of the cleaning series, this article describes several techniques used for cleaning after the kind of stain has been identified. Some of the stains include asphalt, beverages, gum, bronze and copper, clay, dirt, and efflorescence.

_____. "Methods of Removing Some Specific Stains from Concrete: Fire and Soot to Moss, Part III." *Concrete Construction.* Vol. 31, No. 8 (August 1986), pp. 736-743.

Part III of the cleaning series describes cleaning techniques for graffiti, grease, ink, iron rust, and mildew.

_____. "Methods of Removing Some Specific Stains from Concrete: Oil to Wood, Part IV." *Concrete Construction.* Vol. 31, No. 9. (September 1986), pp.821-826.

Part IV of the cleaning series. Some of the stains included are paint, rainwater run off, tire skid marks, tobacco, wax and silica.

_____. "Chemicals for Removing Stains Part V." *Concrete Construction.* Vol. 31, No. 11 (November 1986), pp. 960-965.

Part V of the series. This article describes several chemicals used for cleaning concrete, how to find them, and safety precautions while using them. A concise table of information pertaining to each chemical is included.

Milner, John D. "The Use of Stucco and the Preservation of Mortar, Plaster/Stucco and Concrete." *Preservation and Conservation: Principles and Practices. Proceedings of the North American International Regional Conference*, 1972. Washington, DC: The Preservation Press, 1976, pp. 177-189.

Structural and decorative characteristics, conservation and preservation problems and techniques of mortar, plaster/stucco and concrete. Includes definitions, uses, problems of conservation and a bibliography.

Nenee, R.L. "Repairs and Restoration of Reinforced Concrete Columns." *Rehabilitation, Renovation and Preservation of Concrete and Masonry Structures*. Edited by Gajanan Sabnis. Detroit, MI: American Concrete Institute, 1985.

Presents an effective method of repair and restoration of reinforced concrete columns, which eliminates the drawbacks of the guniting process. It provides an in-situ reinforced concrete shell through the use of an epoxy coat.

Neville, Adam. Editor *Proceedings from Symposium on Creep of Concrete. American Concrete Institute Publication SP - 9.* Detroit, MI: ACI, 1964.

Six papers on different aspects of creep of concrete. Four papers deal with factors in creep and its prediction, its mechanisms and its effects and treatments in analysis. Two papers deal with the recovery of creep and creep in torsion.

Perkins, Philip H. *Concrete Structures: Repair, Waterproofing and Protection.* London, England: Applied Science Publishers, 1978.

Deterioration of concrete, steel and other metals used in structures. Repair of buildings and water retaining and water excluding structures. Marine environment and chemical attack are discussed. Testing methods of concrete are included in the appendix.

Philips, Paul. "A Cost-Effective Approach to the Investigation and Repair of Defective Concrete Structures." *Building Appraisal, Maintenance and Preservation. Proceedings from Symposium at the University of Bath.* London, England: Department of Architecture and Building Engineering, 1985.

Develops an approach to the long-term cost-effective repair of the legacy of defective concrete structures. Guidelines for crack investigation, testing methods, diagnosis of damages, techniques for both load-bearing and non load-bearing repairs of concrete structures.

Prudon, Theodore. "Confronting Concrete Realities." *Progressive Architecture*. No. 11 (1981).

Report on 19th century concrete construction and its repair including uses of concrete and historical development in concrete types such as the use of reinforcement. Includes causes of deterioration, composition mix, use of additives, corrosion of reinforcement, cracking, thermal expansion, repair techniques, resins, injections, gunite and reinforcement.

Rizzo, Edward M., and Martin B. Sobelman. "Selection Material for Concrete Repair." *Concrete International.* Vol. 11, No. 9 (September 1989), pp. 46-49.

Discusses properties necessary for successful concrete repair such as adhesion and bond, thermal movement and cracking, chemical deterioration of embedded steel, mechanical strength and ease of application. Methods for testing these characteristics are also outlined.

Sabnis, Gajanan. Editor. *Rehabilitation, Renovation and Preservation of Concrete and Masonry Structures, SP 85*. Detroit, MI: American Concrete Institute, 1985.

A collection of papers from three ACI symposia. Includes steps in modifying old structures for new uses, evaluating existing repair materials, selection of repair materials and non-destructive testing methods. Case studies are used for many of the papers.

Shoff, Avanti C. "Old Concrete Arches." *Concrete International*. Vol. 8, No. 5 (May 1986), pp. 52-57.

A methodological approach to the repair of the Pelham Parkway Bridge, in the Bronx, NY. An indepth inspection of the bridge was made using various inspections equipment and techniques. An innovative use of photographic techniques was used to prepare the report. Outlines the analytical tests undertaken to properly repair the bridge.

Tracy, Robert G., and Robert S. Fling. "Rehabilitation Strategies. " *Concrete International*. Vol. 11, No. 9 (September 1989), pp. 41-45.

Outlines a logical method to organize data for a restoration program. The three matrices include concrete condition survey with definitions, structure aspects investigation and repair program solution.

Van Gemert, Dionys, Vanden Bosch, and C.J. Mark. "Renovation of Reinforced Concrete Structures by Epoxy-bonded Steel Plates." *Materials Science and Restoration. Proceedings from the International Conference*. Esslinger, 1983.

Repair of damaged floors and beams by bonding steel plates on the surface of concrete is evaluated. Reports that long term exposure to 65 degree temperature (fahrenheit) causes weakening of the joint and calls for insulation measures. Steel must be sandblasted before adhesion, otherwise corrosion of iron at joints is likely to occur under open air exposure.

Warner, James. "Selecting Repair Materials." *Concrete Construction*. (October 1984), pp. 865-871.

A primer on the selection of repair materials for concrete structures for historical appropriateness and to prevent early repair failure.

Cast Stone

Cast stone is an artificial building stone manufactured from cement or mortar that is cast in a mold to be used as exterior trim, facing, pavement or ornament. Pigments and aggregate are often added to simulate the appearance and color of natural stone. [Due to the similarity between cast stone and concrete, reference should also be made to the concrete section.]

General Reference

Allan, W.D.M. "1931 -- A Year of Achievement in Concrete Masonry Industry." *Concrete.* (January 9, 1932), p. 135.

Contained in this general article on the masonry industry in 1931 is a note on the adoption of specifications for cast stone and concrete masonry by the Federal Specifications Board of the U.S. Government. Details on the manufacture, proper curing and fire-resistance of cast concrete blocks are provided.

"Artificial Stone." *The Manufacturer and Builder.* No. 1 (June 1869), p. 175.

Following the collapse of the Freedman's Hospital in Washington, DC, this article proposed the Coigent system of artificial stone, using a mixture of sand, hydraulic lime and a small quantity of water pounded into molds, as a viable alternative to patent building block with superior compressive strength.

"Artificial Stone." *The Manufacturer and Builder.* No. 3 (November 1871), p. 246.

Notes on several inventors of artificial stone; Ransome from England; Frear from Chicago; and Coignet and Sorel from France. The discussion focuses on Sorel and the use of magnesia for setting cement as a means of producing harder and a more durable product than ordinary lime mortar.

"Artificial Stone as a Building Material." *American Architect and Building News.* Vol. 14 (September 1883), pp. 99-100.

The advantages of using artificial and cast stone rather than natural stone are promoted in this short article.

Building Research Establishment. "Design and Appearance - 2." (Digest 46). *Building Materials, Essential Information from the Building Research Establishment.* Lancaster, England: The Construction Press, 1977.

This guide is complementary to Digest 45 of the British Building Research Establishment. The appearance of cast stone and various facing materials as a consequence of weathering is presented, compiled from examples throughout the country.

Chamberlain, William P. "Q. A. Gillmore and the Concrete Arch." *Concrete International.* No.1 (1985), p. 15.

This is one of two articles explaining the role of Quincy Adams Gillmore and precast artificial stone (beton agglomere) in the construction of the Cleft Ridge Span in Prospect Park, Brooklyn, New York. The bridge was cast on-site with intricately detailed period ornamentation and patterns in the ceiling, walls, and floor. The concrete was impregnated with different colored pigments to simulate various stones.

Childe, H.L. *Concrete Products and Cast Stone.* London, England: Concrete Publications Limited, (ninth edition) 1961.

This book is a thorough documentation of the materials and processes involved in the

manufacture of cast concrete, cast stone and prestressed concrete for decorative and structural architectural elements. The book is replete with photographs and diagrams illustrating examples and the various processes.

Code of Practice for Stone Masonry, British Standard 5390. London, England: The British Standards Institution, 1976.

This book applies a set of building construction standards for cast stone and other stone types, covering aspects of inspection and testing, thermal conductivity, mortar, metal dowels, damp proof courses as well as work off site and on site.

Cron, Frederick W. *The Man Who Made Concrete Beautiful, A Biography of John Joseph Earley.* Ft. Collins, CO: Centennial Publications, 1977.

The biography of John Joseph Earley chronicles the work of this fifth generation stone carver in Washington, DC, at the beginning of the twentieth century, who made a significant contribution to the development of precast concrete. Earley refined a technique for exposing the aggregate of concrete by freshly stripping "green" concrete. This architectural concrete was achieved by using step-grading of aggregate for a uniform appearance, and removing excess free water, and it was applied to precast concrete architectural elements. Major architectural and park projects in the Washington area are presented.

Due to extensive deterioration of green serpentine or green Maryland sandstone on the facade of this late 19th century rowhouse in Washington, DC, cast stone was used as a replacement material for the restoration. Photo: David W. Look, AIA.

"Federal Specifications for Stone: Architectural, Cast." *Federal Standard Stock Catalogue.* Section 4, Part 5 (November 10, 1931).

Specifications for cast stone and cast concrete adopted by the U.S. government for federal projects.

"Frear Artificial Stone, Patented 1868." *Journal of the Society of Architectural Historians.* Vol. 13, No. 1 (March 1954), pp. 27-28.

This is a short account of an American patent for concrete cast in molds. It includes a portion of an original pamphlet from the Metropolitan Museum of Art in San Francisco (undated) titled *Frear's Patent Artificial Stone, Stucco, Mastic Cement, Etc. and the Pressing Machine.*

Houghton, Albert Allison. *Concrete from Sand Molds: A Practical Treatise Explaining a Simple System of Molding Ornamental and Plain Concrete or "Cast Stone" with Molds of Wet Sand.* New York, NY: The N.W. Henley Publishing Company, 1910.

A small but well-illustrated and thorough "How-To" book written for the general reader who desires to apply the production of cast stone to everyday work. Chapters cover all aspects of cast stone, including mixture selection, making sand molds, casting from various pattern materials, and combining molds for large monolithic work. This book

could well be useful for contemporary cast stone repair and restoration work.

Huxtable, Ada-Louise. "Historical Survey." *Progressive Architecture.* 41 (October 1960), p. 147.

This is a broad, but well-documented survey of concrete, reinforced concrete, cast stone and concrete block construction. The historical account notes the use of each material related to architectural fashion, technology and economy.

Maccaig, Ian. "Cast Stone." *Traditional Homes.* Vol. 4, No. 2 (1987), pp. 117-118.

Definitions of artificial stone, including cast stone, reconstruction stone, reconstituted stone, plastic stone resin-bound substitutes, mineral fibre/cement stucco scagliola, and ceramic substitutes.

"Manufactured Stone." *Proceedings of the Second Convention of the National Association of Cement Users 2.* (1906), p. 269.

These proceedings discuss the various manufacturing techniques of cast stone and concrete, including types of finishes and molding techniques.

Mason, Joseph B. "Architectural Use of Cast Stone." *The Architectural Forum.* (August 1928), p.255-257.

This article describes the formation of the Association of Cast Stone Manufacturers, and discusses public perception of cast stone versus natural stone of the period. Included is information on its manufacture, its inherent qualities for molding of repeated elements that simulate natural stone in texture and color, and also its applicability for steel reinforced structural use.

Prudon, Theodore H. M. "Simulating Stone, 1860-1940, Artificial Marble, Artificial Stone, and Cast Stone." *Association for Preservation Technology Bulletin.* Vol. 21, No. 3/4 (1989), pp. 79-91.

This is a well-researched overview on the subject of artificial and cast stone, particularly in North America. The extensive footnotes are useful for pursuing the topic in further detail.

Ritchie, T. "Roman Stone and Other Artificial Stones." *Association for Preservation Technology Bulletin.* Vol. 10, No.1 (1978).

This article reviews the history of patents for artificial stone in Canada from 1824 with Joseph Aspdin to the end of the nineteenth century, including the Stevens' process of packing concrete in sand molds and its development by the Roman Stone Company.

"Specification for Cast Stone, ACI 704-44." *Journal of the American Concrete Institute.* Vol. 16, No. 6 (June 1945).

Specific recommendations and guidelines are established for the manufacture of cast stone, including mix, casting and finishes.

"Stone, Architectural, Cast." *Federal Specification, SS-S-721c.* Washington, DC: US Government Printing Office, 1964.

Federal specifications applied to the cast stone and artificial stone industry, with tables of accepted aggregate size, colors, and types of finishes.

"Stone and Terra Cotta." *Progressive Architecture.* (June 1983), p.94.

A short account of the revival in the craft tradition associated with ornamental masonry and the companies that produce cast stone as a form of pre-cast concrete.

Tucker, John, Jr., G.W. Walker, and J. Arthur Swenson. *The Physical Properties of Cast Stone.* Detroit, MI: American Concrete Institute, 1932. [Authorized reprint from *Journal of the American Concrete Institute.* Vol. 3, No. 4 (December 1931) ACI Proceedings, Vol. 28, p. 243.]

This paper is a result of tests made to establish a basis for the preparation of a Federal specification for cast stone. Samples were made of various textures using the common casting methods of wet-cast, dry tamped, puddled and the vibrated processes. The samples were submitted to tests for compressive strength, absorption and porosity, and freeze-thaw cycles. Results are reported along with charts and tables.

U.S. Department of Commerce, National Bureau of Standards. *Colors and Finishes for Cast Stone, Commercial Standard CS53-35.* Washington, DC: U.S. Government Printing Office, 1936.

This standard establishes the colors and finishes (including aggregate size, proportions of the mix, and method of molding) accepted for cast stone by the Bureau of Standards initially promulgated by The Cast Stone Institute in 1935. Also included as a guide, but not part of the Commercial Standard, are Federal Specifications and private specification guidelines, a list of associations and cast stone production firms.

Watson, Charles D. "Manufactured Stone." *Cement Age 2.* (1906), p. 838.

This is a short account of the various processes involved in the production of cast and artificial stone.

Whipple, Harvey. *Concrete Stone Manufacture.* Detroit, MI: Concrete-Cement Age Publishing Company, 1918.

This book covers the various manufacturing processes for concrete and artificial stone. It is well-illustrated, including plates, plans and diagrams.

Deterioration Mechanisms

Building Research Establishment. "Design and Appearance, 1-2." *Building Defects and Maintenance, Essential Information from the Building Research Establishment.* Lancaster, England: The Construction Press, 1974.

The effects of weathering of cast artificial stone, Portland stone, and other building materials are discussed in terms of appearance and architectural design.

Kaskel, Bruce, Bernhard Wonneberger, and Seymour Bortz. "Freeze-Thaw Durability of Cast Stone." *Concrete International.* Vol. 13, No. 11 (November 1991), pp. 32-7.

This is a technical article that describes the performance of air-entrained cast stone. The detailed programs follow ASTM testing methods and include tables and photos of samples and equipment.

Treatment and Repair

"Artificial Stone for Garden Architecture." *The Manufacturer and Builder.* Vol. 10 (January 1878), p.16.

This is a short description of the use of Coignet artificial stone as a substitute material instead of natural stone for reconstruction of the Gardens of Rentilly, Paris, France. Also mentioned is the construction of the Belvedere Terrace in Central Park, New York.

elomestnova, E.N., L.E. Bober, V.I. Vereshchagin, N.V. Mishunina, and T.V. Nikitenko. "Construction Materials Based on Melts of the Diopside-Phlogopite System." *Glass and Ceramics*. Vol. 46, Nos. 5-6 (January 1990), pp. 184-187.

This article focuses on the industrial application of cast stone and is specific regarding the compositional properties of mixtures used in wear-resistant stone castings. The technical information may be useful in the future development of special weather-resistant cast stone building materials.

Blatterman, John F. "Architectural Cast Stone." *Architectural Record*. 178 (June 1990), p. 115.

Potentially useful in restoration projects, this article describes the use of a spectrophotometer in combination with CAD software for objectively measuring color in the matching of cast stone architectural features to replace natural stone elements. The spectrophotometer measures the balance of lightness, chroma and hue in exterior light as well as interior lighting situations.

Dawes, Rosemarie. "Preservation and History of the Cleft Ridge Span: Restoration of the Span." *Concrete International*. Vol. 7, No.1 (1985), pp. 14-20.

This second article on the Cleft Ridge Span, in Prospect Park, Brooklyn, NY, deals with the preservation issues related to the elaborate ornament and polychromatic effects of the cast stone. Replacement and repair of deteriorated sections included recasting from historic stones and face-Dutchman repairs. Surface treatments and masonry consolidation was also described.

"Details Cast Stone." *Southern Living*. 23 (May 1988), p. 146.

This is a short article demonstrating contemporary examples of cast stone as a replacement material for interior and exterior architectural features.

Gauri, K. Lal. "Conservation of the California Building, San Diego, U.S.A. A Case History." *Deterioration and Protection of Stone Monuments, Preprints International Colloquium, Paris*. Louisville, KY: University of Louisville, Department of Geology, 1978.

A report on the deteriorated cast stone decorated surfaces of the California Building where heavy ornamentation was replaced with lightweight replicas of artificial stone and the existing cast stone was cleaned and consolidated. Also covered are repairs of adjacent structural elements and desired properties of the fabricated stone based on ASTM standards.

Jewell, Linda. "Cast Stone." *Landscape Architecture*. 76 (September/October 1986), pp. 122-5.

A brief overview of cast stone, including definitions, inherent characteristics and manufacturing processes, with examples of applications in architecture and landscape architecture. Also included is a list of cast-stone manufacturers.

Poerschmann, Moritz. "Causes and Avoidance of Cracking Implied from Technology." *Betonwerk und Fertigteil-Technik*. Vol. 55, No. 7 (July 1989), pp. 34-41.

This paper, from a technical German periodical on concrete, focuses on shrinkage cracking as exhibited by fine crazing in cast stone, related to the manufacturing process. The paper analyzes the requirements of cast stone production, cast stone mixes, and the use of concrete technology in cast stone manufacturing.

"Stone and Terra Cotta." *Progressive Architecture.* (June 1983), p. 94.

This is a short account of the revival of ornamental manufactured masonry as a replacement material in preservation projects, and includes a list of companies that can produce the material.

Szabo, E.F., and G.T. Szabo, Jr. "Cleaning and Restoration of the California Building, Balboa Park, San Diego, California." *Deterioration and Preservation of Stone Objects, 4th International Congress, Proceedings, July 7-9, 1982,* pp. 321-333.

The facade of the California Building is cast stone which required cleaning and consolidation. Massive free-standing ornamentation was replaced with fiberglass replicas, and highly damaged areas were patched with polymeric composites designed to duplicate the properties of cast stone. The repair work was performed in two phases, and the building was reported in excellent condition four to seven years later.

Wagner, Charles, and Ian Maccaig. "Cast Stone." *Traditional Homes.* Vol. 4, No. 1 (1987), pp. 10-20.

Various imitation stones, including cast stone and artificial stone, are described in this paper. The article begins with a historical introduction, describes manufacturing techniques and problems of durability, and includes recommendations for its conservation. Also included are British Standard Specifications, a bibliography and useful addresses in England.

Sources Consulted

A. Information Networks

1. Computerized data bases
    a. Getty Conservation Information Network
    b. WilsonDisk CD-ROM Data Base
    c. National Technical Information Service

2. On-line card catalogs
    a. RLIN (Research Library Information Network)
    b. Franklin (University of Pennsylvania On-Line Catalog)
    c. Drexel University On-Line Card Catalog

B. Books

1. General Conservation Texts (Relevant chapters)
2. Material Specific Texts

C. Periodicals

1. Conservation
    a. *Building Research Station Digest*
    b. *Bulletin of the Association for Preservation Technology*
    c. *Conservation News*
    d. *The Conservator*
    e. *English Heritage Magazine*
    f. *Journal of the American Institute for the Conservation of Artistic and Historic Works*
    g. *Preservation and Conservation: Principles and Practices*
    h. *Studies in Conservation*
    i. *Technology & Conservation*

2. General construction
    a. *Builder & Contractor*
    b. *Building Design & Construction*
    c. *Building Renovation*
    d. *Construction Specifier*
    e. *Engineering News-Record*
    f. *Manufacturer and Builder*

3. Architecture
    a. *American Architect and Building News*
    b. *Architectural History*
    c. *Architectural Record*
    d. *Architecture Review*
    e. *Journal of the American Institute of Architects*
    f. *Journal of the Society of Architectural Historians*
    g. *Landscape Architecture*
    h. *Progressive Architecture*
    i. *Renovation*

4. Material specific publications
    a. Concrete
        1. *Cement Age*
        2. *Cement and Engineering News*
        3. *Concrete*
        4. *Concrete Construction*
        5. *Concrete Engineering*
        6. *Concrete International*
        7. *Magazine of Concrete Research*
    b. Stone
        1. *Lithoclastia*
        2. *Stone Industries*
    c. Terra Cotta
        1. *Friends of Terra Cotta Newsletter*

5. Miscellaneous
    a. *American Scientist*
    b. *The Archaeological Journal*
    c. *Archeomaterials*
    d. *Heritage Australia*
    e. *Journal of the Minerals, Metals & Materials Society*
    f. *Journal of the Royal Society of Arts*
    g. *New Scientist*
    h. *Newsletter of the Association for Gravestone Studies*
    i. *Parks*

D. Professional organizations and their publications

1. American Ceramic Society
    a. *Bulletin of the American Ceramic Society*
    b. *Transactions of the American Ceramic Society*
2. American Concrete Institute
    a. *American Concrete Institute Journal*
    b. *Rehabilitation, Renovation and Preservation of Concrete and Masonry Structures 1985*
3. American Society for Testing and Materials
    a. Special Technical Publications
4. Associated General Contractors
5. Associated Builders and Contractors
6. Brick Institute of America
7. Building Research Establishment
8. Cement and Concrete Association
9. Central Council for the Care of Churches
10. Geological Society of America
11. International Association for Bridge and Structural Engineering
12. International Masonry Institute
13. Limestone Institute of America
14. Marble Institute of America
15. National Limestone Institute
16. National Masonry Institute
17. National Precast Concrete Institute

18. Portland Cement Association
19. Precast Concrete Institute

E. Government organizations and their publications

1. United States Department of the Interior, National Park Service, Preservation Assistance Division
2. United States Department of Commerce, National Institute of Standards and Technology, Building Materials Division
3. Smithsonian Institution, Conservation Analytical Laboratory
4. United States Army Construction Engineering Research Laboratory
5. National Institute of Building Sciences
6. National Trust for Historic Preservation
7. United States Army Corps of Engineers
8. United States Department of Transportation
9. United States National Research Council
10. National Research Council of Canada
11. National Trust of Australia, Sydney

F. Conference reports and proceedings

1. General conferences
    a. Building Materials. Proceedings of the 1980 European Conference
    b. Materials Science and Restoration. Proceedings of the 1983 International Conference, Esslingen
2. Material specific
    a. Concrete
        1. National Research Council (U.S. Transportation Research Board) 53rd Annual Meeting of the Highway Research Board
        2. International Conference on Performance of Concrete in Marine Environments, 1980
        3. Cement and Concrete Association. Annual Meetings (1935-1985)
    b. Brick and stone
        1. Conservation of Stone and Wooden Objects, New York, 1970 Preprints
        2. Proceedings of the Meeting of the Joint Committee for the Conservation of Stone, Bologna, 1971
        3. 1st International Congress on the Deterioration of Building Stone, La Rochelle, 1972
        4. ICOM Committee for Conservation, Venice, 1975
        5. 2nd International Congress on the Deterioration of Building Stone, Athens, 1976
        6. ICOM Committee for Conservation, Zagreb, 1978
        7. Conservation of Stone and Wooden Objects, New York, 1979
        8. The Conservation of Stone. Preprints, Bologna 1981
        9. ICOM Committee for Conservation, Ottawa, 1981
        10. 3rd International Congress on the Deterioration and Preservation of Stone, Venice, 1982

11. 4th International Congress on the Deterioration and Preservation of Stone Objects, Louisville, Kentucky, 1982
12. 5th International Congress on the Deterioration and Conservation of Stone, Lausanne, 1985
13. 6th International Congress on the Deterioration and Preservation of Stone, Torun, Poland, 1988
14. 7th International Congress on the Deterioration and Preservation of Stone, Lisbon, Portugal, 1992

G. Published bibliographies

1. Vance Bibliographies-Architectural Series

Granite, although one of the harder building stones, still lends itself to carving as illustrated in the carved cannons on these entry pylons at Fort Washington, 1858, Cambridge, Massachusetts. John R. Hall, architect. *Photo:* Cambridge Historical Commission.

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