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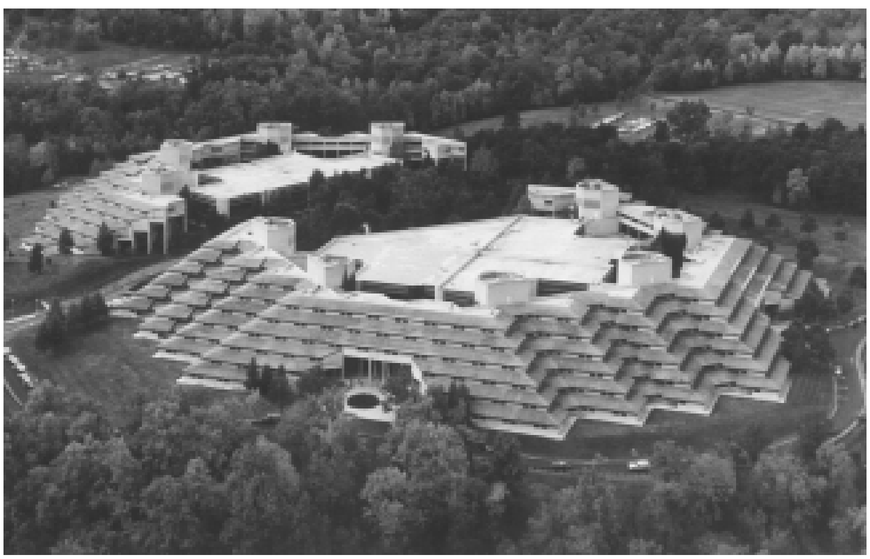
Concrete Repair: A Case of Weighing the Options

Bruce R. Soden

All concrete deteriorates; it's simply a question of when and to what extent. Pinpointing the cause of the deterioration requires expert knowledge and careful research. But the building owner's real challenge comes in choosing the repair solution that best satisfies the situation from among the alternatives presented by the design professional.



Aerial view of Xerox Document University in Leesburg, Virginia.

As Project Manager for Hoffmann Architects, Bruce R. Soden investigates and designs the remediation of concrete deterioration problems within facades, plazas, parking garages, and structural systems of existing facilities.

Hoffmann Architects is currently helping Xerox Corporation do just that. The firm has been working since 1993 on a complex concrete repair effort at Xerox Document University, a 1.25 million square-foot educational and training facility located just outside of Leesburg, Virginia.

In this case, the challenge for the firm, the client, and the client's facility manager, Premisys Real Estate Services, Inc., was to weigh the various repair methods against the project's multiple and often conflicting technical, cost, and facility usage issues. Each repair solution had differing implications for the budget and the occupants' ability to use the facility. For example, one repair solution fit the technical and aesthetic requirements, but exceeded the budget. In other cases, one solution met all technical and budget needs, but proved too disruptive to ongoing facility use.

Helping the client choose the best solution meant finding a concise and manageable method to sort through the pros and cons of each repair method to find the one which best answered the client's primary concerns and met the project's technical requirements. To do so, the firm used a simple yet innovative computer-based spreadsheet analysis.

This spreadsheet identified the various repair issues and assigned a technical weight factor to each based on how it related to the repair methods being considered. The client's key project concerns, called "importance factors" on the spreadsheet, were then identified and given numerical values, with 10 being the most important and 1 the least. Determining which repair method best satisfied the largest number of concerns was then a simple question of multiplying the importance factor by the technical weight factor. *(A sample spreadsheet is shown on page 3.)*

For the Xerox project, each repair method was measured against a number of concerns, including the following:

Extensive shoring and demolition is required for the "full removal and replacement" method.

- Its technical merit in resolving the problem.
- The client's budget and aesthetic expectations.
- The effect of the repair work on the occupants' ability to use the facility.
- The client's long-term plans for the facility. For example, a less expensive and less durable repair method would most likely be chosen for a building that would be phased out of use in a few years' time.

The Project

The facility, with more than 1000 resident rooms and 250+ classrooms, is a series of five interconnected buildings with substantial amounts of exposed concrete. Built in 1972-74, the concrete had experienced varying degrees of deterioration over the years. The primary problems of high water/cement ratios and low percentages of air entrainment were traced directly to the original concrete mix. Marginal concrete cover over the embedded steel, exacerbated by 3/4"-deep reveal strips, provided little protection for the steel and had led to extensive corrosion problems. High chloride content in the concrete at some locations also contributed to the problems.

By 1993, the facade had taken on an unsightly patchwork-quilt appearance, the result of numerous repairs by various contractors, with each employing different repair methods. In some cases, those repair solutions had the unwanted effect of hastening the deterioration through "patch effect." *(Patch effect is caused by the chemical interaction between patched areas. Each patched area creates a cell of new concrete which will most likely be of a differing pH content than the surrounding concrete. The interaction between the two can often speed up corrosion activity in adjacent areas.)* Another problem was the potentially dangerous level of deterioration in some column areas, where chunks of concrete were falling from the building facade to sidewalks below.

Xerox initially called in Hoffmann Architects in 1993 to conduct an existing conditions survey, evaluate the problems, and make recommendations for the repair. The "full removal and replacement" method was under serious consideration, although Xerox had legitimate concerns about the cost of this solution. Hoffmann Architects and Xerox agreed to treat a test area using this method, which required demolition and removal of the original concrete and replacing it with new.

Applying sodium carbonate in preparation for re-alkalization.

For the test treatment, the firm specified hydro-demolition to remove the concrete skin from two columns and a spandrel face. This required extensive shoring down to grade level through adjacent guest rooms. That meant gutting the guest rooms, removing built-in furnishings, walls, ceilings — and then restoring all areas to their original condition once the repair was completed. The net result was all new concrete from one monolithic pour, which provided a well-controlled chemistry, a good passivating film, and an aesthetically acceptable match with the original concrete facade. *(Concrete passivity is discussed in more detail in "Causes and Symptoms of Concrete Deterioration" on page 5.)* Although full removal and replacement offered an excellent technical solution for the long-term use of the facility, it was expensive and highly disruptive to daily usage. Hoffmann Architects and the client agreed that this was not a viable solution.

Hoffmann Architects then explored other alternatives, including "repair and coat" and "partial removal and replacement." The repair and coat method calls for repairing all deteriorated

Factored and Weighted Repair Comparison

Repair factors	Importance Factor*	Technical Weight Factors† Hydro Demo Full Rplcmnt Conc. Face	Segmented Repair Hydro Demo & Replcmnt	Repair & Cost	Remarks
Maintain existing concrete profile	6	5	5	5	
Corrosion protection	10	5	2	4	Repair of a segment is no guarantee that adjacent sections will not corrode.
Color & texture match among exterior elements	10	3	2	5	
Color & texture comparison of exterior or interior concrete elements	8	4	3	2	Color and texture will no longer match.
Reduce corrosion potential	9	4	2	4	Unrepaired segments may corrode. Coating reduces moisture intrusion.
Arrest present corrosion	10	5	4	4	
Reduced construction noise levels	10	1	2	5	
Limit promulgation of cracking	9	5	4	4	
Reduced shoring	9	2	3	5	
Reduced scaffolding	6	5	4	3	Coating requires access to spray and backroll.
Reduced disturbance to adjacent spaces	10	1	3	5	
Minimize stirrup & tie replacement	7	1	3	5	
Minimize impact on landscaping	5	1	3	3	
Best access	3	1	3	4	
Most weather-sensitive	5	5	5	2	Coating's limitations include no rain within 48 hrs.
Best long-term repair	10	5	3	3	
Consistency with original design	6	5	5	3	Interior concrete surfaces are expected to remain unpainted.
Least initial cost	7	2	4	5	
Least maintenance cost	8	5	4	3	Coated surface will need more frequent recoating.
Least exposure to added unit costs	5	1	2	4	
Least initial time on site	7	2	3	5	
Least maintenance time on site	5	4	3	2	
Repairs generally limited to plazas	5	4	5	3	Coat non-repair exterior surfaces to match.
Mitigation of poor quality concrete	7	5	4	3	Hydro-demolition is best removal method.
Reduction of chlorides at reinforcing	6	4	3	2	Hydro-demolition is best solution.
Factored totals**		633	596	703	

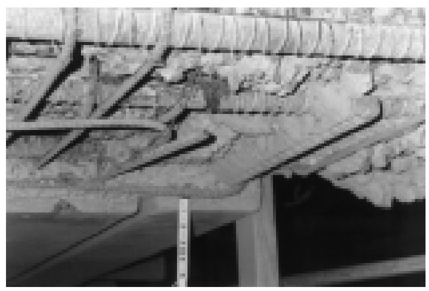
The above spreadsheet sample shows how three repair methods measure up in meeting key client concerns.
To aid in understanding the spreadsheet, please note the following:
* Importance Factor (Client's perspective on project issues): 10 = most important, 1 = least important
† Technical Weight Factors (Evaluates each repair method): 5 = most desirable technical attribute, 1 = least desirable techical attribute
** Factored totals are a sum of each Technical Weight Factor multiplied by the corresponding Importance Factor

sections and then treating the structural columns and beams with a migrating corrosion inhibitor and a breathable elastomeric coating. Partial replacement and removal requires demolition and replacement of deteriorated concrete.

Using the spreadsheet comparison, the firm found that "repair and coat" minimized disruptions to daily usage, met the client's budget, and fit the life expectancy requirements for the facility. It was also an excellent technical solution, and satisfied the project's aesthetic goals.

The elastomeric coating recommended for this project offered multiple benefits:
• It has recently been found to be highly effective in virtually eliminating any future intrusion of carbonation (a primary cause of deterioration in reinforced concrete structures containing porous concrete).
• It will visually match the exposed concrete on the building's interior, a key element in the original design and a major aesthetic concern for the client.
• It will create a unified appearance for the entire facility, eliminating the patchwork effect now present.
• Migrating corrosion inhibitors, used in combination with the coating, will mitigate future damage from chlorides, air, and moisture.
• The coating will easily bridge cracks of up to 1/16", a vital attribute, as the building's intricate geometry makes it difficult otherwise to compensate for thermal movement and the resultant cracking in the concrete face.
• Labor and scheduling issues are less costly than other repair methods.

Although the repair and coat method will create some additional maintenance costs for the facility, Hoffmann Architects has determined this to be the most cost-effective solution in the long run. Treated surfaces should greatly extend the life expectancy of the existing structure. That is not the case with partial removal and repair, where some repair areas may require reworking within three years. Total removal and replacement, on the other hand, will last thirty or more years — but is seldom a viable option due to the expense and extent of work.



Deteriorated concrete is removed with hydro-demolition.

Although Xerox has opted for the repair and coat method, the company is also interested in testing the effectiveness of re-alkalization, a repair method relatively new to the U.S. In response, Hoffmann Architects has treated one structural element using re-alkalization, and will be monitoring that test site periodically for comparison to the chosen repair and coat method.

The goal of re-alkalization is to set up a passivating film around the embedded steel. To do so, titanium mesh is attached to the concrete surface. A wood pulp mâché is applied to the concrete surface and the mesh, which is then sprayed with special chemicals designed to set up the passivating film. An electrical current is impressed through the mâché and mesh to force the chemicals into the concrete. One week is usually needed to force the chemicals to the depth of the reinforcing steel. The mesh is removed afterwards.

With the repair project now under construction, Hoffmann Architects will be documenting the effectiveness of both repair methods for the client. The firm is taking baseline readings of the electrical activity now occurring within the unrepaired columns. *(Electrical activity is associated with the corrosion of reinforcing steel within concrete, where a high electrical reading indicates a correlative increase in the potential for corrosive activity.)* Electrical probes have already been installed in the repaired columns, and an independent testing lab will monitor the electrical levels through periodic linear polarization readings over the next 12 months or longer. This monitoring will also be done in the test site using the re-alkalizing method, providing in-depth data on how well the two methods perform over time.

How Owners Can Get The Best Results

Most concrete repair projects deal with complex technical and performance issues, along with budget, scheduling, and aesthetic concerns. Reconciling these issues can be a major hurdle in the project process. The following guidelines may help owners achieve the

Vertical cracks in face of column at glass enclosure.

best solution:
• Focus on causes, not symptoms.
• Approach repairs holistically, rather than piecemeal. Concrete deterioration is seldom limited to a confined area, particularly if the problem is within the original concrete mix. If one area is deteriorating, be assured that adjacent areas are probably not far behind. Piecemeal repairs end up costing more in the long run, particularly poorly done ones.
• Be candid about budget issues and long-term expectations for the facility.
• Be realistic about how repair work will affect the facility's daily use, and let your consultant know what disruptions can be lived with.
• Identify long-term expectations for the facility up front to help determine the most cost-effective solution for the building's life span.
• Work with a consultant who is qualified to find the causes of deterioration and develop solutions which treat those causes, rather than one who focuses on treating symptoms only. The best choice would be an architect or engineer who has a proven track record on similar repair projects and in meeting a client's budget and schedule.

The spreadsheet has proven to be an invaluable planning and communication tool for Hoffmann Architects, Xerox, and Premisys Real Estate Services, Inc.. in developing a suitable solution for the Virginia project. The spreadsheet helped clarify complex issues during project meetings and allowed each team member to share and address specific concerns and viewpoints. The facility staff at Xerox and Premisys were also able to use the spreadsheet in-house to review various repair scenarios and to aid in the company's decision-making process. In the future, Hoffmann Architects expects to use similar spreadsheets to help other clients facing equally complex decisions.
■

Causes and Symptoms of Concrete Deterioration

Cracking is the primary cause of virtually all deterioration in reinforced concrete structures. Any cracks — visible or not — which develop in the protective concrete that covers the steel open the door to the damaging effects of water, oxygen, carbon dioxide, and chloride contamination. These in turn lead to further deterioration from corrosion, carbonation, damage from thermal change, and . . . more cracking.

All concrete will crack. Causes include shrinkage, volume changes in the concrete due to external thermal changes, poor placement of concrete, dynamic loads, and other structural and design problems. The solution, then, is to limit the entry of water, air, and other contaminants, and thereby slow down the inevitable.

The following describes the types of concrete deterioration and some suggested remedies for repair.

Corrosion of embedded reinforcing steel: Corrosion will affect all reinforcing steel over time, and there is no known way to halt this naturally occurring process once it has begun. Its effects can be mitigated, however. Corrosion occurs when steel is exposed to water and air, causing the formation of iron oxide (rust) on the steel. Over time, this cumulative process reduces the effective cross-sectional area of the reinforcing steel and compromises its structural integrity. In addition, the iron oxide can have up to four times the volume of the steel it replaces. This increased volume, in turn, exerts tremendous pressure (up to 4000 psi) on the surrounding concrete. The result is cracking and other structural problems.

Corrosion is accelerated by factors which increase the steel's exposure to air and water. These include inadequate concrete cover over the steel, cracks which allow water/air entry, chloride contamination, and carbonation.

Carbonation: Carbonation occurs on all exposed Portland cement surfaces. It takes place when carbon dioxide in the air or in rainwater reacts with compounds in the hardened cement paste, creating carbonates, primarily calcium carbonate. The most harmful result of this interaction is the reduced alkalinity of the affected concrete. During curing, concrete creates a natural passivating film which helps protect the embedded steel from corrosion. When the concrete's natural pH is decreased due to lowered alkalinity, the passivating film is compromised, and moisture and air can reach the steel, beginning the corrosion process.

In deterioration situations, carbonation is a usual suspect, and a chemical analysis of the damaged concrete is usually done to measure the extent of carbonation. Carbonation itself does not cause corrosion, but fosters an environment that hastens corrosion. Once damaged areas are repaired, a surface-applied elastomeric coating can help limit future carbonation problems by limiting the entry of carbon dioxide.

Chloride contamination of concrete: The presence of chloride ions will hasten natural corrosive activity, as these contaminants conduct electrical currents, accelerate the oxidation of iron atoms, speed the entry of water and air, and destroy the passivating film. Contamination can occur during the original mix if calcium chloride is used as a curing accelerant. The most prevalent source of chlorides, however, comes from de-icing salts used in snow and ice removal, as well as from chlorides present in the air in the form of acid rain.

Chloride contamination also reacts synergistically with carbonation, so that even low concentrations of chlorides can affect de-passivated concrete (concrete which has lost its protective passivating film due to carbonation) and hasten the corrosion of the embedded reinforcement. A lab test to measure the extent of contamination is usually done in most repair projects.

Inadequate air entrainment: Achieving the proper air entrainment during the original pour is critical to the life span of concrete. Air entrainment is a chemically achieved result which creates microscopic flat-sided "bubbles" within the concrete. This allows the concrete to more easily expand and contract during temperature changes and freeze-thaw cycles without cracking. Air entrainment can be measured through petrographic analysis in a testing laboratory. In repair situations, there is no way to improve air entrainment percentages in existing structures.

Solutions:
There are four key steps to take to achieve the overall goal of preserving reinforced concrete structures:
• Reduce and safeguard against the potential for causative cracking.
• Reduce the natural electrical activity within the concrete (which causes the steel to electrochemically react with any moisture within the concrete).
(continued on page 8)

The Facility Manager's Bookshelf: **Concrete Rehabilitation Strategies**

A. Technical Articles: Concrete Assessment and Analysis

1. Chung, Hung W. "Assessment of Damages in Reinforced Concrete Structures," *Concrete International,* Vol. 16, March 1994, p. 55-9.
2. Thompson, Neil G.; Islam, Moavinul; Lankard, Dave A. "Environmental Factors in the Deterioration of Reinforced Concrete," *Materials Performance,* Vol. 34, September 1995, p. 43-7.
3. Yuan, Ying-Su and Marosszeky, Marton. "Analysis of Corroded Reinforced Concrete Sections for Repair," *Journal of Structural Engineering,* Vol. 117, July 1991, p. 2018-34. Discussion: Vol. 118, September 1992, pps. 2634 - 36.

B. Technical Articles: Corrosion

1. "Preventing Further Corrosion in Repaired Concrete," *Concrete Construction,* Vol. 34, June 1989, p. 558-9.
2. Wheat, H. G. and Harding, K. S. "Galvanic Corrosion in Repaired Reinforced Concrete Slabs — An Update," *Materials Performance,* Vol. 32, May 1993, p. 58-62.
3. Worthington, J. C.; Bonner, D. G.; Nowell, D. V. "Influence of Cement Chemistry on Chloride Attack of Concrete," *Materials Science and Technology,* Vol. 4, April 1988, p. 305-13.

C. Technical Articles: Surface-Applied Corrosion Inhibitors

1. McGovern, Martin S. "A New Weapon Against Corrosion: Surface-Applied Corrosion Inhibitors Extend the Life of Reinforced Concrete Structures and Can Reduce Concrete Removal Costs," *Concrete Repair Digest,* June/July 1994, p. 185.
2. "Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques. Corrosion Inhibitors and Polymers." SHRP-S-666. Strategic Highway Research Program, National Research Council, July 1993.

D. Technical Articles: Corrosion Inhibiting Admixtures

1. Nmai, Charles K.; Farrington, Stephen A.; Bobrowski, Gregory S. "Organic-based Corrosion-inhibiting Admixture for Reinforced Concrete," *Concrete International,* Vol. 14, April 1992, p. 45-51.

E. Technical Articles: Cathodic Protection

1. Polder, Rob. B.; Nuiten, Peter C. "A Multi-element Approach for Cathodic Protection of Reinforced Concrete," *Materials Performance,* Vol. 33, June 1994, p. 11-14.

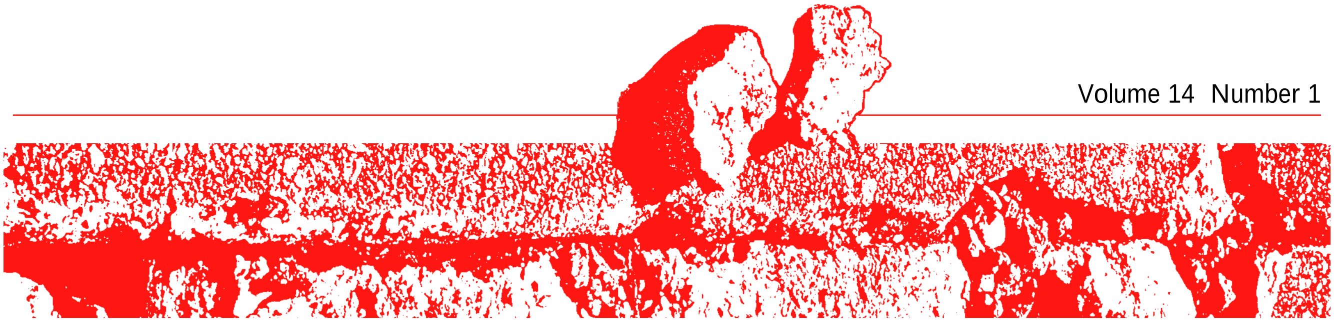
F. Technical Articles: Re-Alkalization and Chloride Removal

1. Wright, Andrew, G. "ZAP! No More Concrete Chlorides (Electrolytic removal of chlorides from concrete by Norcure process)," *Engineering News Record,* Vol. 231, December 6, 1993, p. 29.

G. Additional resources:
Catalogs of related publications are available free of charge from the following organizations:

1. American Concrete Institute (ACI), P.O. Box 19150, Detroit, MI 48219-0150, (313) 532-2600, fax (313) 538-0655
2. American Society of Civil Engineers (ASCE), 345 E. 47th Street, New York, NY 10017-2398, 1-800-548-2723, fax (212) 705-7300.
3. National Association of Corrosion Engineers (NACE), P.O. Box 218340, Houston, TX 77218, (713) 492-0535, fax (713) 492-8254

Compiled by Alan P. Eddy, Technical Information Specialist ■



REPRESENTATIVE PROJECTS

Concrete Rehabilitation

Hoffmann Architects has worked extensively with numerous clients in resolving deterioration problems in structural reinforced concrete. The firm's architects and engineers develop repair recommendations after conducting a thorough analysis of existing conditions and diagnosing the causes of deterioration. Repair options are researched and evaluated based on technical merit and ability to meet budget, life cycle goals, occupancy needs during construction, and aesthetic considerations.

Once the repair method has been selected, the firm prepares detailed plans and specifications for competitive bidding. On-site project staff and contract administrators track the progress and quality of construction throughout the project.

Hoffmann Architects has resolved concrete deterioration problems for a variety of facility types. Among its projects are the following:

State University of New York
Health Science Center
Brooklyn, New York
(State University Construction Fund)

Union Carbide
Corporate Headquarters
Danbury, Connecticut
(Union Carbide Corporation)

Bishop's Corner
West Hartford, Connecticut
(Samuels & Associates)

340 George Street
New Haven, Connecticut
(Southern New England Telephone)

General Electric
Corporate Headquarters
Fairfield, Connecticut
(General Electric Company)

1166 Avenue of the Americas
New York, New York
(Marsh & McLennan Companies, Inc.)

George Washington University
Smith Hall
Washington, District of Columbia
(George Washington University)

Sheraton University City
Philadelphia, Pennsylvania
(MetLife/Continental Companies)

Northeast Utilities
Berlin, Connecticut
(Northeast Utilities) ■

NYNEX, 222 Bloomingdale Road in White Plains, New York.

Met Life Building in New York, New York.

• Prevent air and water from reaching the embedded steel.
• Prevent chloride contamination.

Severe spandrel spall over east entrance of Xerox Document University.

The following recommendations can help achieve these goals:
• Carefully control mix proportions during the original pour to limit the amount of chloride ions in the mix. Ensure adequate air entrainment to minimize the potential for cracking that can occur during temperature changes. Consider using silica fume and other admixtures.
• Remove damaged areas and replace with relatively non-porous patching material.
• Ensure proper drainage for concrete floor slabs to avoid pooling water, which is likely to contain contaminants.
• Cover reinforcing steel with a minimum of 1-1/2" of concrete dense enough to limit the migration of chlorides, water, and air. Under severe conditions, 2" to 2-1/2" is recommended.
• Eliminate chloride use near exposed concrete surfaces wherever possible and consider using less damaging alternatives to de-icing salts, such as calcium magnesium acetate.
• Apply protective coatings to inhibit the intrusion of chlorides, air, and water, which in turn slows carbonation.
• Use repair mortars that contain corrosion-inhibiting agents, and apply migrating inhibiting agents to areas which have not been replaced. Corrosion inhibitors displace chloride ions at the surface of the reinforcing steel, thereby providing a protective film.
• Use cathodic protection, which applies an electrical current to the concrete over a period of time as a way to re-direct the flow of electrically charged ions away from the steel.
• Use re-alkalization, which restores the natural pH of the concrete through the application of special chemicals that are impressed by means of a low-voltage current. ■

JOURNAL is a publication of Hoffmann Architects, specialists in investigative and rehabilitative architecture/engineering, including the analysis and solution of problems within roofs, exterior walls, glazing, and structural systems of existing buildings, plazas, and parking garages.

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