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.

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:

- 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.

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 concrete and replacing it with new.
### Factored and Weighted Repair Comparison

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

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 technical 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 replace-
ment 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 contain-
ing 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 Archi-
tects 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 effec-
tiveness 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 compari-
son 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 reinforc-
ing 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 correla-
tive 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.
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)
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.

MetLife 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.

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