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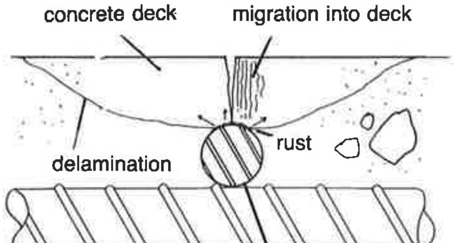
Preventing Reinforcement Corrosion in Parking Garages

by John Hoffmann, AIA

When the steel reinforcement in a concrete parking garage corrodes, the deterioration to the concrete caused by the swelling of the rust results in severe problems and expensive and time consuming repairs. If the problems are not solved in time, the progressive nature of the rust/crack/rust cycle can eventually result in an unsafe structure. By good design and construction practices, preventing or at least slowing the onset of corrosion in the reinforcement is possible. Use of materials to keep corrosive agents from reaching the steel or methods to prevent the electrochemical reaction can also help.

Structural steel and reinforcing bars left out in the open will rust. But, reinforcing bars properly encased in concrete do not rust because the alkaline environment of the concrete does not support corrosion. When the steel is exposed to the corrosive atmosphere created by the presence of chloride salts and water, the acidic environment sets up a chemical reaction similar to that of a giant battery. As the chloride ion amounts vary, so do the amounts of electric potential in the steel rebar. This causes electricity to flow from one part of the steel, the anode, to another, the cathode. The iron ions migrate away from the corrosion site and react with oxygen to form iron oxide – rust. Rust has a volume of four times that of the steel from which it was created. This expansion in volume puts great forces on the concrete causing cracks. Through the cracks, more water and chloride salts enter the concrete causing further rusting, which causes more cracking, delamination, more rusting, more cracking in a progressive cycle of deterioration.



concrete deterioration due to rust expansion

testing adhesion of deteriorated concrete to reinforcing bars

Construction Requirements

The first defense against corrosion is proper design and construction. Due to the special exposure of parking garages to deicing salts, careful attention must be given to the requirements as specified in the American Concrete Institute (ACI) Manual of Concrete Practice, especially ACI 318, Building Requirements for Reinforced Concrete, to be sure of concrete that will resist chloride ion intrusion. These requirements are:

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1. Sufficient air entrainmentment (air content). This will help to minimize the spalling caused by freeze thaw. Salts will concentrate in low spots, such as spalls.
2. Low soluble chloride ion content from ingredients. Use of chloride accelerators was common at one time to compensate for slow strength gain during cold weather concrete. New accelerators have been developed that do not use calcium chloride and reduce the potential for chloride intrusion.
3. Moist condition curing for a sufficient length of time to prevent cracking. Cracks caused by shrinkage during curing can allow salt water to easily penetrate the slab and attack the steel.
4. Use of minimal amounts of water. The chloride ions do not need cracks to get to the steel surface. They can enter the concrete through the capillaries formed during curing. The lower the ratio of water to cement, the less porous the resulting concrete will be. A reduction in the water/cement ratio of less than ten percent (from .51 to .40) will result in an *80% reduction* in porosity!
5. Maintaining minimum levels of concrete cover over the reinforcing bars — 2 inches over ¾ to 2-¼ inch diameter bars, and 1-½ inches over ⅝ inch diameter and smaller bars. When the reinforcing steel is too close to the surface, the potential for deterioration is increased dramatically since the chloride ions do not need to travel far to disturb the alkaline environment of the concrete. Also, the top surface of the concrete is more prone to cracking due to shrinkage, temperature differentials, etc. and will more easily let the salt water in to attack the steel.

Other design and construction procedures can also help prevent corrosion by keeping salt water off the steel. First, it is imperative that proper drainage be designed and installed to remove salt laden water and eliminate puddles where the salts will concentrate. Second, the use of fibers as an additional reinforcement can help to minimize cracking which will slow chloride penetration.

Cathodic Protection

One way of protecting the steel is through cathodic protection. In this method, the corrosion is stopped by reversing the processes of electrochemical action that cause the corrosion. By applying a direct current to the rebar in opposition to the current causing the corrosion, the corrosion causing current is overcome. According to ACI 222R - Corrosion of Metals in Concrete, "Although cathodic protection is a viable method of protecting reinforcing steel against corrosion in new construction, most installations to date have been to arrest corrosion in existing structures." Cathodic protection eliminates the electrochemical action that causes the corrosion but has several design requirements to fulfill that, if not properly addressed, will cause the system to not work, at best, or damage to the concrete at worst.

1. Excessive current density has a detrimental effect on the concrete. Anything over ten milliamperes per square foot of anode surface area will cause the alkaline concrete to react with the acid generated by the anode.
2. Current distribution within concrete is not good so it is difficult to provide protection more than six inches from the anode. Thus the anode material used must be placed no more than 12 inches apart.
3. The anode material must remain continuous throughout the structure. Although in most cases, the construction methods using rebars, ties, metal chairs, etc. will fulfill this requirement, it must be tested and verified.
4. The system must be designed to eliminate voltage drop and take into consideration the different amounts and placements of reinforcement throughout the structure.

The system is, in general, more costly to install than other methods, but if designed, installed and maintained properly, will not allow corrosion to begin.

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photo courtesy of Matcor, Inc.

installing anode material in cathodic protection system

photo courtesy of Matcor, Inc.

installing wearing surface over anode

Sealers

Various types of sealers have been used to prohibit or slow the penetration of chloride ions into the concrete. Some of these are silanes, siloxanes, acrylic copolymers, fluorosilicates, and boiled linseed oil. Most of these materials are curing compounds, and, in truth, market themselves as such with an aside that they are also sealers.

The intent of the sealer is to close off the pores in the concrete, thereby slowing or prohibiting the migration of chloride ions into the concrete. They are relatively low cost methods, but care must be taken in specifying them.

1. Sealers do not bridge cracks. Although the porosity of the surface of the concrete is reduced, the sealer cannot guard against chloride instrusion through cracks that may develop. This is a large disadvantage since very rarely does a slab not crack somewhere.
2. Most sealers require maintenance in that they need to be reapplied, generally every two to three years.
3. Depending on the formulation, sealers can be toxic, highly combustible, or require special handling. All require ventilation during installation.
4. Installation of some formulations will interfere with the installation of concrete toppings or grout.
5. Some formulations will darken the appearance of the concrete.
6. The usefulness of the sealer is directly dependent on the amount of penetration into the concrete. Since the application rates are on the order of 200-400 square feet per gallon, the applied thickness is only .03 - .07 inch.

installing sealer - note darkening of concrete

Coatings

Coatings are generally liquid polyurethane formulated to act as a barrier to water migration to the steel. They have an advantage over sealers in that, being elastomeric in nature, they can stretch to bridge small (up to $^{1}/_{16}$ inch) cracks in the substrate. Larger cracks can be filled with gunnable sealants before applying the coating to create the same barrier over larger cracks. This keeps the corrosive salt water from ever reaching the steel. Coatings can improve the appearance of the deck since the coverage is total and the color opaque. There are several things to keep in mind before specifying coatings.

1. The cost per square foot is generally greater than other liquid applied materials.
2. Coatings require regular maintenance and need to be reapplied when worn or damaged.
3. Since the coatings rely on adherence to the deck for long term performance, the concrete must be completely clean and dry before application, and free of ridges, sharp projections or other defects.
4. The coatings will not stick to decks using chlorinated rubber, wax, or resin base curing compounds, nor will they adhere to grease, oils or tar.
5. Steel deck, over which concrete is poured, must be perforated to allow escape of trapped moisture on exterior exposed applications. Moisture trapped below the coating will cause it to blister.
6. Where aggregate is not applied, the surface of the coating may become slippery when wet.
7. Product is flammable during application.

Overlays

Overlays are generally used as a repair method for existing structures. Various additives and modifiers are used in the overlay mix to improve bonding capability to the existing structure or to lessen the porosity. Regular portland cement concrete is most used as an overlay. Its advantages are lowest cost, familiarity and compatibility with existing concrete. A thick (3 inches) layer must be used that adds a significant amount of weight to the structure. This means that an evaluation must be done to determine if the structure can support the added weight. Bonding agents are usually required to assure that the overlay will not delaminate from the existing concrete.

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concrete deterioration in parking garage

Latex modified concrete (LMC) is used as a thin overlay. The polymer latex forms a film within the concrete which coats the walls of the capillaries. This gives it a greater resistance to water penetration than plain portland cement concrete. It also adds flexural strength and keeps cracks from opening up and reduces shrinkage cracking. However, it also has special handling requirements in that the LMC should not be mixed for more than 5 minutes, making on-site batchers imperative. Also, the latex modified concrete has a working time as short as ten minutes, thus requiring that placement and finishing be done very quickly. Latex modified concrete is very expensive.

Polymer impregnated concrete reduces water and chloride ion penetration by filling the voids in the concrete. The polymer replaces the water in the capillaries with solid material. The main disadvantage is that, although water and chloride ions are inhibited from penetrating through the concrete itself, they will still enter through cracks.

Coated Reinforcing Bars

Galvanized or epoxy coated reinforcing bars can resist chlorides that reach the steel even through cracks. The epoxy coating acts as a barrier to keep the chlorides from contact with the steel. Galvanizing sacrifices the zinc coating to the electrochemical action, and resists steel corrosion only as long as there is sufficient zinc to sacrifice.

The reinforcing bars to be epoxy coated are first cleaned to near white metal. This ensures that no built-in rust problems happen. The epoxy is applied to the steel in a powder form. The steel and coating are subjected to temperatures of about 450 degrees where the epoxy melts and cures. This in-factory application assures minimal voids and thin spots in the coating.

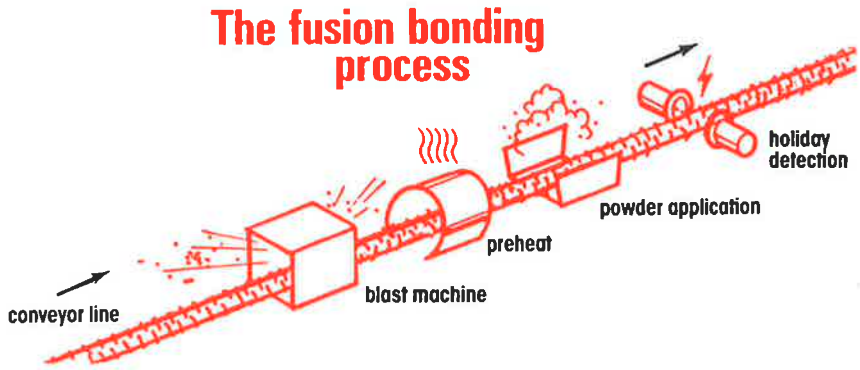
The problem with coated reinforcing bars is that the coating can be abraded during handling and installation. Thus, the bars require special handling and storage. The bundles must be tied with padded ties, and the bundles picked up at multiple points to keep the coating from cracking. Sharp bends during installation will cause the coating to crack. Each bar must be carefully bent and inspected for voids, cracks or thin spots. These defects and any cut ends must be repaired. Wherever a crack or void in the coating occurs, corrosion will result.

The advantage of epoxy over galvanized is that the epoxy coating will last longer. Epoxy coated bars are preferred by installers, since the coating causes the bar to be less rough on the hands. The advantages of galvanized bars are that the coating can more easily be repaired than epoxy and, in general, they cost less.

Conclusion

No individual strategy for reducing the risk of chloride induced corrosion in concrete parking structures can work in all cases. A belt and suspenders approach, utilizing the advantages of one system to offset the deficiencies of another, is the best way to deter corrosion. Each system has its advantages and disadvantages. All cost money to implement. Each will require proper design and installation to work. Nevertheless, the cost and inconvenience of preventing corrosion in a parking garage is far less than rehabilitating the garage when it fails.

courtesy of 3M Corporation



Representative Projects

Hoffmann Architects continues to provide specialized consulting services for **roofing, exterior wall** and **structural problems.** The following is representative of our recent projects:

Roofing

Architectural services, including preparation of construction documents and assistance in the bidding process, will be provided by the firm for the reroofing of the **New York Hilton Hotel** in New York City.

Hoffmann Architects is inspecting eleven buildings in the Bronx, New York, for **Consolidated Edison Company.** The roofs on these buildings include metal, built-up, tile, slate and asphalt shingles.

Sylvan Lawrence Company, New York City

Williams Center, Tuscon, AZ

For **Sylvan Lawrence Company, Inc.,** a New York City real estate developer, the firm surveyed a newly installed modified bitumen roofing system to report on its condition and the adequacy of the insulation.

Roofing and Facade

The firm inspected the seven year old EPDM single ply roof and the brick masonry facade at **GE Capital Corporation** in Stamford, Connecticut. The roof survey was done to point out any existing defects while the 67,000 square foot roof was still under warranty.

Parking Garage

HRA, Inc., the realty advisory arm of the **Hartford Insurance Group,** commissioned Hoffmann Architects to investigate the causes of leakage at the parking garage of Williams Center, an office building located in Tuscon, Arizona.

Other

At the Monterrey Village Apartments, a 120 unit garden apartment complex in Modesto, California, Hoffmann Architects surveyed the condition of the balconies for **Goldman, Sachs & Co.**

Facade Rehabilitation

The firm is also surveying the condition of the steel sash windows on a building in New York City for **Sylvan Lawrence Company, Inc.** The building, twelve stories high, covers approximately half of an entire city block.

Hoffmann Architects is continuing its services at historic Rockefeller Center with facade inspections on four buildings managed by **Rockefeller Center Management Company.** They are as follows:

As a precursor to a cleaning of the building, Hoffmann Architects was commissioned to examine the 54 story Exxon Building to determine the condition of the facade and check to see if water intrusion would occur. The building, owned by the Japanese firm **Mitsui Fudosan (New York) Inc.,** is limestone faced with piers and windows in vertical bands.

At the 33 story Warner Communications building, Hoffmann Architects is investigating a one story glass wall and granite fascia. At 10 Rockefeller Plaza, the firm is conducting a curtain wall survey of the 16 story limestone and bronze facade. The firm surveyed a two story high glazed curtain wall of the Simon & Schuster building.

GE Capital Corporation, Stamford, CT

technical notes

How to Handle the Curled Joint

Peter Craig, Materials Specialist
JK Sales, Topsham, ME

An effective and attractive solution to the problem of curled joints in industrial floor slabs has been developed by concrete technicians at Floortech, Lewiston, ME.

The 'curse' of curling

Curling is an oft-encountered cast-in-place flatwork problem. It is caused primarily by differential drying shrinkage between the top and bottom of a slab.

When a slab curls, the ends of slab sections or placements actually lift, to varying degrees, off the substrate. The trouble occurs when heavy wheeled loads travel across undoweled curled joints. As the load approaches the joint, the temporary settling of the loaded section can expose the top edge of the adjacent section. Exposed, the joint edge can easily be broken as traffic continues across the joint. Repeated travel across a badly curled joint can result in significant concrete deterioration to the point that high loads can be jolted, tossed and damaged. Travel may have to be restricted.

How to correct curling

To correct the curled - joint situation effectively, the slab sections must first be stabilized. A series of holes are drilled through the slab on each side of the joint and fluid non - shrink grout is pumped in to fill the void beneath the slab. In the case of broken or spalled edges, parallel saw cuts are made on each side of the joint to a minimum depth of one inch and to a width sufficient to encompass the entire spalled area (generally not less than one inch on each side of the joint.) The concrete between the saw cuts is removed mechanically and checked thoroughly for soundness and cleanliness. The area is then primed and filled with epoxy mortar.

The following day the joint is re-cut, cleaned and filled with flexible epoxy joint sealant. The joint sealant is purposely placed just slightly higher than the slab so that it may be sanded flush to the floor after initial curing. Properly completed, the result will be a smooth, attractive, functional control joint that will provide trouble free service for years.

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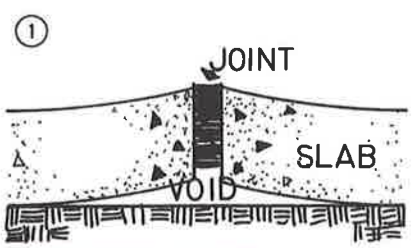
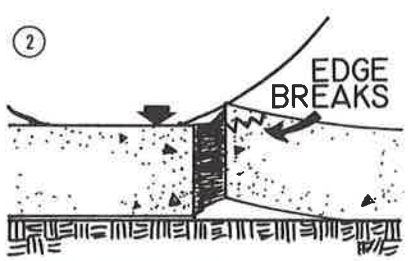
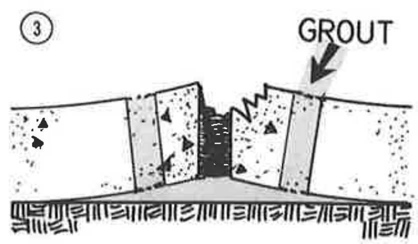


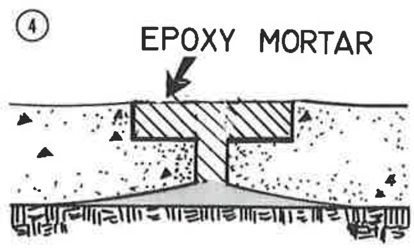
slab lifts slightly off ground



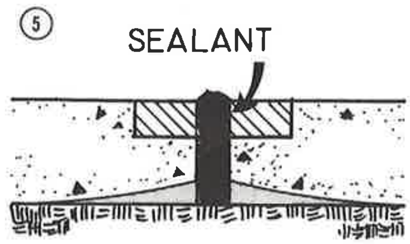
wheel breaks edge of joint



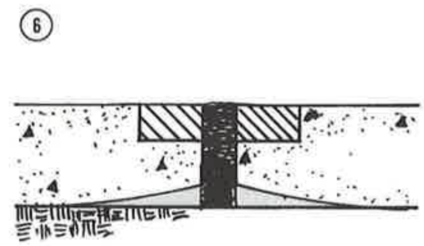
grout installed to fill void



edges saw cut and filled with epoxy



joint is re-cut. Sealant is gunned into cut



result is smooth, flat joint

Where Does Salt Come From?

When someone talks about parking garage deterioration, salt is invariably mentioned. You may say, "But I don't use salt in my garage. Why do I have to worry about it?"

The major contributor of salt is your state Department of Transportation. According to The Trailblazer, the newsletter published by the New Jersey Turnpike Authority, last winter there were 19,000 tons of rock salt dumped on the turnpike alone. On Connecticut highways, the last winter season required the use of 105,000 tons of salt to keep the highways clear. Not all of this salt ends up in the storm sewers. Some ends up in your garage.

This salt melts the snow and ice on the roads. It then refreezes on the wheel wells of the automobiles. These chunks are carried by the car into the parking garage from outside and melt as the car sits parked. The salty water drops off onto your garage floor slabs and finds its way to the lowest point in the garage – either into cracks or down the drains. When it gets into any cracks in the slab, the salt water will begin the corrosion of the steel reinforcing bars. If the water evaporates, the problem does not go away – the salt is left behind, waiting for any rainy weather to dissolve it again. Where the drainage is poor, the salty water will puddle, concentrating the salt and increasing the problem.

Another contributor, although not as common as deposits of road salts, is the accelerator used in concrete during cold weather construction. Calcium chloride has commonly been used as an accelerator to offset delays in strength gain and setting caused by cold temperatures. Poor mixing of dry calcium chloride added to the concrete causes non-uniform strength gain and localized corrosion of reinforcing steel when water is present. However, this use has lessened due to the fact that non-chloride accelerators have been developed that do not have the same potential for reinforcement corrosion as calcium chloride.

Even if you don't have cold weather, salts may still be included in the composition of your garage. Unscrupulous contractors have been known to use seawater as mixing water, and beach sand as the fine aggregate. Both of these contain salt and will contribute to concrete degradation.

Any of these sources of salt can cause deterioration, so beware. Even though you may not add to the problem, you may still have it brought in from the outside world. □□■□

Journal is a publication of Hoffmann Architects, specialists in investigative and rehabilitative architecture/engineering, including the analysis and solution of roofing, exterior wall, glazing and structural problems. Our office is located at 3074 Whitney Avenue, Hamden, Connecticut 06518, Phone (203) 281-4440.

We welcome contributions to HA J from our clients and friends. Please send news and technical information to Peter Borgemeister, Hoffmann Architects Journal at the Connecticut office. Address changes or requests for free subscriptions for others not currently receiving the publication should also be sent there.

While Hoffmann Architects Journal attempts to provide the most accurate information on general subjects, it is not intended to be a substitute for professional architecture and engineering surveys, construction documents or other services. We strongly urge you to consult a qualified rehabilitative architecture/engineering firm (ours) for answers to specific questions.

staff news

Staff News

Brian Schafer, Marketing Manager, has been appointed to the Professional Members Committee of the New York City Chapter of the Building Owners and Managers Association (BOMA).

Walter E. Damuck, AIA and **Theodore Babbitt, AIA** are serving as corresponding members of the American Institute of Architects Historic Preservation Committee.

Intern architects **Jane Beaudry, Wayne Bonin and Frank Scherr** have completed the instructional course given by General Electric Company and have been qualified as Regional Inspectors for the General Electric Company Silicone Roofing System.

Amy Kilburn, AIA was appointed to the American Institute of Architects Building Performance and Regulations Committee as a corresponding member.

Harwood W. Loomis, AIA lectured on the topic of Fire Resistive Construction Requirements at a seminar entitled "The Building Code: A Design Tool." The seminar was co-sponsored by the Connecticut Society of Architects and the Connecticut Professional Chapter of the Building Officials and Code Administrators International (BOCA).

Plywood Alert

The American Plywood Association (APA) released a bulletin regarding problems noted in fire retardant plywood. It seems that plywood treated with the so-called hygroscopic interior fire treatment has been reported to be losing strength and buckling after about two to three years. Strength loss can be as much as 50 per cent, and panels have failed under light walking traffic.

Analysis of the failed plywood has shown destruction of the cement that holds the wood fibers together. Preliminary studies by the U.S. Forest Products Laboratories show that the chemicals used in the fire retardant treatment are very reactive with water, creating phosphoric acid. This can cause breakdown of the cellulose chains in the wood, severely degrading it over time.

The three primary ingredients for degradation appear to be time, water and elevated temperatures, all of which can occur in the construction environment, especially in the roof. Moisture can contact the wood through leaks, condensation or humidity. The potential for problems becomes enormous when one realizes that, even though the bulletin was released by the APA, the problem is occurring in the **wood**, not the plywood glue, thus broadening the scope to include **any** wood products treated with the hygroscopic interior fire retardant treatment.

Until more is known about the phenomenon, extreme caution should be used in specifying these products in uses which rely on strength, such as plywood decks, or flatness, such as blocking.

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