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Journal

Parking Structure Maintenance:

Early Detection, Early Cure

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Part parking lot, part building and part bridge, the modern parking garage is like no other structure. These structures are designed to meet an ever-expanding array of criteria while enduring the harshest of environmental extremes. They must withstand wide temperature variations and resist extremely corrosive environments, all while supporting impressive loads. Increasingly, they have also become architectural statements, viewed for more than the utility that they provide.

Garages and parking decks deteriorate more rapidly than other built structures. In addition to water infiltration, thermal expansion and contraction, improper construction and/or substandard materials, and age, they suffer the damaging effects of vehicular traffic and the corrosive impact of acid rain and de-icing salts.

The risk associated with deterioration in these structures is severe; the threat of costly and time-consuming lawsuits associated with drive and/or tripping hazards, unacceptable.

Costs associated with deferred maintenance increase exponentially over time. And though it may be tempting to forego parking structure maintenance in favor of improvements to tenant spaces within a building's interior – to lobbies or offices – the return on those investments may significantly diminish if the paint on tenants' vehicles is damaged by caustic salt-laden water from leaking joints. In more severe cases, damage and safety issues arise from falling pieces of concrete.

Early detection of parking structure deterioration allows for the development of pro-active maintenance and repair programs that minimize disruption to normal operation of a facility and maximize a building owner's return on investment.

Types of Construction & How They Behave

Understanding your parking structure's construction type, and how its structural components behave, may give you that extra maintenance edge.

The types of construction employed vary widely but are usually dictated by cost, configuration, construction and scheduling, and maintenance requirements. A garage frame may be cast-in-place concrete, pre-cast concrete, or steel. A garage deck is commonly cast-in-place or pre-cast

CAUTION! Severe parking structure deterioration leads to drive and/or safety hazards.

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Lawrence E. Keenan, PE and Bruce R. Soden, Senior Project Engineer and Senior Project Manager with Hoffmann Architects, direct a variety of parking structure rehabilitation projects for the firm.

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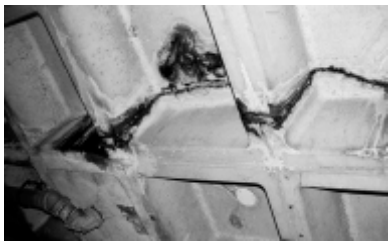
concrete, with a number of possible variations. Concrete members can be conventionally reinforced or pre-stressed.

The list of variations can go on and on. But for the purpose of discussing maintenance and repairs, garages can be placed within two general categories: those with cast-in-place decks and those with pre-cast decks.

Cast-in-place decks

While both types of construction have been successfully used for years, garages with cast-in-place decks have been around far longer. Numerous deck configurations exist, but the deck itself is usually a single, contiguous, reinforced concrete membrane spanning between steel or concrete framing. This type of deck is generally more prone to deterioration from chloride intrusion than its pre-cast counterpart. Consequently, performance of these decks is directly related to provisions that mitigate this chloride attack.



Cracking and spalling of the pans and ribs on a parking deck soffit.

While there is no substitute for good design and materials, the arsenal for combating chloride intrusion has grown over the years. At one time, boiled linseed oil was used to seal the concrete surface against chloride migration. However, this material had limited success and broke down quickly. Today, an entire industry

Crumbling parking deck.

dedicated to the protection of concrete thrives. Among others, methods of protection include coatings for reinforcement, corrosion inhibitors added to the concrete, sealers and densifiers applied to the concrete surface, and traffic bearing membranes. Pro-active maintenance efforts for cast-in-place decks are generally associated with maintaining these provisions. For the decks that are left unprotected, maintenance dollars are spent chasing defects.

Pre-cast decks

Pre-cast members behave much differently. These elements, cast in a factory setting, benefit from the dense, high quality concrete used and from stringent quality control measures. Also, since these members are typically pre-stressed in compression, shrinkage cracks are virtually nonexistent.

Under these conditions, chloride migration through the concrete surface is typically not a problem. In fact, most garages with pre-cast decks perform successfully with little more than the periodic application of low cost surface sealers. However, this is not to say that pre-cast garage decks do not have maintenance requirements. To the contrary, maintenance for pre-cast garages can be far more demanding than that required by the cast-in-place variety. Pre-cast concrete garages are often constructed of slender elements that have very little tolerance for defects in design or construction. These elements tend to crack when restrained from thermal expansion and contraction. Consequently, the garage must be designed such that sufficient movement is allowed between these concrete elements. Since these elements must also transfer loads in multiple directions, this becomes a source for many problems.

Cracks, when formed, pose a serious threat to pre-cast elements, as they allow a direct path for salts to the embedded reinforcement. This reinforcement typically consists of wire that is thinner than the reinforcement bars used for cast-in-place decks. As such, a relatively small amount of corrosion can cause a significant loss in strength. To make matters worse, repair of these thin elements is often difficult and costly. Cracks, then, require prompt repair and ardent maintenance.

Cracks and settlement of concrete slab.

Finally, pre-cast members typically require sealant joints where they are joined. These joints, extending around each member, very quickly add up to miles of sealant that must be maintained and periodically replaced. Water migration through failed joints can cause problems for cars below and accelerated deterioration of the members themselves.

Survey

So, you've decided to take an enlightened approach toward parking

structure maintenance and repairs. How, then, do you begin?

Ideally, the facility manager should conduct his/her own visual survey on a regular basis to recognize and address early indicators of failure. But, what exactly are you looking for, or—more aptly—what are you hoping *not* to find? Symptoms of deterioration include cracks, leaks, spalls (areas where concrete has broken off completely) and efflorescense (salt staining), among others. These symptoms are merely red flags that tip you off to larger problems.

Realizing that there exists a problem - or a potential problem - is half the battle. When evidence of deterioration is observed, a design professional can often quickly ascertain the cause or the requirements for further investigation.

Investigation & Testing

Imagine for a moment that your garage is riddled with cracks and spalls. Vehicle tires crunch along the crumbling parking deck. And, pools of water make for sloppy vehicle entrance and egress. Aware of the situation and eager to repair the structure, you consult a design professional to conduct an investigation to determine the cause of these defects. But, what does this investigation entail?

Following visual observations, the results from field probes (limited concrete demolition to expose a condition that is otherwise not observable), field testing

Concrete core has been extracted from a parking deck for analysis.

Obvious indicators of water infiltration are ponding and staining.

and laboratory testing complete the necessary data to properly quantify damage and affect a successful repair and maintenance program.

As every garage contains concrete, concrete testing is an inevitable component of the investigative process. Various concrete tests reveal the material's integrity by disclosing what is often not visible on the surface. The results of these tests yield information to accurately evaluate the condition of the parking structure and determine the scope of repair action necessary.

If, for example, chloride ion testing reveals that chloride levels are high throughout a parking deck, broad action may be recommended to cease and/or prevent further corrosion of the entire deck. Conversely, if testing reveals that chloride intrusion poses a threat to only a single, isolated area, it may be that the rehabilitation effort will focus on that area alone.

Other frequently used tests include:

- sounding/chain dragging to detect delaminations and voids;
- corrosion potential/corrosion rate testing to indicate the condition of steel reinforcing bars in concrete and the likelihood of corrosion activity;
- petrographic analysis to reveal the air content (to differentiate between *entrained* and *entrapped* air), the composition of concrete (proportions of aggregate, cement, water and air), and the overall quality;
- pH testing to detect carbonation; and,
- compressive strength testing to determine the strength of concrete.

Testing methods can be broken down into two broad categories: Non-Destructive Testing (NDT), which is non-invasive and least disruptive to the parking structure, and Destructive Testing (DT), which by nature is intrusive to the structure. Destructive Testing includes field testing, in which all of the information is collected on site, and laboratory testing, in which material samples are collected on site for further analysis at a remote facility.

Which tests are necessary?

Testing requirements vary with the type, age and condition of the structure being examined.

Case in point: if cracks cover a concrete deck, sounding or chain dragging may be ordered to determine if laminations (horizontal cracks) exist within the deck. These tests are useful, "low-tech" non-destructive methods which involve striking a concrete surface with a hammer or rod or dragging a chain over a concrete surface, as laminated sections of concrete emit a sound that differs from adjacent intact areas. Generally, sounding and chain dragging do not yield much information regarding vertical cracks; however, these can be documented visually.

Just as the evaluation of observed conditions determines which tests

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may be required, the results of one test may lead to initiation of further testing. If, for example, a minimally invasive chloride test indicates that an area of concrete has high potential for corrosion, corrosion rate testing may be ordered to more precisely determine the degree to which chlorides are causing corrosion within the concrete.

The evaluation of test results form the basis upon which to accurately recommend a program of repairs, whether it be localized repairs or rehabilitation of an entire parking deck. And though there are many more tests available than those mentioned here, not all of these are usually necessary to properly evaluate a parking structure.

A qualified design professional will order those that are vital to the successful completion of a comprehensive investigation.

Preventive Maintenance

The effects of corrosion on our infrastructure become evident as we sit in traffic while crews make repairs to

Parking Structure Checklist

A periodic parking structure visual survey should include attention to the elements listed below.

I. Concrete Slab

A. Floor (Top of Slab)

- Concrete Condition
- Structural Reinforcing Steel Corrosion
- Slab Protection (*Membrane, sealer)*
- Cracks
- Spalled Concrete

B. Ceiling (Underside of Slab)

- Water Stains
- Rust Stains
- Efflorescence
- Cracks
- Spalled Concrete

II. Expansion Joints/Control Joints

A. Damage from Traffic or Snow Plows
B. Failed Sealant

III. Drainage

A. Ponding/Puddles
B. Ice Formation
C. Clean Drains

IV. Beams and Girders

A. Concrete Condition
B. Structural/Reinforcing Steel Corrosion
C. Cracks
D. Spalled Concrete

V. Support Columns

A. Concrete Cover Over Reinforcement
B. Structural/Reinforcing Steel Corrosion
C. Impact Damage
D. Cracks
E. Spalled Concrete

VI. Walls

A. Leaks
B. Structural/Reinforcing Steel Corrosion
C. Rust Stains
D. Cracks
E. Spalled Concrete

VII. Spandrels and Guard Rails

A. Impact Damage
B. Anchorage

bridges and overpasses. It is interesting, then, to note that garages do not have the benefit of periodic rains that wash away salts creating this corrosion. Consequently, the effects of chlorides in parking structures can be even more devastating than to these other types of structures.

Semi-annual cleaning of the deck is an often recommended and much overlooked pro-active approach to garage maintenance. In fact, cleaning is perhaps the most cost-effective method of protecting the garage. However, a multi-faceted approach to maintenance will provide the most protection.

Parking structure owners and managers can very effectively mitigate expensive repairs. After all, who is more familiar with the structure? Establish a schedule of regular "walk-throughs" and make a concerted effort to recognize symptoms of distress. Then take steps to correct them by contacting your design professional.

Plan a Smooth Operation

The parking structure manager's primary concern is to minimize disruption to the normal operation of the facility while maximizing the owner's return on investment. A qualified design professional understands this concern and can be counted on to plan design and construction solutions that are innovative and cost effective, which meet the owner's needs, and are both technically appropriate and aesthetically appealing.

It is reasonable to expect - and possible to ensure - maximum and safe utilization of the garage while at the same time permitting enough construction area to allow efficient completion of repairs. Express your expectations early in the design phase. Appropriate phasing and planning recommendations will ensure smooth and timely completion of the work.

Conclusion

"Early detection, early cure" is the key to successfully maintaining a parking structure. It is not enough to merely chase after defects, to randomly patch cracks and spalls. Regularly scheduled walk-throughs and a comprehensive investigation that includes appropriate testing allow for the prevention of structural failures. With the help of a design professional, a manager can develop effective parking structure maintenance and repair solutions that lower total cost and forego tenant and managerial headaches.

Please see pages 6-8 for a listing of representative projects.

GLOSSARY

Cracks – Fissures created by tensile stress from shrinkage, thermal contraction or tensile loads.

Chlorides – In the form of water-soluble road salts.

Chloride Migration – Penetration of chloride through concrete often measured in relation to depth of reinforcement.

Lamination – Stress-induced internal fracture created by corrosion of reinforcing steel.

Delamination – Separation or debondment of strata within a laminar component. i.e. debondment of overlay.

Efflorescence – Dissolution and surface deposition of naturally occurring salts from within concrete causing white staining and/or build-up of white, crystalline structures.

Carbonation – A naturally occurring process that causes the naturally alkaline (high pH) concrete to become more acidic (lower pH). This reduces the natural ability of concrete to protect embedded reinforcement steel.

Scaling – Loss of concrete paste from the surface resulting in exposed aggregate. This is often caused by poor air entrainment or finishing techniques.

Air Entrainment – Intentional addition of air in the form of microscopic bubbles to aid in freeze-thaw resistance.

Air Entrapment – Unintentional addition of larger voids causing reduction in strength and durability of concrete.

Water Cement Ratio – Direct or indirect indication of concrete strength, resistance to shrinkage and permeability.

Pre-stressed Concrete – Intentional addition of compressive load by use of embedded tendons. This reduces likelihood of cracking and increases strength while allowing the use of smaller concrete members.

Pre-cast Concrete – Cast concrete sections that are lifted into place.

Spalls – Laminations that break off due to corrosion of reinforcement/ embedded items.

representative projects

Parking Structure Rehabilitation

Hoffmann Architects has developed and implemented parking structure maintenance and rehabilitation programs for a number of its clients. The following narratives briefly discuss the diverse programs implemented for some of these clients.

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

Hoffmann Architects performed a survey and provided design, construction administration and construction management services for a preventive rehabilitation effort of the two-level, 239,000 square foot parking structure at General Electric Corporate Headquarters in Fairfield, CT. Located directly beneath a three-story steel framed office building, the second floor parking deck was deteriorating.

The firm carefully phased the repair work to minimize disruption to the highly trafficked parking structure (usage is consistently greater than 110% capacity). Fast-curing coatings and repair mortars were specified to expedite completion of repairs, and construction was performed during evenings and weekends. Special precautions were taken during construction to protect against damage to the electrical distribution system that was embedded in the concrete parking decks.

Bishops Corner
West Hartford, CT
(Edens & Avant)

Hoffmann Architects performed a survey and provided consultation for emergency repairs, then prepared a schematic design for the rehabilitation of this 25-year-old, 300-space, three-level steel framed and metal deck garage with cast-in-place composite concrete slabs. A materials testing program revealed that, due to low air entrainment and severe chloride migration, the decks of the garage were past their useful life.

To restore the garage, Hoffmann Architects recommended that a rehabilitation project be performed and provided design and construction administration services that included full replacement of the existing decks and repair to steel members.

Foxwoods Resort Casino
Mashantucket, CT
(Mashantucket Pequot Tribal Nation)

The Mashantucket Pequot Tribal Nation's Foxwoods Casino is among the nation's most popular gaming destinations. The Great Cedar Parking Garage, located directly beneath the Foxwoods Casino, is subject to an exceptionally high amount

General Electric Company Fairfield, Connecticut. Hoffmann Architects designs parking structure rehabilitation solutions that are minimally disruptive to the normal operation of corporate headquarters facilities.

Buckingham Condominiums Stamford, Connecticut. Hoffmann Architects designed parking structure rehabilitation solutions that maximized the owner's return on investment.

of traffic. The garage is divided into two sections: a pre-stressed concrete section and a cast-in-place section, and the total footprint measures approximately 1,040 feet by 240 feet.

Following field testing, field probes, laboratory testing, and structural analysis, Hoffmann Architects developed a program of repairs to correct existing deficiencies and to suspend further deterioration of the garage.

Bishops Corner Parking Facility
West Hartford, Connecticut (Edens & Avant)

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

This 10-level, 300,000 square foot parking structure, with three levels below grade and seven levels above grade was constructed in 1965 using waffle slab pans to form the deck construction. Following an in-depth investigation that included chloride ion testing, petrographic testing, core breaks, load tests and hydro-demolition, Hoffmann Architects recommended a program of repairs – first field-tested on site – to rehabilitate the structure's deficiencies. The firm provided design through construction administration services for rehabilitation of beams, columns, and a structural overlay of the floor slabs, and coordinated mechanical, electrical and lighting upgrades.

One Beacon Street
Boston, MA
(CB Richard Ellis)

The building at One Beacon Street is a 34-story, steel framed office tower with two sub-grade parking levels that extend beyond the tower footprint and below the street. The basement level parking deck is a waffle slab design and the sub-basement level flooring is slab-on-grade construction. Built in 1972 and rehabilitated in 1988, the parking structure showed signs of severe deterioration due to chloride-induced corrosion of reinforcing steel.

Hoffmann Architects conducted a survey of the garage and developed and implemented a rehabilitation program to address damage to the concrete reinforcement caused by the high level of chlorides attributable to road salts deposited by incoming vehicles.

State University of New York Downstate Medical Center
Brooklyn, New York (New York State University Construction Fund)

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

The offices for Union Carbide Corporate Headquarters facility are constructed around the curvilinear center core garage structure. The garage – comprised of pre-stressed and cast-in-place concrete – is one million square feet, consists of four levels, and services 16 office pods that project out from the center core. The parking structure is accessed via a 600+ foot ramp system that approximates the scale and construction of an elevated highway interchange.

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SNET's George Street Garage
New Haven, Connectict (Southern New England Telephone Company)

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Hoffmann Architects conducted an investigation that included chloride ion testing and petrographic testing in order to recommend and administer a successful program of repairs for the deteriorated concrete ramp and deck surfaces.

Other Parking Structure Rehabilitation Projects:

Buckingham Condominiums
Stamford, Connecticut

Temple Street Garage
New Haven, Connecticut

One Chestnut Street
Worcester, Massachusetts

Bell Laboratories
Short Hills, New Jersey

Champion International Headquarters
Stamford, Connecticut

Chase Manhattan Bank Atria Complex
Garden City, New York

Southern New England Telephone Company
New Haven, Connecticut
Norwalk, Connecticut

General Reinsurance Corporation
Stamford, Connecticut
Greenwich, Connecticut

JOURNAL is a publication of Hoffmann Architects, specialists in the rehabilitation of building exteriors. The firm's work includes investigative and rehabilitative architecture/engineering services for the analysis and resolution of problems within roofs, facades, glazing, and structural systems of existing buildings, plazas/terraces, and parking garages.

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