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Concrete Deterioration

Concrete deterioration generally falls into one of several major categories: spalling, cracking, leaching, scaling, and joint deterioration. Joint leaking also contributes to concrete distress. These deterioration mechanisms are, to varying degrees, the cause of durability problems experienced by many parking structures today.

Reinforced Concrete Spalling

Definition

Spalls or potholes in reinforced concrete surfaces are usually dish shaped cavities from one to several inches deep and one to several square feet in surface area. Spalls can occur individually or in groups covering several hundred square feet.

Spalling is preceded by horizontal fractures called "delaminations" which usually develop parallel to the exposed concrete surface. Fractures originate at corrosion damaged embedded reinforcement or other embedded metal and migrate to the nearest surface. Freeze-thaw, traffic action and additional corrosion influence the rate of fracture migration and spall development.

Contamination

Concrete is a naturally porous material. Excess water not required for hydration eventually dries, leaving behind an interconnected network of pores and capillaries. Concrete capillaries have diameters ranging from 10 to 1000 Angstroms in diameter. The chloride ion is less than 2 Angstroms in diameter. Penetration of chloride ions into concrete and subsequent accumulation occurs readily on surfaces exposed to deicing salts, wetting and drying and freeze-thaw cycles. Locations in coastal areas are also exposed to salts. Essentially all concrete is susceptible to chloride ion contamination by virtue of its natural porosity.

Concrete porosity can be reduced by the use of low water cement ratios and increased cement factors. By removing excess mix water, the number of pores and possibly their size is reduced.

Reinforcement embedded in concrete is usually protected by a thin oxide film remaining after manufacturing and the passive effect of highly alkaline concrete. Salts, either calcium or sodium chloride, can penetrate sound high quality concrete and accumulate in sufficient quantities to cause corrosion of embedded reinforcement. Research indicates that corrosion begins when salt accumulation exceeds 1.1 to 1.6 pounds per cubic yard.

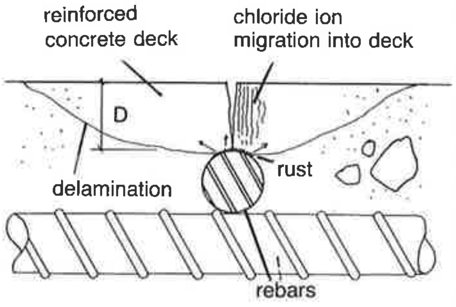


figure 1. rebar corrosion spalling mechanism

Corrosion

Metallic corrosion is a dynamic electro-chemical process and induces *progressive* deterioration. Corrosion by-products, "rust," develop at the steel surface causing high stress in the surrounding concrete. Rust occupies a volume at least 2.5 times that of the parent metal. The by-product accumulation causes high tensile stress (5,000 psi minimum) which cracks the surrounding concrete (see Figure 1). Initial cracking occurs when section loss of the parent metal is 5% or less. Cracks first appear vertically over the reinforcement nearest the exposed surface. These cracks allow direct access of moisture and additional chloride to the reinforcement causing accelerated corrosion and subsequent delamination.

Once initiated, corrosion stops only when a correcting electrical current is applied to the reinforcement network (cathodic protection) or the parent metal is entirely consumed by rusting. Corrosion and subsequent deterioration can be slowed by reducing the availability of moisture and oxygen.

Corrosion Induced Stress

The effect that corrosion has on a structural member is variable. Five things happen, all of which are detrimental to structural integrity:

- Surface spalling occurs, causing a maintenance and serviceability problem.
- The reinforcement loses significant cross-section and stress redistribution throughout the remaining network occurs.
- The reinforcement debonds from the concrete, causing loss of monolithic interaction.
- Progressive movement of reinforcement can reduce load-carrying capacity.
- Concrete cross-section loss, in addition to reinforcement cross-section loss, impairs the load carrying capacity of floor slabs and beams. (See Figure 2)

One aspect of the corrosion phenomena which makes repairs so difficult is that multiple delaminations occur as the condition progresses deeper into the floor slab. Where spalling coincides with full depth floor slab cracks, it is common to find ceiling spalls directly below floor spalls. The bottom reinforcement corrodes similar to the top, thus causing a multiple effect of concrete and reinforcement section loss. Surface spalling near mid-span reduces the concrete section. At the same time, severe corrosion of bottom (tension) reinforcement can result in over stressing and possible reinforcement yielding.

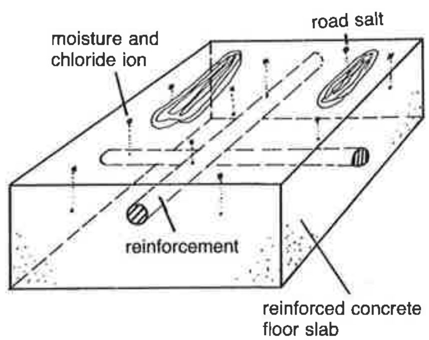
Spalling may occur on all structural members. Floor slab systems frequently experience the most extensive and widespread effect of spalling (See Figure 3). Beams, columns and walls are also susceptible to spalling when subject to excessive chloride contamination from runoff or spray.

Influence Factors

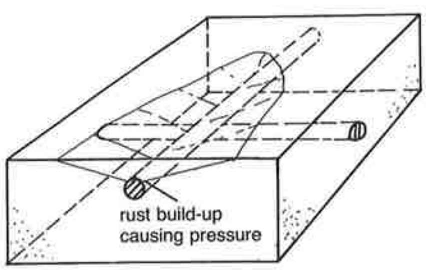
The depth of clear cover over embedded reinforcement is perhaps the single most important aspect of design and construction which can delay the onset of spalling. Floor slabs with less than recommended cover over reinforcement, subject to intense deicing exposure, will undergo rapid and severe spalling. Floor slabs constructed with lower water cement ratio concretes, additional clear cover at top reinforcement and protected from intense deicing exposure will provide adequate service for many years.

In preparing maintenance programs for parking facilities, consideration should be given to the areas

1. Moisture with chloride ion penetrates concrete and reaches steel in sufficient quantity to cause corrosion. Corrosion proceeds at a rate controlled by chloride concentration and availability of moisture and oxygen.



2. Rust builds up around steel causing high stress or pressure. Delamination occurs and migrates to surface under influence of traffic action and freeze-thaw cycling.



3. Concrete breaks away leaving open spall or pothole. Full circumference corrosion proceeds until complete debonding of reinforcing occurs; section loss accelerated.

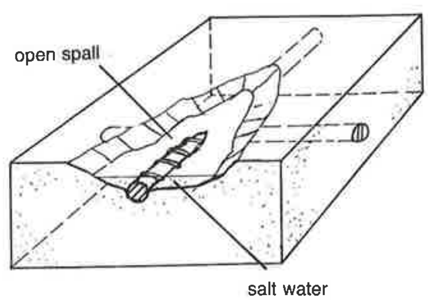
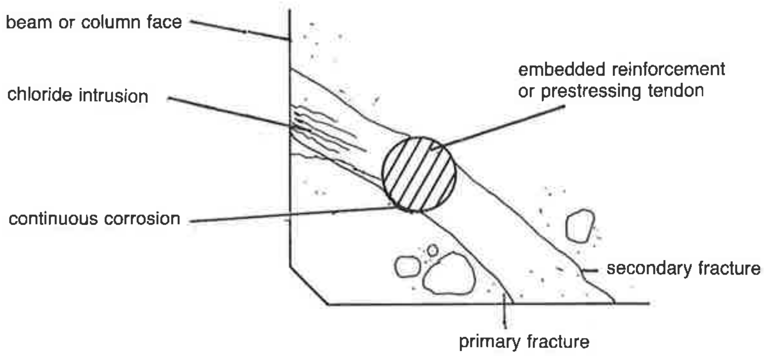


figure 2. corrosion induced spalling process



1. Chloride ion intrusion contaminates concrete – lowers pH and induces corrosion of embedded reinforcement.
2. Corrosion by-products "RUST" develop at bar surface and require expansion room.
3. Rust expansion causes high tensile stress which cracks surrounding concrete.
4. Additional salt water gets into cracks.

figure 3. spall development beams and columns

where concentrations of reinforcement occur near the surface. With flat plate designs, this involves the column capital and drop head areas. For one way slab and beam designs, the area above the beam typically has more top reinforcement than at mid-span. Maintenance efforts directed at protecting these areas from intense exposure will pay off in reduced spalling and extensions of repair-free service life.

In order to properly prepare restoration contract documents, it is necessary to first evaluate the effect spalling has had on the capacity of individual members and then to evaluate the cost effectiveness of repair procedures with regard to the total restoration program. A structural engineer must be retained to perform the required investigation, analysis and evaluations.

Cracking

Concrete cracking is caused by stress. This stress is either construction or service related. Cracking commonly attributed to construction is caused by improper concrete placement, improper consolidation, improper curing of the concrete, premature removal of form supports, or by plastic shrinkage of the concrete. Service related cracking is usually due to temperature changes, load, settlement, or internal stress. Corrosion of rebars and aggregate chemical reaction are common causes of internal stress.

Not all cracking is detrimental to the concrete member. In many cases, cracks are anticipated and reinforcement is provided to transfer stress across the crack. Properly positioned reinforcement arrests crack development by keeping cracks short and tightly closed. Cracking can be detrimental when it occurs to an extent and frequency not expected. If this happens, steps are necessary to minimize the effect cracking has on long term structure durability or durability of a specific member.

Leaching

Leaching is caused by frequent water migration through the floor slab or cracks. As water migrates through, it takes along part of the cementing constituents, depositing them as a white film, stain, or a stalactite on the ceiling below. This process will weaken the concrete over a period of years and is accelerated by porous or perpetually moist concrete. Leaching frequently occurs from cracks beneath gutterlines.

leaching

Scaling

Concrete scaling is a deterioration mechanism which attacks the mortar fraction (sand and cement) of the concrete mix. It is characterized initially as a minor flaking and disintegration of the concrete surface. With passing time it progresses deeper into the concrete, eventually exposing aggregate which breaks away (see Figure 4).

This further contributes to the process by exposing more paste to the elements. In extreme cases, apparently sound concrete can be reduced to a gravel-like condition in a short period of time.

Concrete scaling is caused by freeze-thaw action. When concrete is frozen in a dry state, there is little damage. If concrete is frozen in a saturated state, excess water freezing in the concrete causes high stress and weakens the mortar. Exposure to cyclic freeze-thaw action is very destructive to concrete in a saturated state.

Joint Deterioration

The two most common provisions made for crack control or relief of restraint in concrete slabs are control joints and expansion joints. Such joints have long been a source of maintenance problems. Joints on supported floor slabs must be sealed against water leakage and intrusion of incompressibles. Both situations are damaging to the joint system.

Construction joints deteriorate for several reasons, usually associated with failure of the sealant or failure of the adjacent concrete. Joint sealants may not have the required degree of flexibility, bond, strength, or durability for a particular application. If concrete adjacent to the joint is not sufficiently durable, then local scaling will cause joint sealant failure.

Expansion joints are also susceptible to premature deterioration. The most common causes of early deterioration are: improper joint design or sealant material specifications, incorrect installation of the expansion device, and in-service damage from traffic or snow plows.

1. Concrete becomes saturated by water penetrating through pores and capillaries.
2. Concrete is frozen in a saturated state causing high stress. Loose flakes appear on surface as the mortar breaks away.
3. As flaking progresses, aggregate is exposed and eventually breaks away, thereby exposing more paste to freeze-thaw damage.

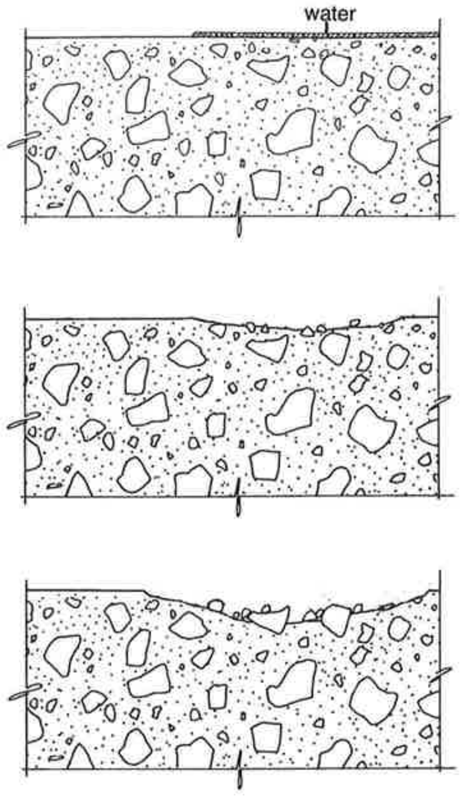


figure 4. concrete surface scaling

exposed reinforcement

deterioration of joint sealant

Concrete Deterioration was reprinted with permission from *Parking Garage Maintenance Manual* published by the National Parking Association, a trade association serving parking professionals for over 30 years. Copies of the manual, $20.00 each, as well as NPA membership information and lists of other NPA publications are available from Robin Rhodes, National Parking Association, 1112 16th Street NW, Suite 2000, Washington, DC 20036.

Concrete Maintenance

The first step to any well planned maintenance program, whether for a new or old garage, is a regularly scheduled walk-through survey – a visual inspection of the entire garage. During the survey, observe the location and extent of conditions which could cause, or have already caused, concrete or steel deterioration. Items to be looked for include surface deterioration on the top and bottom surfaces of the floor systems; evidence of water leakage and/or staining through or on floors, walls or other structural elements; cracks in floors, beams, columns and walls; and rusting of exposed steel. Such a survey can be done by any conscientious observer, provided that if evidence of deterioration, e.g. scaling, spalling, cracks or leaks, is observed, an engineer knowledgeable about garages is consulted. However, at least every two years the inspection should be made by an engineer or architect to be sure that no potentially serious conditions have been overlooked.

Next, determine the nature and extent of the problem. The walk-through survey is a start, but it must be understood that a visual survey reveals only visible deterioration. A review of the survey results may indicate the need for a more comprehensive survey which would include testing for subsurface fractures and delaminations and/or deicing salt contamination. Despite the most thorough investigation, some hidden deterioration may be revealed only after the start of repair work.

Repairs to scaled and spalled areas must be undertaken with care. Improper repairs hide, but do not cure the problem. An example is an asphalt patch over a spall. Asphalt is porous and will permit salt-laden water to collect unseen at the bottom of the spall. If the steel is exposed there, the salt water will attack it and the resulting corrosion of the steel and weakening of the floor will become visible only after the corroding steel has caused a larger spall.

Patching is a generally effective repair for isolated spalls. A good patch must be durable, watertight, and must bond well to the concrete substrate. Patch edges should not be feathered. The patch must also react to temperature changes in the same way that concrete does and must be compatible with it. When the total area to be patched is a signficant part of the floor area, an overlay becomes more cost effective than isolated patches. An overlay can also modify floor gradients to improve drainage and eliminate ponding. Overlays will add thickness to the original floor system and increase the structure weight (dead load). Headroom will be less than what was originally designed. These considerations must be examined by a qualified structural engineer or architect to ensure that the overlay does not cause more problems than it solves.

To be sure that the new concrete will last, two options to inhibit corrosion are a waterproofing membrane or cathodic protection. The waterproofing membrane or sealer is a liquid applied to protect and preserve concrete by filling the pores and sealing the surface against moisture and salt penetration. A quality material, properly applied and renewed periodically, will also provide supplemental protection against freeze-thaw damage and wear. An elastomeric membrane will bridge small shrinkage cracks. Cathodic protection involves running a small low-voltage electric current through the reinforcing bars. The current reverses the flow of chloride ions away from the steel, inhibiting corrosion.

It may be that by the time maintenance action is taken, deterioration has progressed to the point where the only effective repair is complete reconstruction. Consult a qualified structural rehabilitation engineer to determine the state of the garage and further action required.

core showing subsurface cracking

Concrete Cracking

– by Jane E. Estey, P.E.

There are several possible reasons for cracking in a structural concrete slab. Cracks can be caused by design deficiencies such as lack of adequate slab depth, insufficient reinforcing steel or an improper mix design. Cracking can also be a function of poor or inadequate workmanship during construction.

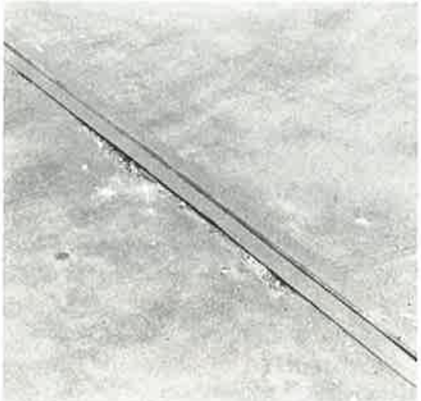
Some cracking occurs normally during the curing of the concrete due to settlement of the new concrete and shrinkage during drying. Additional cracking can be caused by any of the following construction practices: insufficient vibration of the concrete during placement, use of poorly designed formwork, placement of high slump concrete or stripping of the formwork before the concrete is strong enough to support itself and any applied loading. One result of early removal of the forms is a tendency for radical cracking to appear at columns as the columns attempt to punch through the newly placed slab.

Once the concrete has hardened, cracking may occur because of temperature stresses, weathering, loading causing excessive deflection or excessive stresses due to an attained strength of concrete lower than that specified.

Once cracking exists in the slab, there is a danger of corrosion of the steel reinforcing bars as water and chlorides are able to infiltrate the slab. Rust produced by the corroding steel will expand, causing further deterioration and weakening of the structure to a possible point of failure.

Because of this, the placement of concrete and removal of formwork in a structural concrete slab should be monitored carefully in an attempt to prevent improper construction practices which could lead to excessive cracking.

cracking in a waffle slab



deterioration of concrete at expansion joint

Joint Deterioration

Problem

Failure of major expansion joints in a precast, prestressed concrete parking garage allowed moisture and chloride penetration into the concrete, deteriorating and weakening the structure.

Cause

Each plank in the structure had a different camber from the adjacent plank, causing the edges to be as much as ¾ inches off vertically from the next. The joint sealant, being a soft material, was destroyed when snow plow blades caught on the uneven edges of the concrete planks. The open joints allowed moisture and chloride penetration.

Solution

After removal of any existing scaling, deteriorated concrete, a new reinforced concrete structural topping will be installed to provide an even surface for pedestrian and vehicular traffic and also to improve drainage. The new monolithic topping will eliminate most of the joints that currently exist between planks, thus minimizing the potential for joint damage by snow plows and car tires. The structure will be strengthened by reinforcement of connections supporting the deck and new concrete topping. Expansion joints will be replaced and an elastomeric coating applied to the surface of the topping to prevent further infiltration of salt-laden moisture.

Representative Projects

Hoffmann Architects is providing construction observation services for Property Management Systems for the reroofing of an office building in Saxon Woods Office Park in Harrison, NY. In Stratford, Connecticut, we surveyed the roof of Southern New England Telephone's maintenance garage. For the State of Connecticut, the firm is preparing plans and specifications for reroofing the Hartford Community Correctional Center.

Recent real estate consulting services include: reviewing contract documents and construction monitoring of a shopping mall in Baxter, Minnesota for Broadview Savings and Loan Company, Cleveland, Ohio; pre-purchase inspections of seven industrial buildings around Chicago for a private real estate investor; and a pre-acquisition building condition survey of a 36 unit apartment building in Hartford, Connecticut for a Connecticut-based property management firm.

We surveyed the roofs and provided recommendations for repairs for two industrial buildings in Langhorne, Pennsylvania, and investigated the condition of the masonry in another industrial building in Philadelphia, Pennsylvania for Teachers Insurance and Annuity Association, New York, New York. Hoffmann Architects also examined the precast concrete and aluminum curtain walls of an eleven story office building for the Singer Company, Stamford, CT.

If you would like further information about the services we offer, please let us know.

Questions and Answers

With the next issue, Hoffmann Architects will be initiating a question and answer column. We invite our clients and friends to submit questions of a general nature on topics related to our areas of specialization – roofing, facade, structural, parking, or fire safing problems, and real estate consulting services. Please send your questions to Karen L. Warseck, Editor, Hoffmann Architects/*Quarterly*, Hoffmann Architects Southeast Regional Office, 1925 Century Boulevard, Suite 4, Atlanta, GA 30345.

staff and technical notes

Surety Bonds
– by Harwood W. Loomis, AIA

Recently, Robert D. Camilleri, Vice President of Francis M. Jackson Associates, Inc., and Gary Craft, Bond Underwriter for Aetna Casualty and Surety Company, presented a seminar and narrated slide show at our Connecticut office on surety bonds, what they are and why they are important in construction.

There are generally three parties in a bond situation: the Owner, the Principal (the contractor), and the Surety (the insurance company or other backer issuing the bond). In construction, there are usually three different bonds involved, which act in a complementary fashion to protect the Owner's interests. These are: the Bid Bond, the Performance Bond, and the Labor and Materials Payment Bond. In each, the Surety agrees to financially guarantee to the Owner the contractor's performance with respect to certain aspects of the construction contract.

The Bid Bond is issued as a guarantee that the low bidder will, in fact, execute a firm construction contract in accordance with the project plans and specifications for the amount of his bid, and that he will provide a Performance Bond and a Labor and Materials Payment Bond (if required by the contract documents). The bid bond is written for a percentage amount of the bid price (usually between ten and twenty-five percent), which amount is paid to the owner by the surety if the bidder fails to execute the contract to make up the difference between the contractor's bid and the next lowest bid.

The Performance Bond provides financial assurance to the Owner that the contractor will follow the plans and specifications and will complete the project as agreed.

Performance bonds are written with maximum limits, most often 100 percent of the contract price. In some instances the limit may be set lower, and in a few instances may be more than 100 percent. If the contractor defaults or fails to complete the contract as agreed, the Surety will pay to the Owner the difference between the contract amount and the actual cost to the Owner of getting the project completed, up to the limit of the bond.

The Labor and Material Payment Bond provides financial backing to assure the Owner that workers on the project and material suppliers are paid. This provides protection against mechanics liens being filed against the Owner's property in the event that a contractor, for whatever reason, does not use monies paid him by the Owner to pay these obligations.

Staff News

John J. Hoffmann, AIA was the focus of an article that appeared in the New Haven, Connecticut newspaper, the *New Haven Register*. The article entitled "Trouble-shooter finds career on the roof" appeared on Sunday, October 21, 1984.

Martin A. Benassi, AIA is the Connecticut State Coordinator for the Intern-Architect Development Program.

Walter E. Damuck, AIA addressed the Eastern Region of the Association of Physical Plant Administrators in Toronto, Canada on November 5, 1984. He spoke about roofing technology and specifically, single-ply roofing and its applications.

Quarterly *is a publication of Hoffmann Architects, specialists in investigative and rehabilitative architecture/engineering, including the analysis and solution of roofing, masonry, glazed curtain wall and structural problems. Our offices are located at 3074 Whitney Avenue, Hamden, CT 06518, Phone (203) 281-4440 and 1925 Century Boulevard, Suite 4, Atlanta, GA 30345, Phone (404) 633-7817.*

*We welcome contributions to HA/Q from our clients and friends. Please send news and technical information to Karen L. Warseck, Editor, Hoffmann Architects/*Quarterly *at the Atlanta address. Address changes and additions to the mailing list should be sent to Nancy H. Bostwick in Hamden.*