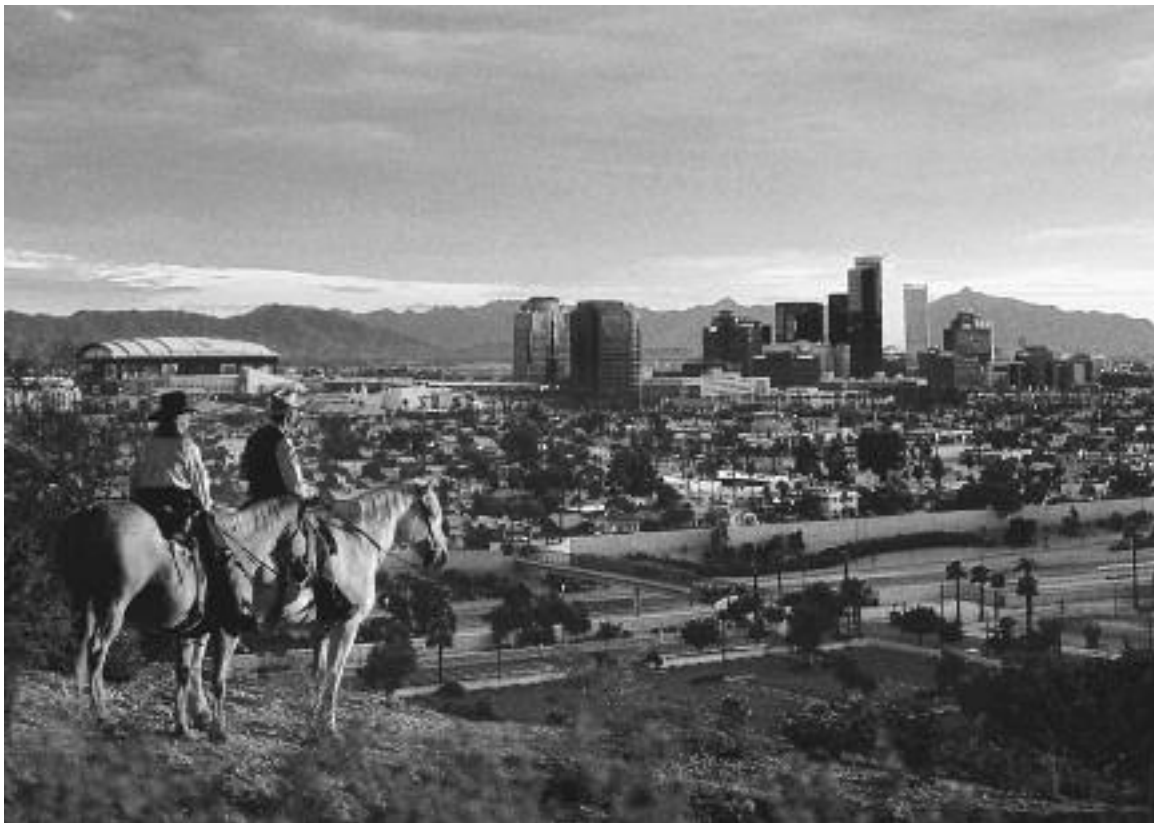


Topics in Underground Parking Structure Repair

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ABSTRACT

The assessment and repair of underground parking structures provide a unique business opportunity for many roofing/waterproofing and building envelope consultant firms. This presentation will discuss the following topics in underground parking structure assessment and repair:

- Key members of the assessment and design team
- Sources of exterior water infiltration
- Sources of interior water infiltration and moisture control
- Typical concrete repair techniques
- Expansion joint repair and rehabilitation
- Waterproofing repair and rehabilitation
- Parking and horizontal deck membrane repair and rehabilitation
- General project considerations

SPEAKER

THOMAS GERNETZKE has served as project manager on multiple projects involving underground parking structures. These projects include initial condition assessments and recommendations, waterproofing and expansion joint rehabilitation, structural concrete repair, parking deck membrane replacement, and cathodic protection.

Topics in Underground Parking Structure Repair

INTRODUCTION

The assessment and repair of underground parking structures provide a unique business opportunity for many roofing, waterproofing, and building envelope consultant firms. Discreet beneath the surface, these structures are continuously subjected to moisture from external and internal sources. These represent some of the harshest conditions in the built environment. Conversely, these structures often provide the first impression of a facility to a visitor. Dripping water, spalling concrete, stalactites, and other moisture infiltration-related conditions present an appearance of poor maintenance and public safety concerns. Moisture infiltration and electro-chemical corrosion processes develop exponentially. Unchecked, these processes will cause eventual structural failure. With construction costs sometimes exceeding \$40,000 per parking stall, combined with the less-discernable value of damaged first impressions, these structures represent a significant investment to an owner.

STRUCTURE ASSESSMENT

As with any rehabilitation project, the first requirement is assessment. The assessment of the structure should be completed in multiple phases. The initial phase should include the assessment team: owner's representatives, waterproofing consultant (WC), corrosion specialist, and structural engineer. The owner's representatives should include the person most knowledgeable about the structure in question. The corrosion specialist and

structural engineer can be one and the same. The intent of the initial phase is site orientation for the assessment team and collection of relevant documentation, such as as-built drawings and repair history. Operations and logistics, such as security and off-hours access, should also be discussed. During this initial phase, the owner should describe specific concerns or questions he may have, as well as specific requirements for the assessment.

Based on the initial observations, owner requirements, and a plan review, a thorough inspection should be conducted. Whenever possible, as-built and record drawings should be reviewed. It is important to consider shop drawings; construction and contract documents may not reflect actual conditions. Much of the assessment will and should occur off-hours, when there is the least amount of traffic. The engineer will probably require chain dragging, hammer tapping, or other initial non-invasive tests. The WC may want to observe the structure during a rain event. In any event, flexibility in scheduling inspections is critical; off-hours inspections are often beneficial and necessary for multiple reasons.

First, it is very important to consider that a parking structure can be a dangerous work environment. Second, a parking structure can be loud and distracting for an assessment team. In many instances, the assessment team members should conduct their inspections independently of each other. While each party is looking for deficiencies, different deficien-

cies can be distracting for the other members. A thorough record of findings should be made by each party and then compared upon completion of the inspection.

After the assessment is complete, a consolidated list of deficiencies should be generated. It may be beneficial to involve an experienced parking structure repair contractor if unusual or difficult repairs are being considered.

COMMON AND RECOMMENDED ASSESSMENT TECHNIQUES

One of the most important assessment techniques is visual inspection of all surfaces. Visual inspection should include all surfaces of a parking structure for any indication of abnormal conditions. Use of a drawing of the structure and maintaining an easily discernable pattern is important. Carrying a masonry hammer during the inspection to sound questionable surfaces may improve efficiency as well as defining finish surface blemishes from spalling or other deterioration.

Chain dragging is an important and effective assessment technique to determine the quantity and location of horizontal surface spalling. Typically, supported concrete slabs are covered with membrane or coating to protect the slab from water and subsequent chemical contamination. These coverings or coatings obscure spalls. Chain dragging is conducted by dragging a length of chain over the area to be inspect-

ed. When the chain drags over a spall, a distinct hollow sound is heard. The size and location of the spall can be determined by "sounding" around the perimeter and marking it with spray paint. If the client is sensitive to permanent marks, chalk can be used.

Hammer tapping is the same principle as chain dragging. Hammer tapping is primarily used for vertical and overhead surfaces. It can be used to more clearly define spall perimeters discovered during chain dragging. Any amount of overhead inspection will require the use of a sounding tool.



**ASSESSMENT BY
STRUCTURAL
ENGINEER/
CORROSION
SPECIALIST**

Chain Dragging. When the chain drags over a spall, a distinct hollow sound is heard. Spray-painted areas indicate spalls.

The involvement of a structural engineer during the assessment process is critical. While WCs are trained to look for signs of moisture infiltration (and possible subsequent damage), a structural engineer is trained to look for signs of stress, fatigue, and other damage or deterioration. A structural engineer should determine the extent of deterioration of moisture infiltration and needed repairs.

A structural engineer should perform an analysis of the structure to determine load capacities. This is required information for design and construction phases to establish weight limits and capacities, what removal techniques are appropriate, and what repair techniques may be possible or required.



Sounding tool attached to pole. Teeth on gears tap on concrete. As tool rolls over spalled areas, the sound changes.

A structural engineer may recommend testing to determine the condition of a structure. Testing may range from non-invasive (Swiss hammer, X-ray) to invasive (coring).

A corrosion specialist may recommend various testing methods to determine the extent and severity of corrosion in a structure. These specialized methods include chloride ion content sampling, half-cell corrosion potential testing, and electrical continuity testing. These test results can be used to determine appropriate corrosion mitigation or corrosion prevention techniques.

SOURCES OF EXTERIOR MOISTURE INFILTRATION

Underground parking structures experience the same external moisture sources as any other underground structure. Typically, these sources of moisture include stormwater (site) run-off, irrigation systems, and naturally occurring underground springs and elevated water tables. In coastal regions, salt water and salt spray are a significant concern for parking structures because of the presence of chloride.

SOURCES OF INTERIOR MOISTURE AND MOISTURE CONTROL

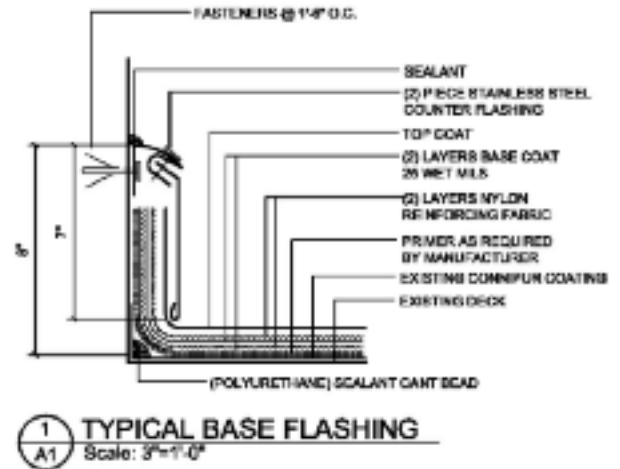
Parking structures often experience internal sources of moisture that must be managed. A prevalent source of moisture is excessive humidity in unconditioned structures. Underground parking structures have code-required mechanical ventilation systems to expel vehicle combustion gases. Local code may define ventilation in air changes per hour, CFM per square foot, or CFM per operating vehicle.¹ Whatever the condition, volumes of fresh, unconditioned air enter these structures. Warm, moist air

contacting large, cold concrete surfaces produces large quantities of condensation. This phenomenon can propagate itself for extended periods of time, depending on conditions.

Condensation moisture must be managed. It may be prudent to detail membrane transitions similar to exterior applications by using appropriate sheet metal flashings. Prolonged exposure to moisture will deteriorate expansion joint terminations, traffic-bearing membrane terminations, and other critical sealing components. In addition, sheet metal and related redundant flashings can provide additional protection at slab-to-wall transitions where movement may disturb membranes and coatings.

Vehicles are a source of moisture. In northern climates, vehicles are often covered in road salt and snow. De-icing materials often contain a variety of chloride. Chloride ion contamination is a significant cause of deterioration in parking structures and will be discussed later. Over a season, a parking structure full of vehicles covered with salt and snow creates tremendous exposure to chloride ion contamination. The condition is exacerbated with the application of ice-melting materials to maintain slip-resistant surfaces. In coastal regions, saltwater dripping from vehicles presents another source of chloride ion contamination.

Vehicles discharge a variety of liquid substances. Automotive air conditioning systems are similar to building HVAC systems. Condensate from automotive sys-



tems contains the same copper ions as HVAC systems and may interact with less noble metallic surfaces. While anti-freeze and oil typically do not cause moisture concerns, they can penetrate unprotected concrete and cause adhesion or contamination problems during future repair work. These materials can also damage prefabricated joint systems and sealant joints. Engines create volumes of water vapor during combustion. This warm, moist air is another source for condensation on cool concrete surfaces.

Maintenance activities, particularly pressure washing and cleaning, provide large quantities of moisture, sometimes complicated by humid conditions. Faulty plumbing systems may also contribute large sources of moisture to the structure.

CAUSES OF COMMON MOISTURE-RELATED CONCRETE DETERIORATION

Corrosion of reinforcement in concrete is a significant cause of moisture-related concrete deterioration in parking structures. "Corrosion-induced deterioration is the most dominant and aggressive form of deterioration of parking structures located in the

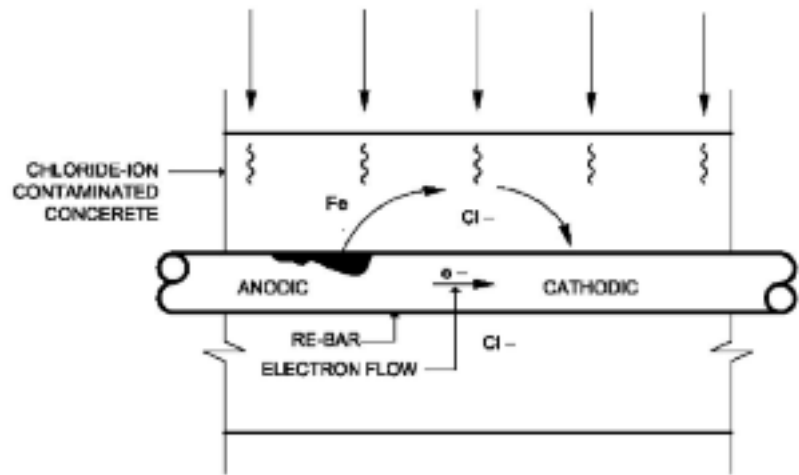
northern climactic region.”²

Reinforcing steel in new or uncontaminated concrete does not corrode because a passivating layer of protective oxide forms on the steel during the cement hydration process. The presence of calcium hydroxide in concrete creates a high pH environment of 12 to 13. The presence of chloride ion contaminant reduces the high pH of concrete and will initiate the corrosion process once the contamination reaches the reinforcing steel. If the pH falls below 11.5, the passivating layer on the steel will become unstable and can lead to corrosion.^{3,4}

Concrete is a porous material. Concrete pores have a diameter ranging from 15-1000 Angstroms. The diameter of a chloride ion is less than two Angstroms. One angstrom is equivalent to ten millionths of a millimeter.⁵ Traffic-bearing membranes and clear water repellants provide a measure of protection but cannot stop chloride ion contamination. Slab areas with poor drainage or standing water exacerbate contamination.

Older structures are more susceptible to chloride ion contamination. Structures built prior to the mid 1980s do not benefit from air entraining admixtures, corrosion inhibiting additives, or crack reduction techniques. Prior to 1977 the minimum concrete cover over reinforcement was 3/4-inch. This minimal concrete cover provides optimal conditions for rapid chloride ion saturation and subsequent corrosion. Today, ACI 362 requires a minimum of two inches of cover.⁶

“Corrosion of a metal is an electro-chemical process that requires an oxidizing agent, moisture, and electron flow within a metal; a series of chemical reactions takes place on and adjacent to the surface of the metal.”⁷ This electrochemical process requires



1 CORROSION DETAIL
A1 Scale: NTS

an anode, a cathode, an electrolyte, and a return circuit. The anode is the point where corrosion occurs by migration of ions into the electrolyte; the cathode is the point where electrons are consumed and no corrosion occurs. The electrolyte (water-based solution) carries ions capable of conducting current. The return circuit is usually the steel reinforcement itself.⁸

Rust is a byproduct of the corrosion process. The rust from the reinforcement occupies a volume greater (2.5 times or more) than the steel itself. This expansion causes stress in the surrounding concrete resulting in cracking. Once the concrete is cracked, electrolyte, oxygen, and chloride have a direct path to the steel, further accelerating the corrosion process. This cracking then develops into delamination and eventual spalling of the concrete.⁹

REPAIR TECHNIQUES

1. Horizontal Surface Spall Repair

Horizontal surface spalling is the predominant deterioration mechanism in underground park-

ing structures. Even when protected by traffic-bearing membranes, these surfaces are still susceptible to corrosion activities. In order to perform these repairs, an accurate delamination survey must be conducted. During this survey, it is important to remember the markings will be a guide for sawing. It is very difficult to saw a radius or elaborate shapes into concrete. Angles should be kept (as close as possible) to 90 degrees or larger. Tight angles often break off during the repair process, creating unnecessary work. For detailed information, refer to the International Concrete Repair Institute (ICRI) “Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion,” Guide No. 03730.

Prior to beginning any spall repair, it is critical to determine the effects of the repairs to the integrity of the structure. Buried electrical conduits, prestressing or post-tensioning tendons must also be located prior to work. Disrupting these items with a saw or other means can create an imminent safety threat.

The perimeter of the spall must be cut, typically with a concrete saw. It is desirable for the depth of cut to be greater than 1/2-inch as long as the reinforcement is not cut. After saw cuts have been made to define the perimeter, removal of the deteriorated concrete above the corroded reinforcement can begin. Concrete removal should be limited to 15-lb. chipping hammers or smaller. Larger hammers often do more damage than good. Occasionally, larger hammers can be used in certain situations by trained technicians.

After initial removals have been completed, the reinforcement-to-concrete bond and the condition of the concrete in the vicinity of the rebar should be checked. After the initial removal, if the concrete is in good condition and the rebar is well bonded, further removal is unnecessary. The rebar-to-concrete bond is checked by lightly tapping the rebar with a hammer. Heavy blows to exposed rebar will de-bond the rebar, requiring further repair. If lightly striking the rebar with a hammer produces a ping-type noise without vibration, the bond is acceptable. If striking the rebar produces a thud and is accompanied by vibration of the bar, the rebar is not bonded, requiring further removal and undercutting. Concrete removal and undercutting must be completed until both ends of the exposed bar are well-bonded to surrounding concrete.

Undercutting of reinforcement steel should provide a minimum of 3/4-inch clearance around the bar or 1/4-inch larger than the largest aggregate in repair material, whichever is greater. A good rule of thumb is a hand should be able to be wrapped around all portions of the exposed bar. This will ensure there is sufficient clearance for cleaning and preparation of the bar. Any reinforcement that is loose shall be

secured in place by tying to other secured bars or by approved methods, as directed by the structural engineer.

Once the rebar has been exposed and prepared, all heavy corrosion and scale should be removed by media blasting. An oil-free abrasive blast is the preferred method. By changing the angle of the blast, all portions of the bar can be addressed, either by direct contact with the abrasive or by rebounding the abrasive off the concrete substrate. The concrete substrate should also be blasted to ensure laitance and other foreign matter is removed. This blast will help to achieve adequate bond between repair (patch) material and existing concrete.

If a rebar has a loss of significant cross-section, the structural engineer should be consulted. There are multiple methods to repair deteriorated rebar. The structural engineer should determine the most appropriate and effective method for the repair. Also, the corrosion specialist should determine if epoxy or other treatments should be applied to the rebar. Rebar treatment will depend on existing conditions and future corrosion protection or mitigation methods.

Once the removal, undercutting, cleaning, and repair process has been completed, the concrete excavation needs to be final checked for remaining spall conditions. The structural engineer should select the appropriate repair (patch) material to be used. Material considerations should include time to cure, temperature, size of repair, ease of use, return to service time requirements, and possible future cathodic protection or mitigation efforts.

2. Vertical and Overhead Spall Repair

Vertical and overhead spall repair is similar in principle to

horizontal spall repair, with differences being location of the repair and techniques used to perform the repair. Removal, undercutting, cleaning, and repair requirements are still the same. Repair (patch) material and its placement technique will dictate the preparation required. Vertical and overhead spall repairs often require different material than horizontal repairs.

For all repairs, care must be taken to follow the manufacturer's instructions for bonding methods and placement methods.

Corrosion Mitigation and Cathodic Protection Systems

There are multiple methods to mitigate or reduce corrosion activity; their effectiveness is relatively short-term. The two commonly accepted methods are chloride ion extraction and re-alkalization. These methods are similar but deliver different results. Both are intended to return passivity to the steel reinforcement. Both will allow future contamination and may require additional treatments. Chloride ion extraction is achieved by applying a conductive media and electric current to the slab. Re-alkalization is similar to chloride ion extraction in that an electric field is applied to the slab. Re-alkalization also introduces an alkaline electrolyte to the concrete. The combination of the applied electric field and the electrolyte results in higher pH levels and returns the reinforcement steel to a passive condition.

For nearly-permanent results, cathodic protection (CP) method is "in concept, the only method which will effectively stop the corrosion of embedded reinforcement in chloride contaminated slabs..."¹⁰ Simply, CP introduces electric current into the slab to be protected.

Currently, CP installations are limited to conventional, mildly-

reinforced concrete structures. With caution, CP has been applied in limited applications to prestressed and post-tensioned structures. These structures present potential hydrogen ion development, causing embrittlement and failure of high-strength prestressing steel and post-tension tendons.

EXPANSION JOINTS

The *Construction Waterproofing Handbook* claims the 90%/1% principle of water intrusion: “As much as 90% of all water intrusion problems occur within 1% of the total building or structure exterior surface area.”¹¹ Expansion joints are the epitome of this principle. Waterproofing expansion joints are the most difficult, expensive, and important detail preventing long-term moisture infiltration into an underground parking structure.

1. Vertical Joints

Vertical expansion joint leakage is a primary moisture path into an underground parking structure. These joint systems are often subject to intense hydrostatic pressures, seismic movements, building movement induced by thermal expansion and contraction and vehicular influences, positive- and negative-side chemical contamination, and vandalism.

Below-grade vertical expansion joint repair and remediation is difficult. A typical short-term solution is epoxy injection of the joint. Epoxy injection does not allow for joint movement;¹² however, chemical grout injection can provide some protection in movement joints and is sometimes an alternative to costly full-depth joint excavation and repair.



Dewatering responsibilities must be delineated prior to start of work. Note the ladder in the water.

Chemical grout injection requires detailed cleaning and preparation to remove mineral deposits and other contaminants in order to be effective. The grout injection process can also cause additional cracking if blind-side concrete or joint conditions are deteriorated.

Full-depth excavation and joint repair can provide assured, long-term results, but this method is expensive and can be very disruptive. Depending on conditions and depth of the joint, these repairs can exceed \$2000 per linear foot of joint. The primary expense is the excavation and shoring required to expose these joints. Depending on the depth of excavation, piling, lagging, and related shoring items must be designed by a registered professional engineer (OSHA 29 CFR 1926.652). Shoring systems must allow for adequate access to the entire joint. This includes a minimum of five feet on either side of the joint to allow assessment of

the concrete as well as enough area to tie-in to existing waterproofing systems.

Dewatering responsibilities must also be delineated prior to the excavation. These excavations can very easily fill with water, exposing the under-construction joint to premature water exposure as well as deteriorating shoring and piling systems. These excavations are also defined as confined spaces. Adequate protective measures, such as harnesses, safety lines, and ventilators, must be used by anybody entering the excavation.

Once the excavation and shoring have been completed, the existing joint system is removed and the surface prepared for the new joint. The preparation work must be inspected prior to the new joint system being installed. The inspection should include a thorough sounding (hammer-tapping) to determine if any concrete

spalling or deterioration has occurred. If spalling or other deterioration is observed, the area must be repaired and restored to its original condition. The primary concern is the restoration of a smooth and even surface condition to allow the new joint system to bond to the surface. Irregular, cracked, or deteriorated surfaces will cause joint failure.

Given the cost of these repairs, redundant joint systems are preferred. Each layer of the membrane used should be secured to the substrate independently to secure against differential movement and increased hydrostatic pressures. For expansion joints, the joint system selected must also be able to transition from vertical to horizontal at the top of the joint. After the joint system is installed, a bentonite, clay-backed HDPE sheet can be secured over the joint to protect the joint as well as provide additional waterproofing capabilities. The HDPE sheet should be considered as minimum to protect the joint during the back-fill process. Protection mat, drainage board, XPS insulation, and other means and methods can and should be used to protect the new joint from damage during back-fill and finish grading.

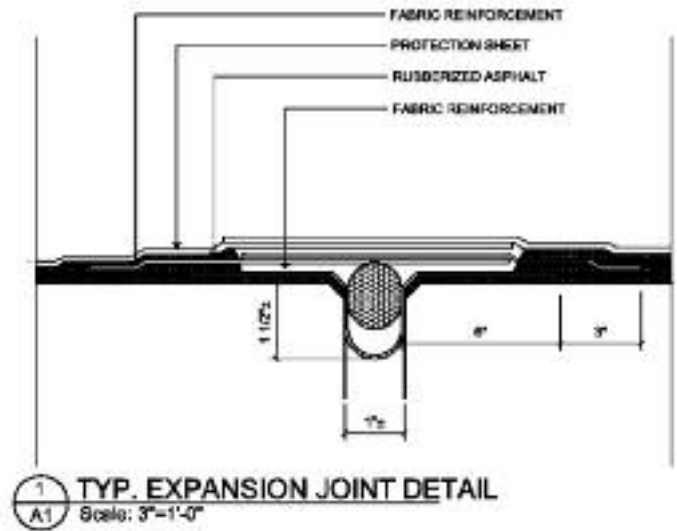
The joint can be installed continuously or by lifts as the excavation is back-filled. Depending on conditions, the back-fill material and drainage systems must be selected to (if possible) minimize hydrostatic pressure on the new joint. Back-fill materials can range from coarse sand to clear stone, pea gravel, or slurry fill. If slurry fill is used, "half-bag" or "diggable" slurry should be used. Slurry with more Portland cement content will be very difficult, if not impossible, to excavate if any future joint work or surface work in the vicinity needs to occur. Even with a half-bag mix, the concrete cream will rise to the surface

and may create a nearly impenetrable surface. During the backfill process, the shoring system may be cut down or removed as necessary.

2. Horizontal Joints

Below-grade horizontal expansion joints are common sources of water infiltration. Though not as expensive to repair as below-grade vertical joints, horizontal expansion joints require the same care and attention. Waterproofing manufacturers specify joint details to be used during the replacement of waterproofing systems.

Below-grade horizontal expansion joints are often located on plaza-deck type systems. These joints are often covered with overburden, or can have asphaltic concrete pavement applied directly to them. Care must be taken during the removal of the overburden, as any existing joint integrity will be lost during the removal process. This is a critical consideration if waterproofing over finished spaces, pedestrian tunnels, etc. Many do not consider parking structures critical spaces, but repainting vehicles damaged by debris carried through open construction joints is an expensive and embarrassing proposition. In addition, an open horizontal joint can allow quantities of water into a parking structure greater than the available floor drain capacity of the structure. Parking structure floor drains are often restricted or clogged with sand and debris, or vehicle tires obscure them. Vehicles should not be



allowed to park under joints during construction.

3. Traffic-Bearing Joints

Traffic-bearing expansion joints receive tremendous abuse in a parking structure. These systems must withstand UV exposure, chemical exposure, vehicular traffic, traffic-induced deflection across joints, snow plowing and removal operations, vandalism, seismic movement, and other deleterious influences. In addition, these joint systems must often be aesthetically pleasing and meet accessibility requirements.

When detailing a new expansion joint or a remedial application, a primary consideration must be the potential movement of the joint. The structure must be analyzed by a structural engineer to predict movement. Possible movement includes expansion and contraction, shear stress, and differential movement unrelated to thermal expansion and contraction.

Joint termination must often accommodate the following conditions: floor joints, wall-to-floor joints, building-to-floor joints, intersections with curbs, intersections with columns, joints at

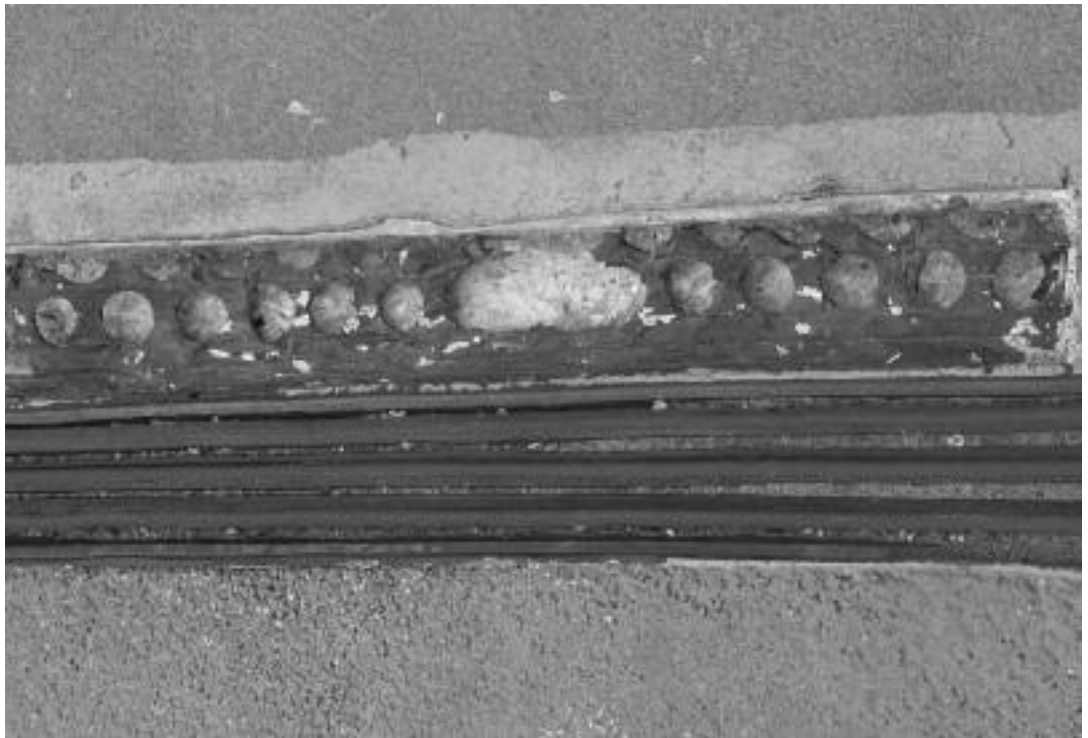
ramps, ramp-to-floor joints, intersections of two or more joints, changes in direction, and joint terminations.¹³

Joint systems must not create trip hazards. Depending on individual situations, joints may have to be ADA-compliant.

These joints must perform flawlessly through the entire life-span of the system. This continuous performance can be assured with a bi-annual inspection and maintenance program. This program should be included or added to the required warranty for the joint. Traffic-bearing expansion joint system warranties are void if maintenance is not performed and documented on a regular basis.

Manufacturers' warranties must be carefully considered for traffic-bearing joints. As previously stated, consider movement analysis by a structural engineer in the design. This information, including a worst-case movement scenario, must be included in bid documents. If building movement exceeds the limits set by the engineer, joint warranties are typically voided.

Traffic-bearing joint warranty considerations should include "joint and several" warranties and approved installer programs. Joint and several warranties bind the manufacturer and the contractor for the life of the warranty. If either party to the warranty defaults or becomes unresponsive, the other party becomes responsible for the warranty. Joint manufacturers that do not have approved or licensed



Localized failure of a pre-formed, traffic-bearing expansion joint. Photo shows components of joint system.

installer programs should be further scrutinized. These joint systems require skilled, experienced technicians to ensure proper installation.

There are 11 main types of expansion joint systems.¹⁴ They are: sealant, T-joint, expanding foam, hydrophobic expansion seals, sheet, bellows, preformed rubber, combination rubber and metal, vertical, heavy-duty metal, and below-grade applications. Only T-joint systems, pre-formed rubber systems, combination rubber and metal systems, and heavy-duty metal systems are appropriate for use as traffic-bearing expansion joint systems. Systems should be carefully chosen based on its inherent strengths and weaknesses.

The most popular and durable traffic-bearing expansion joint systems used in parking structures are classified as pre-formed rubber and combination rubber and metal. These systems consist of a pre-formed rubber gland,

mounting flanges, and elastomeric concrete nosing set into block-outs on either side of the joint. The pre-formed rubber glands consist of different profiles to allow for different joint movements and ADA requirements, if necessary. These glands are typically manufactured with a chemical-resistant thermoplastic elastomeric (TPE) material. TPE materials can be heat-welded and have similar properties to other thermoplastics, such as TPO and PVC roofing membranes.

The joint glands are attached to perforated flanges. Flanges are set into the block-out area and secured with elastomeric concrete. The perforations in the flanges provide an improved mechanical connection of the gland to the structure. The elastomeric concrete provides the mechanical connection to the structure as well as providing protection for the gland from vehicular traffic and snow-removal operations. Attention must be directed to the particular manufacturer's



Water stop that migrated up into the concrete slab during the initial pour. Concrete at corner of expansion joint subsequently spalled, causing joint leakage.

material being used. Some manufacturer's elastomeric concrete is not UV-stable and requires a coating after installation. Depending on the material, this coating can deteriorate, causing deterioration of the elastomeric concrete.

As with any waterproofing system, preparation is essential for long-term performance of traffic-bearing joint systems. Block-outs to receive the joint gland must be prepared exactly as required by the manufacturer's installation instructions. This often includes sounding of the concrete to inspect for spalling or other concrete deficiencies, concrete repairs, and media blasting of the block-out surfaces. Block-out surfaces must be true and level. If not, the joint gland may pivot on uneven surfaces and create a ratcheting action under flexural movements, leading to adhesive or cohesive cracking of the elastomeric concrete nosing material.

Traffic-bearing expansion joint systems are available with manufacturers' transition details. As with all expansion joint systems, transition details are the Achilles heel to these systems. Consult a manufacturer's representative during the design process to ensure the correct specification of joint transition details and materials.

CONSTRUCTION AND PHASE JOINTS

Construction joints (often referred to as "cold joints"), phase joints, and control joints often are sources of water infiltration. During initial construction, water stops are often specified at these critical locations. If the water stops are actually installed during initial construction, they frequently are poorly installed or damaged during concrete formwork and placement.

During the leak investigation, assessment, or design phase of a

remedial waterproofing project, a careful review of as-built drawings should be conducted to determine the presence of known construction, control, or phase joints. Typically, control joints should be located 30 feet apart or closer. These control joints are designed to crack during plastic concrete shrinkage and settlement. They are not intended for movement other than settlement. A cracked control joint with a poorly installed water stop is an ideal moisture infiltration source.

"Cold joints" are often not indicated on as-built drawings. Due to the inherent weakness of these joints, they can crack more easily than the surrounding concrete and allow moisture infiltration. To aggravate matters, water stops are often not included in these joints. Depending on original construction methods used, these joints can traverse entire lengths of below-grade walls. If a cold joint crack is detected from the interior, a determination must be made if there is movement of the joint. This helps to determine a course of action. Depending on the importance of the interior space, epoxy injection or chemical grout injection should be attempted as a first course of action. If injection systems do not perform adequately or if the joint cannot be accessed from the interior, excavation and external repair may be the only course of action.

Horizontal cold joints can be a source of water infiltration.

WATERPROOFING REPAIR AND REHABILITATION

Perhaps the most familiar parking structure repair for WCs is waterproofing repair and rehabilitation. Many parking structures are contained below-grade, with the exception of entrance doors and ramps. Typically, the

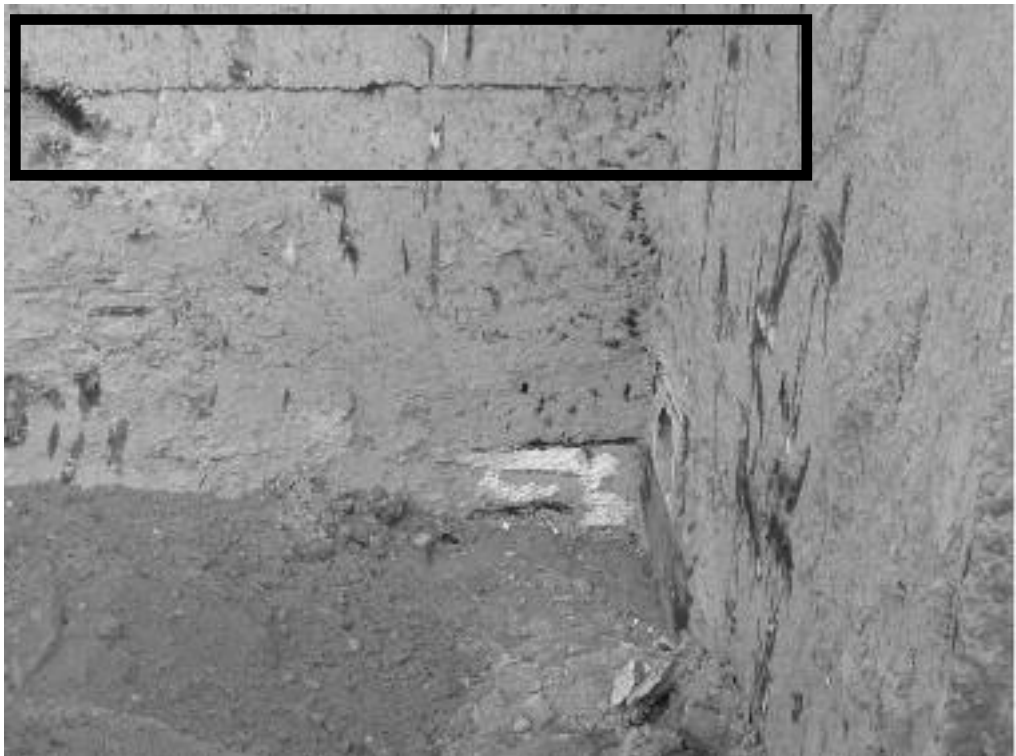
overburden consists of pea gravel, filter fabric, clayey fills, and top soil. Overburden like this is used to retain moisture to support plant growth.

All structures should have analysis conducted by a structural engineer to determine load capacities with and without overburden in place. Knowledge of capacity by excavation, landscape, and paving contractors assists them to formulate means and methods during rehabilitation

Free-draining stratum atop waterproofing systems is the key component to maximized life-expectancy. For this, protection mat, drainage board, insulation, and, of course, overburden, must be considered. These materials must provide, at a minimum, exemplary protection to the primary waterproofing membrane, including during construction and back-fill. Drainage layers, insulation, root barriers, and other items are placed in the system to perform specific tasks and can also provide protection to the primary membrane.

CONCLUSION

The effect of moisture infiltration into underground parking structures is complex business. There are numerous components that typify the moisture-protection system of the structure. Additionally, there are dynamics that require foresight and ingenuity if one endeavors to thwart long-term maintenance investment or expensive repair for the owner's benefit. The subject presents its advantages for the expertise of the waterproofing consultant. The principles of moisture migration are consistent. Con-



Localized failure of a pre-formed, traffic-bearing expansion joint. Photo shows components of joint system.

sulting owners of these structures with the utmost confidence, whether providing peer review or providing positive conclusion to remedial activity, is possible with the materials and methods that exist. If a waterproofing consultant is not comfortable undertaking consultancy individually, underground parking structure repair is ideal for a team approach. For many, it is a natural progression.

FOOTNOTES

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