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What's Wrong with My Precast Concrete Parking Garage?

Steven J. Susca, PE and Robert A. Marsoli, Jr.

Developers of new parking structures often choose precast concrete construction, both for its cost savings and for the fast track construction schedule it allows. Fabricated in a manufacturing plant, precast concrete elements are shipped fully formed to the construction site, where they are assembled. Because it is cast and cured under factory-controlled conditions, precast concrete tends to exhibit better consistency, higher quality, and greater durability than does concrete fabricated on site.

Trimming a chord connection rod as part of a precast concrete garage rehabilitation.

Yet, in spite of these assets, there has been a spate of precast concrete parking garage failures in recent years. While some have been catastrophic and highly publicized, the vast majority of failures don't make the headlines. Nonetheless, if ignored, even inconspicuous defects can lead to dangerous conditions. The average motorist would be shocked to learn that upwards of tens of thousands of precast concrete structures exhibit some degree of structural distress.

Given such dire potential consequences, parking garage owners may worry that the spall, crack, or displacement they've noticed could be indicative of greater problems. The causes of failure, though, can be as varied as the symptoms, ranging from inadequate design to defective fabrication to installation error to lack of maintenance. Armed with a basic understanding of precast concrete construction and its potential flaws, garage owners and managers will be better able to detect emerging issues that merit intervention.

How They're Built

Reinforced Concrete Fabrication

Precast concrete garages are usually made up of a system of conventionally reinforced precast concrete columns and prestressed concrete beams and

Steven J. Susca, PE, senior engineer, and Robert A. Marsoli, Jr., project manager, diagnose and resolve parking garage deterioration with Hoffmann Architects. They develop engineering solutions that address defects in design and workmanship, structural movement, corrosion, concrete degradation, exposure, and stress.

Glossary of Common Defects			
Defect	Characteristic	Possible Causes	Location on Diagram (pg. 3)
Crazing (also called Map or Pattern Cracking)	Fine, shallow, interconnecting cracks that mimic roads on a map	Excess water in mix; Improper curing; Poor finishing techniques; Alkali Silica Reaction (ASR)	1, 3-8
Drying Shrinkage Crack	A surface crack that forms as water evaporates during curing	Excess water in mix; Inadequate control joint spacing	3
Plastic Shrinkage Crack	A surface crack that forms in freshly placed concrete prior to or during final finishing	Rapid evaporation of water from concrete, typically due to climatic conditions	1, 3-8
Chevron Cracks	Diagonal cracks that form a "V" pattern	Shear force between beam stem and flange after de-stress	1
Longitudinal Crack	A crack along the length of a concrete element	Bending stress due to excessive gravitational loading; Corrosion of embedded steel reinforcing	1, 4, 5, 7
Shear Crack	An inclined crack at an area subject to high shear stress	Tensile stress that exceeds the design load of the concrete	1, 5-8
Freeze-Thaw Damage	Deterioration of concrete matrix during temperature cycling	Insufficient air entrainment	3
Scaling	Surface flaking that yields an uneven patchwork appearance	Insufficient air entrainment; Over-finishing; Insufficient curing	3
Spall	Broken or missing pieces of concrete	Corrosion and/or expansion of embedded steel; Impact damage	1-9
Failed Connection	Fracture of embedded steel connecting elements, such as at flanges, spandrels, or girders	Corrosion; Fabrication deficiencies; Poor installation technique; Misalignment	1-9
Sealant Failure (Adhesive)	Failure of sealant to bond to a surface	Inadequate surface preparation	1, 2A, 3, 5-7, 9
Sealant Failure (Cohesive)	Tearing within sealant material	Inappropriate sealant selection	1, 2A, 3, 5-7, 9

Note: This glossary is intended to provide general knowledge of the types of defects most commonly found in precast garages. Defects and signs of distress may require evaluation by a design professional to determine their causes and to develop appropriate repairs.

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girders. Conventional reinforcement consists of embedded steel bars or wires within concrete and is generally reserved for columns, load-bearing walls, and other members that undergo compressive stresses.

Flexural members, however, including precast horizontal slabs, are typically reinforced with steel tendons that are *prestressed*. Embedded tendons are tensioned before the concrete is cast and set. Once the prestressed concrete is installed on site, the internal stresses applied by the tendons work to counteract gravity and service loads, yielding lighter members that can span longer distances than their conventionally reinforced counterparts.

Beams that comprise the parking surface are most commonly fabricated in the form of a *double tee* (TT), with horizontal, cantilevered *flanges* supported by vertical *stems*. Single tee and quad tee beams have been used as well, although less frequently. Placed side-by-side, the horizontal flanges create a large slab or deck that acts as the parking surface of the garage. Embedded steel plates in each beam are welded to those of adjacent members, creating a unified structural system. When these connections are properly configured, the parking surface also acts as a diaphragm to resist lateral loads applied to the garage through wind or seismic forces.

Field Assembly

After the precast concrete elements are cast and allowed to cure, they are removed from the forms and delivered to the site where the garage is to be constructed. Each piece is marked with a unique identifier to facilitate correct assembly. Lifted into place by large cranes, precast members are joined to columns, supporting girders, or shear walls via welded connections. Embedded plates in the precast beams, usually fabricated of stainless steel to resist corrosion, are welded together at joints using a filler plate or rod. To prevent moisture intrusion, joints between individual members are usually filled with flexible sealant.

Precast concrete garages don't rely exclusively on shop-fabricated concrete, however. Cast-in-place elements at the ends of beams are sometimes used to direct runoff to drains, and cast-in-place concrete toppings may be applied to the parking

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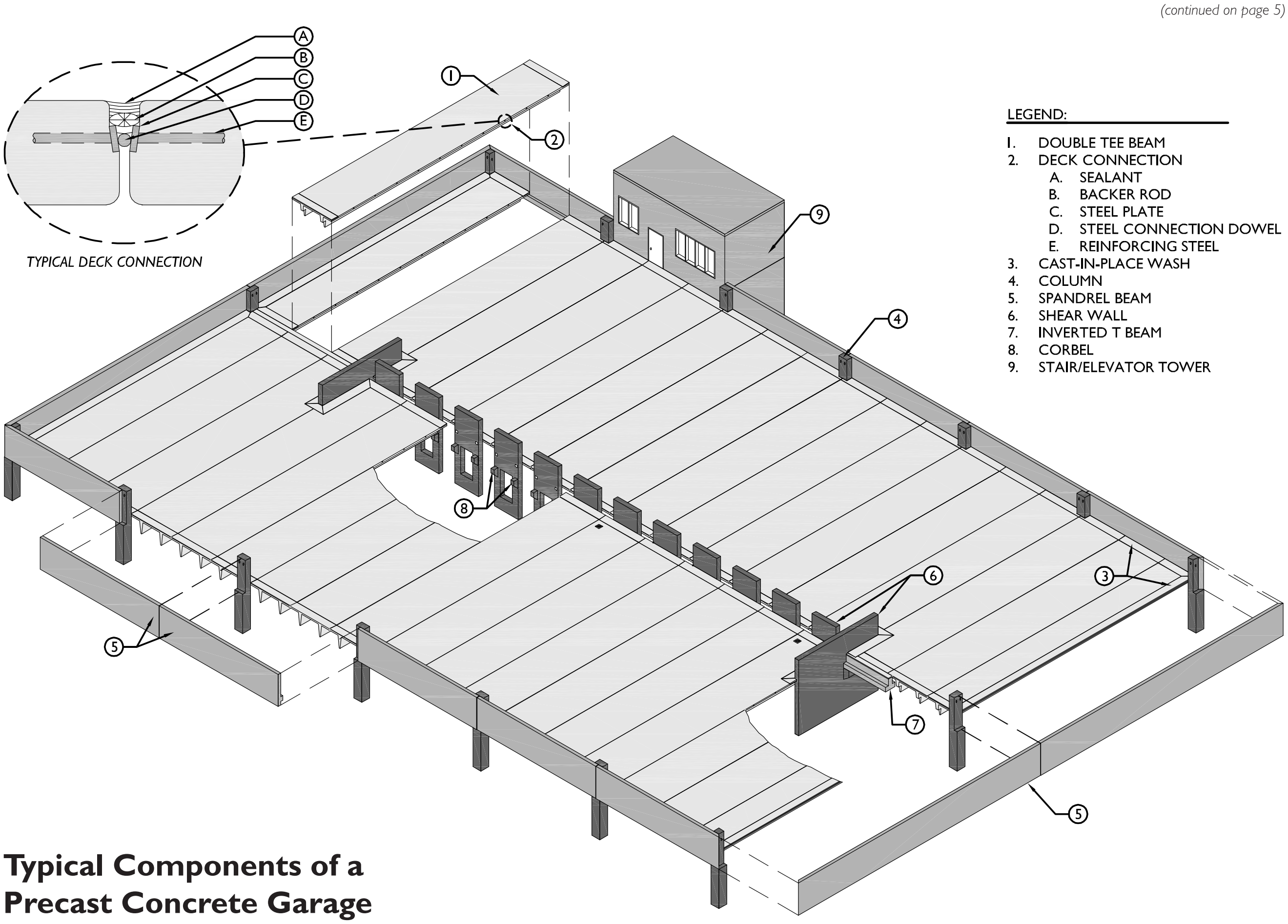

Typical Components of a Precast Concrete Garage

Sample Maintenance Program

A properly designed and consistently executed maintenance program is critical to the safety, functionality, and longevity of a precast concrete garage. Below is a sample program that highlights some of the typical maintenance items associated with precast garages. It is not meant to be inclusive of all defects or housekeeping items that should be periodically addressed, as garage conditions and situations vary. As such, a comprehensive program should be tailored to the needs of your specific structure.

Monthly

- Conduct walk-through inspection of the garage to assess general condition and locate obvious hazards or defects.
- Repair all observed defects as necessary.
- Clean soil and debris from expansion joints to ensure proper functionality. During winter months in colder climates, this operation may be required more frequently.
- Replace light bulbs in stairwells as necessary and remove debris.

Twice per year

- Flush / power wash deck surfaces.
- Check for broken flange connections. If observed, retain a design professional for diagnosis and remediation.
- Inspect deck surfaces for signs of excessive wear or deterioration.
- Examine expansion joints for tears and broken header material.
- Check deck membranes or other coatings (if present) for signs of wear or distress.
- Inspect undersides of all sealant joints for signs of water stains. Repair or replace damaged or defective sealant as necessary.
- Examine stair treads, landings and railings for loose or damaged elements or connections.
- Inspect drains. Remove debris that has accumulated in sediment buckets.
- Check windows and frames for leaks, peeling paint, or other associated defects.
- Wash windows to maintain clear visibility and overall clean appearance.
- Inspect light fixtures.

Once per year

- Inspect previous concrete and connection repairs for deterioration such as cracking, debonding, or abrasion.
- Examine structural connections at ends of beams, girders, or spandrels for distress or deterioration. Seek professional assistance for proper repair of defects.
- Inspect bearing pads at ends of precast double tee beams for defects.
- Check spandrels and columns for impact damage.
- Clean light fixtures.
- Inspect pavement markings. Re-stripe as necessary.
- Check signage and graphics.
- Drain potable water systems for winter months.

Once per 5 years

- Professional assessment of garage condition.
- Professional assessment of previously performed repairs.

Note: In colder climates, snow removal is an integral part of a garage maintenance program. Selection of appropriate deicing chemicals, snow removal equipment, and techniques should be thoroughly evaluated before being implemented, as improper products and methods can have devastating effects on a parking garage.

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deck as a wearing course or structural diaphragm.

Because major elements are pre-fabricated, precast concrete construction is usually the quickest and most economical type of parking structure to build. Furthermore, when the T-beams are produced in large quantities, the forms are reused multiple times, resulting in even greater efficiencies and cost savings.

Why They Fail

In engineering terms, "failure" does not necessarily mean a catastrophic event. Often, failures occur in individual components of the overall structural system: concrete spalls and cracks, sealant debondment, and fractures in welded components are among the most common. Such failures usually do not, on their own, result in building collapse. However, if allowed to progress unabated, even seemingly unassuming deficiencies can escalate into serious conditions.

Common Types of Failures

Cracks. Shrinkage, flexure, shear, overloading: concrete cracking is so ubiquitous that conventionally reinforced concrete is designed with this eventuality in mind. However, prestressed members are designed not to crack due to normal service loads. Therefore, when a crack is discovered in a prestressed element, it generally means that something is amiss. An engineer should evaluate the crack to determine whether it is indicative of a larger issue that is detrimental to the overall health and stability of the garage.

Spalls. A spall is a small to medium-sized chunk of concrete that has broken away from a wall, beam, or other concrete member. In some cases, especially in parking garages, impact is the cause of the spall; however, in many more instances, the spall is indicative of something more serious.

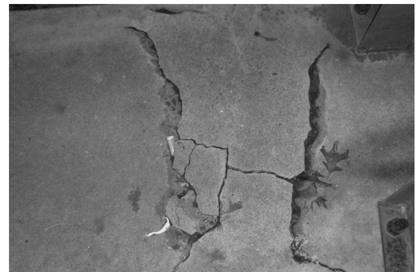
Corrosion. In the presence of water and dissolved chlorides (as from deicing salts), reinforcing steel corrodes, leading to internal distress within the concrete matrix. As it corrodes, rebar can expand up to 8 times its original size. Because it is embedded in concrete, the corroding rebar can release the expansive pressure in only one way: by cracking the concrete. Typically, these cracks begin as fissures at the site of corrosion. Eventually, a spall results, exposing the reinforcing steel to yet more moisture and corrosive chemicals in a self-propagating cycle of deterioration.

Connection Failures. The most serious type of failure is related to the connections between precast concrete structural elements.

Flange-to-Flange Connections. Let's start with the most common connection in a precast parking garage. Adjacent precast concrete tee beams are connected along their length through welds between metal plates embedded in the flanges. Functionally, the welds turn individual beams into one unified slab, allowing the flanges to mutually support one another against gravity loads. The connections also are designed to resist tensile loads induced by thermal expansion and contraction, as well as shear across the joint caused by lateral loads.

As these loads are applied, the flanges work as a system, distributing forces across multiple connections. For this reason, failure of one connection does not result in a catastrophic failure of the garage. However, each severed connection does have a deleterious, if subtle, effect.

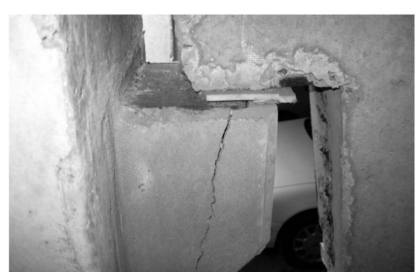
When a connection fractures, it can no longer resist any load. Therefore, the load that would be carried by that connection is redistributed to adjacent


Spalling


Freeze-Thaw Damage


Adhesive Sealant Failure


Flange Connection Fracture


Cracked Corbel

connections, increasing the load that each must withstand incrementally. When enough of these connections fracture, the joint will "unzip," severing all flange connections along its length. Loads from the unzipped joint are transferred to adjacent joints, leading to excess stress and further connection failures. In a snowball effect, overall loads on the garage are resisted by fewer and fewer intact joints. As more joints unzip, the structural integrity of the diaphragm created by the tee flanges is compromised. Eventually, the garage becomes unstable.

A qualified structural engineer can diagnose connection failure in its early stages and identify the root cause. A program of preventative action can then be initiated to arrest deterioration before it becomes hazardous.

Beam End Connections. Configured similarly to flange connections, beam end connections comprise a vital part of a garage's lateral force resisting system. Embedded plates in the tees are welded to plates cast into a shear wall, column, or spandrel beam, by means of a connection plate. Differential movement or corrosion of embedded steel can compromise the integrity of these connections.

Common Causes of Failures

Design Flaws. Design-related failure is the result of errors such as underestimating or, in some instances, overestimating the loads that will be applied to a structure. Case in point: to accommodate a planned future expansion, a parking garage is designed to handle lateral forces beyond those associated with the current structure's height. The excessively rigid vertical members restrict the movement of precast beams as they undergo volumetric changes due to temperature differentials. Enough force then builds up at connection points to cause overloading and, eventually, failure. Improper installation and corrosion can accelerate the damage.

Fabrication Deficiencies. Although manufactured under controlled conditions, precast concrete is nonetheless a product of human industry, and, thus, is subject to human error. For example, in far more instances than would be expected, embedded connection plates in precast concrete elements are improperly positioned. They don't need to be off by much to create a problem during construction. As an example, consider a flange connection plate that is displaced laterally by a small amount, say 1½". Because the displaced plate doesn't fully align with the facing flange plate, the connection will be 1½" shorter than designed. The smaller, weaker connection is now prone to failure through overloading.

Fabrication error is also responsible for the chevron cracking sometimes observed at the ends of beams. These V-shaped cracks are caused by premature release of stress in the tensioning strands. If concrete has not reached a specified strength when the tendons are de-stressed, a corresponding shortening of the beam stem will result. Since the flange contains no tendons, it will resist this shortening. The resulting shear stress between the stem and the flange will be released through diagonal cracks at the surface of the beam.

Installation Errors. Many times, precast concrete garage elements don't fit together exactly as designed. When field changes aren't structurally comparable to originally designed connections, components are placed under unanticipated stress that may lead to premature failure. Incorrectly performed field welds can also compromise the integrity of connections between precast elements.

Unintended Usage. All structures are designed to withstand specific loading conditions. In the case of parking garages, where access lanes may be large enough to admit more than the structure can hold, this is especially important. It is all too easy to unknowingly overload a parking deck by driving a massive vehicle (like a snow plow) over it. With precast garages, this can result in broken flange or beam end connections, or even shear or flexural cracks in the beam stems.

^ Coordinate repairs to maximize continuous operation.

Identifying the source of an observed deficiency can be more complicated than simply marking the location of a crack or severed connection. Failure in one part of the parking structure may manifest as a crack in a distant area, as redistributed loads from the compromised section place excessive strain on other elements. Moreover, accurately determining the severity of a crack, spall, or fracture is not as straightforward as it may seem. While some might be the result of a fabrication error, such as removal from forms before the concrete has achieved sufficient strength, others may be innocuous surface cracks. Still others might look like innocuous surface cracks, but may actually be a sign of bigger problems.

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representative projects

Precast Parking Garages

As exterior specialists, Hoffmann Architects is well versed and experienced in resolving the design flaws, faulty construction, structural distress, and material failures that threaten the integrity of precast concrete structures. Experience with high-traffic garages means sensitivity to usage and scheduling demands, with technically appropriate solutions that are cost-effective and long-lasting.

Hoffmann Architects has evaluated and resolved precast garage distress at corporate, educational, municipal, industrial, and medical facilities, including:

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Farmington, Connecticut
Garage Rehabilitation

Baltimore City Parking Facilities Little Italy Garage
Baltimore, Maryland
Assessment and Repair

Seneca Niagara Casino and Hotel
Niagara Falls, New York
Garage Rehabilitation

Middlesex Hospital
Middletown, Connecticut
Garage Condition Assessment, Feasibility Study, Repair Design

Hospital of Central Connecticut at New Britain General
New Britain, Connecticut
Garage Rehabilitation

BMW of North America Headquarters in Woodcliff Lake, New Jersey. *Garage Rehabilitation.*

West*Group Corporate Campus
McLean, Virginia
Investigation of Two Garages

Town Center Retail Complex
West Hartford, Connecticut
Garage Rehabilitation Design

Northeast Utilities Headquarters
Berlin, Connecticut
Garage Rehabilitation Design

Foxwoods Resort Casino Grand Pequot & Great Cedar Garages
Mashantucket, Connecticut
Rehabilitation

Bell Laboratories
Short Hills, New Jersey
Rehabilitation of Two Garages

George Street Parking Garage
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Quinnipiac University, Anthem Campus in North Haven, Connecticut. *Condition Evaluation.*

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What to Do

Precast concrete parking structures can be resilient, durable, and efficient. Yet every day, unwitting motorists park their cars in structurally deficient precast garages, some little more than a few years old. While deferred maintenance can be an issue, more often the culprit is inappropriate design, a manufacturing defect, or faulty construction.

Some deterioration conditions, such as concrete cracking and reinforcement corrosion, are self-accelerating and non-reversible. If allowed to proliferate, they will diminish the effectiveness of subsequent repairs. Likewise, even a single connection failure increases the probability of further connection failures. Left unchecked, the condition can become quite serious.

If your garage reaches the point where maintenance repairs can no longer adequately keep pace with deterioration, it's probably time to have an architect or engineer conduct a condition assessment and offer a diagnosis. The sooner rehabilitation measures are implemented, the better the stability of your precast garage will be. ■

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