WJE

Parking Garages: Common Problems and Best Practices

Michael W. Lee, P.E.
Wiss, Janney, Elstner Assoc., Inc.
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Minnesota Concrete Council
Dedicated to Cast-in-Place Concrete

PCI MIDWEST

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Objectives

- Review differences between garages and other structures
- Describe common performance problems
- Discuss three case histories
- Review remediation, damage mitigation, and best practices

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Relevance

- Garages are essential to most large developments
- Garages can be subjected to extreme loads
- Structure is exposed so distress is often readily apparent
- Rehabilitation can be disruptive and costly

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What is a Parking Garage?

- Building
- Bridge
- Mixed Use
  - Retail
  - Residential
- Fuel Load
- Exhaust

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Garage vs. Bridge

- Similarities
  - Vehicular traffic and environmental exposure
- Bridges
  - Designed for end user, proactively inspected, and generally maintained adequately
- Garages
  - Often change owners, are infrequently inspected, and typically maintained reactively

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Evolution of Garage Structural Systems

- Early Period (1950s to 1960s)
  - CIP systems – flat slab, waffle, and pan joist
- Transition Era (1960s to 1970s)
  - CIP systems – emergence of P/T
  - Early precast – channel, single-tees, small DTs
- Contemporary (1980s to current)
  - CIP P/T
  - Modern precast – deeper, wider, and pretopped DTs

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Structural Damage During Construction

- During construction
  - Precast erection
  - CIP/PT tendon stressing
  - Shoring
  - Overload
  - Equipment Impact

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Forklift Impact to DT Stem

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Structural Damage During Occupancy

- Vehicular load
  - Concentrated
  - Bumper
- Environmental load
  - Thermal
  - Seismic
- Maintenance
  - Snow piling
  - Construction debris

Source: ACI 440

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Deck Punch-through Slab-on-Metal Deck

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Deck Punch-through Precast DT

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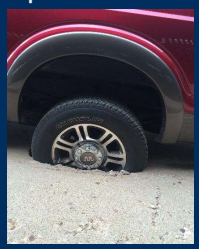
Deck Punch-through Cast-in-place



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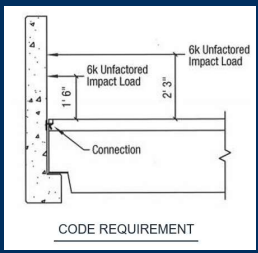
Vehicular Barrier Systems



Source: PCI MNL-129

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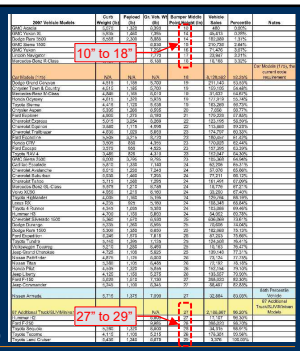
Bumper Loads

- Resisted by:
  - Concrete panels
  - Steel barrier cables
- Older codes: 18” above deck
- SUV/truck bumpers > 18”
- IBC 2009 and ASCE 7-10 revisions (18” to 27”)

(Monaham/NPA; 2008)



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Bumper Heights

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Barrier Cable Damage

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Barrier Panel Damage

Source: ICC/NPA

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Serviceability Problems

- Vibration
- Water leakage
- Overhead concrete debris
- Premature deterioration:
  - Cracking
  - Spalling
  - Staining

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Common Problems in Precast Garages

- Erection instability
- Connection distress
- Connectors weld failure
- Concentrated loads
- Deck vibration
- Water leakage

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Common Problems in CIP/PT Garages

- Deck cracking, spalling, and delamination
- Tendon anchorage distress
- Tendon reverse-curvature cracking
- Volume change cracking
- Short-column cracking adjacent to ramps

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Short-column Cracking at Ramps

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Common Problems in Steel Garages

- Concrete deck deterioration
  - Cracks
  - Spalls
- Metal deck corrosion
- Steel shape corrosion
- Excessive vibration

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General Remediation Strategies

- CIP P/T
  - Deck patching or full-thickness replacement
  - Tendon removal and splicing
- Precast
  - Connection repair: bolted angles and plates; concrete ribs
  - Dap: steel brackets and concrete haunches
- Steel
  - Steel bridging and thicker concrete deck

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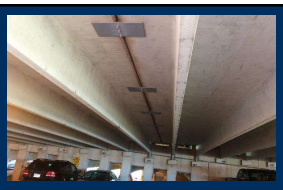


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Case Study #1

Slab-on-Metal-Deck Distress

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Description

- 2.5” net concrete over metal form deck (0.60”, 26-ga.)
- Steel joists 32” o.c.
- Joists spanning between wide flange beams

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Problems

- Extensive cracking
- Excessive vibration
- Crunching noises
- Ineffective repairs
- Within 5 years of construction

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Load Test

- Determine sharing of wheel load between adjacent joists
- Joist deflections measured
- Car used as test load
- Slab removed and replaced
- Test load replicated
- Measurements compared

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Deflection Measurements

- Static loading
- Three joists
- Car front axle positioned at center joist
- Weights suspended from each joist
- Dial gages supported by slab on level below

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Replacement Slab

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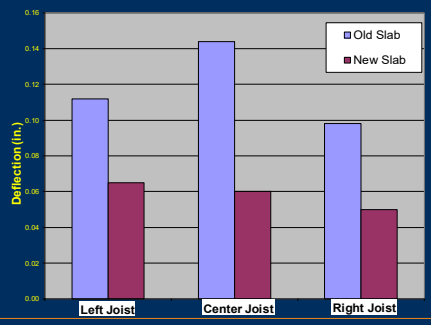
Results



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Case Study #2

Precast DT Deck Vibration

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Description

- Single level deck
- 10-ft precast DTs spanning 60 feet
- Pre-topped deck
- High traffic volume

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Problem

- Excessive vibration
- Banging noises
- Flange connection damage
- Ineffective repairs
- Main entrance

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View Looking South

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View Looking North

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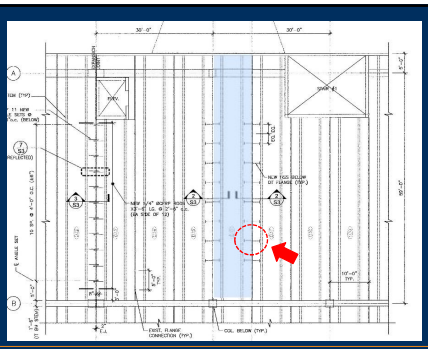
Framing Plan



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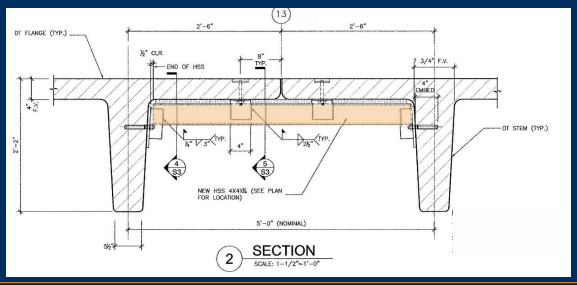
Supplemental Steel (HSS Header)



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After Remediation

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Case Study #3

CIP P/T Tendon Reverse Curvature

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Description

- Cast-in-place post-tensioned concrete 4-level garage
- Girders 24” x 36” spanning 60 feet
- Slab 8” thick spanning 15 feet
- Girder prestressing force = 760 kips

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Problem

- Girder cracking
- Near mid-span
- After stressing
- Atypical crack pattern

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Midspan Cracking

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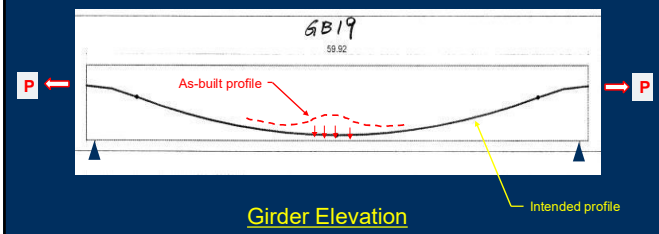
Reverse Curvature at Midspan



Girder Elevation

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Concrete Removal at Mid-span

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Reducing the Incidence of Problems

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Durability Enhancement

- All types of structural systems:
  - Reduce moisture penetration into concrete
    - Cover over reinforcement
    - Reduce concrete permeability
  - Positive surface drainage
  - Deck sealers and coatings
  - Corrosion-resistance reinforcement

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Durability Enhancement

- CIP P/T
  - Encapsulated tendons
  - Attention to cutting/capping/grouting of ends
  - Reduce restraint stresses from stiff elements (i.e., walls)
  - Incorporate slip sheets, pins, etc. at key locations
- Steel
  - Account for concentrated loading on deck
  - Use high-performance coatings or HDG

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Distress Mitigation (Precast)

- DT flange-to-flange performance
  - Allow time in construction schedule for more volume change to occur prior to welding connections
  - Avoid welding connections during extreme temperatures
  - Implement findings from ongoing PCI research on weld fatigue
- Properly position bearing pads
- Corrosion protection of steel elements
  - Appropriate materials for environment

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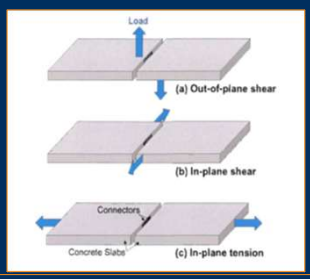
Precast DT Flange Connection Research

- Shear
  - Vertical:
  - In-plane:
- Tension
  - In-plane:



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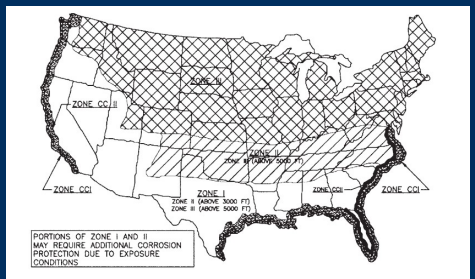
Environmental Exposure Zones



Source: ACI 362.1R

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Design Criteria for Durability (precast)

Table 6.3.2.2a—Precast/prestressed concrete with cast-in-place topping

Design element		Exposure zone*		
		I	II/CC-I	III/CC-II
Topping concrete	28-day strength, psi (MPa)	4000 (28)	4500 (31)	5000 (35)
	Air, percent†	Not required	ACI 318-08 –moderate	ACI 318-08 – severe
	w/cm (maximum)	0.45	0.40	0.40
Precast concrete	Strength, psi (MPa)	5000 (35)	5000 (35)	5000 (35)
	Air, percent†	Not required	ACI 318-08 –moderate	ACI 318-08 – severe
	w/cm (maximum)	0.40	0.40	0.40
Minimum reinforcement cover‡§¶	CIP topping—top and edge, in. (mm)	1-1/2 (40)	1-1/2 (40)	2 (50.8)
	PC— slab bottom, in. (mm)	3/4 (20)	3/4 (20)	3/4 (20)#
	PC—beam side and bottom, in. (mm)	1-1/4 (30)**	1-1/4 (30)**	1-1/2 (40)
	Precast column, in. (mm)	1-1/4 (30)**	1-1/2 (40)	1-1/2 (40)
	Walls (exposed face), in. (mm)	3/4 (20)	1-1/2 (40)	1-1/2 (40)
PC member ends	—	§	§	§
PC flange edge connectors	—	Rust-preventive paint	HDG or SS	SS
PC exposed plates	—	Rust-preventive paint	EC†† or HDG	EC†† or HDG
Sealer‡‡§§	—	—	Roof only	All floors and roof

Source: ACI 362.1R

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Maintenance

- Pro-actively identifies conditions in need of attention
- Avoids unplanned repair and service interruption
- Results in cleaner, safer, and more user-friendly facility
- Reduces life-cycle costs

Source: PCI/Rowland

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Types of Maintenance

- Housekeeping
- Snow Removal
- Preventive
- Structural Repairs

Source: PCI

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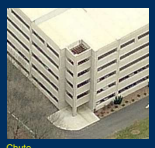
Snow Removal

- Requires Planning
- No metal blades
- Assess effect of snow and equipment on structure
- Avoid damaging deck coatings and EJs


Gate


Chute


Plow & Remove


Dump

Source: PCI/Rowland

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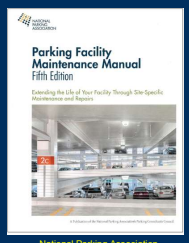
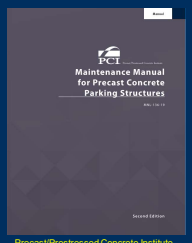
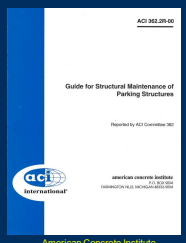
Resources for Maintenance



National Parking Association



Precast/Prestressed Concrete Institute



American Concrete Institute

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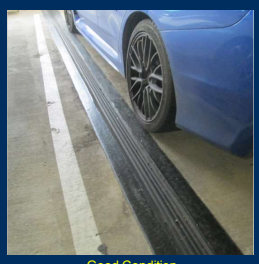
Deferred Maintenance - EJs


Poor Condition


Good Condition

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Deferred Maintenance - Drains

Poor Condition

Good Condition

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Traffic Control

- Height
- Weight
- Problematic vehicles:
  - Tow trucks
  - Armored vehicles
  - Tour buses
- Speed

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Presentation Summary

- Garages present unique challenges to design and construction
- Cyclic concentrated loads, temperature changes, and moisture make garages more vulnerable to distress than buildings
- Current structural systems are more robust than early generation systems
- Maintenance is needed to extend service life and avoid unplanned disruptions

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Industry Literature

- American Concrete Institute
  - Committee 362 (ACI 362.1R and 362.2R)
- Precast/Prestressed Concrete Institute
  - *Recommended Practice for Design & Construction of Precast Concrete Parking Structures (MNL-129)*
  - *Manual for Maintenance of Parking Structures (MNL-135)*
- Post-Tensioning Institute
  - *Design, Construction, and Maintenance of CIP PT Parking Structures* (DC20.7)
- American Institute of Steel Construction
  - Design Guide 18: *Steel Framed Open-Deck Parking Structures*

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Questions/Comments?

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