Existing Post-Tensioned Concrete Structures

structural TECHNOLOGIES
A Structural Group Company

How to repair, strengthen, modify and maintain existing post-tensioned concrete structures

Agenda

- Basics of Post-Tensioning / Prestressed Concrete
- Common Problems with Post-Tensioned Concrete
- Solving Problems with Post-Tensioned Concrete
- Case Studies
- Q&A / Discussion

Making New & Existing **Post-Tensioned Structures** Stronger & Last Longer

- Post-Tensioning Repair Services & Systems

structural group

structural TECHNOLOGIES

Investigation	Products	Engineering
• Evaluation Assistance • Specialized Evaluation & Testing Protocols	• Post-Tensioning Repair Systems • Supplemental Strengthening Systems • Protection Systems	• Solution Development • Design Assist

structural VSL PULLMAN

Specialty Contracting
• Planning & Scheduling • Safety / Quality • Field Execution

About STRUCTURAL TECHNOLOGIES

Making new and existing structures stronger and last longer

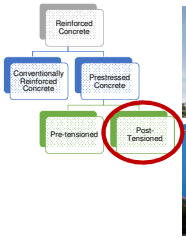
Products & Engineered Solutions:

- Post-Tensioning Repair Systems
- VSL® Post-Tensioning for New Construction
- Strengthening
- Corrosion Control
- Concrete Restoration
- Force Protection
- Pipe Rehabilitation
- Moisture Control

Basics of Post-Tensioning / Prestressed Concrete

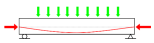
Prestressed Concrete Advantages

- Serviceability
  - Controlling stresses
  - Reduce cracking
  - Reduce deflections
- Reduction in cross-section
  - Weight savings
  - Height savings
- Long spans



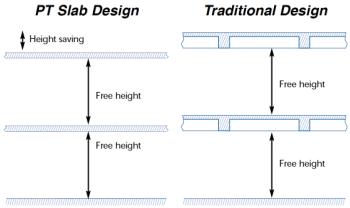
Post-Tensioned Concrete Advantages

Engineering
- Design flexibility
- Structural depth
- Continuous structures
- Load balancing controls deflections
- Effective use of high strength concrete



Post-Tensioned Concrete Advantages

Economic
- Material savings
  - M/E/P
  - Elevator
  - Cladding connection
  - Reinforcing bar reduction
- Labor savings
- Schedule Efficiencies
  - After stressing, forms can be pulled
  - Reduction in shoring and re-shoring time



Prestressing Steel

High Strength 7-wire strand
- ASTM A416
- Ultimate Strength 270 ksi
- Low Relaxation
- Primarily 0.60"Ø for Bonded Multistrand PT
- Primarily 0.50"Ø for Unbonded PT

Buttonhead Wire
- ASTM A421
- Ultimate Strength 240ksi
- 0.25"Ø

Post-Tensioning System Types




	MONOSTRAND	WIRE SYSTEMS	BAR SYSTEMS	MULTISTRAND
Types	▪ Paper wrapped ▪ Push through ▪ Heat sealed ▪ Extruded	▪ Buttonhead ▪ Paper wrapped	▪ High strength threaded bars	▪ Bonded ▪ Unbonded

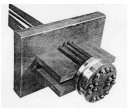
Evolution of Unbonded PT Systems

1955 Buttonhead wire in paper sheathing

1960 Strand in loose plastic sheathing

1980 Strand in extruded plastic sheathing

1985 Encapsulated tendon system



Evolution of Unbonded Monostrand PT Systems

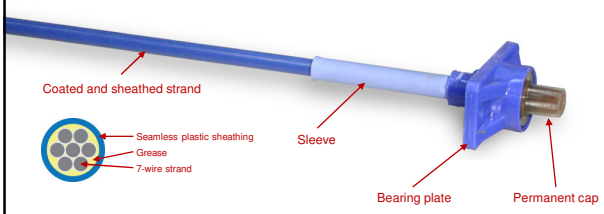

Paper Wrapped


Push Through


Heat Sealed


Extruded (with Grease & Sheathing)

Modern Unbonded Monostrand PT Systems



Common Problems with Post-Tensioned Concrete

Common Problems with Post-Tensioned Concrete

MODIFICATIONS

- Slab openings
- M/E/P penetrations
- Change in use (code/load)

MORE

DAMAGE

- Cut tendons
- Impact / overloads

MORE

DETERIORATION

- Corrosion
- Moisture effects

MORE

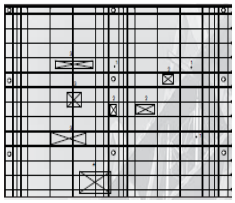
DEFECTS

- Design
- Construction

MORE

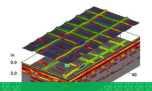
Post Tensioned Slab Openings

- PT slabs can be modified to accept small and large penetrations
  - Mechanical and electrical penetrations (small)
  - Stair towers, elevator shafts (large)
- With proper knowledge of structural behavior and PT experience, installing openings and other penetrations in PT slabs can be safely achieved



PTI-DC80.2-10

Slab Opening Procedure (Overview)



1) ANALYSIS / DESIGN

- Analyze slab to determine effect of slab opening
- Design proper shoring system to support the slab before, during and after tendon cutting

2) FIELD PREPARATION

- Locate the existing PT tendons
- Mark tendon locations on slab

3) FIELD PT WORK

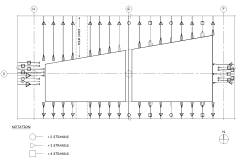
- Remove concrete where tendons intersect opening perimeter
- Lock off tendon as required
- Detension tendons
- Place new anchorages and reinforcement
- Place concrete
- Stress tendons

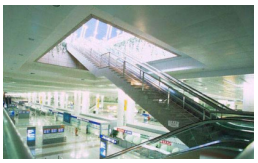
Small Penetrations – Mechanical & Electrical

- The effect of small penetrations will be negligible and the slab will behave similar to the slab without penetrations, provided that:
  - None of the existing PT strands are cut
  - The opening is not located near a concentrated load
  - A large number of small openings in a concentrated area can have a significant effect on slab strength and stiffness, particularly if several reinforcing bars or PT tendons are cut.
  - May require punching shear check if < 10 x slab thickness from column
  - Judgment of LDP required

Large Openings

- New staircases, elevator shafts, mechanical openings





Large Openings

- Several PT tendons may be interrupted
- Analyze slab to verify strength and serviceability requirements
- Consider relocating to less critical regions.

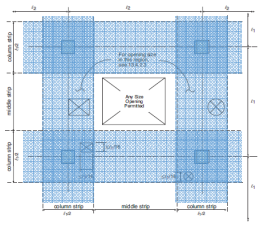
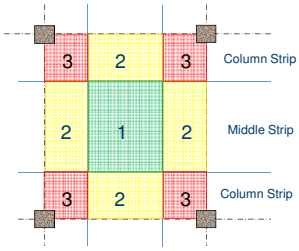


Figure 18-8 Permitted Openings in Slab Systems without Beams for $l_2 > l_1$

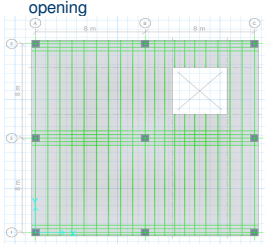
Large openings in two way slab

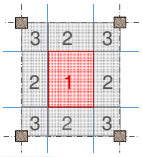
- **Zone 1** is the most desirable region
- **Zone 2** intermediate condition
- **Zone 3** is most critical. Highest bending stresses and punching shear forces.

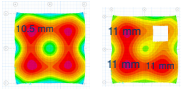


Large openings – Analyze affected structural elements for each opening location

- Tendons in the uniform direction will be interrupted by the cutting of the opening



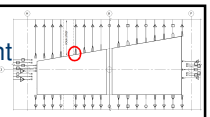


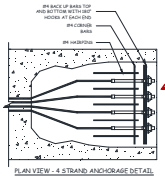


BEFORE AFTER

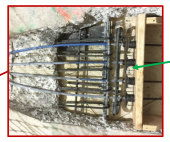
Deflection and stresses in remaining structure determined

Slab Opening – Anchorage Replacement

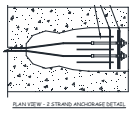




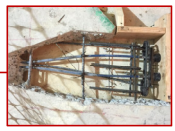
PLAN VIEW - 4 STRAND ANCHORAGE DETAIL



Place appropriate back up bar reinforcement



PLAN VIEW - 2 STRAND ANCHORAGE DETAIL



Slab Opening – Place Concrete & Stress Tendons

- Replacement concrete develop > 3000 psi strength
- Stress tendons 80% ultimate or lower force per LDP
- Record elongations, cut and finish tendon

Completed Slab Opening

- Additional Case Studies

Common Problems with Post-Tensioned Concrete

MODIFICATIONS

- Slab openings
- M/E/P penetrations
- Change in use (code/load)

MORE

DAMAGE

- Cut tendons
- Impact / overloads

MORE

DETERIORATION

- Corrosion
- Moisture effects

MORE

DEFECTS

- Design
- Construction

MORE

Common PT Problems: Damaged Tendons

Common PT Problems: Overload



◄PREV PROBLEMS NEXT►

Common Problems with Post-Tensioned Concrete

MODIFICATIONS

- Slab openings
- M/E/P penetrations
- Change in use (code/load)

MORE

DAMAGE

- Cut tendons
- Impact / overloads

MORE

DETERIORATION

- Corrosion
- Moisture effects

MORE

DEFECTS

- Design
- Construction

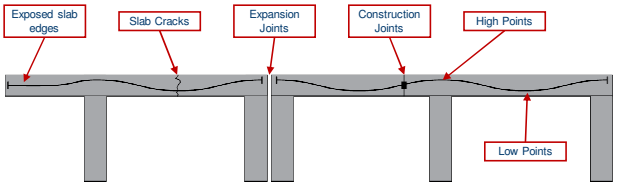
MORE

Common PT Problems: Corrosion

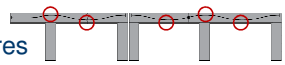



◄PREV PROBLEMS NEXT►

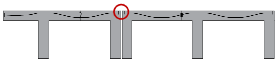
Corrosion: Vulnerable Areas of PT Tendons



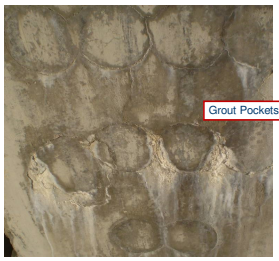
High Point and Low Point Failures

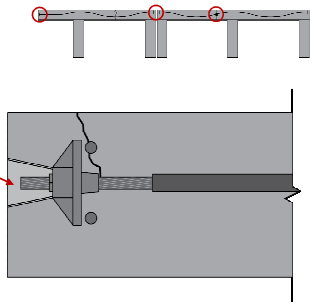


Expansion Joint

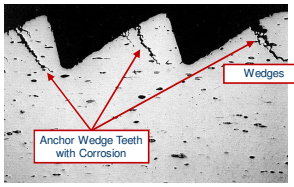


Corrosion: Anchorage Zone

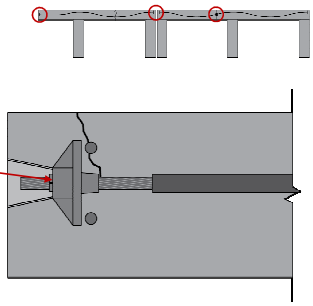




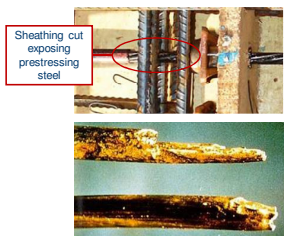
Corrosion: Anchorage Zone

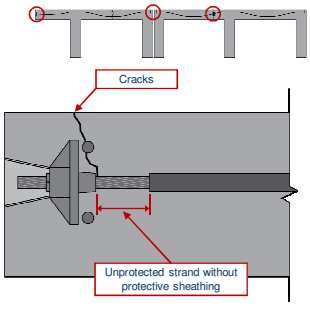


Microscopic View of Anchor Wedges

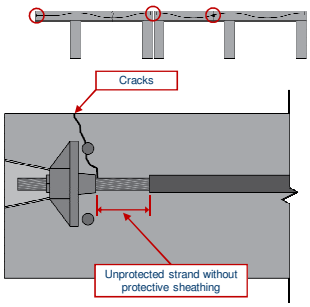


Corrosion: Anchorage Zone





Corrosion: Anchorage Zone



Strand Corrosion / Pitting Classifications

Common Problems with Post-Tensioned Concrete

MODIFICATIONS
- Slab openings
- M/E/P penetrations
- Change in use (code/load)

MORE

DAMAGE
- Cut tendons
- Impact / overloads

MORE

DETERIORATION
- Corrosion
- Moisture effects

MORE

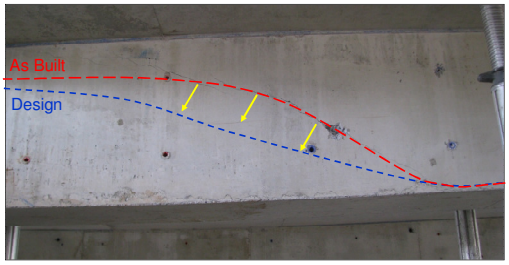
DEFECTS
- Design
- Construction

MORE

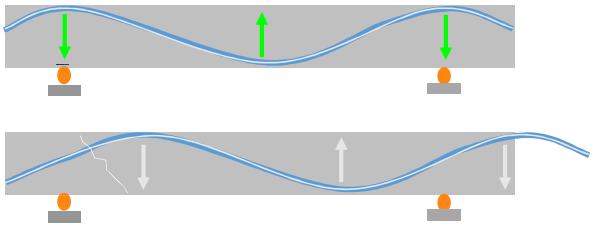
Design / Construction Defects

- Defects in post-tensioning system engineering, detailing and installation may lead to:
  - Slab edge splitting
  - Tendon erupting through top or bottom of slab
  - Concrete Spalling
- Resulting in potential property damage and personal injury

Improper Strand Profile



PT Reinforcement Placement – Improper Profile



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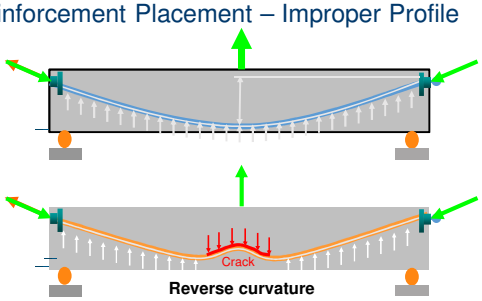
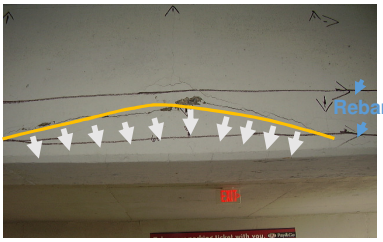


Reverse Curvature of PT Tendons – Placement Issues



Tendon “Blowouts”

- Anchorage Zone Blowouts
- Internal Slab Blowouts
- Tendon Eruption
- Surface Spalls at Tendons

Tendon “Blowouts”: Anchorage Zone

- Common Causes:
  - Inadequate or misplaced bursting steel
  - Inadequate confining steel
  - Low strength concrete
  - Concrete voids in anchorage zone

Tendon “Blowouts”: Internal Slab

- Common Causes:
  - Sharp tendon sweeps/near surface
  - Inadequate confinement
  - Stage Stressing not done

Tendon “Blowouts”: Tendon Eruption

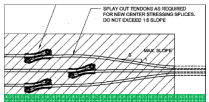
- Common Causes:
  - Anchorage slip
  - Corrosion –tendon breakage
  - Saw cutting or drilling

Solving Problems with Post-Tensioned Concrete

3 Steps to Solve Post-Tensioned Concrete Problems

1 / UNDERSTAND THE PROBLEM

CONDITION ASSESSMENT
- Determine severity of problem(s)
- Understanding of root cause



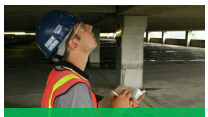
2 / DEVELOP THE SOLUTION

ENGINEERING
- Analysis of assessment and test results
- Establish repair criteria
- Solution engineering: PT Products + Protection + Methods

3 / IMPLEMENT THE SOLUTION

CONSTRUCTION
- Safety / access
- Planning & scheduling
- QA/QC plans

PT Structure **Condition Assessment**



1) REVIEW

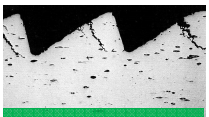
Gain basic understanding of a structure's current condition and history

- Review design, construction and/or repair documentation
- Construction sequencing
- Review exposure conditions
- Visual inspection

2) FIELD TESTING

Field testing to determine condition of post-tensioning system and overall structure (i.e. concrete, protective systems)

- Non-Destructive Testing (NDT)
- Exploratory testing



3) LABORATORY TESTING

Optional testing to gain detailed understanding of a structure's condition

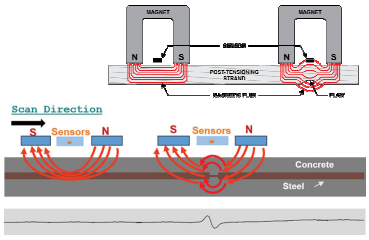
- PT system material analysis
- Concrete testing

2) Field Testing Techniques

REVIEW | TESTING | LAB TESTING

Non-Destructive Testing (NDT)		Exploratory Testing	
Magnetic methods ▪ Flux leakage ▪ Pachometer	**Electromagnetic** ▪ Ground penetrating radar (GPR)	**Monostrand stress testing** ▪ Strand tension test ▪ Lift-off test ▪ Screwdriver penetration test	**Anchorage inspection** ▪ Monostrand – pocket inspection ▪ Bonded Multistrand
Mechanical impact/wave propagation ▪ Acoustic testing/monitoring ▪ Acoustic impact testing ▪ Impact echo ▪ Impulse response ▪ Ultrasonic Tomography	**Penetrating radar** ▪ X-ray/Gamma ray **Load Test** **Electrochemical** ▪ Half-cell potential ▪ Corrosion potential ▪ Corrosion rate monitoring	**Multistrand stress testing** ▪ Lift-off test	**Borescope** **High and low point inspections**
Advanced Testing Methods			
▪ Testing of post-tensioning components	▪ Concrete Testing		▪ Service-Life Modeling

Magnetic Flux Leakage (MFL) Testing



◄PREV ASSESSMENT NEXT►

Magnetic Flux Leakage (MFL) Testing

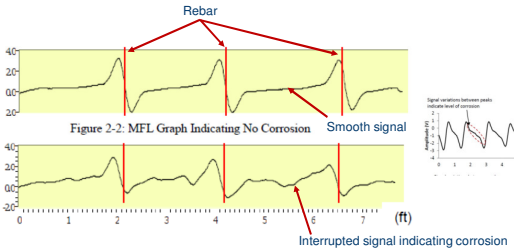
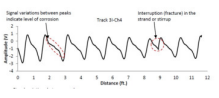


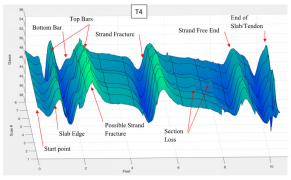
Figure 2-2: MFL Graph Indicating No Corrosion

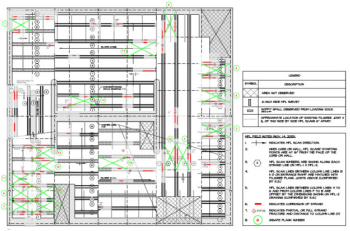


◄PREV ASSESSMENT NEXT►

Magnetic Flux Leakage (MFL) Testing

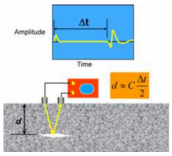
- Project examples

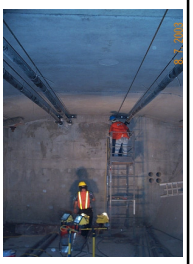




Ultrasonic Tomography

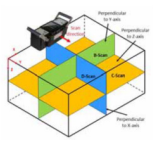
4 x 12 transducer array

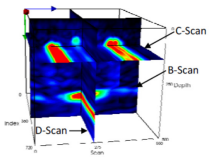


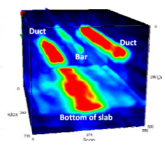


Ultrasonic Tomography

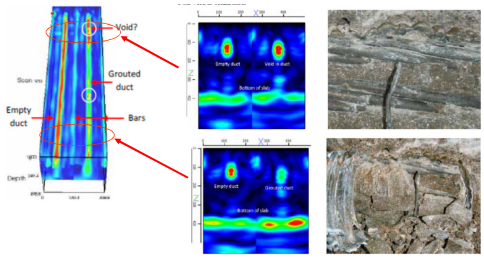
- Converts 2 –D image to 3-D image





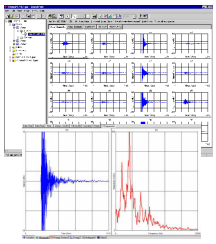


Ultrasonic Tomography



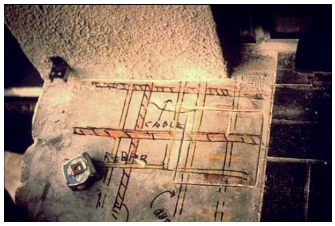
Acoustic Monitoring

- Detecting wire and strand breakage over time
- Sensors (accelerometers) detect wire break signal
- Location determined
- Wire break record, reporting and verification



X-Ray

- Can detect tendon locations, and wire breaks and section loss in bonded tendons
- Accurate depiction of slab reinforcement / embedments
- Limitations:
  - Safety Considerations
  - Time Consuming
  - Cost considerations
  - 2 sided access
  - Bulky equipment



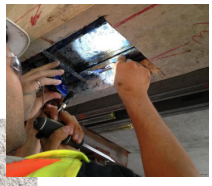
2) Field Testing Techniques

REVIEW | TESTING | LAB TESTING

Non-Destructive Testing (NDT)		Exploratory Testing	
Magnetic methods ▪ Flux leakage ▪ Pachometer	**Electromagnetic** ▪ Ground penetrating radar (GPR)	**Monostrand stress testing** ▪ Strand tension test ▪ Lift-off test ▪ Screwdriver penetration test	**Anchorage inspection** ▪ Monostrand – pocket inspection ▪ Bonded Multistrand
Mechanical impact/wave propagation ▪ Acoustic testing/monitoring ▪ Acoustic impact testing ▪ Impact echo ▪ Impulse response ▪ Ultrasonic Tomography	**Penetrating radar** ▪ X-ray/Gamma ray **Load Test** **Electrochemical** ▪ Half-cell potential ▪ Corrosion potential ▪ Corrosion rate monitoring	**Multistrand stress testing** ▪ Lift-off test	**Borescope** **High and low point inspections**
Advanced Testing Methods			
▪ Testing of post-tensioning components		▪ Concrete Testing	▪ Service-Life Modeling

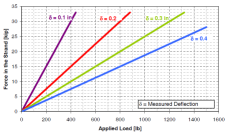
Screwdriver Test

- Screwdriver driven between wires
- Used as a qualitative measurement of wire/strand tension
- Slide hammer test – variation of baseline screwdriver test



In-situ strand tension test / deflection testing

- Applying a controlled lateral load to a fixed free-length of cable, and measuring the associated deflection to find effective force on strand



In-situ strand tension test / deflection testing

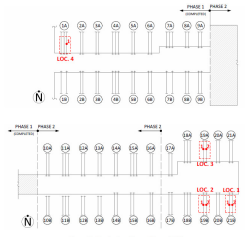


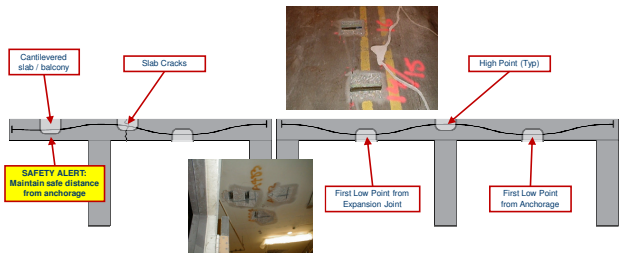
Figure 4 – Testing Location and Tested Cables

Table 1 – Test Results

Location	Cable	Applied Load (lbf)	Measured Deflection (in)	Applied Load (lbf)	Measured Deflection (in)	Force in Cable (lbf)	Force in Cable (lbf)
1	1	200	0.0837	500	0.2093	17917	17960
		200	0.0832	500	0.208	18029	
	2	200	0.0836	500	0.2091	27934	12339
		200	0.1215	475	0.2886	12344	
		200	0.1208	475	0.2869	12417	
2	1	200	0.1224	500	0.306	12255	25136
		200	0.0601	500	0.1508	24867	
		200	0.0602	500	0.1514	24769	
	2	200	0.0580	500	0.1455	25773	21427
		200	0.0680	500	0.1724	21752	
		200	0.0701	500	0.1769	21198	
3	1	200	0.0703	500	0.1758	21331	20225
		200	0.0751	500	0.1879	19957	
		200	0.0731	500	0.1848	20292	
	2	200	0.0732	500	0.1836	20425	21141
		200	0.0724	500	0.1812	20695	
		200	0.0694	500	0.1736	21601	
4*	1	200	0.0711	500	0.1775	21127	24812
		200	---	500	0.1276	29398	
		200	---	500	0.1724	21757	
		200	---	500	0.1611	23283	

* Due to difficulties during the test, the preload was not applied

High Point / Low Point Inspections

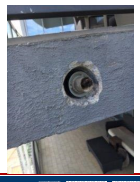


Borescope Inspection

- Visually inspect tendons
  - Strand condition
  - Grout condition / voids
  - Anchorages

Monostrand Anchor Inspection

- Opening anchorage pockets
  - Inspect wedges: seating & corrosion
  - Inspect anchor casting
  - Encapsulated anchor inspection



◄ PREV ASSESSMENT NEXT ►

2) Field Testing Techniques

REVIEW | TESTING | LAB TESTING

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Magnetic methods ▪ Flux leakage ▪ Pachometer	**Electromagnetic** ▪ Ground penetrating radar (GPR)	**Monostrand stress testing** ▪ Strand tension test ▪ Lift-off test ▪ Screwdriver penetration test	**Anchorage inspection** ▪ Monostrand – pocket inspection ▪ Bonded Multistrand
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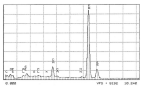
Advanced Testing Methods		
▪ Testing of post-tensioning components	▪ Concrete Testing	▪ Service-Life Modeling

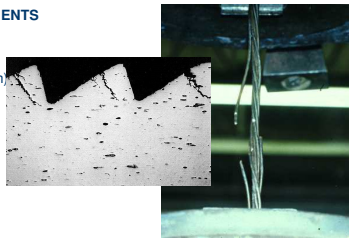
3) Laboratory Testing Techniques

REVIEW | TESTING | ADVANCED TESTING

TESTING OF POST-TENSIONING COMPONENTS

- Hydrogen embrittlement
- Metallography
- SEM/EDS (energy dispersive spectrograph) investigation
- Grease / inspection testing
- Tensile testing





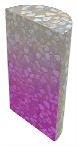
◄ PREV ASSESSMENT NEXT ►

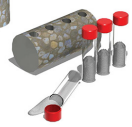
3) Materials Testing Techniques

REVIEW > TESTING > ADVANCED TESTING

CONCRETE TESTING

- Chloride
- Strength
- Petrographic
- Carbonation

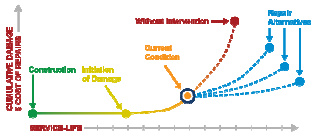



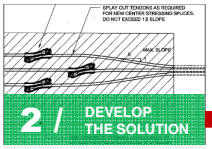
3) Service-Life Modeling

REVIEW > TESTING > ADVANCED TESTING

- In partnership with SIMCO
- Service Life Modeling & Prediction, Durability Engineering
  - Determine residual service life (time to failure) without corrective measures
  - Estimate service life of applicable repair and protection options



PT Structural Analysis & Repair Design Process



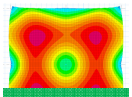
2 / DEVELOP THE SOLUTION

ENGINEERING

- Analysis of assessment and test results
- Establish repair criteria
- Solution engineering:
  PT Products + Protection + Methods

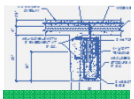
1) REVIEW

Evaluate whether the post-tensioning system (as designed) is adequate for strength and serviceability



2) EVALUATION

Evaluate deficiency (loss of strength) based on results of field investigation



3) SOLUTION BUILDING

Develop solution to deliver strength, durability and serviceability needs

PT Structural Analysis & Repair Design: **Solutions**

UNBONDED POST TENSIONING REPAIR TECHNIQUES		

POST-TENSIONING SYSTEM REPAIR	▪ Tendon detensioning
	▪ Full tendon replacement
	▪ Anchor replacement
		▪ Partial tendon replacement
		  ▪ Center stressing anchor
		  ▪ Torque stressing coupler
		  ▪ Splice
		  ▪ Combination system
		▪ Sheathing Repair

STRUCTURAL STRENGTHENING	▪ External post-tensioning ▪ FRP composites ▪ Enlargement & overlays	

PT Tendon Detensioning Methods

GRINDER

Blade cuts one wire at a time to remove tension.

TORCH

High temperature torch allows steel to slowly relax, expand and remove tension

DETENSIONING RAM

Used at midpoint of tendons to mechanically detension tendons

PLATE METHOD

Steel plates sandwich tendons with bolts. After cutting tendons, bolts are slowly loosened

PT Structural Analysis & Repair Design: **Solutions**

UNBONDED POST TENSIONING REPAIR TECHNIQUES		

POST-TENSIONING SYSTEM REPAIR	▪ Tendon detensioning
	▪ Full tendon replacement
	▪ Anchor replacement
		▪ Partial tendon replacement
		  ▪ Center stressing anchor
		  ▪ Torque stressing coupler
		  ▪ Splice
		  ▪ Combination system
		▪ Sheathing Repair

STRUCTURAL STRENGTHENING	▪ External post-tensioning ▪ FRP composites ▪ Enlargement & overlays	

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Full Tendon Replacement



PT Structural Analysis & Repair Design: **Solutions**

UNBONDED POST TENSIONING REPAIR TECHNIQUES		

POST-TENSIONING SYSTEM REPAIR	▪ Tendon detensioning
	▪ Full tendon replacement
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		▪ Partial tendon replacement
		  ▪ Center stressing anchor
		  ▪ Torque stressing coupler
		  ▪ Splice
		  ▪ Combination system
		▪ Sheathing Repair

STRUCTURAL STRENGTHENING	▪ External post-tensioning ▪ FRP composites ▪ Enlargement & overlays	

Anchor Replacement



Tendon Lock Off – Monostrand

- Lock off anchors - Monostrand
  - Technology for temporary lock-off of tendon tension

Anchor Replacement

- Anchorage zones susceptible to corrosion
- Solution: Removal and replacement
  - Lock off and detension
  - Splice new strand and encapsulated anchor
  - Place new concrete
  - Stress and finish

PT Structural Analysis & Repair Design: **Solutions**

UNBONDED POST TENSIONING REPAIR TECHNIQUES		

POST-TENSIONING SYSTEM REPAIR	▪ Tendon detensioning
	▪ Full tendon replacement
	▪ Anchor replacement
		▪ Partial tendon replacement
		  ▪ Center stressing anchor
		  ▪ Torque stressing coupler
		  ▪ Splice
		  ▪ Combination system
		▪ Sheathing Repair

STRUCTURAL STRENGTHENING	▪ External post-tensioning ▪ FRP composites ▪ Enlargement & overlays	

Partial tendon replacement technologies

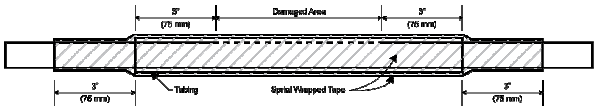
Splice

Torque stressing coupler

Combination anchor

Center stressing anchor

Sheathing Repair



PT Structural Analysis & Repair Design: **Solutions**

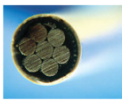
UNBONDED POST TENSIONING REPAIR TECHNIQUES		

POST-TENSIONING SYSTEM REPAIR	▪ Tendon detensioning
	▪ Full tendon replacement
	▪ Anchor replacement
		▪ Partial tendon replacement
		  ▪ Center stressing anchor
		  ▪ Torque stressing coupler
		  ▪ Splice
		  ▪ Combination system
		▪ Sheathing Repair

STRUCTURAL STRENGTHENING	▪ External post-tensioning ▪ FRP composites ▪ Enlargement & overlays	

Strengthening Overview

- Used to increase the load-carrying capacity of reinforced concrete and other structure types
- Methods &Technologies
  - **Post-Tensioning**
  - FRP Composites
  - Enlargement
  - Supplemental Steel
  - Epoxy Injection

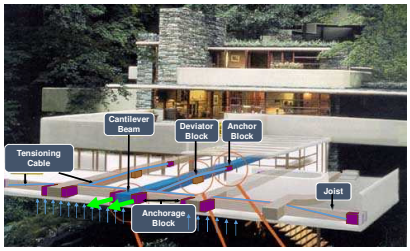
Strengthening with Post-Tensioning

Overview:
- External post-tensioning to offset deficiencies and deflections caused by external loads
- May be installed internally as an enlargement for added protection
- A variety of PT systems may be used including monostrand, grouted multistrand or bars

Benefits:
- Provides significant strength increase
- Effective for long spans
- May be used to correct excessive deflections

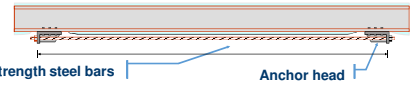

Strengthening with External Post-Tensioning

- Fallingwater

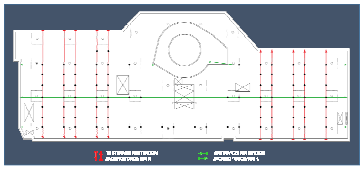
Strengthening with External Post-Tensioning

- Steel reinforcement



Strengthening with External Post-Tensioning

- Multistrand tendon application



Strengthening with Composites

Overview:

- Externally bonded carbon and glass fiber reinforced polymer (FRP) systems
- Bonded with adhesive resins
- Utilize lightweight, high-strength fibers

Benefits:

- Can be shaped to strengthen columns, beams, walls and slabs
- Low profile
- Very high strength

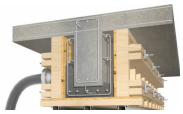
Strengthening with Enlargement & Overlays

Overview:

- Bond additional reinforced concrete to structural members
- Utilizes pressurized formwork, proper surface preparation and specialized concrete materials to ensure proper bond / composite behavior

Benefits:

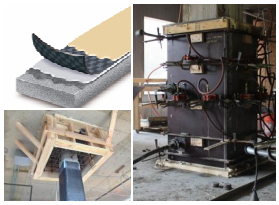
- Ability to significantly add additional capacity to existing members
- Controls deflection
- High levels of fire resistance



◄PREV SOLUTIONS NEXT►

Strengthening Products

- Products
  - Structural Technologies Internal / XPT ™ External Post-Tensioning Systems
  - Structural Technologies VStrand™ Fire Resistant Tendon Systems
  - Vwrap™ Composite Systems
  - Tstrata™ Enlargement Systems
  - DUCON® Micro-Reinforced Concrete



◄PREV SOLUTIONS NEXT►

Case Studies

Partial tendon replacement with combination system

Supplemental strengthening of PT slab with External PT

PT Slab Modification

Parking Structure Repair

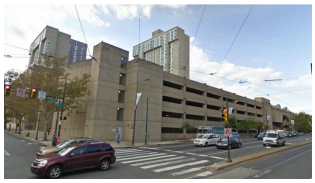
Plaza Deck Overload

Roof Slab Opening

External PT strengthening of precast parking structure

University of Pennsylvania - Parking Garage LOT 14

- Overview
  - Philadelphia, PA
  - 5-level / split level design (10 decks)
  - Built in 1960's
- Symptoms
  - Concrete delamination
  - Concrete spalling

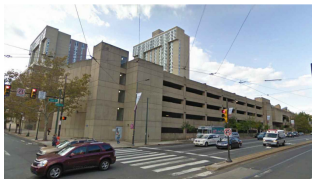


University of Pennsylvania - Parking Garage LOT 14

- PT System & Structure Evaluation Overview
  - The parking deck PT reinforced with 7 wire Buttonhead System and Cast-In-Place concrete ramps
  - Extreme weather conditions, de-icing salts and long time service has caused the concrete to delaminate and spall
  - Corrosion to the existing reinforcement has caused some of the buttonhead wires to fail

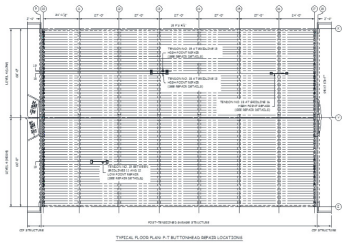
University of Pennsylvania - Parking Garage LOT 14

- Repair Design Overview:
  - PT Repair Strategy:
    - Partial tendon replacement using combination system technology
  - Concrete Repair Strategy:
    - Partial and full depth repair of concrete
  - Protection Strategy:
    - Installation of galvanic anode cathodic protection system
    - Trench drain and expansion joint replacement
    - Waterproofing and roof level topping repairs



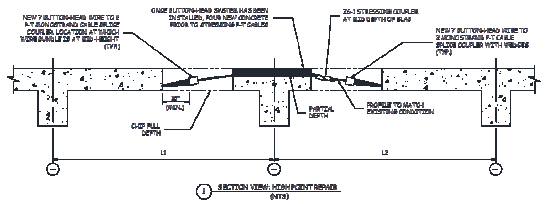
University of Pennsylvania - Parking Garage LOT 14

- PT Repair Strategy: Typical floor – PT buttonhead repair locations



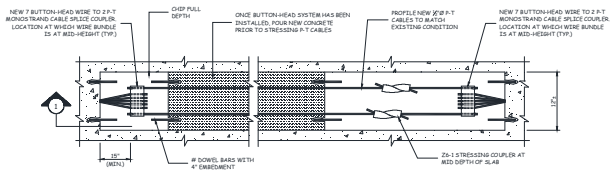
University of Pennsylvania - Parking Garage LOT 14

- PT Repair Strategy: **High point** repair detail



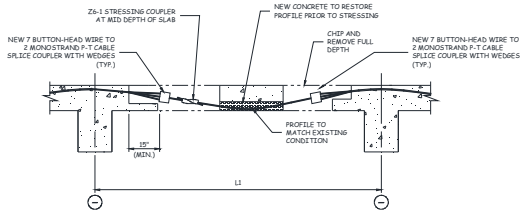
University of Pennsylvania - Parking Garage LOT 14

- PT Repair Strategy: **High point** repair detail



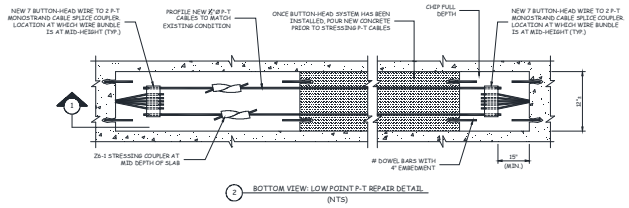
University of Pennsylvania - Parking Garage LOT 14

- PT Repair Strategy: **Low point** repair detail



University of Pennsylvania - Parking Garage LOT 14

- PT Repair Strategy: **Low point** repair detail



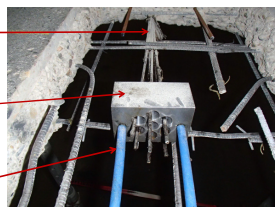
University of Pennsylvania - Parking Garage LOT 14

Installation of Buttonhead Anchor and New Strands

Cut and remove all corroded or damaged P-T wires until NO signs of corrosion are evident (proper seating of wedges)

Install new 7 Buttonhead wire VBM™ Splice Coupler on prepared wires

Install new ½" diameter P-T cables in 7 wire Button-head VBM™ Splice Coupler

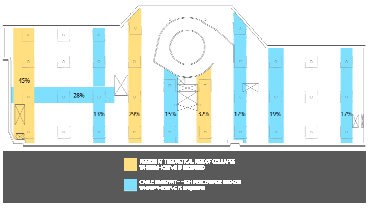


Washington DC Office Building

- Overview
  - Washington D.C.
  - Built in 1960's
- Symptoms
  - Plaza deck waterproofing issues
  - Corrosion of strand and anchorages

Washington DC Office Building

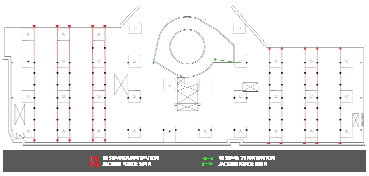
- Assessment Findings
  - Reduced capacity due to deterioration (corrosion)
  - Excess dead load
  - Reinforcing steel not installed as designed
  - Tendons not stressed at all or stressed below design assumptions (25 kips vs. 22 kips avg.)
  - Original design not meeting code without repairs



Plaza Level Dead Load Capacity

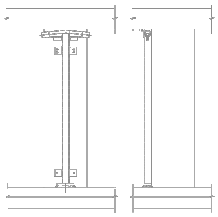
Washington DC Office Building

- Solution Design:
  - Multistrand tendon external post-tensioning strengthening system
- Project Challenges:
  - Active building with tenants
  - Various obstructions (utilities, walls, etc.)



Washington DC Office Building

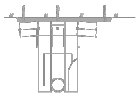
- External Post-Tensioning Tendon Deviators



Washington DC Office Building

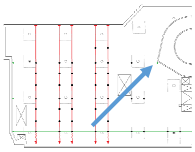
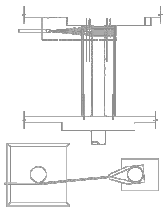
- External Post-Tensioning Crossover Deviators






Washington DC Office Building

- External Post-Tensioning Wrap-around Anchorage


Washington DC Office Building

- Installation / Stressing



1800 K Street Office Renovation – Roof Slab Opening

- Overview
  - Washington, DC
  - 11-floor building
  - Built in 1970 (Buttonhead PT)
- Project Overview
  - Create slab opening for stairwell

1800 K Street Office Renovation – Roof Slab Opening

- Project Challenges
  - Tight working space due to obstructions (mechanical room, HVAC)
  - Tight schedule for completion (6 weeks)

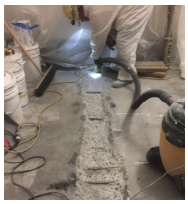
Existing Mechanical Room: >>>
Protection of equipment from dust and debris produced by demolition of slab to be constructed

1800 K Street Office Renovation – Roof Slab Opening

Shoring installed prior to detensioning of PT tendons

FRP carbon fiber fabric installed prior to PT work to avoid overstressing the structure during detensioning/retensioning

1800 K Street Office Renovation – Roof Slab Opening

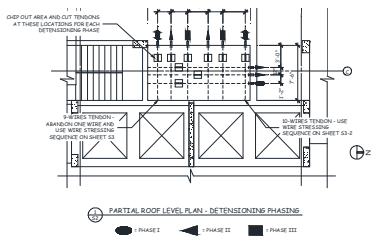


Locate PT tendon locations using GPR (Ground Penetration Radar), as-built drawings or structural plans. Remove concrete to expose PT tendons.

Grinder used to cut individual wires to detension tendon

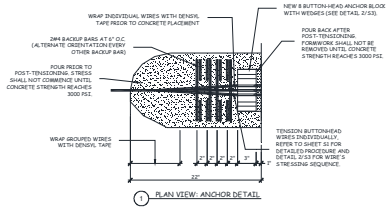
1800 K Street Office Renovation – Roof Slab Opening

- PT Tendons: Detensioning Phasing Sequence



1800 K Street Office Renovation – Roof Slab Opening

- Details – PT Anchorage



1800 K Street Office Renovation – Roof Slab Opening

Formwork installed at slab edge

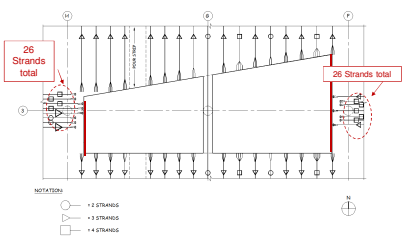
Concrete cured, forms removed

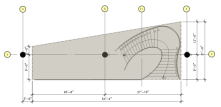
1800 K Street Office Renovation – Roof Slab Opening

Following stressing sequence, each PT wire stressed to specified force

New Stairway Opening (Finished Product)

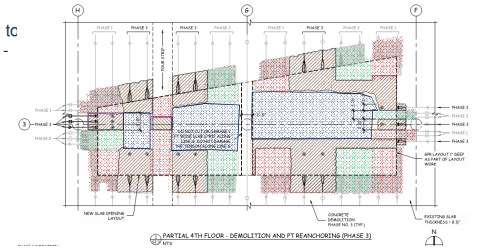
Post-tensioned Structure Modification- Slab opening





Slab opening – Phased demolition work

- Minimize disruption to building operations - Shoring limitations

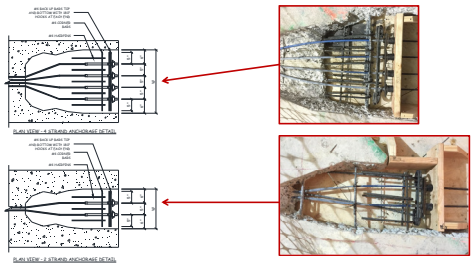


Slab opening – Tendon detensioning



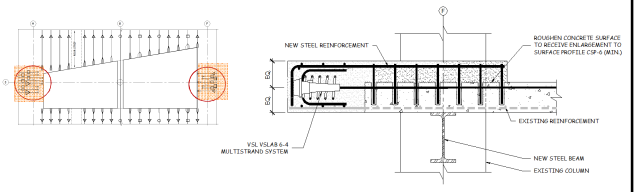

1. Locate existing tendons using GPR
2. Remove concrete to expose strands
3. Torque detensioning device
4. Detension strands

Replace anchorage at openings – Uniform Tendons



Banded Tendon Anchorage Replacement

- Anchoring in banded direction was achieved using multi-strand system



Banded Tendon Anchorage Replacement

- Anchoring in banded direction was achieved using multi-strand system

VSLAB 6-4 System, spiral reinforcement and back-up bars installed

Stressing Tendons

Completed Slab Opening

Plaza Deck Overload

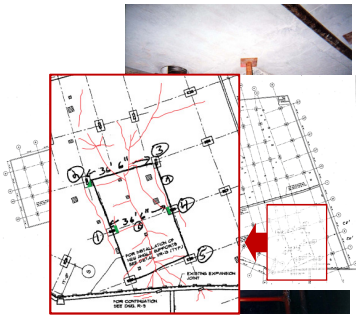
- Post-tensioned plaza deck
- 36'-6" x 28' column grid
- Landscaping contractor installing soil for planter
  - 8-ton dump truck
  - Skid steer loader
  - Soil materials

Plaza Deck Overload

- Conditions
  - 2' of wet compacted soil in place
  - Soil being dumped in piles on deck
  - Soil not being spread as directed

Plaza Deck Overload

- Deck deflecting / cracking
- Column capital spalling



Plaza Deck Overload

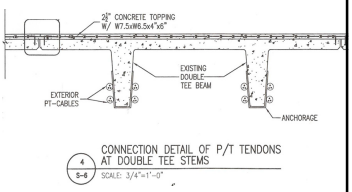
- Emergency shoring installed
  - Deck stabilized
- Repair Solution:
  - Shore/Mechanically Jack slab
  - Install Steel Framing/Grout
  - Epoxy inject cracks

Retail Parking Structure Strengthening

- Overview
  - Springfield, VA
  - Multi level precast parking structure
- Project Overview
  - Maximum vehicular weight capacity increased from 9,000 lbs. to 20,000 lbs.
  - Desired fire rating achieved using VStrand™ Heat Resistive Tendons

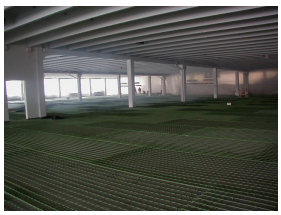
Retail Parking Structure Strengthening

- Strengthening Design
  - Full-depth repair of cracked slab edges
  - 2.5-in. bonded reinforced concrete overlay for entire deck
  - Install steel brackets to support double tee flanges
  - Strengthen double tees using External PT
  - Strengthen inverted tees using bonded FRP composites
  - Strengthen inverted tee ledges w/ steel brackets



Retail Parking Structure Strengthening

- Bonded reinforced concrete overlay (2.5") for entire deck and full depth repairs



Retail Parking Structure Strengthening

- Double tees strengthened using External PT (VStrand™ Heat Resistive Tendons)

Retail Parking Structure Strengthening

- Precast beam strengthening

Retail Parking Structure Strengthening

- Slab edge and beam supports

Baltimore Ave. Parking Structure – Detroit MI

- Overview
  - Detroit, MI
  - 4-level / split level design (7 decks 5 are elevated)
  - Built in 1960's
- Symptoms
  - Concrete delamination/spalling
  - Embedded metal corrosion
  - Grout pocket deterioration
  - Exposed/Broken PT Tendons
  - Beam/slab deflection/cracking
  - SOG settlement
  - Poor drainage
  - Poor lighting

Baltimore Ave. Parking Structure – Detroit MI

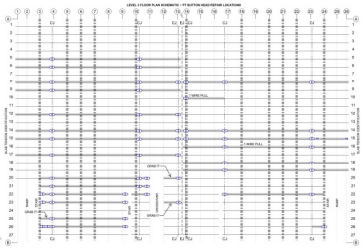
- PT System & Structure Evaluation Overview
  - Buttonhead Wire parking deck floor slab system, Precast PT Beams with 2- 20 wire bundles and conventionally reinforced concrete ramps
  - Extreme weather conditions, poor drainage, de-icing salts and long time service has caused the concrete to delaminate and spall
  - Corrosion to the existing reinforcement and PT hardware had caused many of the wires to corrode and break

Baltimore Ave. Parking Structure – Detroit MI

- Repair Design Overview:
  - PT Slab Repair Strategy:
    - 234 Unbonded partial tendon replacements using combination system technology
  - PT Beam Repair Strategy:
    - 32 External post-tensioning repairs utilizing existing threaded bar anchorages, new post tensioning tendons, deviators and new steel couplers.
  - Concrete Repair Strategy:
    - Partial and full depth repair of concrete
  - Protection Strategy:
    - Encapsulated connections to existing beam anchorages
    - Grout external XPT™ tendons
    - Fire resistant coatings to steel deviators
    - Expansion joint replacements
    - Improved drain system

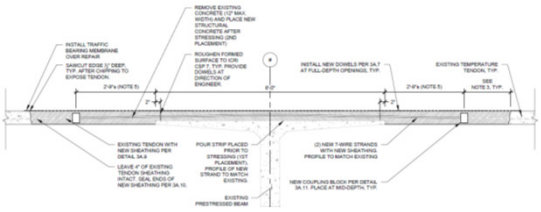
Baltimore Ave. Parking Structure – Detroit MI

- PT Repair Strategy: Typical floor – PT buttonhead repair plan drawing



Baltimore Ave. Parking Structure – Detroit MI

- PT Slab Repair Strategy: Mid Span Detail (Type 4)

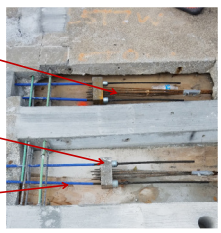


Baltimore Ave. Parking Structure – Detroit MI
Installation of Buttonhead Anchor and New Strands

Cut and remove all corroded or damaged P-T wires until NO signs of corrosion are evident (proper seating of wedges)

Install new 8 wire splice block on prepared wires, secured using ¼" wire wedges

Install new .5" P-T tendons and T5 threaded barrel anchor w/grease cap in 8 wire Splice Coupler

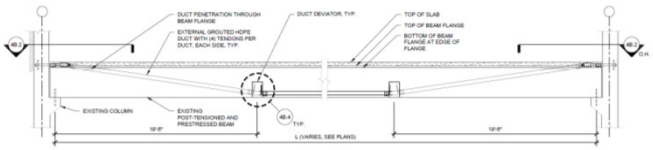


Baltimore Ave. Parking Structure – Detroit MI
Installation of Buttonhead Anchor and New Strands

Typical End Anchor Detail

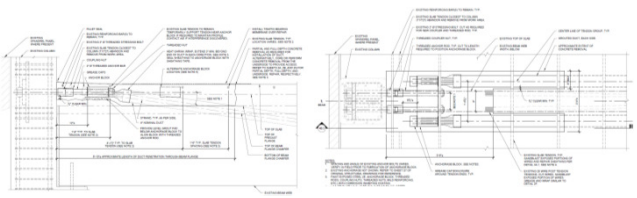
Baltimore Ave. Parking Structure – Detroit MI

- PT Beam Repair Strategy: External PT Beam Elevation



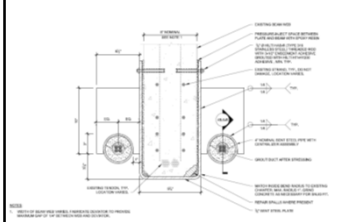
Baltimore Ave. Parking Structure – Detroit MI

- PT Beam Repair Strategy: **External PT Detail**



Baltimore Ave. Parking Structure – Detroit MI

- PT Beam Repair Strategy: **Protective Measures – Encased Cables/Encapsulated Anchors**



Baltimore Ave. Parking Structure – Detroit MI

- PT Beam Repair Strategy: External XPT™ post-tensioning was used to strengthen beams at 32 locations

Duct Deviator

Duct Penetration through beam flange to tie PT Tendons into columns

Grout Encapsulated PT Tendons (4 EA) within 4" HDPE Duct

Thank You!
Questions / Comments?

- Making New & Existing Post-Tensioned Structures Stronger & Last Longer

structural group

structural TECHNOLOGIES		
Investigation	**Products**	**Engineering**
• Evaluation Assistance • Specialized Evaluation & Testing Protocols	• Post-Tensioning Repair Systems • Supplemental Strengthening Systems • Protection Systems	• Solution Development • Design Assist

structural / PULLMAN	
Specialty Contracting	
• Planning & Scheduling • Safety / Quality • Field Execution